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Estimates of Genetic Parameters of Certain Production and Carcass Traits in Beef Cattle

Marion Fitzgerald

ESTIMATES OF GENETIC PARAMETERS OF CERTAIN PRODUCTION AND CARCASS TRAITS IN BEEF CATTLE

BY

MARION FITZGERALD

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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

Head of the Major Department

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INTRODUCTION

The knowledge of genetic parameters of any population is essential so selection of livestock can bring about maximum improvement and consequently increase the profits of the producer, the processor and supply a product that appeals to the consumer. This study is concerned with the determination of: 1) the heritability estimates of production traits, carcass characteristics, live animal measurements and subjective scores of the live animal; 2) the genetic, environmental and phenotypic correlations of production and carcass traits with measurements and scores and 3) the value of measurements and scores of the live animal for estimating carcass merit.

The heritability estimate is the expression upon which all of the possibilities of improving the population by breeding methods depends. Because of this the estimate of heritability is considered one of the most important parameters in animal breeding. Obtaining an estimate of the genetic variation is necessary so the breeder will be able to utilize this source of variation more effectively and increase the production in livestock.

In considering the nature of the phenotypic correlation between two traits, Hazel (1943) pointed out that such a correlation may exist for two reasons, either it is caused by the same genes affecting both characteristics or the two traits are correlated because of common environmental influences. In breeding studies it is necessary to separate the two causes of correlation to ascertain the improvement which can be expected.

If objective measurements can be correlated with desirable carcass traits, then these measurements will have the advantage of being independent of human judgment and will remain standard over a long period of time in contrast to subjective conformation and type standards which can and probably do change with time. Such measurements may aid in the assessment of conformation differences but give little indication of balance and refinement or quality of the animal which must be considered in the overall evaluation. Hence, it is important that scores which will indicate symmetry be studied to provide a complete picture of the animal.

A knowledge of the heritability of traits and genetic correlation among characteristics is necessary to accomplish the goal set forth by Earl L. Butz (1959), Dean of Agriculture, Purdue University. Dean Butz, after studying the rising per capita meat consumption and the population increase, stated that the United States will need an additional 25 million head of cattle in 20 years and is assuming ". . . that we can in the same time increase our beef output per <u>animal</u> by one-fourth."

REVIEW OF LITERATURE

Heritability Estimates

In any group of animals of like age, breed and sex maintained under similar conditions, some will express a trait differently than others. Part of this variation may be due to differences in heredity and part to differences in reaction to environmental influences which cannot be identified easily. The part due to inherited differences has been labeled heritability.

Gowen (1933) analyzed body measurement data of 300 bulls and 6,000 cows which had been recorded by representatives of the Jersey Breed Association. These animals were from herds in 15 states. Estimates of heritability from parent-offspring correlations under the assumption of somatic assortive mating and no dominance were height at withers, .60; depth at withers, .61; circumference of heart girth, .65; width at hips, .81 and length of body, .68.

Knapp et al. (1946) reporting data from 177 steers sired by 23 bulls produced at the U. S. Range Livestock Experiment Station, Miles City, Montana, obtained estimates of heritability for: weaning weight, .12; slaughter grade, .63; carcass grade, .84; dressing percent, .01; and rib eye area, .69. Estimates were obtained by the intra-sire correlation method. In revising estimates of heritability from the progeny of 110 sires, Knapp et al. (1950) calculated estimates by the half-sib correlation method. These heritability estimates were weaning weight, .28; gain in feedlot, .65; initial score, .28; slaughter grade,

.45; carcass grade, .33 and area of eye muscle, .68.

Heritability estimates, based on data from 101 Shorthorn and 62 Milking Shorthorn steers raised and fed at the Agricultural Research Center, Beltsville, Maryland, were calculated and reported by Schott et al. (1950). Steers used in this study were slaughtered at a constant weight of 900 pounds. Heritability of the different characteristics was estimated by the paternal half-sib correlation method on a within year and breed basis. Estimates based on the combined group of 163 steers were: height at withers, 1.00; height at floor of chest, .83; width of shoulder and length of body, each .00; circumference of foreflank, .58; carcass grade, .52; and slaughter grade, .38.

Data from 613 record of performance Hereford steers were used to estimate heritabilities by Knapp et al. (1951). These steers were raised and fed at the Miles City, Montana Experiment Station, and were the progeny of 85 sires. Estimates obtained by the paternal half-sib correlation method for weaning weight and gain in feedlot were .31 and .70, respectively.

Touchberry (1951) derived estimates of heritability of five body measurements from 187 Holstein daughter-dam pairs in the Iowa State College herd during the period from 1932 to 1945. Measurements were taken at three years of age. The daughters were sired by 22 different bulls. Analyses were on an intra-sire basis. The heritability estimates for wither height, chest depth, body length, heart girth, paunch girth and weight were 73, 80, 58, 26 and 37 percent, respectively.

Yao et al. (1953) estimated the heritability of tenderness of the

longissimus dorsi from 298 beef and dual purpose Shorthorn steers. These parameters were calculated by the paternal half-sib correlation method. The heritability for the beef and dual types were .01 and .49, respectively, for organoleptic score and .93 and .52, respectively, for shear force values. Pooling the heritability estimates gave a heritability of .30 for organoleptic score and .76 for shear force value.

Dawson, Yao and Cook (1955) estimated the heritability of three beef characteristics and 19 body measurements from 58 Milking Shorthorn steers raised at the Agricultural Research Center, Beltsville, Maryland. These steers were fed on record of performance test during the period from 1943 to 1949 and were the offspring of 9 bulls and 51 cows. Paternal half-sib correlations were used to estimate heritability. The characteristics were arbitrarily grouped as follows:

1. High heritability group (above 40 percent): carcass grade, .66; height at withers, .65; width between eyes, .63; slaughter grade, .58; width of muzzle, .50; depth of chest, .40.
2. Medium heritability group (20 to 40 percent): circumference of shin bone, .33; height of floor of chest, .33; circumference of foreflank, .33.
3. Low heritability group (1 to 20 percent): daily gain, .18; width of last rib, .15; width at chest, .09; height of flank, .04; width of loin, .04.
4. Zero heritability group (less than 1 percent): width of hips, .005; length of body, .00; length of rump, .00;

length of coupling, .00; length of nose, .00; width at shoulder, .00; circumference of navel, .00; circumference at rear flank, .00.

Estimates of heritability, obtained for weaning weight and weaning score by the paternal half-sib correlation method, were reported by Koch and Clark (1955a). The data used were 4553 weaning records and 3831 weaning scores collected over the period of 1929 to 1951. The calves were the progeny of 124 sires. This method of analysis yielded heritability estimates for weaning weight of .24 and for weaning score of .18. Analyzing the above data by the correlation between parent and offspring allowed Koch et al. (1955b) to make further estimates of genetic parameters. Heritability estimates obtained by regressing offspring on dam were .11 for weaning weight and .16 for weaning score. Estimates of .25 and .15 were obtained by regressing offspring on sire for weaning weight and weaning score, respectively.

Studies of the performance testing data collected at the U. S. Range Livestock Experiment Station at Miles City, Montana were reported by Shelby et al. (1955). The estimates were based on 635 steers from grade cows which were mated to 88 bulls from 9 lines over a 10 year period (1941-1952). Estimates obtained by the paternal half-sib correlation method were: slaughter grade, .42; carcass grade, .16; color of lean, .31; area of rib eye, .72; thickness of fat, .37.

Dinkel (1958) reported heritability estimates for rate of gain from record of performance bulls. The data were analyzed by the method of least squares with constants fitted for sires, years and inbreeding

classes. The 149 bulls represented in the data were the progeny of 22 sires. The heritability estimates of rate of gain for the 140 day feeding period, the 168 day feeding period and for the 196 day feeding period were .45, .52, and .65, respectively.

Kieffer et al. (1958) reported estimates from 60 Angus steers and heifers produced by seven different bulls with six to 14 animals per sire group. The average age at the end of the 159 day feeding period was 386 days and the average slaughter weight was 886 pounds. Heritability estimates for tenderness and rib eye area were calculated by the paternal half-sib correlation method. Tenderness of the longissimus dorsi, as measured by the mechanical shear force technique, was estimated to have a heritability of .92 with a 95 percent confidence interval of approximately .40 to 1.44. Heritability of rib eye area, unadjusted for differences in carcass weight, was .56 with a 95 percent confidence interval of approximately .04 to 1.08.

In an experiment designed to estimate heritability from response to sire selection, Carter and Kincaid (1959) reported data collected on 177 steers and 192 heifers during the period of 1947 to 1954. The 19 high and 19 low gaining bulls were selected from record of performance tests, paired and mated to grade Hereford cows. The breeds used in this study included Hereford, Angus and Shorthorn. Heritability estimates of weaning weight ranging from 26 to 31 percent for steers and 21 to 26 percent for heifers were obtained.

Shelby et al. (1960) estimated heritability of rate of gain using data from 542 Hereford bulls fed on record of performance tests from

1940 to 1954 at the Miles City station. The animals were sired by 116 bulls from 11 inbred lines of different pedigree origin. An estimate of .46 was obtained for gain in the feedlot.

Genetic, Environmental and Phenotypic Correlations

In studies of the breeding of farm animals considerable emphasis has been placed on the investigation of correlated variation. However, in data reported thus far practically all of the emphasis has been placed on phenotypic variations with little work being reported relative to the genetic and environmental variance. Consequently, the literature concerning phenotypic correlations is voluminous but very little has been reported about genetic and environmental correlations.

Black (1938) studied the phenotypic relationships of body measurements to rate of gain and certain carcass characteristics from data collected from 50 head of steers of beef, dual, and dairy breeding that had been tested in record of performance trials. Steers were slaughtered at a near constant weight of 900 ±20 pounds. Black reported that height at withers, depth of chest, length of body and width of loin were negatively correlated with rate of gain, dressing percent, percent fat, percent lean and slaughter grade. Heart girth, width of shoulder, width of hips and slaughter grade were positively correlated with the above mentioned production and carcass traits. The correlations of slaughter grade with percent fat and percent lean were .82 and .83, respectively.

Hopper (1944) reported phenotypic correlations calculated from

data of 92 cattle. The wholesale rib, edible portion of the wholesale rib, the 9-10-11 rib, and the edible portions of the 9-10-11 rib were studied as indicators of the physical composition. The edible portions of the wholesale rib and the composition of the 9-10-11 rib were found to be highly correlated with the physical composition of the carcass and the edible portion of the carcass. The correlations between the composition of the 9-10-11 rib with percent fat and the edible portion of the wholesale cuts were .85 and .97, respectively.

Cook et al. (1951) analyzed data from steers fed individually in a record of performance test to a final weight of 900 pounds. Body measurements were taken just before slaughter. These steers were 157 Milking Shorthorns bred and raised at the Beltsville Research Station from 1932 to 1949. Simple phenotypic correlations of slaughter grade, carcass grade and dressing percent with five body measurements and with rate of gain were calculated.

Slaughter grade was negatively correlated with height at withers, -.40; height at floor of chest, -.51; and length of body, -.16. The same characteristic was positively correlated with circumference of foreflank, .26; width of shoulder, .16; and rate of gain, .15. Simple negative correlations of -.42, -.46, and -.21 were calculated with carcass grade and height at withers, height at floor of chest and length of body, respectively. Positive correlations of .09, .16 and .17 were computed between carcass grade and circumference of foreflank, width of shoulder and rate of gain. Dressing percent was negatively correlated with height at withers, -.20; height at floor of chest, -.18; circum-

ference of foreflank, -.02; and length of body, -.20. Positive correlations of .08 and .21 existed between dressing percent and width of shoulder and dressing percent and rate of gain. Slaughter grade was positively correlated with carcass grade and dressing percent, .69 and .25, respectively. A positive correlation of .45 was calculated between carcass grade and dressing percent.

Knapp et al. (1951) reported a study based on data of 613 steers from 83 Hereford sires in experiments conducted at the Montana Agricultural Experiment Station. Steers were scored prior to the feedlot test. The initial scores ranged from common to fancy feeder. The feeding periods were 224 to 270 days. The phenotypic correlation between score and gain was .0001; the genetic correlation was .30, while the environmental correlation was -.30. The negative environmental correlation was attributed to two causes: (1) some compensating gains in the feedlot for the relatively poorer conditions of environment before weaning, and (2) negative correlation that may exist between milk production and gains. They concluded that there was little value in selecting feeders for rate of gain if sole dependence is placed on the visual method of selection.

Durham and Knox (1953) analyzed data from 424 steers fed as long yearlings and 59 cattle fed as post-weaning calves. The data from the yearlings were collected over a period of 13 years, while the records of the calves were collected over a period of three years. The cattle were on feed 196 days. Phenotypic correlations were calculated within age and years. The ability of an animal to gain rapidly or to hang a desirable carcass could not be predicted by feeder grade as these

correlations were very low and accounted for only 4 percent of the variation present. Feedlot gain accounted for about 20 percent of the variation in fat grade and 10 percent of the variation in carcass grade. The correlation between fat grade and carcass grade was .44 for the yearlings and .36 for the calves.

Four production characteristics and nineteen body measurements from 101 beef Shorthorns and 62 Milking Shorthorn steers raised at the Beltsville Agricultural Research Station were studied by Yao et al. (1953). Since the material was from two different breeds, the variance and covariance caused by breed differences was calculated and subtracted from the total variance and covariance for characters and measurements. Width and circumference measurements were positively correlated with slaughter grade, carcass grade and dressing percent. Height and length measurements were negatively correlated with slaughter grade. Positive correlations were obtained between carcass grade, slaughter grade and dressing percent. The correlations involving the measurements were very low and accounted for approximately 15 percent of the phenotypic variation in the production factors.

Weaning weights, weaning scores and fall yearling scores of Hereford calves were analyzed by Koch and Clark (1955a). The data used were weaning weights on 4553 calves, weaning scores on 3831 calves and fall yearling scores on 1483 animals. The weaning weights and scores were obtained over the years of 1929 to 1951 from 137 different sire groups. Yearling scores were obtained from 1936 through 1951 from the progeny of 124 different sires. Data were adjusted to a heifer basis.

The genetic, environment and phenotypic correlations between weaning weight and weaning score were .47, .68 and .64; the correlations between weaning weight and yearling score were .23, .27 and .26 and between weaning score and yearling score were .45, .26 and .29, respectively. No negative genetic correlations which would hamper selection were found.

Cartwright et al. (1958) reported data from 18 Hereford and 20 Brahmam X Hereford steers fed for 140 days. Measurements of separable lean from the 9-10-11 rib and estimated lean in the carcass were closely parallel. A positive correlation, accounting for 75 percent of the variation in slaughter score, was found between feeder score and slaughter grade. Slaughter grade was also correlated with separable fat in the 9-10-11 rib .59, with fatness over rib eye .49, and negatively correlated with separable bone in the 9-10-11 rib -.54. However, the correlation between separable lean in the carcass and slaughter grade was positive but very small.

Carter and Kincaid (1959) reported genetic and phenotypic correlations among various traits from data from 195 steers and 190 heifers calved over a five year period. The animals were sired by 36 bulls. The sires were selected for rapid and slow gain on the basis of a 168 day performance test. The selected bulls, 22 Herefords, 12 Angus and four Shorthorns, were mated to random samples of grade Hereford cows. The steer progeny were full fed individually for 200 days after weaning and slaughtered at the end of the test. The heifers were wintered largely on roughage and tested for gain on pasture the following summer. Genetic correlations were estimated from paternal half-sib analyses

using the sire components of variance and covariance. As a result of the high selection pressure on the sires, there may have been some bias in the results; but the authors did not state the nature of such a bias. The genetic and phenotypic correlations between feeder grade and slaughter grade were .66 and .36, respectively. The genetic correlation between feeder grade and carcass grade was .65, while the phenotypic correlation was .16.

An experiment involving 98 yearling steers was conducted over a two year period by Kidwell et al. (1959) to study the relation of selected production factors to conformation scores and body measurements. No relationship was found between feeder grade and subsequent rate of gain; however, feeder grade was positively associated with percent fat in the 9-10-11 rib. Feeder grade and carcass grade were negatively associated with percent bone and percent muscle in the 9-10-11 rib and they were only slightly related to percent of the various wholesale cuts. Slaughter grade had a high relationship with carcass score and percent bone, muscle, and fat in the 9-10-11 rib. A low but significant relationship existed between slaughter grade and percent of wholesale cuts. Carcass grade was largely a function of fat in the carcass as higher grading carcasses yield more fat and less bone and muscle.

A total of 31 long yearling steers, consisting of 8 Angus and 23 Herefords from the Michigan State University performance test, were used by Orme et al. (1959) in studying relationships of live animal measurements to various carcass measurements. Average slaughter weight of these steers was 856 (±76) pounds. The steers had an average numerical carcass

grade of 19.5 (±1.3) when high prime was 24 and high good was 18.

Rib eye area and live weight were correlated with live animal measurements. Correlation coefficients of .51, .52, and .53 were obtained between rib eye area and circumference of body at foreflank, hind flank and middle, respectively. Thus steers with larger body circumference tended to have larger rib eyes. Other relationships between various live animal measurements and rib eye area which were significant at the 5 percent level of probability included width of rump, .35, circumference of hind leg, -.36, and .38 for live weight. Standard partial regression coefficients were calculated to study the relationships of various live animal measurements to rib eye area eliminating the effects of live weight. With weight held constant, circumference of body at foreflank accounted for 81 percent of the variation in rib eye area.

Data were collected at the U. S. Range Livestock Experiment Station at Miles City, Montana by Woodward et al. (1959) in an attempt to evaluate the phenotypic relationships among certain carcass characteristics. These data were collected from 1953 to 1957, inclusive, and included the records of 210 steers which were the progeny of 28 sires. Steers were marketed on a time constant basis. Fifty-six of the steers were randomly selected for physical separation of the 9-10-11 rib and tenderness tests.

Simple correlations indicated that final weight was correlated with carcass grade, .21; dressing percent, .03; area of eye muscle, .20; thickness of fat at the 12th rib, .33; weight of lean in the 9-10-11 rib,

.70; weight of eye muscle in 9-10-11 rib, .37; weight of fat in the 9-10-11 rib, .60; shear test, .10; and slaughter grade, .46.

Carcass grade, area of eye muscle and thickness of fat in the 12th rib were correlated with the weight of lean, eye muscle, fat and bone of the 9-10-11 rib. Correlations obtained between carcass grade and the weight of the lean, eye muscle, fat and bone in the 9-10-11 rib were .18, .16, .64 and .07, respectively. The thickness of fat at the 12th rib when correlated with the various components of the 9-10-11 rib yielded correlations of .32, -.10, .63 and .17, respectively. Shear test was correlated with carcass grade, -.07; area of eye muscle, -.28; thickness of fat at the 12th rib, .13; weight of lean in rib, -.05; weight of eye muscle, -.33; weight of fat, .05 and weight of bone, -.10. No significant sire differences for tenderness were found in these data.

Wheat _et al_. (1960) evaluated slaughter scores of 688 Hereford steers and heifers which were graded to the nearest one-third of a grade by members of the Department of Animal Husbandry at Kansas State College. Each carcass was then graded to the nearest one-third of a grade by an official of the U.S.D.A. Federal Grading Service. Slaughter grade was correlated with carcass conformation .56, carcass grade before ribbing .38, and carcass grade after ribbing .22. The correlations between carcass conformation and carcass grade before ribbing, after ribbing and degree of marbling were .42, .25, and .25, respectively. Correlations between carcass grade before ribbing and after ribbing averaged .53. Average correlation between carcass grade after ribbing and degree of marbling was .89.

SOURCE OF DATA

The data used in this study were production traits, objective measurements, subjective scores and carcass information collected from 184 grade Hereford steers during the two year period of 1959 and 1960 in cooperation with commercial producers in the State of South Dakota. The project was supported in part by the North Central States Regional NC-1 project and the Agricultural Research Service of the U.S.D.A.

These steers were the progeny of 29 sires. Nineteen of the sires were produced by the South Dakota Experiment Station and leased to cooperating breeders in a field testing program. The remaining 10 bulls, which sired 85 of the calves, were bred and raised by purebred breeders in South Dakota and surrounding areas and purchased by the cooperating breeders for use in their herds. Eleven ranches are represented in this analysis. These ranches are located throughout South Dakota and the climatic and environmental conditions to which the calves were subjected varied widely.

Calves were purchased from the cooperating breeder at weaning time. An effort was made to purchase an equal number of calves from the producer's own bull as from the leased bull. The only basis of selection was that calves from the different sires of a ranch were as nearly alike in date of birth as possible. After a short period of adjustment at the Brookings Experiment Station, the calves were started on a half oats, half corn ration with alfalfa hay free choice. The oats was gradually reduced until the calves were on a full feed of corn in April. Alfalfa hay was continued free choice and soybean oil meal was added to the

ration in the later stages to keep the protein level sufficiently high. Calves were implanted with 24 mg. of stilbestrol at the beginning of the trial and with an additional 24 mg. about midway in the feeding period. All steers were fed in the same lot. The animals were on feed 259 days in 1959 and 270 days in 1960.

In 1959 the steers were slaughtered in two groups, the slaughter dates being one week apart. The following year the steers were divided into three lots for slaughter. One week separated the first two groups. The third group was not slaughtered until two weeks after the second. All animals from the same ranch were slaughtered at the same time.

Production Traits

The three production traits discussed in this study are adjusted weaning weight, rate of gain and final type. The weaning weights of the calves were adjusted to a constant age of 190 days by linear correction factors developed by Johnson and Dinkel (1951). Weights were also corrected for age of dam and sex of calf using factors computed by Minyard (1960). The sire means for adjusted weaning weight are presented in Table 1. The lowest sire average of 360 pounds was in 1959 and the highest sire average of 469 pounds was in 1960.

Rate of gain was the average daily gain of each steer. This was computed by dividing the total gain during the feeding period by the number of days in the feeding period. The high average sire group was 2.51 pounds per day and the low average sire group was 1.98 pounds per day.

At the end of the feeding phase the steers were weighed off the feeding trial and scored for type. The final type score was the average numerical score of six judges working independently. The following scoring system was used:

Score	Code	
1+	17	
1	16	Prime
1-	15	
2+	14	
2	13	Choice
2-	12	
3+	11	
3	10	Good
3-	9	
4+	8	
4	7	Commercial
4-	6	
5+	5	
5	4	Utility
5-	3	
6+	2	
6	1	Cull
6-	0	

Sire means for type score are presented in Table 1.

Measurements and Scores

Linear and circumference measurements were taken on each animal prior to slaughter. All linear measurements were taken with the aid of a caliper and were recorded in centimeters to the nearest millimeter. Circumference measurements were taken by means of a steel tape and were recorded in centimeters. Steers were restrained in a conventional stock

and measurements were recorded only when the animal was standing in a normal position; that is, with head up and standing squarely on all four legs. Measurements used in this analysis and the instrument and method used to obtain the measurement were:

1. Circumference of forearm - measured with a steel tape in a horizontal plane around the forearm and as close to the body as possible while keeping the tape parallel to the floor.
2. Circumference of foreflank - measured with a steel tape in a plane perpendicular to the body axis just behind the forelegs.
3. Circumference of single round at patella - taken in a horizontal plane with a steel tape around the patella while keeping the tape parallel to the floor.
4. Length of body - measurement from the point of the shoulder to the pin bone of the steer by means of a caliper.
5. Width of shoulder - the horizontal distance across the widest point of the shoulders as measured with a caliper.
6. Width of loin - horizontal distance across the loin just anterior to the hooks, measured with a caliper.
7. Width of hooks - measured with a caliper, horizontally, across the body from hip bone to hip bone.
8. Length from hooks to bottom of round - measurement from hip bone to bottom of the bulge of the round as measured

with a caliper.

9. Length from pins to bottom of round - measured with a caliper from pins to bottom of the bulge of the round.

10. Length of rump - horizontal measurement from hooks to pins as taken with a caliper.

11. Height at withers - perpendicular distance from withers to the floor measured with a caliper.

12. Depth of chest - calculated as the difference between height of animal at withers and height of chest floor.

13. Quarter width at patella - horizontal distance measured with a caliper across the lower round at the level of the patella.

14. Circumference of cannon bone - measured with a steel tape in a horizontal plane around the small portion of the ulna and radius.

15. Thickness of hide - measured by grasping the skin in the upper rib section with the hand and measuring the thickness by means of a small caliper. Such a measurement is designated as thickness of hide in this study, although it actually represents a double hide thickness.

16. Head width - distance across the head measured above the eyes with a caliper. Only the steers in 1960 were measured for width of head.

Subjective scores placed on the live animals were the averages of six members of the Animal Husbandry Department working independently.

In addition, the 1960 scores were supplemented by the opinions of two fieldmen of the South Dakota Hereford Association who assisted in scoring final type and final condition. Market grade was the subjective score of the cattle buyer who graded each individual steer as the animal was weighed at the slaughter house in Huron, South Dakota. The steers were divided into two lots in 1959 and three lots in 1960 for slaughter. This may have caused some bias due to the tendency of the buyer to grade the second and third groups of steers on the basis of the rail grade of the first groups. Such a bias may be significant if the variability within a sire group was affected, but otherwise would not be important since the method of analysis was on a within year-ranch basis.

Scores used to describe the various components of the live animal and their description are as follows:

1. Plumpness of forearm - describes the bulge, thickness and meatiness through the fore shank.
2. Plumpness of shoulder muscle - describes evidence of muscling through the shoulder or chuck region.
3. Fullness of crops - denotes the width and muscling through the withers.
4. Fullness of loin - describes the width through the loin area of the back.
5. Fullness of rump - the squareness and plumpness from hooks to pins.
6. Width of pins - the distance between pin bones as viewed from the rear.

7. Fullness of outside round - describes the bulge of the rear quarter as viewed from the side.
8. Depth of round - the extension of the round to the hock of the animal.
9. Fullness of twist - describes the plumpness and depth of twist.
10. Initial type - conformation of the steer at the beginning of the trial.
11. Final type - conformation of the steer at the end of the trial.
12. Final condition - score denoting the amount of external fat on the live animal.
13. Carcass conformation - type of the carcass according to U.S.D.A. standards.
14. Market grade - slaughter grade of the steer on foot.
15. Carcass grade - score by the U.S.D.A. official placed on the carcass after considering marbling of the eye muscle, carcass conformation and maturity of the carcass.

Sire means of the scores and measurements are presented in Table 1. The following scoring and coding systems were used in this analysis for the subjective scores.

Initial and Final Type

Score	Code	
1+	17	
1	16	Fancy
1-	15	
2+	14	
2	13	Choice
2-	12	
3+	11	
3	10	Good
3-	9	
4+	8	
4	7	Commercial
4-	6	
5+	5	
5	4	Utility
5-	3	
6+	2	
6	1	Cull
6-	0	

Condition Scores

Score	Code	
A+	14	
A	13	Prime finish
A-	12	
B+	11	
B	10	Choice finish
B-	9	
C+	8	
C	7	Good finish
C-	6	
D+	5	
D	4	Commercial finish
D-	3	
E+	2	and below
E	1	
E-	0	

Market Grade, Carcass Grade and Carcass Conformation

Score	Description
24 23 22	Prime
21 20 19	Choice
18 17 16	Good
15 14 13	Standard
12 11 10	Utility
9 8 7	Commercial
6 5 4	Canner
3 2 1	Cutter

Component scoring of the live animal

Score	Description
7	Exceptional
6	
5	
4	Average
3	
2	
1	Inferior

Carcass and Quality Characteristics

The carcasses were ribbed after 24 hours of chilling. Marbling score, carcass conformation score and carcass grade were placed on each carcass by an official of the U.S.D.A. Federal Meat Grading Service. The scoring and coding system for marbling was:

Code	Score
12	Extremely abundant
11	Very abundant
10	Abundant
9	Moderately abundant
8	Slightly abundant
7	Moderate
6	Modest
5	Small
4	Slight
3	Traces
2	Practically devoid
1	Devoid

The scoring system is the official U.S.D.A. grading system used for grading beef carcasses; the code is needed for the interpretation of the results. Sire means for marbling are presented in Table 1.

Color of lean was estimated with the Muncell color paddles approximately 40 minutes after the carcasses were ribbed. The Muncell color paddles have ten colors designated as A1 through A10 - the lightest to the darkest. Sire means for color of lean are shown in Table 1. The coding system as used for color of lean was:

Score	Code	
A 1	10	Lightest
A 2	9	
A 3	8	
A 4	7	
A 5	6	
A 6	5	
A 7	4	
A 8	3	
A 9	2	
A10	1	Darkest

Chilled carcasses were weighed and the right sides were broken down into the wholesale cuts; chuck, rib, loin and round. Sire means are presented in Table 1 for the above traits. Means are also presented for the combined weights of round + loin + rib and for the total weight of the four wholesale cuts.

Tracings were made of the eye muscle and fat thickness of the 12th rib. Rib eye area was measured by the use of a planimeter and recorded in square inches. Fat thickness as listed in Table 1 was the average of three measurements and was recorded in inches.

The ribs of the right side of the carcasses were purchased for detailed study by the meats personnel. The 9-10-11 rib was removed and the fat, lean and bone were separated according to the procedure outlined by Hankins and Howe (1946). The separable components were weighed to the nearest tenth of a pound. Using regression equations developed by Hankins and Howe, the values were converted to percent lean, bone and fat of the carcass. Multiplying these percentages by the carcass weight gave an estimate of the pounds of lean, bone and fat in the carcass. Table 1 presents the sire averages for these characteristics.

A one inch thick steak of the longissimus dorsi of the 12th rib was excised and wrapped with freezer paper for tenderness analysis. Hot shear value determinations were calculated by the use of the Warner Bratzler shear. The mercury bulb of a thermometer was positioned in the center of each steak and the steak was cooked in deep fat to an internal temperature of 160 degrees F. in a constant temperature vat of 295 degrees F. When the internal temperature was reached, the thermometer was removed and 5 one-half inch cores were taken from each rib steak. Each core was cut parallel to the direction of the muscle fiber using a circular motion and exerting a little pressure. A mean for each steak was derived from the average of the five individual shear values. These measurements were recorded in pounds per square inch. Sire means for tenderness are shown in Table 1.

Table 1. Sire Means

		No. of prog-eny	Adj. wng. wt.	Rate of gain	Marb-ling	Tender-ness	Color of lean	Lbs. of round	Lbs. of loin	Lbs. of rib
1959	071	6	418.0	2.50	5.8	8.40	8.8	76.79	55.96	30.83
	072	6	399.5	2.45	3.8	6.88	9.0	73.29	53.71	28.71
	073	6	386.2	2.35	5.2	6.75	7.7	70.00	51.29	29.08
	081	4	368.0	2.41	5.5	7.16	7.2	72.69	52.62	29.12
	082	4	402.5	2.32	5.0	6.19	7.2	69.62	51.62	26.81
	091	6	401.7	2.36	5.0	7.24	8.8	74.42	50.33	28.71
	092	6	381.5	2.44	4.0	6.33	8.2	72.25	51.71	29.50
	101	6	406.2	2.46	4.5	8.00	7.7	77.25	52.96	30.08
	102	5	360.0	2.27	5.0	7.44	8.0	72.55	49.40	27.90
	111	3	437.7	2.13	4.0	6.48	7.7	70.58	51.75	27.17
	112	8	434.6	2.49	4.4	6.42	8.4	79.34	55.38	30.72
	113	4	370.0	2.43	4.5	6.72	8.5	73.50	51.44	27.81
	114	4	457.0	2.41	4.5	6.29	8.2	74.25	52.62	28.19
1960	051	3	421.7	2.47	3.7	3.58	7.3	81.00	54.17	31.08
	052	4	387.0	1.98	2.5	5.15	6.5	64.81	46.19	26.50
	061	6	364.2	2.24	3.8	4.39	7.8	76.25	53.25	28.08
	062	6	392.5	2.19	4.2	5.11	7.5	75.92	55.58	29.62
	063	6	409.3	2.16	4.3	5.49	8.2	77.33	53.92	29.12
	074	5	442.0	2.21	4.0	4.37	7.8	75.30	54.10	31.50
	075	5	414.0	2.20	4.6	3.46	8.8	76.70	51.30	29.90
	076	6	440.8	2.28	4.2	4.51	8.0	77.25	53.08	30.67
	091	6	413.3	2.11	4.5	3.48	8.0	76.71	54.83	28.92
	092	6	365.3	2.67	4.3	3.51	8.0	76.38	53.17	29.21
	102	6	430.7	2.51	3.7	3.87	7.3	83.00	60.96	30.83
	103	6	389.7	2.38	3.5	5.91	7.0	74.12	53.08	28.83
	112	4	428.8	2.17	3.8	3.71	7.8	81.88	54.44	28.62
	113	6	359.8	2.15	4.0	3.87	8.3	76.71	54.42	31.50
	131	6	449.3	2.24	3.8	4.55	6.8	76.67	53.92	29.29
	132	6	442.7	2.18	4.0	5.65	6.8	76.21	54.04	29.38
	171	6	481.0	2.35	5.3	4.57	8.7	85.25	61.88	35.50
	172	4	469.0	2.19	3.8	3.90	8.3	79.00	57.06	33.75
	191	6	413.2	2.22	4.0	5.12	7.8	78.04	56.38	30.46
	192	6	365.5	2.06	3.7	4.80	7.8	72.25	50.12	26.71
	211	4	459.5	2.03	4.8	4.46	7.3	73.31	56.44	32.50
	212	3	453.7	2.11	4.3	5.27	7.7	75.33	55.33	29.33
Mean			410.4	2.28	4.3	5.42	7.89	75.82	53.79	29.67
Standard deviation			51.96	.22	.98	.19	.93	6.82	5.21	3.15

Table 1 Continued

		Lbs. of chuck	Lbs. of round ≠ loin ≠ rib	Lbs. of whole-sale cuts	Dressing Percent	Rib eye area	Carcass grade	Chilled carcass weight
1959	071	87.25	163.58	250.83	61.56	11.45	19.7	649.8
	072	87.75	155.71	243.46	61.04	12.05	17.8	624.9
	073	83.38	150.38	233.76	62.52	12.70	18.8	498.5
	081	80.12	154.44	234.56	61.50	11.64	19.0	608.2
	082	85.25	148.06	233.31	60.38	10.23	18.5	595.2
	091	82.83	153.46	236.29	61.81	11.83	18.7	614.4
	092	82.33	153.46	235.79	60.00	11.33	18.0	617.5
	101	84.54	160.29	244.83	60.46	10.91	17.7	644.1
	102	79.20	149.85	229.05	61.17	10.50	18.2	592.8
	111	80.58	149.50	230.08	59.13	10.03	18.0	594.1
	112	89.47	165.81	255.28	61.88	12.09	18.4	660.6
	113	82.50	152.75	235.25	62.22	10.68	19.0	610.6
	114	84.19	155.06	239.25	61.16	10.79	18.5	630.1
1960	051	96.17	166.25	262.36	63.79	11.95	18.3	672.4
	052	72.38	137.50	209.88	60.37	11.17	17.5	536.5
	061	88.08	157.58	245.66	62.48	12.27	17.8	627.1
	062	90.42	161.12	251.54	63.28	11.73	18.3	635.8
	063	91.00	160.38	251.38	62.76	11.75	18.2	635.7
	074	86.10	160.90	247.00	61.22	11.88	17.6	629.3
	075	87.80	157.90	245.70	62.04	11.20	18.4	628.3
	076	88.83	161.00	249.83	60.98	12.18	17.8	628.9
	091	89.92	160.46	250.38	63.00	11.27	18.5	636.5
	092	89.25	158.75	248.00	63.44	11.68	18.2	634.9
	102	96.21	174.79	271.00	63.08	12.22	17.7	687.2
	103	86.29	156.04	242.03	61.94	10.57	17.5	621.7
	112	93.12	164.94	258.06	61.75	13.18	16.3	649.8
	113	89.58	162.79	252.37	62.34	12.40	17.3	637.3
	131	88.83	159.88	248.71	61.59	12.09	17.5	634.2
	132	88.04	159.62	247.66	61.07	11.69	18.0	627.4
	171	96.75	182.63	279.38	63.71	12.33	18.8	719.9
	172	91.25	169.81	261.06	61.19	12.16	17.5	664.0
	191	93.12	164.88	258.00	63.06	12.22	18.0	657.6
	192	83.08	149.08	232.16	62.52	12.03	17.8	578.5
	211	90.31	162.25	252.56	63.87	11.82	18.8	641.6
	212	89.67	160.00	249.67	62.75	11.49	17.3	632.5
Mean		87.51	159.30	246.79	61.93	11.70	18.1	628.5
Standard deviation		7.89	11.45	21.00	1.49	1.16	1.03	73.37

Table 1 Continued

		Lbs. of est. carcass fat	Lbs. of est. carcass lean	Lbs. of est. carcass bone	Circum. of forearm	Circum. of fore-flank	Circum. of single round patella	Length of body
1959	071	240.29	339.64	81.53	44.9	189.2	49.6	134.7
	072	211.04	335.09	86.26	44.7	184.9	52.0	137.5
	073	162.23	284.01	60.72	44.5	182.9	51.2	135.4
	081	233.21	315.64	71.21	43.5	188.3	51.2	130.5
	082	212.91	317.05	74.76	43.3	183.2	49.2	133.0
	091	204.35	342.18	77.64	42.8	183.4	50.2	137.5
	092	209.26	339.34	78.38	44.0	186.3	50.9	135.5
	101	240.07	332.64	81.27	43.7	187.4	50.8	140.2
	102	201.22	324.86	75.88	43.4	185.6	49.2	136.5
	111	214.79	314.58	73.84	42.9	182.3	50.1	133.0
	112	223.85	357.95	86.91	45.9	193.5	53.9	138.6
	113	203.45	336.72	79.22	44.7	187.0	49.8	139.8
	114	218.52	335.98	83.93	48.4	189.5	51.9	141.5
1960	051	243.80	318.24	107.91	51.9	185.2	55.2	140.1
	052	169.70	272.76	84.01	44.1	178.5	52.1	134.0
	061	203.98	337.98	93.48	48.9	186.0	53.7	137.9
	062	217.16	327.95	94.70	46.6	188.1	52.8	133.7
	063	225.74	319.78	92.52	48.7	185.6	51.9	135.6
	074	238.22	312.70	88.70	50.1	191.5	53.1	138.7
	075	219.12	325.04	93.17	48.9	188.8	52.1	139.1
	076	211.19	337.40	90.16	50.2	190.1	54.0	136.4
	091	209.17	341.19	94.81	50.6	188.3	53.3	136.6
	092	219.71	332.37	92.29	48.3	185.2	53.8	138.8
	102	238.62	359.53	99.64	47.2	186.6	52.0	134.2
	103	221.06	319.99	90.18	50.2	191.7	53.1	145.7
	112	193.22	370.69	95.18	49.8	191.2	54.7	140.6
	113	217.62	339.16	90.89	18.9	189.4	52.1	141.2
	131	223.89	322.19	96.04	48.2	189.7	52.9	140.4
	132	210.62	327.46	96.72	49.0	189.6	54.2	140.2
	171	275.85	355.64	100.77	48.8	198.0	54.9	139.9
	172	246.57	334.61	93.87	47.9	192.8	52.3	143.2
	191	223.41	348.99	96.00	48.4	187.9	51.6	139.7
	192	185.82	317.08	84.79	46.1	182.3	52.2	136.0
	211	248.85	310.26	116.75	45.2	191.2	51.6	137.9
	212	234.61	315.61	92.15	50.0	190.0	52.4	138.6
Mean		218.33	330.70	88.45	47.0	187.9	52.2	137.9
Standard deviation		39.19	38.83	13.24	3.45	6.51	2.40	5.17

Table 1 Continued

		Shoulder width	Width of loin	Width of hooks	Length from hooks to btm rnd	Length from pins to btm rnd	Length of rump	Height at withers	Depth of chest
1959	071	53.6	35.8	48.8	61.1	46.8	43.7	115.6	65.9
	072	53.8	34.2	47.0	61.5	47.9	42.8	115.1	64.7
	073	52.4	34.7	47.0	59.3	45.4	41.9	110.2	63.0
	081	53.8	35.5	47.0	58.6	45.5	42.0	113.0	64.8
	082	52.8	34.2	46.4	58.2	45.2	40.6	110.2	61.6
	091	51.8	35.5	47.2	59.1	47.1	42.3	113.5	63.4
	092	52.7	35.0	47.3	59.8	47.3	42.0	112.6	64.0
	101	52.1	33.9	47.9	59.1	47.1	42.8	116.7	63.1
	102	50.5	35.1	46.5	59.6	45.6	43.7	116.6	63.6
	111	53.0	33.6	47.8	58.6	43.8	41.6	112.6	65.0
	112	54.4	34.1	49.3	61.9	48.8	44.8	114.4	68.0
	113	52.1	35.5	47.0	59.7	47.3	42.7	115.6	64.6
	114	50.7	35.4	49.5	58.7	47.3	43.2	114.6	67.0
1960	051	56.1	38.0	46.9	60.8	45.7	45.6	119.4	65.9
	052	49.9	33.8	45.8	57.7	42.2	43.4	114.1	64.8
	061	53.8	37.4	46.5	58.2	45.2	44.0	113.3	64.7
	062	54.6	37.5	47.2	58.6	44.5	44.3	115.0	66.0
	063	53.9	37.7	47.4	58.7	43.0	44.5	116.0	66.5
	074	55.1	39.3	46.8	62.0	42.8	44.1	115.7	66.6
	075	54.2	39.2	47.1	60.2	44.8	44.4	118.2	65.7
	076	54.9	38.4	48.4	59.4	44.8	44.4	113.1	66.9
	091	54.4	37.5	47.3	61.5	43.8	45.3	117.0	66.9
	092	53.2	37.4	46.7	58.3	48.8	44.8	118.2	66.8
	102	54.0	39.5	48.4	63.2	45.5	45.7	121.7	68.5
	103	54.2	39.5	48.7	60.7	44.1	44.6	115.2	65.3
	112	55.6	38.3	49.4	63.7	47.8	44.9	121.0	68.2
	113	54.5	38.3	47.1	60.9	45.3	44.4	116.8	67.8
	131	53.5	38.0	48.7	61.6	45.2	45.9	117.2	65.9
	132	54.2	38.9	46.9	59.4	43.4	45.9	118.2	68.1
	171	55.7	39.5	50.1	61.8	45.7	46.8	119.8	70.6
	172	56.0	39.0	48.7	61.6	45.0	45.8	120.3	69.0
	191	53.9	38.2	47.8	59.9	45.4	44.4	117.8	65.7
	192	52.4	36.0	45.0	57.9	42.0	42.8	112.2	65.5
	211	55.6	37.8	48.6	58.8	43.9	44.7	118.9	68.6
	212	55.1	39.9	49.0	61.7	42.4	45.0	117.7	67.5
Mean		53.7	36.9	47.6	60.1	45.4	44.1	115.9	66.0
Standard deviation		2.41	2.50	2.17	2.96	3.18	2.11	4.38	3.16

Table 1 Continued

		Quarter width at patella	Circum. of cannon bone	Thick-ness of hide	Head width	Fat thick-ness	Final type	Init. type	Final condi-tion	Plump-ness of forearm
1959	071	52.8	19.8	1.36		.84	11.7	10.0	9.8	4.2
	072	52.8	20.3	1.30		.63	11.0	10.7	8.3	4.3
	073	51.2	19.7	1.46		.58	12.2	11.3	9.0	4.1
	081	51.9	19.6	1.30		.74	12.0	10.5	9.0	4.2
	082	50.7	20.6	1.32		.67	12.2	9.2	8.8	4.0
	091	51.6	19.2	1.31		.67	10.5	10.0	8.2	3.9
	092	50.9	20.2	1.46		.59	10.8	11.3	8.3	3.7
	101	51.6	19.7	1.40		.68	10.8	9.7	8.5	3.7
	102	50.3	19.4	1.26		.70	8.0	8.6	6.2	3.1
	111	49.9	19.7	1.37		.76	11.0	11.3	9.0	3.6
	112	53.0	20.7	1.56		.65	12.2	9.5	9.6	4.7
	113	51.6	19.6	1.25		.70	11.8	10.0	9.0	4.1
	114	51.9	21.3	1.46		.56	12.5	10.0	9.8	4.8
1960	051	54.1	20.7	1.33	22.4	.84	11.7	10.2	9.3	4.6
	052	50.7	19.6	1.21	21.1	.54	8.6	9.8	7.3	3.7
	061	51.9	20.7	1.29	21.7	.61	11.7	10.1	8.7	4.5
	062	53.9	20.3	1.23	21.8	.67	11.6	10.6	9.0	4.6
	063	52.6	20.3	1.42	21.9	.67	10.9	10.2	8.5	4.3
	074	55.9	20.2	1.68	22.3	.77	12.0	11.4	9.7	4.4
	075	55.2	19.6	1.28	22.0	.81	10.5	11.6	8.8	3.9
	076	54.7	21.1	1.44	22.6	.70	13.9	13.6	11.0	5.1
	091	52.7	20.2	1.31	22.4	.61	9.0	10.2	7.2	3.7
	092	52.2	19.8	1.31	22.0	.67	9.5	8.9	7.6	3.8
	102	54.8	20.8	1.36	22.9	.66	10.2	9.4	8.3	3.6
	103	53.5	20.2	1.30	22.8	.79	11.5	9.5	9.3	4.0
	112	54.9	20.8	1.35	22.4	.56	8.9	8.4	7.4	3.4
	113	55.1	20.2	1.32	22.4	.69	12.6	10.8	10.0	4.4
	131	52.8	20.2	1.31	22.1	.85	10.7	10.6	8.4	4.3
	132	53.0	20.3	1.27	22.0	.71	10.0	10.1	7.7	4.2
	171	55.9	20.6	1.47	22.1	.91	12.6	11.6	11.0	4.0
	172	54.4	20.3	1.65	22.2	.86	9.7	10.6	8.3	3.9
	191	53.7	20.6	1.28	22.2	.76	10.2	9.1	8.5	3.9
	192	52.1	20.2	1.23	21.7	.60	11.2	10.0	8.8	3.9
	211	52.0	19.0	1.34	22.2	.93	8.9	10.5	8.2	3.6
	212	54.3	20.1	1.28	21.7	.70	11.1	9.1	8.4	4.3
Mean		52.9	20.2	1.36	22.2	.70	10.9	10.2	8.7	4.1
Standard deviation		2.32	.90	.20	.67	.16	2.05	1.60	1.64	.75

Table 1 Continued

		Plump-ness of shoulder muscle	Full-ness of crops	Full-ness of loin	Full-ness of rump	Width of pins	Full-ness of outside round	Depth of round	Full-ness of twist	Car-cass conf.	Market grade
1959	071	4.9	4.6	4.9	4.7	4.4	4.8	4.4	4.7	21.3	19.8
	072	4.6	4.5	4.3	4.4	3.8	4.3	4.0	4.1	20.3	19.2
	073	4.4	4.4	4.5	4.6	4.2	5.2	4.1	4.2	21.0	19.7
	081	4.9	4.9	4.8	4.1	4.2	4.9	4.0	4.5	20.2	20.0
	082	4.7	4.8	4.8	4.1	3.2	4.5	4.2	4.5	20.0	19.8
	091	3.9	4.0	4.2	4.1	3.6	3.8	3.4	3.7	19.7	19.3
	092	4.0	4.0	4.4	4.3	3.7	4.1	3.5	3.6	19.3	19.5
	101	4.3	3.8	4.4	3.8	3.6	4.0	3.9	4.0	18.8	19.2
	102	3.2	3.0	3.5	3.7	3.1	3.3	2.9	3.0	19.0	18.6
	111	4.4	3.9	4.0	4.3	3.8	4.8	4.7	4.7	20.7	19.3
	112	4.8	4.4	4.4	4.6	4.3	4.4	4.1	4.1	20.5	19.8
	113	4.6	4.4	4.7	4.8	3.9	4.5	4.2	4.2	21.0	19.2
	114	4.6	4.1	4.4	3.7	3.8	4.5	4.8	4.2	20.5	19.8
1960	051	4.7	4.8	4.7	4.8	4.8	4.6	4.4	4.3	20.7	18.7
	052	3.6	3.8	4.0	4.1	3.7	3.6	3.4	3.4	20.0	18.3
	061	4.7	4.5	4.3	4.5	4.2	4.5	4.3	4.2	20.7	19.8
	062	4.7	4.7	4.6	4.4	4.1	4.6	4.3	4.2	20.7	19.3
	063	4.4	4.2	4.3	4.5	4.0	4.3	4.2	4.3	20.5	19.5
	074	5.0	4.8	5.0	4.4	4.1	4.4	4.0	4.1	20.4	19.4
	075	4.3	4.3	4.6	4.3	4.1	4.7	4.2	4.4	20.4	19.4
	076	5.2	5.3	5.3	4.9	4.7	5.4	5.3	5.5	20.8	20.2
	091	3.8	3.7	3.5	3.8	3.6	3.8	3.5	3.6	20.3	19.3
	092	4.2	3.9	4.0	4.3	3.9	4.0	3.6	3.9	20.5	19.3
	102	3.8	3.7	4.3	4.4	4.3	4.4	4.0	4.5	20.8	18.7
	103	4.2	4.3	3.8	4.0	4.0	4.2	3.8	4.0	20.3	19.3
	112	3.9	3.7	3.9	4.2	4.1	4.1	3.8	3.7	19.5	19.0
	113	4.2	4.3	4.4	4.4	4.0	4.9	4.5	4.6	20.0	20.0
	131	4.5	4.0	3.8	4.2	4.2	3.9	3.8	3.8	20.5	19.3
	132	4.4	4.1	4.1	4.2	3.9	4.2	3.9	3.9	20.5	18.7
	171	4.5	5.4	5.3	4.9	4.8	5.5	5.1	5.5	21.2	19.8
	172	4.0	4.3	4.5	4.3	4.4	4.4	4.0	4.4	21.3	20.3
	191	4.0	3.8	4.4	4.3	4.0	4.3	3.8	3.8	20.7	19.3
	192	4.0	4.0	4.0	4.4	4.2	4.3	3.9	4.1	20.5	19.7
	211	4.4	4.5	4.2	4.4	3.8	4.1	3.7	3.7	20.5	19.0
	212	4.1	3.9	4.3	4.5	4.1	4.9	4.6	4.6	21.0	20.0
Mean		4.3	4.3	4.4	4.3	4.0	4.4	4.1	4.2	20.4	19.4
Standard deviation		.76	.85	.78	.72	.68	.85	.80	.84	.96	.83

STATISTICAL PROCEDURES

Adjustment of Characteristics for Weight

The live weight of the steers in this study varied from 800 to 1216 pounds. An initial study by Minyard and Dinkel (1961) indicated that weight influenced a large number of the characteristics in this study. In order to remove this source of variation, traits were adjusted for live weight according to the method outlined by Snedecor (1956). The procedure involves the adjustment of all values of trait (Y) to a common weight (X), in this case the mean weight on a within year basis. The adjusted value of Y may be obtained directly by the use of the formula

$$\text{Adjusted } Y = Y - bx,$$

where b is the regression coefficient of the trait on weight and x is the deviation of each individual animal from the mean weight of the population (average weight of the steers in the respective year). The sire means of the traits adjusted for weight are given in Table 3.

Heritability Estimates

Of the methods for estimating heritability listed by Lush (1940), the paternal half-sib correlation method is applicable to this study. The analysis was made on an intra-year, intra-ranch basis. This should eliminate the effects of ranch and year variations from the sire differences. From this intra-class analysis, the components of genetic and environmental variance were estimated. The variation within years and

ranches must be separated into two mean squares, the between sire mean square and the within sire mean square. The form of the analysis of variance and the composition of the mean square is illustrated in Table 2. Fisher (1940) and Snedecor (1956) outlined the procedure involved in separating the sources of variation.

Table 2. Form of Analysis of Variance and Composition of Mean Square

Source of variation	Degrees of freedom	Mean square	Composition of mean square
Between sires	a-1	MS_s	B + kA
Within sires	a(g-1)	MS_w	B

The genetic interpretation of the means squares has been discussed by Lush (1948) and Falconer (1960). The notation used in describing the composition of the mean square was introduced by Fisher (1940). The between sires mean square contains two components. The within sire component (B) expresses the variation between individual offspring by the same sire. The between sire component (A) is a measurement of the differences between averages of sire groups within ranch and year. Therefore, calves with different sires have the variance A + B. Furthermore the between sire component is multiplied by k which signifies the average number of calves per sire group. In the situation of unequal numbers of calves per sire group, k is expressed by Snedecor (1956) as

$$k = \frac{1}{a-1} \cdot \left(N - \frac{g^2}{N} \right),$$

where a is the number of sire groups, g is the number of calves per sire group and N is the total number of calves.

Under the conditions of random mating, half-sibs are correlated on the average by one-fourth of the additive genetic variance, dominance deviations from genic linearity are uncorrelated and epistatic deviations from genic linearity are correlated by a small but undetermined amount (Lush, 1948). Therefore, calculation of the between sire component, by the formula $1/k\ (MS_s - MS_w)$, is equal to one-fourth of the additive genetic variance plus a small amount of the epistatic variance. If the assumptions are made that the sampling errors were minimized, the environmental effects were completely removed and the mating system was random, the genic, environmental and phenotypic variances can be estimated accurately by:

$$V(G) = 4(A)$$
$$V(E) = B - 3(A)$$
$$V(P) = V(G) + V(E).$$

The genic variance (G) represents that due to the effects of genes which combine additively and the environmental variance (E) represents the combined effects of environment, dominance and epistasis. The estimate of heritability should be equivalent to the ratio of genic variance to the total variance which is $\frac{V(G)}{V(P)}$ for animals from non-inbred populations under the conditions of random mating.

Since some of the bulls leased to the cooperating breeders were inbred, it would be expected that half-sibs of these inbred sires would receive some additional common inheritance. Consequently, the heritability estimates were divided by $1 + f$ to correct for the sire's

inbreeding where f is Wright's (1921) symbol for the inbreeding coefficient. This procedure was given by Hazel and Terrill (1945). In this analysis the average inbreeding of the sires was .0454. The standard error of the estimate of heritability was calculated using the formula

$$s_{\bar{x}} = \frac{B(B + kA)}{(A + B)^2 \cdot \sqrt{\tfrac{1}{2}(k - 1)ka}} \cdot \frac{4}{1 + f}$$

as given by Hazel and Terrill (1945).

Sires with steers in both years were considered as two separate sires for the purpose of estimating heritability and genetic correlations. The estimates should not be biased by this method since each yearly sample of steers would be an independent sampling of the sire's genotype. However, the actual number of sires was used in calculating the standard error of the heritability estimate.

Genetic, Environmental and Phenotypic Correlations

The specific method for estimating genetic correlations was developed by Hazel (1943) and is essentially the extension of the analysis of variance shown in Table 2 to include the covariance between traits. The composition of the sums of products in the covariance analysis may be interpreted in exactly the same way as the composition of the mean square from the analysis of variance. The assumptions which apply to the half-sib variance terms also apply to the covariance terms. Thus the component of covariance between sires is equal to one-fourth of the additive genetic covariance of the two traits plus an undetermined amount of the epistatic covariance. The genic,

environmental and phenotypic covariances between traits can then be computed as:

$$\mathrm{Cov}(G_iG_j) = 4\,\mathrm{Cov}(A_iA_j)$$

$$\mathrm{Cov}(E_iE_j) = \mathrm{Cov}(B_iB_j) - 3\,\mathrm{Cov}(A_iA_j)$$

$$\mathrm{Cov}(P_iP_j) = \mathrm{Cov}(G_iG_j) + \mathrm{Cov}(E_iE_j).$$

For the estimate of the correlation, the components of variance for each trait were obtained from the analysis of variance. Genetic, environmental and phenotypic correlations were obtained by the formula

$$r_{XY} = \frac{\mathrm{Cov}_{XY}}{\sqrt{V_X \cdot V_Y}}$$

which is the conventional correlation formula given by Snedecor (1956).

Table 3. Adjusted Sire Means

	Sire	Progeny	Lbs. of round	Lbs. of loin	Lbs. of rib	Lbs. of chuck	Lbs. of R/L/R	Lbs. of wholesale cuts	Dressing %
1959	071	6	74.53	54.13	29.81	84.85	158.45	243.31	61.43
	072	6	72.56	53.12	28.38	86.97	154.05	241.02	61.00
	073	6	73.44	54.07	30.64	87.02	158.17	245.17	62.72
	081	4	75.20	54.66	30.26	82.79	160.14	242.92	61.65
	082	4	71.76	53.35	27.78	87.52	152.91	240.41	60.50
	091	6	75.65	51.33	29.27	84.15	156.26	240.40	61.88
	092	6	71.41	51.03	29.12	81.44	151.56	233.01	60.05
	101	6	74.08	50.40	28.65	81.18	153.12	234.32	60.27
	102	5	75.33	51.65	29.16	82.15	156.15	238.28	61.33
	111	3	73.16	53.83	28.33	83.32	155.34	238.65	59.28
	112	8	75.62	52.36	29.03	85.51	157.37	242.53	61.66
	113	4	75.89	53.37	28.89	85.03	158.17	243.19	62.36
	114	4	72.93	51.56	27.59	82.79	152.08	234.86	61.08
1960	051	3	78.96	52.60	30.24	93.74	161.80	255.54	63.72
	052	4	73.79	53.08	30.22	83.07	157.10	240.15	60.65
	061	6	77.46	54.18	28.58	89.52	160.23	249.75	62.52
	062	6	77.04	56.44	30.09	91.75	163.57	255.32	63.31
	063	6	78.05	54.47	29.42	91.85	161.94	253.79	62.78
	074	5	74.91	53.80	31.34	85.63	160.06	245.68	61.20
	075	5	77.73	52.09	30.33	89.03	160.16	249.19	62.07
	076	6	76.47	52.47	30.34	87.90	159.29	247.19	60.96
	091	6	77.36	55.42	29.19	90.69	161.88	252.65	63.02
	092	6	78.23	54.59	29.98	91.47	162.81	254.27	63.50
	102	6	78.54	57.53	28.99	90.89	165.05	255.96	62.94
	103	6	75.85	54.41	29.55	88.35	159.81	248.15	62.00
	112	4	79.59	52.68	27.68	90.40	159.94	250.35	61.68
	113	6	76.69	54.40	31.49	89.56	162.74	252.13	62.33
	131	6	76.55	53.83	29.24	88.70	159.63	248.33	61.59
	132	6	76.32	54.13	29.42	88.17	159.87	248.04	61.07
	171	6	77.16	55.66	32.15	87.11	164.95	252.08	62.45
	172	4	74.77	53.81	32.00	86.20	160.56	246.77	61.06
	191	6	76.67	55.33	29.89	91.50	161.89	253.39	63.02
	192	6	77.63	54.25	28.94	89.49	160.83	250.31	62.69
	211	4	74.12	57.06	32.83	91.27	164.01	255.28	63.90
	212	3	76.79	56.45	29.94	91.40	160.19	254.58	62.79
Mean			75.84	53.80	29.67	87.53	159.29	246.85	61.93
Standard deviation			3.75	2.66	1.96	4.48	5.58	8.64	1.47

Table 3 Continued

	Sire	Rib eye area	Carcass grade	Chilled carcass wt.	Lbs. of est. car. fat	Lbs. of est. car. lean	Lbs. of est. car. bone	Circum. of forearm
1959	071	11.31	19.55	626.14	227.82	330.30	79.04	44.56
	072	12.00	17.79	617.31	206.99	332.06	85.44	44.55
	073	12.91	19.02	534.51	181.15	298.19	64.48	45.09
	081	11.79	19.13	634.47	247.05	326.00	73.96	43.91
	082	10.37	18.61	617.60	224.67	325.87	77.10	43.65
	091	11.91	18.73	627.36	211.15	347.28	79.00	42.98
	092	11.28	17.95	608.74	204.64	335.88	77.46	43.88
	101	10.72	17.50	611.01	222.64	319.58	77.79	43.17
	102	10.67	18.35	621.90	216.51	336.32	78.92	43.89
	111	10.19	18.14	621.05	228.97	325.21	76.66	43.35
	112	11.86	18.18	621.56	203.33	342.58	82.82	45.31
	113	10.83	19.13	635.58	216.60	346.57	81.83	45.06
	114	10.71	18.43	616.26	211.24	330.53	82.47	48.16
1960	051	11.82	18.24	653.40	234.48	310.13	105.56	51.38
	052	11.76	17.89	620.11	210.20	308.41	94.29	46.50
	061	12.35	17.89	638.36	209.51	342.78	94.86	49.26
	062	11.80	18.38	646.29	222.28	332.39	95.98	46.89
	063	11.80	18.20	642.40	229.01	322.62	93.33	48.89
	074	11.86	17.58	625.63	236.44	311.14	88.25	49.97
	075	11.27	18.44	637.95	223.84	329.15	94.35	49.22
	076	12.13	17.80	621.57	207.60	334.28	89.25	50.00
	091	11.32	18.53	642.57	212.13	343.76	95.54	50.74
	092	11.81	18.25	652.22	228.21	339.75	94.42	48.77
	102	11.93	17.47	645.64	218.24	341.80	94.53	49.05
	103	10.68	17.57	637.81	228.94	326.84	92.15	47.72
	112	13.03	16.15	628.55	182.77	361.60	92.55	49.23
	113	12.40	17.33	637.11	217.51	339.06	90.86	48.86
	131	12.08	17.49	633.19	223.37	321.74	95.91	48.20
	132	11.70	18.00	628.48	211.12	327.89	96.95	49.06
	171	11.80	18.48	644.50	238.88	323.50	91.49	46.60
	172	11.89	17.32	624.53	227.21	317.78	89.01	46.78
	191	12.12	17.94	644.89	217.16	342.55	94.43	48.03
	192	12.38	18.07	628.60	210.39	338.44	90.94	47.52
	211	11.87	18.78	649.07	252.53	313.46	117.67	45.42
	212	11.58	17.40	646.04	241.26	321.70	93.81	50.39
Mean		11.70	18.11	628.69	218.40	330.76	88.46	47.02
Standard deviation		1.10	1.00	47.38	26.27	31.27	11.59	3.19

Table 3 Continued

	Sire	Circum. of fore-flank	Circum. single round patella	Length of body	Shoulder width	Width of loin	Width of hooks	Length of hooks to btm. of round
1959	071	186.95	49.26	133.45	53.02	35.73	48.15	60.61
	072	184.14	51.86	137.11	53.56	34.14	46.77	61.31
	073	186.42	51.72	137.26	53.35	34.75	47.88	60.01
	081	190.88	51.57	131.85	54.48	35.55	47.63	59.10
	082	185.42	49.55	134.15	53.39	34.22	46.98	58.70
	091	184.67	50.45	138.16	52.17	35.50	47.50	59.34
	092	185.48	50.79	135.05	52.45	35.02	47.04	60.12
	101	184.20	50.22	138.47	51.25	33.85	47.04	58.42
	102	188.42	49.68	137.99	51.25	35.09	47.29	60.20
	111	184.95	50.53	134.38	53.68	33.63	48.46	59.14
	112	189.72	53.32	136.63	53.45	34.07	48.28	61.10
	113	189.42	50.22	141.03	52.70	35.55	47.70	60.23
	114	188.18	51.73	140.79	50.35	35.44	49.17	58.42
1960	051	183.31	54.85	139.02	55.52	37.57	46.39	60.23
	052	186.66	53.46	138.92	52.58	35.82	48.01	60.22
	061	187.13	53.89	138.63	54.14	37.69	46.77	58.54
	062	189.14	52.99	134.34	54.97	37.73	47.50	58.90
	063	186.28	51.98	135.96	54.15	37.86	47.54	58.90
	074	191.14	53.02	138.47	54.94	39.17	46.74	61.85
	075	189.78	52.28	139.66	54.47	39.41	47.36	60.49
	076	189.42	53.84	135.95	54.62	38.17	48.19	59.21
	091	188.91	53.37	138.99	54.54	37.65	47.44	61.65
	092	186.94	54.12	139.78	53.79	37.85	47.18	58.79
	102	187.68	52.38	143.28	52.84	38.51	47.62	61.91
	103	188.20	52.22	135.14	54.50	39.87	48.78	61.17
	112	189.10	54.34	139.38	54.97	37.81	48.88	63.08
	113	189.41	52.11	141.20	54.49	38.33	47.04	60.88
	131	189.58	52.88	140.34	53.45	38.02	48.66	61.58
	132	189.73	54.22	140.24	54.22	38.94	46.96	59.45
	171	190.68	53.65	135.53	53.30	37.71	48.05	59.58
	172	188.97	51.66	140.91	54.74	38.02	47.69	60.43
	191	186.67	51.42	138.94	53.54	37.86	47.43	59.50
	192	187.17	52.99	138.95	53.97	37.24	46.37	59.39
	211	191.88	51.68	138.36	55.82	37.98	48.80	58.98
	212	191.32	52.59	139.39	55.50	40.29	49.36	62.11
Mean		187.93	52.23	137.90	53.67	36.91	47.63	60.10
Standard deviation		3.56	2.22	4.14	1.78	2.29	1.53	2.58

Table 3 Continued

	Sire	Length from pins to btm. of rnd.	Length of rump	Height at withers	Depth of chest	Quarter width of patella	Circum. of cannon bone	Thickness of hide
1959	071	46.13	43.31	114.71	65.06	52.23	19.58	1.35
	072	47.78	42.61	114.83	64.42	52.64	20.26	1.29
	073	46.33	42.53	111.65	64.24	52.05	19.95	1.46
	081	46.22	42.52	114.07	65.64	52.50	19.76	1.30
	082	45.81	40.95	111.02	62.36	51.24	20.73	1.32
	091	47.42	42.52	114.00	63.89	51.86	19.26	1.31
	092	47.04	41.83	112.31	63.65	50.67	20.09	1.45
	101	46.26	42.20	115.38	61.94	50.88	19.52	1.39
	102	46.38	44.22	117.69	64.61	50.94	19.60	1.26
	111	44.48	42.05	113.65	65.88	50.48	19.92	1.36
	112	47.80	44.09	112.85	66.65	52.12	20.45	1.55
	113	47.96	43.15	116.55	65.50	52.14	19.75	1.25
	114	46.99	42.98	114.01	66.50	51.58	21.20	1.46
1960	051	45.39	45.28	118.43	65.28	53.64	20.51	1.33
	052	43.69	44.99	118.35	67.48	52.88	20.30	1.22
	061	45.35	44.26	113.89	65.08	52.23	20.76	1.29
	062	44.69	44.50	115.58	66.34	54.16	20.37	1.23
	063	43.10	44.61	116.37	66.72	52.81	20.35	1.41
	074	42.75	44.05	115.47	66.46	55.82	20.21	1.68
	075	44.95	44.56	118.73	66.03	55.43	19.72	1.28
	076	44.69	44.21	112.73	66.68	54.48	21.07	1.44
	091	43.89	45.45	117.34	67.08	52.86	20.28	1.30
	092	49.11	45.09	119.08	67.38	52.62	19.99	1.31
	102	44.76	44.92	119.55	67.14	53.75	20.47	1.35
	103	44.37	44.95	116.02	65.85	53.95	20.38	1.30
	112	47.40	44.47	119.89	67.51	54.37	20.58	1.34
	113	45.30	44.38	116.76	67.74	55.13	20.25	1.31
	131	45.15	45.91	117.10	65.85	52.81	20.19	1.30
	132	43.45	45.95	118.30	68.12	52.99	20.31	1.26
	171	44.32	45.37	115.97	68.14	53.93	19.96	1.45
	172	44.30	45.08	118.32	67.67	53.34	19.98	1.64
	191	45.12	44.18	117.12	65.32	53.38	20.48	1.28
	192	42.86	43.77	114.78	67.09	53.42	20.60	1.24
	211	44.01	44.79	119.28	68.84	52.25	19.06	1.33
	212	42.64	45.25	118.42	67.97	54.62	20.21	1.28
Mean		45.43	44.05	115.87	66.02	52.93	20.18	1.36
Standard deviation		2.92	1.84	3.57	2.55	1.86	.79	.19

Table 3 Continued

	Sire	Head width	Fat thick-ness	Final type	Initial type	Final condi-tion	Plump-ness of forearm	Plump-ness of shoulder muscle	Full-ness of crops
1959	071		.81	11.05	9.75	9.39	4.03	4.84	4.41
	072		.62	10.71	10.51	8.13	4.18	4.55	4.50
	073		.62	12.08	11.47	9.24	4.38	4.66	4.74
	081		.76	11.95	10.58	9.31	4.28	5.11	5.15
	082		.69	12.27	9.43	8.73	4.15	4.84	4.92
	091		.68	10.39	9.96	8.31	3.98	3.88	4.10
	092		.58	10.75	11.29	8.13	3.63	3.91	4.00
	101		.64	10.25	9.46	7.92	3.53	4.02	3.64
	102		.72	7.91	8.66	6.39	3.28	3.30	3.22
	111		.78	10.93	11.16	9.17	3.78	4.57	4.14
	112		.60	11.63	9.13	9.02	4.38	4.57	4.12
	113		.73	11.59	9.93	9.14	4.22	4.76	4.54
	114		.55	12.07	9.91	9.34	4.80	4.51	4.04
1960	051	22.28	.81	10.93	10.15	9.12	4.50	4.60	4.63
	052	21.57	.64	9.64	10.16	8.38	3.97	4.03	4.24
	061	21.80	.62	11.85	10.09	8.79	4.57	4.72	4.55
	062	21.84	.68	11.74	10.59	9.16	4.60	4.75	4.71
	063	21.94	.67	10.99	10.19	8.61	4.28	4.44	4.21
	074	22.27	.76	11.91	11.42	9.61	4.38	4.98	4.74
	075	22.09	.81	10.55	11.64	8.88	3.89	4.24	4.32
	076	22.57	.69	13.82	13.51	10.87	5.09	5.18	5.26
	091	22.38	.62	9.02	10.20	7.25	3.73	3.78	3.68
	092	22.13	.69	9.74	8.91	7.82	3.91	4.28	4.00
	102	22.62	.60	9.64	9.25	7.84	3.49	3.61	3.53
	103	22.90	.80	11.70	9.60	9.50	4.04	4.30	4.38
	112	22.22	.53	8.66	8.31	7.18	3.35	3.77	3.54
	113	22.40	.68	12.63	10.78	10.01	4.38	4.22	4.22
	131	22.09	.84	10.69	10.54	8.37	4.35	4.48	3.98
	132	22.04	.71	10.03	10.07	7.73	4.20	4.39	4.12
	171	21.68	.81	11.69	11.30	10.05	3.80	4.18	5.02
	172	21.94	.81	9.09	10.40	7.78	3.79	3.80	4.03
	191	22.16	.73	10.08	9.03	8.30	3.84	3.90	3.77
	192	22.03	.66	11.81	10.25	9.47	4.05	4.23	4.22
	211	22.24	.94	8.94	10.58	8.27	3.68	4.46	4.51
	212	21.78	.71	11.30	9.16	8.60	4.34	4.13	4.00
Mean		22.15	.70	10.90	10.22	8.69	4.09	4.33	4.26
Standard deviation		.60	.15	1.96	1.57	1.48	.68	.69	.76

Table 3 Continued

	Sire	Fullness of loin	Fullness of rump	Width of pins	Fullness of outside round	Depth of round	Fullness of twist	Carcass conf.	Market grade
1959	071	4.78	4.64	4.22	4.72	4.23	4.55	21.20	19.72
	072	4.25	4.42	3.75	4.31	3.92	4.06	20.29	19.13
	073	4.72	4.76	4.33	5.28	4.27	4.34	21.21	19.84
	081	5.06	4.29	4.42	5.03	4.15	4.73	20.40	20.13
	082	4.89	4.27	3.24	4.57	4.43	4.51	20.13	19.86
	091	4.18	4.17	3.62	3.87	3.54	3.76	19.74	19.40
	092	4.38	4.25	3.64	4.10	3.45	3.62	19.28	19.46
	101	4.23	3.66	3.42	3.89	3.71	3.80	18.64	19.00
	102	3.66	3.80	3.34	3.41	3.05	3.14	19.17	18.74
	111	4.03	4.48	3.90	4.95	4.82	4.93	20.82	19.47
	112	4.13	4.39	4.08	4.28	3.90	3.91	20.28	19.56
	113	4.96	4.88	4.01	4.58	4.34	4.27	21.14	19.37
	114	4.26	3.62	3.66	4.46	4.82	4.18	20.42	19.68
1960	051	4.36	4.57	4.68	4.49	4.10	4.14	20.59	18.53
	052	4.49	4.36	4.07	4.12	3.83	4.04	20.32	18.84
	061	4.36	4.47	4.27	4.55	4.41	4.28	20.71	19.91
	062	4.66	4.47	4.15	4.64	4.39	4.30	20.71	19.41
	063	4.34	4.47	4.08	4.30	4.23	4.33	20.52	19.55
	074	4.94	4.33	4.02	4.40	3.92	4.08	20.39	19.37
	075	4.57	4.31	4.16	4.67	4.27	4.40	20.44	19.47
	076	5.24	4.87	4.62	5.34	5.26	5.42	20.80	20.11
	091	3.60	3.85	3.64	3.77	3.56	3.66	20.36	19.38
	092	4.48	4.33	3.95	4.10	3.69	4.02	20.57	19.46
	102	3.64	3.81	3.77	3.93	3.57	3.75	20.67	18.37
	103	4.26	4.47	4.34	4.52	4.15	4.58	20.39	19.45
	112	3.68	4.10	4.02	3.93	3.64	3.53	19.42	18.85
	113	4.35	4.43	4.05	4.86	4.55	4.62	20.00	20.00
	131	3.74	4.15	4.19	3.88	3.81	3.72	20.50	19.32
	132	4.09	4.19	3.87	4.19	3.87	3.91	20.50	18.67
	171	4.86	4.67	4.46	5.07	4.68	5.04	20.88	19.30
	172	4.28	4.16	4.29	4.52	3.80	4.13	21.10	19.97
	191	4.34	4.24	3.96	4.18	3.73	3.75	20.62	19.24
	192	4.31	4.59	4.40	4.58	4.10	4.46	20.69	20.02
	211	4.24	4.38	3.86	4.12	3.71	3.73	20.53	19.05
	212	4.31	4.55	4.16	4.98	4.67	4.69	21.05	20.10
Mean		4.36	4.33	4.02	4.40	4.05	4.17	20.40	19.42
Standard deviation		.71	.68	.61	.81	.74	.76	.92	.75

RESULTS AND DISCUSSION

Heritability Estimates

The estimation of heritability of quantitative characteristics is important for two reasons. First, it expresses the fraction of total variation which is due to the genic differences between individuals. Another important application of heritability is that it has predictive value. Improvement in livestock can most effectively be brought about when the breeder can select on the phenotype provided there is a relatively high degree of correspondence between phenotypic values and the breeding worth of the animal. This degree of correspondence is expressed by heritability. Knowledge of these estimates can provide information on which to predict the outcome of selection.

It is important to realize that heritability is a property of one character in one population at a specific time. Since the value of heritability is estimated from the components of variance, a change in any component will change heritability. Estimates of heritability from other populations may be more or less the same depending upon the genetic structure of the population and the environmental conditions to which the population was subjected.

Production and Carcass Traits

Mean squares, heritability estimates and standard errors of the heritability estimates for the production and carcass traits are given in Table 4. Highly significant sire differences ($P < 0.01$) were found for final type, estimated pounds of carcass bone, carcass grade and

Table 4. Mean Squares, Heritability Estimates, and Standard Errors of Heritability Estimates of Production and Carcass Traits

	Mean squares			Standard error
	Between sires within ranch and year $B + kA$	Within sire, ranch and years B	Heritability $\frac{4A}{A+B}$	$\frac{4B\,(B+kA)}{(A+B)^2\sqrt{(\frac{1}{2})(k-1)(kn)}}$
Degrees of freedom	20	148		
Traits				
Adjusted weaning weight 1/	3573.4165*	1968.4716	.51	.26
Rate of gain 1/	.0620*	.0375	.42	.25
Final type	7.3585**	2.8491	.89	.30
Pounds of round	13.3915	12.5540	.05	.20
Pounds of loin	5.0595	5.2838	.00 (-.03)	.21
Pounds of rib	5.0115	3.0946	.40	.25
Pounds of chuck	19.8315*	11.2594	.48	.26
Pounds of round, loin and rib	30.9075	23.0793	.23	.23
Pounds of wholesale cuts	65.1010	40.4861	.40	.25
Rib eye area	1.5700	1.0122	.36	.25
Estimated pounds of carcass fat	949.0035	636.8043	.33	.24
Estimated pounds of carcass lean	587.2315	1008.2944	.00 (-.33)	.13
Estimated pounds of carcass bone	145.3875**	56.2795	.89	.30
Carcass grade	1.5370**	.7542	.63	.27
Color of lean 1/	.8295	.6016	.26	.23
Marbling score 1/	1.4150**	.6957	..63	.27
Tenderness 1/	2.1931	2.1797	.005	.20

k ≈ 5.2496

1/ Trait not adjusted for live weight.

* Significant at 5 percent level of probability.

** Significant at 1 percent level of probability.

color of lean. Sire differences were significant at the 5 percent level of probability for adjusted weaning weight, rate of gain and pounds of chuck. The negative heritability estimates calculated for pounds of loin and estimated pounds of carcass lean were the result of the progeny within sires expressing more variation than the progeny between sires. Since the theoretical values of heritability must be positive and between one and zero, these estimates would indicate a heritability of zero.

The three production factors in this study were adjusted weaning weight, rate of gain and final type. These three traits have been studied rather extensively by other workers. The heritability estimate of 51 percent calculated for weaning weight in this study was somewhat higher than estimates reported from other populations. Data reported by Knapp et al. (1950), Koch et al. (1955a, 1955b), Carter and Kincaid (1959a), Dinkel and Musson (1956) and Minyard (1959) indicated the heritability for weaning weight to fall in the range of 20 to 35 percent. Higher estimates of 52, 54 and 49 percent have been reported by Gregory et al. (1950), Rollins et al. (1956) and McCormick et al. (1956), respectively. The high heritability estimate of weaning weight in this study may have been due to the selection pressure on the leased bulls. If the leased bulls were notably above the average for weaning weight as compared to the other bulls used in the test, the variability between sire groups of different bulls would be greater and the heritability estimate would be biased upward.

Estimates for rate of gain reported by Dinkel (1958) and Shelby (1960) were 65 and 46 percent, respectively. Knapp et al. (1950, 1951)

and Dawson et al. (1955) reported the heritability of total gain in the feedlot to be 65, 70 and 18 percent, respectively. The estimate for rate of gain of 42 percent obtained in this study may then be considered somewhat low but still within reasonable limits.

The heritability estimate of 89 percent for final type appears high as compared to the estimates reported by Howarth (1960) and Dearborn (1959) of 36 and 60 percent, respectively. The higher estimate found in this study may have been due to two causes: 1) the animals in this analysis were older and may have expressed the trait more fully, 2) the selection pressure on the sires may have biased the estimate upward.

Heritability estimates of pounds of wholesale cuts have not been reported in the literature. The estimates calculated in this study were 5, 0, 40 and 48 percent for pounds of round, loin, rib and chuck, respectively. These estimates indicate that for this population genetic variability exists in the rib and chuck but not in the loin and round. This variability in the weights of rib and chuck is rather puzzling since the other two wholesale cuts expressed very little variation. The weights used in this analysis are on an untrimmed basis and since animals tend to cover the forepart of the body with fat first, the variability present may be an expression of the differences in fat deposition on the four cuts.

The heritability of rib eye area calculated in this analysis was 36 percent. This is considerably below the estimates of Knapp et al. (1946) and Kieffer (1958) who reported heritabilities of 69 and 56 percent, respectively.

Heritability estimates for estimated pounds of carcass fat, lean and bone were 33, 0 and 89 percent, respectively. Error could have been introduced into these estimates from two sources. First, from inaccurate separation of the fat, lean and bone of the 9-10-11 rib. Secondly, the regression equations from which the percent of estimated fat, lean and bone were calculated may not have been applicable to the population studied in this analysis. The equations used in this study were developed by Hankins and Howe (1946) from the complete separation of 536 beef carcasses.

The literature indicates a great deal of variation in the heritability of carcass grade. Knapp et al. (1946), Schott (1950) and Dawson et al. (1955) estimated heritability to be 84, 52 and 66 percent, respectively. However, Knapp et al. (1950) in revising estimates and including more animals presented an estimate of 33 percent. Shelby et al. (1955) and Carter et al. (1959) both calculated the heritability of carcass grade to be 16 percent. The estimate obtained in this study was 63 percent, more closely agreeing with Schott and Dawson et al. than the others.

The heritabilities given in Table 4 for color of lean, marbling score and tenderness were 26, 63 and 1 percent. These three factors are very important to the retailer and consumer under the present standards of appraising meats. The estimate of color of lean obtained by Shelby et al. (1955) of 31 percent agrees quite closely with the estimate of 26 percent obtained in this study. Harvin et al. (1961) calculated an estimate of 5 percent for marbling which is much lower than the estimate found in this study. Fat deposition as measured by

marbling would seem to be affected by factors relative to the environment, i.e., animals on a concentrate ration would have higher marbling scores than animals on grass. Consequently, variable estimates may be expected depending on the environmental conditions under which the cattle were tested. The heritability for tenderness of 1 percent in this study does not agree with Yao et al. (1953) and Kieffer et al. (1958) who reported estimates of 76 and 92 percent, respectively.

Measurements

Heritability estimates of measurements have received rather limited attention, the most extensive studies being reported by Schott (1950) and Dawson, Yao and Cook (1955). The above analyses included both beef and dual purpose steers produced and fed at Beltsville, Maryland. The most significant difference between the studies was the manner of calculation and the inclusion of more animals in the work of Schott. Gowen (1933) and Touchberry (1951) have reported data from mature dairy animals. Measurements of calves have been reported by Brown (1958), using data from Hereford and Angus calves at weaning.

Table 5 gives the mean squares, heritability estimates and the standard errors of the heritability estimates for the measurements used in this study. Highly significant sire differences ($P<0.01$) were found for length of body and for fat thickness. Significant sire differences ($P<0.05$) were found for circumference of the single round at patella and for circumference of cannon bone.

The estimate of heritability of circumference of forearm was 39 percent. This estimate is similar to the estimate of 31 percent reported

Table 5. Mean Squares, Heritability Estimates and Standard Errors of Heritability Estimates of Measurements

	Mean squares			
	Between sires within ranch and year $B + kA$	Within sire, ranch and years B	Heritability $\frac{4A}{A + B}$	Standard error $\frac{4B\ (B + kA)}{(A+B)^2\sqrt{(\frac{1}{2})(k-1)(kn)}}$
Degrees of freedom	20	148		
Measurements				
Circumference of forearm	8.6855	5.4536	.39	.25
Circumference of foreflank	13.2445	10.0791	.22	.23
Circumference of single round patella	6.3275*	3.5826	.49	.26
Circumference of cannon bone	.9580*	.5241	.52	.27
Width of shoulder	3.4500	2.2517	.35	.25
Width of loin	2.8558	2.4466	.12	.21
Width of hooks	2.5120	2.2463	.08	.21
Width of quarter at patella	2.2815	2.2169	.02	.20
Width of head 1/	.2200	.3184	.00 (-.24)	.18
Length of body	29.7105**	13.4642	.72	.28
Length from hooks to bottom of round	6.3885	6.5104	.00 (-.01)	.19
Length from pins to bottom of round	9.6840	7.2071	.23	.23
Length of rump	1.6215	2.3501	.00 (-.23)	.15
Height at withers	17.0470*	8.9788	.56	.27
Depth of chest	4.8910	4.9016	.00 (-.002)	.19
Thickness of hide	5.5000	3.2835	.44	.26
Fat thickness	.0395**	.0185	.68	.27

$k = 5.2496$

1/ Based on 116 steers.

* Significant at 5 percent level of probability.

** Significant at 1 percent level of probability.

by Dawson et al. (1955). The estimate of 22 percent for heritability of circumference of foreflank was lower than the estimates of 65, 58 and 33 percent reported by Gowen (1933), Schott (1950) and Dawson et al. (1955), respectively. Brown (1958) calculated estimates for circumference of foreflank of 44 and 6 percent for Hereford and Angus calves, respectively. One possible explanation for some of the higher estimates, especially those reported by Gowen, is that the data were collected from mature animals where expression of a trait may be more fully developed. Differences may also have resulted from genetic differences in the populations.

The heritability estimate of circumference of the single round at the patella was 49 percent. No other estimate has been reported for this particular measurement. A heritability estimate of similar magnitude, 52 percent, was calculated for circumference of cannon bone. Dawson et al. (1955) reported an estimate of 33 percent for the same measurement.

The heritability of width of shoulder in this study was 35 percent. This is decidedly higher than those of Schott (1950) and Dawson et al. (1955) which were zero. Brown (1958) calculated estimates for width of shoulder of 12 and 78 percent for Hereford and Angus calves, respectively. Width of loin was estimated to have a heritability of 12 percent. No other estimates for width of loin have been reported. The heritability of width of hooks was computed to be 8 percent. Gowen's (1933) data based on mature animals gave an estimate of 81 percent; however, the estimate of Dawson et al. (1955) was .5 percent and Brown reported heritability of 15 and 32 percent for Hereford and Angus calves, respectively.

Heritability of length of body was 72 percent in this study. This estimate is quite similar to Gowen's (1933) estimate of 68 percent and Touchberry's (1951) estimate of 58 percent. However, Schott (1950) and Dawson et al. (1955) reported this characteristic to have zero heritability. Brown (1958) also reported zero heritability for Hereford calves and a heritability of 10 percent for Angus calves.

The estimate of heritability of length from hooks to bottom of round and length from pins to bottom of round were zero and 24 percent, respectively. The accuracy of these measurements is somewhat limited as it must be decided rather arbitrarily the exact point to be called the bottom of the round. The heritability of length of rump was zero, which is the same as that reported by Dawson et al. (1955).

The estimate of heritability of height as measured from the withers to the floor was 56 percent. This is in close agreement with the estimates of 60, 73 and 65 percent obtained by Gowen (1933), Touchberry (1951) and Dawson et al. (1955), respectively. Schott (1950) reported an estimate of 100 percent for this character. Brown (1958) reported estimates of 29 and 38 percent for Hereford and Angus calves, respectively.

The heritability of depth of chest was zero. This may indicate that in this population the variability expressed in the height of the animal was actually caused by differences in the length of leg. Gowen reported a heritability of 61 percent for this characteristic.

A zero heritability estimate was found for width of head. Dawson et al. (1955) computed an estimate of 63 percent for width between the eyes. The characteristic used in this study was somewhat

different than described in Dawson's work and may account for some of the difference in the two estimates.

The heritability estimate calculated for thickness of hide was 44 percent. There are no other reported estimates for this trait.

Scores

Mean squares, heritability estimates and the standard errors of the heritability estimates are presented in Table 6. Highly significant sire differences ($P<0.01$) were found for initial type, final condition, fullness of twist and depth of round. Significant sire differences ($P<0.05$) were found for market grade. The heritability of initial type was 66 percent. This is much higher than the estimates of 28, 18 and 16 percent reported by Knapp et al. (1950) and Koch et al. (1955a, 1955b), respectively. Final condition also yielded a high estimate of 69 percent.

No work has been reported in the literature relative to component scoring as analyzed in this study. The estimates were from zero to 72 percent, with most of them falling in the range of 20 to 40 percent. The validity of these estimates depend, in addition to experimental design and lack of sampling error, on the ability of the judges to factually denote and keep a clear idea of the portion of the animal they are scoring. The estimates of heritability calculated for component scoring were: plumpness of forearm, 39 percent; plumpness of shoulder muscle, 15 percent; fullness of crops, 22 percent; fullness of loin, 27 percent; fullness of rump, 0 percent; width of pins, 24 percent; fullness of outside round, 21 percent; depth of round, 65 percent; and

Table 6. Mean Squares, Heritability Estimates and Standard Errors of Heritability Estimates of Subjective Scores

	Mean squares			
	Between sires within ranch and year	Within sire, ranch and years	Heritability	Standard error
	$B + kA$	B	$\frac{4A}{A + B}$	$\frac{4B\ (B + kA)}{(A+B)^2\sqrt{(\frac{1}{2})(k-1)(kn)}}$
Degrees of freedom	20	148		
Scores				
Initial type	3.7190**	1.7794	.66	.27
Final condition	3.6315**	1.6804	.69	.28
Plumpness of forearm	.6055	.3803	.39	.25
Plumpness of shoulder muscle	.4455	.3644	.16	.21
Fullness of crops	.6065	.4609	.22	.23
Fullness of loin	.5795	.4132	.27	.23
Fullness of rump	.4130	.4468	.00 (-.06)	.18
Fullness of outside round	.7300	.5618	.21	.23
Fullness of twist	1.0150**	.4583	.72	.28
Width of pins	.4300	.3176	.24	.23
Depth of round	.8755**	.4230	.65	.27
Carcass conformation	.9375	.6583	.29	.23
Market grade	.8910*	.4520	.60	.27

$k = 5.2496$

* Significant at 5 percent level of probability.
** Significant at 1 percent level of probability.

fullness of twist, 72 percent.

The estimate of heritability of carcass conformation was 29 percent. Estimates from other sources have not been reported for this particular trait. The heritability estimate of market grade of 60 percent falls well within the range reported by Knapp et al. (1946) of 63 percent and Dawson et al. (1955) of 58 percent. It is higher than estimates reported by Knapp et al. (1950), Shelby (1955) and Carter et al. (1959), who reported estimates of 45, 42 and 45 percent, respectively. The close agreement of the latter three estimates and the fact that more animals were used in those analyses may indicate that the heritability of market grade in this study may be high.

Genetic, Environmental and Phenotypic Correlations

When a relationship exists between two traits in a population it may be due to two types of forces. First, the genes affecting the two traits may be the same. Secondly, the two traits may be correlated because some environmental influence affecting one may also affect the other. Unless the genetic and environmental sources of correlation are separated it is impossible to predict the genetic consequences of the observed phenotypic correlation.

The genetic portion of this gross observation is of particular interest in breeding practice, although the environmental correlation may also be of some importance as it affects the rate of genetic gain. The significance of the genetic correlation is important for two reasons: 1) the change in one trait when selection is practiced for another can be predicted, and 2) it may be utilized to increase the efficiency of

selection. A positive genetic correlation between two desirable traits presents no difficulties since selection for one trait should result in the improvement of the other. A negative correlation, however, implies that selection for one trait will by itself cause deterioration of the other. It is therefore important to know the genetic relationships between traits to achieve maximum production from our livestock.

The procedure of calculating genetic correlations was not developed until 1943 and very few experiments have been set up to extensively study many of the relationships that exist. One important consideration in interpreting the genetic correlations in this study is that they represent parameters from a population which has been under selection for a period of time. Conceivably these animals or their ancestors have been under artificial selection since man started to change their environment and attempted to produce a more desirable animal from the standpoint of his needs.

Lush (1945), Lerner (1950) and Falconer (1960) have theorized on the interpretation of genetic correlations calculated from populations which have been under man-made selection. Lush stated that a negative genetic relationship may arise between two desirable traits in a population under selection because the gene frequencies of the two traits have been raised to a high value and they contribute little to the total variance of the traits in the population. Lush further hypothesized that negative genetic correlations may then be found more often than positive correlations in populations that have been under selection for a few generations.

In making application of genetic correlations Lerner (1950) has

cautioned that positive environmental correlations may impede selection. The reason for this is that animals selected on the basis of a particular trait may be superior only because of the environmental influences of another trait associated with it. Conversely, a negative environmental correlation may increase genetic progress.

Falconer states that every trait of an animal may be separated into two or three components to account for the variation it expresses and in turn each component may be separated into other metric characteristics. The result is a series of chains of causation which interconnect one with another. The relationship between particular traits thus becomes a very complicated matter.

The theoretical values of a correlation should fall within the range of $+1$ to -1. Due to sampling error present in this study, some of the correlations are not within this range. Consequently, more attention will be given to the sign of the genetic correlation than to the numerical value which it has.

The correlations studied in this analysis will be discussed in two parts. The primary purpose of this portion of the study is to determine the value of measurements and scores as predictors of carcass and quality characteristics. However, before discussing this aspect it is important to realize the interrelationships that may exist among production and quality characters. This is necessary as selection for any part of an animal results in selection of the whole animal and the study of the measurements and scores as predictors may lead to contradictory conclusions if the interrelationships of the economic factors are not first considered.

The interpretation of the interrelationships of characters measured by weight in the same animal is somewhat difficult. This involves the measurement of whole - part relationships, i.e., pounds of chuck must necessarily be correlated with pounds of wholesale cuts as the chuck is a wholesale cut. This situation is further complicated by the adjustment for live weight as both characters are components of live weight. However, the correction for weight is necessary when studying the correlations of the production and carcass traits with the measurements and the scores. This procedure removes a large part of the extraneous variation which may bias the results.

Due to the spurious (whole - part) correlations and the adjustment of traits for weight the interrelationships between the weight components of the carcass are not presented. However, the relationship of these traits with the measurements and scores will be discussed.

Relationships Among Production and Quality Traits

Table 7 presents the correlations among production traits and some of the carcass characteristics. The phenotypic correlation between adjusted weaning weight and rate of gain of .19 was of the same magnitude as the correlation of .24 reported by Carter *et al.* (1959). Swiger (1961) also reported a correlation of .24 between weaning weight and 140 day gain in the feedlot. Woodward *et al.* (1954) calculated a correlation of .03 on a weight constant basis. Koch and Clark (1955), in an extensive study of over 4000 calves, reported that the phenotypic correlation between weaning weight and rate of gain was -.33. The genetic correlation in this study is lower than those reported by Carter

Table 7. Genetic, Environmental and Phenotypic Correlations among Certain Production and Carcass Traits

		Rate of gain	Final type	Rib eye area	Carcass grade	Color of lean	Marbling	Tenderness
Adj. wng. wt.	Gen.	.30	- .52	.01	.59	-.42	.06	6.91
	Env.	.08	1.87	.03	-.51	.54	.40	- .74
	Phen.	.19	- .03	.02	.15	.15	.20	- .15
Rate of gain	Gen.		.44	.58	-.29	.55	.22	5.11
	Env.		- .80	-.20	.53	.18	.34	- .36
	Phen.		.12	.12	.08	.30	.27	- .03
Final type	Gen.			.17	.05	-.33	.15	4.46
	Env.			-.79	.38	.65	-.55	-1.00
	Phen.			-.07	.10	-.02	.03	.03
Rib eye area	Gen.				-.35	.91	-.11	-6.63
	Env.				.17	.40	.12	.23
	Phen.				-.10	.02	.00	- .10
Carcass grade	Gen.					.60	.94	4.99
	Env.					.39	.45	- .43
	Phen.					.06	.77	.03
Color of lean	Gen.						.74	.76
	Env.						.46	- .10
	Phen.						.09	- .05
Marbling score	Gen.							5.63
	Env.							- .55
	Phen.							- .01

Correlation greater than .19 is significant at 1 percent level of probability.
Correlation greater than .14 is significant at 5 percent level of probability.

et al. (1959) and Swiger (1961) which were .66 and .93, respectively. Koch and Clark (1955) found the genetic correlation between weaning weight and rate of gain to be negative though very low, -.03. From the standpoint of this study and the data reported by Carter et al. and Swiger it appears the selection for weaning weight would tend to increase rate of gain.

The negative genetic correlation between weaning weight and final type is somewhat difficult to understand as Koch and Clark (1955) found these traits to be positively associated. Weaning weight is a result of two factors, the milking ability of the cow and the gaining potential of the calf. Type or beefiness of the calf is determined by the genes the calf receives from the dam and the sire. If milk production of the cow has a negative genetic correlation with beef type of the cow and the heavier milking cows are transmitting their poorer beef type to their offspring, then a negative genetic correlation would be caused to exist between weaning weight and type score. This assumption is further substantiated by the phenotypic correlation between weaning weight and final type which was also negative though very small.

The genetic, environmental and phenotypic correlations between weaning weight and rib eye area were low; however, all of the correlations were positive. Woodward et al. (1954) reported a phenotypic correlation of .26 on a weight constant basis. The genetic and phenotypic relationships of weaning weight with carcass grade in this study of .59 and .15, respectively, were somewhat lower than the correlations of .84 and .21 reported by Carter et al. (1959).

The phenotypic correlations of adjusted weaning weight with color of lean and marbling were positive, while the phenotypic correlation of weaning weight with tenderness was negative. Woodward et al. (1954) reported a correlation of .13 between weaning weight and color of lean which agrees quite closely with the phenotypic correlation of .15 in this study. The phenotypic relationship of .20 between weaning weight and marbling was the same as given by Harwin et al. (1961). Of the three quality factors, color of lean was negatively and genetically correlated with weaning weight indicating that some of the genes causing the positive expression of one trait are causing the negative expression of the other trait. The genetic correlations between weaning weight and the other two quality traits, marbling and tenderness, were positive. The positive genetic correlation involving tenderness needs some consideration. The shear values were not coded in this study, therefore, the larger the value the less tender the steak. A positive correlation should then be considered as negative because of the nature of the data.

The phenotypic and genetic correlations between rate of gain and final type were positive while the environmental correlation was negative indicating that the environmental conditions favorable for rate of gain were not necessarily favorable for the expression of final type. The phenotypic relationship between rate of gain and rib eye area was .12 which was within the range of .24 and zero reported by Magee et al. (1958) and Woodward et al. (1954), respectively. Magee's data were not adjusted for final weight while Woodward's were corrected. The genetic correlation between rate of gain and final type in this study was positive.

The phenotypic correlation between rate of gain and carcass grade has received attention from several workers. Cook et al. (1951) reported a phenotypic correlation of .17 which agrees quite closely with the phenotypic correlation of .12 found in this study. Durham et al. (1953), Woodward et al. (1954), Magee et al. (1958) and Carter et al. (1959) reported phenotypic correlations of .30, .35, .33 and .31, respectively. Carter et al. (1959) also reported a positive genetic correlation of .85 between the two traits which is decidedly different from the negative genetic correlation of -.29 calculated from this data.

Rate of gain was positively correlated with color of lean and marbling score and negatively correlated with tenderness. Woodward et al. (1954) reported a negative phenotypic relationship between rate of gain and color of lean. The genetic correlations in this study between rate of gain and the three quality traits indicate that selection for gain would tend to increase tenderness, increase marbling and result in lighter colored lean.

The phenotypic correlations of final type with rib eye area, carcass grade, color of lean, marbling and tenderness were low. The correlation of .10 between final type and carcass grade accounted for approximately one percent of the variation in carcass grade. Genetically, a negative relationship was found between final type and color of lean. The other four traits had positive genetic correlations with final type.

The negative phenotypic correlation of rib eye area with carcass grade in this study was similar to the relationship of -.03 and -.04 reported by Woodward et al. (1954) and Magee et al. (1958), respectively.

Palmer et al. (1958) reported a high relationship of rib eye area with marbling score and tenderness. The genetic correlations of rib eye area with carcass grade, marbling and tenderness were negative while color of lean was positively associated with rib eye area.

The phenotypic correlation between carcass grade and color of lean (.06) is lower than the relationship of .27 reported by Woodward et al. (1954). The genetic correlation between carcass grade and color of lean suggests a strong positive association. The positive phenotypic correlation between carcass grade and marbling would be expected since marbling is a criterion of the grade of the carcass. Wheat et al. (1960) reported a correlation of .89; however, Harwin et al. (1961) reported a correlation of considerably less magnitude, .46. The genetic correlation between carcass grade and marbling in this study was positive. Palmer et al. (1958) reported a fairly high relationship between carcass grade and tenderness which is not in agreement with the correlation of .03 in this analysis.

The genetic correlations among the three quality traits, marbling, color of lean and tenderness, were positive indicating that selection for either color of lean or marbling would decrease tenderness. The phenotypic correlations were of low value. Cover et al. (1956) found a negative phenotypic correlation between marbling and tenderness of -.22; the correlation between the two traits in this study was virtually zero.

Relationships of Measurements and Scores with Production Traits

The genetic, environmental and phenotypic correlations between the production traits (adjusted weaning weight, rate of gain and final type) and the measurements and scores are given in Tables 8, 9 and 10, respectively. Prediction of the three production traits by the measurements and the scores is not important as these characteristics can be measured in the live animal and selection practiced directly for them. However, if measurements and scores are to be used in a selection program the knowledge of these correlations is necessary. For instance, circumference of forearm may have a high positive genetic correlation with pounds of round and a high negative genetic correlation with weaning weight. In this situation selection practiced in the same population for circumference of forearm (to increase pounds of round) and for weaning weight may actually result in little or no improvement. If the negative and the positive genetic correlations were of approximately the same magnitude and the heritability of the two selected traits were equal, the net result would theoretically be zero and there would be no improvement in either weaning weight or pounds of round.

The phenotypic correlations between weaning weight and the measurements and scores were low and accounted for very little of the variation in weaning weight. The measurements with the exception of length from pins to bottom of round and depth of chest tended to have a positive association with weaning weight while the scores were negatively correlated. Koch *et al.* (1955a) calculated positive genetic, environmental and phenotypic correlations between weaning weight and weaning or

Table 8. Genetic, Environmental and Phenotypic Correlations Between Adjusted Weaning Weight and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.55	.29	.11
Circumference of foreflank	-1.33	.94	.10
Circumference of single round patella	- .06	.21	.07
Length from shoulder point to pins	- .33	.69	.03
Width of shoulder	- .38	.34	.02
Width of loin	1.57	- .20	.02
Width of hooks	1.42	- .28	.13
Length from hooks to bottom of round	--	.07	.12
Length from pins to bottom of round	- .49	.24	- .04
Length of rump	--	.25	.07
Height at withers	- .05	.19	.06
Depth of chest	--	.08	- .04
Quarter width at patella	- .98	.18	.02
Circumference of cannon bone	.58	- .48	.09
Thickness of hide	.66	- .16	.24
Head width	.15	.05	.10
Fat thickness	- .55	.93	.00
Initial type	- .81	1.69	.15
Final condition	- .42	.54	- .07
Plumpness of forearm	- .33	.18	- .06
Plumpness of shoulder muscle	- .[illegible]	.09	- .09
Fullness of crops	1.16	- .47	- .12
Fullness of loin	-1.12	.57	- .11
Fullness of rump	--	.65	- .09
Width of pins	-1.03	.51	- .08
Fullness of outside round	-1.10	.43	- .11
Depth of round	- .23	.38	.01
Fullness of twist	- .47	.64	- .08
Carcass conformation	- .83	.52	.04
Market grade	- .86	.91	- .12

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

initial type score of .47, .68, .64, respectively. The comparable correlations between the two traits in this study were -.81, 1.69 and .15.

Positive genetic correlations were calculated between weaning weight and circumference of forearm, width of loin, width of hooks, circumference of cannon bone, thickness of hide and head width. These correlations indicate that some of the same genes contributing to weaning weight are also contributing to these measurements. The balance of the measurements were negatively correlated with weaning weight in the genetic sense.

Negative genetic correlations were found between weaning weight and the scores. This would be expected in view of the negative genetic correlation calculated between weaning weight and final type. The same hypothesis would seem to apply to these correlations as the one between weaning weight and final type.

The negative phenotypic correlations between rate of gain and the measurements appear to be in agreement with Black _et_ _al_. (1933). They reported that height at withers, depth of chest and length of body were negatively correlated with rate of gain and width of shoulder and slaughter grade were positively correlated with rate of gain. Their correlations accounted for about 10 percent more of the variation in rate of gain than the relationships calculated from this study. With the exception of fullness of twist and carcass conformation, the scores manifested a positive association with rate of gain. Durham and Knox (1953) reported that the phenotypic correlation between feedlot gain and

Table 9. Genetic, Environmental and Phenotypic Correlations Between Rate of Gain and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	1.20	- .79	.05
Circumference of foreflank	.13	- .25	-.13
Circumference of single round patella	.88	- .70	.06
Length from shoulder point to pins	.24	- .57	-.08
Width of shoulder	- .02	.11	.06
Width of loin	-1.84	.67	.28
Width of hooks	- .41	.01	-.07
Length from hooks to bottom of round	--	- .34	-.13
Length from pins to bottom of round	1.87	- .77	.12
Length of rump	--	- .50	-.12
Height at withers	.12	- .21	-.04
Depth of chest	--	.24	-.05
Quarter width at patella	1.57	- .06	.11
Circumference of cannon bone	.28	.02	.13
Thickness of hide	.17	.17	.17
Head width	.49	- .21	-.01
Fat thickness	- .05	.02	-.02
Initial type	- .20	- .29	.23
Final condition	.42	- .45	.06
Plumpness of forearm	.46	- .02	.18
Plumpness of shoulder muscle	.85	- .02	.22
Fullness of crops	.39	- .06	.08
Fullness of loin	.57	- .14	.11
Fullness of rump	--	.16	.09
Width of pins	.74	- .23	.10
Fullness of outside round	- .07	.12	.05
Depth of round	.05	.06	.05
Fullness of twist	- .02	.00	-.01
Carcass conformation	- .15	.04	-.03
Market grade	- .47	.66	.06

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

initial type was .16 and the correlation between feedlot gain and market grade was .40.

Genetic correlations between rate of gain and the measurements were positive except for the three width measurements taken on the top line of the steers. This is rather surprising since feeders in selecting cattle for the feedlot will usually attempt to select thicker topped animals. To add to this confusion, the genetic correlations of rate of gain with the subjective scores for fullness of crops and fullness of loin were positive.

One possible reason for the apparent discrepancy is that the persons scoring probably tended to evaluate width on the basis of the overall width or general uniformity of the animal rather than width at a specific location. Hence, an animal that is wider in the hooks than the crops may receive a higher score than the animal which is as wide in the hooks but has more width through the crops. On the other hand, measurements denote the actual differences between animals regardless of their other proportions. If a feeder were to select between two groups of animals on the basis of width, his judgment would be more nearly like the measurements. The feeder would actually be comparing general width of the two groups of cattle instead of scoring each animal and giving a score for proportional width.

If the above statements are true, the assumption may be made that the frequencies of some of the genes governing rate of gain and the three measurements have been raised. This would cause the genetic correlations to be negative as hypothezied by Lush (1948). The

important consideration is whether selection pressure for general width of cattle has been practiced and effective.

Phenotypically final type was found to be negatively correlated with width of hooks, length from hooks to bottom of round, length from pins to bottom of round, length of rump, height at withers and depth of chest. This indicates that the scorers appraising the general appearance of the animal tended to discriminate against these portions. Some of these negative correlations would be expected as the hookier, rangier steers would receive a lower subjective score.

Genetic correlations of final type with circumference of foreflank, length of body, width of shoulder, width of loin, length from pins to bottom of round, height at withers and fat thickness were negative. These correlations indicate that selection for the above mentioned measurements may have an adverse affect on final type. The remainder of the measurements had a positive genetic association with final type score.

The positive phenotypic and genetic correlations between final type and the scores would be expected. The scores were components of final type and therefore the correlations can be considered spurious.

Table 10. Genetic, Environmental and Phenotypic Correlations Between Final Type and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.28	- .55	.05
Circumference of foreflank	- .42	1.35	.12
Circumference of single round patella	.50	-1.60	.04
Length from shoulder point to pins	- .33	.81	.17
Width of shoulder	- .23	.99	.08
Width of loin	- .02	.14	.03
Width of hooks	.17	- .22	-.01
Length from hooks to bottom of round	--	-1.47	-.15
Length from pins to bottom of round	- .08	- .27	-.10
Length of rump	--	- .59	-.23
Height at withers	-1.07	1.34	-.55
Depth of chest	--	.17	-.11
Quarter width at patella	.42	.25	.13
Circumference of cannon bone	.59	-1.61	.13
Thickness of hide	.07	- .07	.03
Head width	.39	- .58	.01
Fat thickness	- .28	2.67	.15
Initial type	.67	- .50	.46
Final condition	.95	.81	.90
Plumpness of forearm	1.27	- .98	.57
Plumpness of shoulder muscle	1.29	.45	.61
Fullness of crops	1.25	.12	.60
Fullness of loin	.81	.83	.61
Fullness of rump	--	1.33	.54
Width of pins	.58	.85	.48
Fullness of outside round	1.17	.59	.67
Depth of round	.89	.08	.72
Fullness of twist	.87	.15	.70
Carcass conformation	.09	1.27	.33
Market grade	.86	- .90	.51

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

Relationships of Measurements and Scores With Pounds of Wholesale Cuts

The correlations between pounds of loin, rib, round and chuck and the measurements and scores are given in Tables 11, 12, 13 and 14, respectively. Genetic correlations between pounds of loin and the measurements and scores could not be calculated due to the negative sire components of variance obtained from the analyses of variance. As can be seen on page 38, the negative sire components cause a negative denominator and calculation is impossible since the square root of a real negative number cannot be computed.

With the exception of fat thickness, head width and thickness of hide, the measurements were positively associated with pounds of round on the phenotypic scale. However, these correlations were low and the measurements have little predictive value as indicators of the pounds of round. The scores also expressed a low association with pounds of round; all were positive except initial type, final condition, width of crops and width of loin.

Negative genetic correlations were found between pounds of round and length of body, width of hooks, circumference of cannon bone, thickness of hide and head width. Selection against the above measurements may be a means of increasing the proportion of this particular wholesale cut. The rest of the measurements expressed positive genetic correlations with pounds of round.

The genetic correlation between pounds of round and the subjective scores, fullness of outside round, depth of round and fullness of twist were negative. This was somewhat unexpected as these scores were

Table 11. Genetic, Environmental and Phenotypic Correlations Between Pounds of Round and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	1.19	- .07	.12
Circumference of foreflank	.18	.14	.15
Circumference of single round patella	.56	.18	.21
Length from shoulder point to pins	- .05	.33	.16
Width of shoulder	.98	- .15	.02
Width of loin	2.46	.08	.14
Width of hooks	-3.07	.31	.09
Length from hooks to bottom of round	--	.01	.10
Length from pins to bottom of round	2.05	- .16	.10
Length of rump	--	- .01	.24
Height at withers	1.47	- .07	.22
Depth of chest	--	- .02	.08
Quarter width at patella	4.11	.07	.23
Circumference of cannon bone	-2.55	.75	.08
Thickness of hide	- .72	- .11	-.19
Head width	- .34	.01	-.02
Fat thickness	1.13	- .54	-.07
Initial type	-2.22	.72	-.02
Final condition	- .46	.22	-.02
Plumpness of forearm	.97	.26	.06
Plumpness of shoulder muscle	1.30	.16	.03
Fullness of crops	- .36	.01	-.03
Fullness of loin	- .71	.08	-.02
Fullness of rump	--	.25	.22
Width of pins	2.21	- .04	.22
Fullness of outside round	-2.29	.57	.26
Depth of round	-1.22	.65	.14
Fullness of twist	- .51	.46	.13
Carcass conformation	.86	.09	.19
Market grade	- .76	.07	.09

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

a subjective measure of the dimensions of the hind quarters. It would seem that the more depth and width an animal has through the hind quarters the greater would be the weight of the round. Phenotypically this tendency was found to be true, genetically it was not. For this reason it is suggested that selection in the past has changed the gene frequency and thereby has forced the correlations to be negative between these particular traits.

The phenotypic and environmental correlations between pounds of loin and the measurements were low and accounted for little of the variation in pounds of loin. The scores, with the exception of width of pins and market grade, were positively related to pounds of loin. Although the genetic correlations were calculated, they were based on negative sire components of variance. Therefore, it was felt that the sampling errors of the genetic correlations were extremely large in this situation and no interpretation has been attempted.

Table 13 gives the correlations between pounds of rib and the measurements and scores. Phenotypically the measurements suggest that shorter, lower set, smaller boned steers would yield a higher proportion of rib than longer, taller cattle since circumference of single round at patella, body length, quarter width at patella, height at withers and circumference of cannon bone were negatively correlated with pounds of rib. All of the scores were positively associated with pounds of rib on the phenotypic scale.

No explanation can be offered for the negative genetic correlations between pounds of rib and the measurements. If selection were to

Table 12. Genetic, Environmental and Phenotypic Correlations Between Pounds of Loin and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm		.03	-.10
Circumference of foreflank		- .06	.18
Circumference of single round patella		.15	-.06
Length from shoulder point to pins		.27	.08
Width of shoulder		.08	.01
Width of loin		.05	.01
Width of hooks		.31	.07
Length from hooks to bottom of round	-1.59	.17	.14
Length from pins to bottom of round		.04	-.11
Length of rump	2.13	- .24	-.08
Height at withers		- .17	.06
Depth of chest		- .19	.06
Quarter width at patella		- .34	-.04
Circumference of cannon bone		- .05	-.23
Thickness of hide		- .16	-.11
Head width		.08	-.01
Fat thickness		.44	.20
Initial type		- .14	.08
Final condition		.16	.13
Plumpness of forearm		.26	.01
Plumpness of shoulder muscle		.15	.03
Fullness of crops		.07	.05
Fullness of loin		.26	.16
Fullness of rump	.21	- .00	.01
Width of pins		- .01	-.08
Fullness of outside round		.08	.05
Depth of round		.40	.05
Fullness of twist		.31	.04
Carcass conformation		.06	.18
Market grade		.58	-.04

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

Table 13. Genetic, Environmental and Phenotypic Correlations Between Pounds of Rib and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	-.51	-.09	.28
Circumference of foreflank	.99	-.08	.27
Circumference of single round patella	-.39	.21	-.08
Length from shoulder point to pins	-.34	.37	-.07
Width of shoulder	.14	.27	.22
Width of loin	.38	.07	.08
Width of hooks	-.86	.29	.04
Length from hooks to bottom of round	--	-.21	.11
Length from pins to bottom of round	-.06	-.06	-.06
Length of rump	--	-.10	.07
Height at withers	-.08	-.04	-.06
Depth of chest	--	-.38	.01
Quarter width at patella	2.99	-.53	-.10
Circumference of cannon bone	-1.49	1.45	-.02
Thickness of hide	.41	-.29	.03
Head width	.66	-.32	.04
Fat thickness	.75	-.27	.31
Initial type	.42	.01	.24
Final condition	.67	-.44	.22
Plumpness of forearm	.25	.07	.15
Plumpness of shoulder muscle	.69	.06	.23
Fullness of crops	.56	.19	.31
Fullness of loin	.70	.11	.33
Fullness of rump	--	.01	.18
Width of pins	.46	.13	.24
Fullness of outside round	.51	.05	.20
Depth of round	-.36	-.74	.12
Fullness of twist	-.02	.44	.16
Carcass conformation	.41	.04	.18
Market grade	.21	-.03	.10

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

be practiced for pounds of rib, special emphasis should be given to circumference of foreflank, width of shoulder and loin, width of lower round, thickness of hide and head width. These measurements were positively correlated with pounds of round indicating that the genes favoring one trait were influencing the other trait in the same direction. The scores with the exception of depth of round and fullness of twist manifested positive genetic correlations with pounds of rib.

The phenotypic relationships between pounds of chuck and the measurements and scores were low and have little predictive value. The negative correlations between weight of the chuck and the scores for carcass conformation and market grade may indicate the trend of the packing industry to discriminate against animals with a heavy front quarter. The chuck is the lowest priced cut of the four major wholesale cuts. Increased emphasis is therefore being placed on the loin and the round which are more valuable.

The negative genetic correlation between pounds of chuck and circumference of foreflank appears somewhat contradictory as it indicates that some of the genes contributing to the weight of the chuck will cause a decrease of heart girth. Without doubt the depth and width of the animal, especially through the forequarters, has received major emphasis in the mass selection of beef cattle. Furthermore, final type has also been associated with depth of body which is a component of the circumference of the foreflank. It may be that direct selection for final type and, consequently circumference of the body at the heart, has forced negative correlations to exist. Table 10 also

Table 14. Genetic, Environmental and Phenotypic Correlations Between Pounds of Chuck and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.50	- .21	.11
Circumference of foreflank	-1.45	.85	.03
Circumference of single round patella	.17	- .07	.06
Length from shoulder point to pins	.20	.15	.18
Width of shoulder	.35	.12	.22
Width of loin	.54	- .13	-.03
Width of hooks	- .99	.20	-.05
Length from hooks to bottom of round	--	- .04	.02
Length from pins to bottom of round	.97	- .35	.13
Length of rump	--	- .09	.04
Height at withers	.22	.00	.12
Depth of chest	--	.18	.07
Quarter width at patella	1.35	.09	.08
Circumference of cannon bone	.00	.03	.01
Thickness of hide	.08	- .01	-.04
Head width	.63	- .25	.02
Fat thickness	.16	- .15	.04
Initial type	- .54	.92	.04
Final condition	- .33	.52	.01
Plumpness of forearm	- .07	.18	.06
Plumpness of shoulder muscle	- .57	.24	-.01
Fullness of crops	- .41	.36	.09
Fullness of loin	- .58	.32	-.03
Fullness of rump	--	.07	.07
Width of pins	- .18	.10	.01
Fullness of outside round	- .53	.38	.06
Depth of round	- .21	.41	.04
Fullness of twist	- .43	.87	.04
Carcass conformation	- .04	.16	-.07
Market grade	- .65	.48	-.16

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

indicates that a positive phenotypic relationship exists between final type and circumference of foreflank.

Tables 15 and 16 present the correlations between the combined weight of the wholesale cuts and the measurements and scores. The first table measures the effects of the objective measurements and subjective scores on the three highest priced cuts, the rib, the loin and the round. The second table includes the weight of the chuck in addition to the previously mentioned cuts. Since the chuck accounts for approximately 35 percent of the total weight of the wholesale cuts, it would be expected to have a marked effect on the correlations in Table 16.

Green (1954), in an analysis of data from 50 market steers, found that width of shoulder accounted for about 20 percent of the variation of rib + loin + round. The rest of the correlations in Green's study between the various measurements and the weights of the wholesale cuts were essentially zero. The phenotypic correlations in Table 15 were of the same order. The phenotypic correlation involving width of shoulder with pounds of rib + loin + round in this study was .01.

The genetic correlations indicate that selection for animals exhibiting width through the loin, shoulder and lower round will increase the weight of the three higher priced cuts. The scores for carcass conformation and market grade also expressed a positive genetic relationship with the sum of the three wholesale cuts. These scores may be of value in the selection of animals for breeding purposes. The use of carcass conformation scores for selection of breeding animals would be restricted to progeny or sib testing.

Table 15. Genetic, Environmental and Phenotypic Correlations Between Rib ≠ Loin ≠ Round and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	- .34	.04	-.08
Circumference of foreflank	1.06	.07	.30
Circumference of single round patella	- .27	.31	.10
Length from shoulder point to pins	- .30	.57	.12
Width of shoulder	.68	- .27	.01
Width of loin	.11	.15	.12
Width of hooks	-1.74	.49	.15
Length from hooks to bottom of round	--	.07	.16
Length from pins to bottom of round	.48	- .16	-.00
Length of rump	--	- .15	.17
Height at withers	.66	- .17	.15
Depth of chest	--	- .24	.10
Quarter width at patella	3.95	- .22	.10
Circumference of cannon bone	-1.76	.80	-.17
Thickness of hide	.04	- .28	-.17
Head width	.20	- .07	.02
Fat thickness	.86	- .36	.18
Initial type	- .25	.44	.12
Final condition	.11	.25	.16
Plumpness of forearm	- .61	.43	.10
Plumpness of shoulder muscle	- .22	.22	.13
Fullness of crops	- .27	.21	.10
Fullness of loin	- .03	.27	.19
Fullness of rump	--	.21	.23
Width of pins	.77	.02	.21
Fullness of outside round	- .73	.57	.27
Depth of round	- .96	1.11	.16
Fullness of twist	- .45	.83	.16
Carcass conformation	.62	.15	.28
Market grade	.74	.42	.06

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

With the inclusion of the chuck (Table 16) the phenotypic correlations are of the same magnitude as before; however, some of the signs of the genetic correlations changed indicating the influence of chuck on the total weight of the wholesale cuts. The change of the signs may indicate that selection pressure will be effective in changing the distribution of the lean in the animal. For instance, the genetic correlation between circumference of forearm and pounds of round + loin + rib was negative (Table 15). In Table 16 circumference of forearm was positively correlated with pounds of wholesale cuts. Selection pressure against circumference of forearm should tend to increase the proportion of the rear wholesale cuts. Circumference of foreflank, as indicated by the genetic correlations, could possibly work in the same direction. The limitations of such selection will probably be due to functional efficiency of the animals, i.e., will the fitness of the population be maintained if selection is against the forequarters? Visual judging standards in the past have associated depth of body with strength and constitution of the animal.

Relationships of Measurements and Scores With Rib Eye Area

Phenotypically no measurement or score appears useful in the prediction of rib eye area (Table 17). Orme et al. (1959) reported the correlation of rib eye area with circumference of foreflank to be .51 and with circumference of hind leg to be -.36. Other measurements by Orme indicated that the variation in rib eye area could be predicted with greater accuracy than the correlations in this study indicated. The effects of weight were not removed in their data and the correlations

Table 16. Genetic, Environmental and Phenotypic Correlations Between Pounds of Wholesale Cuts and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.26	.16	.01
Circumference of foreflank	- .27	.46	.23
Circumference of single round patella	- .03	.21	.10
Length from shoulder point to pins	- .03	.52	.19
Width of shoulder	.54	- .14	.13
Width of loin	.73	.03	.08
Width of hooks	-1.35	.50	.11
Length from hooks to bottom of round	--	.15	.10
Length from pins to bottom of round	.78	- .28	.07
Length of rump	--	- .19	.14
Height at withers	.49	- .13	.18
Depth of chest	--	.04	.06
Quarter width at patella	3.49	- .28	.13
Circumference of cannon bone	- .90	.61	.11
Thickness of hide	- .06	- .23	-.15
Head width	.42	.18	-.01
Fat thickness	.51	.32	.14
Initial type	- .50	.87	.10
Final condition	.11	.41	.11
Plumpness of forearm	- .21	.34	.12
Plumpness of shoulder muscle	- .51	.31	.09
Fullness of crops	- .15	.26	.13
Fullness of loin	- .33	.36	.12
Fullness of rump	--	.20	.20
Width of pins	.36	.05	.15
Fullness of outside round	.60	.22	.33
Depth of round	- .06	.56	.21
Fullness of twist	- .43	1.00	.14
Carcass conformation	.39	.18	.25
Market grade	- .74	.54	.12

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

Table 17. Genetic, Environmental and Phenotypic Correlations Between Rib Eye Area and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.60	- .56	-.11
Circumference of foreflank	.68	- .14	.10
Circumference of single round patella	1.66	-1.14	.15
Length from shoulder point to pins	1.69	.89	.04
Width of shoulder	.12	- .00	.01
Width of loin	-3.50	.43	.03
Width of hooks	- .07	.08	.02
Length from hooks to bottom of round	--	.02	.08
Length from pins to bottom of round	.63	.05	.25
Length of rump	--	- .06	.10
Height at withers	- .52	.26	-.03
Depth of chest	--	.22	.03
Quarter width at patella	.12	- .12	-.01
Circumference of cannon bone	.16	- .50	-.08
Thickness of hide	.86	- .63	.06
Head width	- .07	.00	-.02
Fat thickness	.63	-1.13	-.14
Initial type	.08	- .23	-.06
Final condition	.00	- .01	-.06
Plumpness of forearm	.70	- .50	-.03
Plumpness of shoulder muscle	.34	- .19	-.05
Fullness of crops	.22	- .11	-.01
Fullness of loin	.54	- .08	.12
Fullness of rump	--	.02	.01
Width of pins	1.01	- .29	.11
Fullness of outside round	.49	.03	.16
Depth of round	- .70	.68	-.05
Fullness of twist	- .59	.64	-.06
Carcass conformation	- .06	.11	.05
Market grade	.01	- .10	-.04

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

reported would be spurious, i.e., larger steers would probably have larger rib eyes.

Negative genetic correlations were found between rib eye area and width of loin, width of hooks, height at withers and head width. Height at withers and head width were also negatively correlated phenotypically. The scores, with the exception of depth of round, fullness of twist and carcass conformation, were positively associated with rib eye area in the genetic sense.

Relationships of Measurements and Scores With Estimated Pounds of Carcass Fat, Lean and Bone

One of the most significant phenotypic correlations in this study was between estimated pounds of carcass fat and fat thickness. In this case fat thickness accounted for approximately 26 percent of the variation in total fat as estimated from the 9-10-11 rib. The genetic correlation between the two traits was positive which may indicate a means by which we can partially select for the amount of fat in the live animal. Woodward *et al.* (1954) also reported a phenotypic correlation of .63 between fat in the 9-10-11 rib and fat thickness. In other work Carter *et al.* (1959b) and Kidwell (1959) reported a positive phenotypic association of percent fat in the 9-10-11 rib with slaughter grade and carcass grade. The correlations reported by Carter *et al.* and Kidwell were considerably higher than the correlation in this study, but they were not adjusted for live weight.

Other aspects of this table are interesting from the standpoint of the methods of appraising cattle in the show ring. According to the genetic correlations selection for longer bodied, wider hipped cattle

Table 18. Genetic, Environmental and Phenotypic Correlations Between Pounds of Estimated Carcass Fat and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	- .50	.17	-.08
Circumference of foreflank	- .70	.50	-.16
Circumference of single round patella	-1.13	.45	-.22
Length from shoulder point to pins	- .56	.52	-.07
Width of shoulder	.15	- .04	.03
Width of loin	2.88	- .22	.05
Width of hooks	-1.40	.45	.10
Length from hooks to bottom of round	--	- .01	-.06
Length from pins to bottom of round	.08	- .22	.13
Length of rump	--	.14	.09
Height at withers	- .97	.39	-.23
Depth of chest	--	- .00	.02
Quarter width at patella	2.66	- .21	.06
Circumference of cannon bone	-1.05	.29	-.30
Thickness of hide	.27	- .16	.01
Head width	.56	.26	.07
Fat thickness	1.17	- .08	.51
Initial type	- .39	.71	.14
Final condition	.25	.51	.34
Plumpness of forearm	- .53	.53	.14
Plumpness of shoulder muscle	.49	.23	.29
Fullness of crops	- .41	.54	.27
Fullness of loin	.15	.33	.28
Fullness of rump	--	.20	.32
Width of pins	- .68	.70	.29
Fullness of outside round	- .52	.40	.15
Depth of round	- .23	.70	.21
Fullness of twist	.14	.42	.24
Carcass conformation	- .11	.26	.14
Market grade	- .26	.57	.16

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

standing on larger bone would result in selection against fat in the carcass. In the show ring the opposite appears to be true in most cases. Consequently, under today's standards though they may be changing somewhat, we are actually selecting animals which would hang a wastier carcass.

In this analysis it is unfortunate that negative sire components of variance resulted for estimated pounds of carcass lean. The amount of lean in cattle is of major concern, but because of the sampling errors it is not safe to assume that the sign of the genetic correlations could be indicated from the covariances which were calculated.

All of the measurements, except width of loin, width of hooks and fat thickness, were positively correlated with pounds of lean phenotypically. The relationship of carcass lean with market grade was negative. This is also the conclusion reported by Carter et al. (1959b). However, Kidwell et al. (1959) found a positive relationship between the two traits. Carter's work involved 38 Hereford and Hereford X Brahma steers and Kidwell reported data from 98 Hereford steers. Neither Carter's nor Kidwell's analysis was on a weight constant basis.

The correlations of estimated carcass bone with measurements and scores are presented in Table 20. Circumference of foreflank, width of shoulder and width of loin were negatively correlated with estimated carcass bone while the length and height measurements were positively correlated with bone on the phenotypic scale. The height and length measurements may be considered as skeletal measurements. The circumference and width measurements are more apt to change with the condition of the animal.

Table 19. Genetic, Environmental and Phenotypic Correlations Between Pounds of Estimated Carcass Lean and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm		.13	.10
Circumference of foreflank		.05	.07
Circumference of single round patella		.10	.12
Length from shoulder point to pins		.08	.06
Width of shoulder		.03	.00
Width of loin		- .13	-.06
Width of hooks		.00	-.00
Length from hooks to bottom of round	1.25	.01	.10
Length from pins to bottom of round		- .16	.09
Length of rump	.46	.01	.16
Height at withers		- .15	.12
Depth of chest	2.45	.19	.17
Quarter width at patella		.03	.05
Circumference of cannon bone		.12	.10
Thickness of hide		- .37	.03
Head width		.10	.03
Fat thickness		- .34	-.15
Initial type		- .58	.02
Final condition		.18	-.11
Plumpness of forearm		.18	.01
Plumpness of shoulder muscle		.07	-.05
Fullness of crops		- .08	-.13
Fullness of loin		- .07	-.13
Fullness of rump	.23	.05	.02
Width of pins		.13	.04
Fullness of outside round		- .16	.10
Depth of round		.15	-.03
Fullness of twist		.15	-.03
Carcass conformation		.02	.00
Market grade		.16	-.22

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

Table 20. Genetic, Environmental and Phenotypic Correlations Between Pounds of Estimated Carcass Bone and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.56	- .41	.26
Circumference of foreflank	- .28	.33	-.05
Circumference of single round patella	- .21	1.11	.06
Length from shoulder point to pins	- .07	1.07	.09
Width of shoulder	- .09	- .06	-.07
Width of loin	- .22	- .37	.11
Width of hooks	-1.07	.89	-.08
Length from hooks to bottom of round	--	.26	.01
Length from pins to bottom of round	.76	- .81	.17
Length of rump	--	.59	.20
Height at withers	.58	1.16	.22
Depth of chest	--	.93	.13
Quarter width at patella	- .70	.54	.05
Circumference of cannon bone	- .44	2.19	.08
Thickness of hide	.62	2.18	-.03
Head width	.33	- .25	.09
Fat thickness	.64	-3.83	-.03
Initial type	- .22	.11	-.17
Final condition	- .28	.10	-.21
Plumpness of forearm	.57	-1.39	.06
Plumpness of shoulder muscle	.05	.36	-.07
Fullness of crops	.23	1.23	-.18
Fullness of loin	- .20	.75	-.27
Fullness of rump	--	.41	-.11
Width of pins	- .84	1.37	-.09
Fullness of outside round	-1.19	1.01	-.29
Depth of round	- .44	.87	-.22
Fullness of twist	- .48	1.30	-.22
Carcass conformation	- .54	.30	-.22
Market grade	- .88	2.43	-.27

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

The scores, with the exception of plumpness of forearm, were negatively associated with pounds of bone. Cartwright et al. (1958) reported that the phenotypic correlation between market grade and percent bone in the 9-10-11 rib was .54. Kidwell et al. (1959) found that percent bone had a low negative relationship with feeder grade or initial type.

The body circumference, length and width measurements were negatively correlated with pounds of estimated carcass bone in the genetic sense. Depth measurements tended to be positively correlated. The negative genetic correlation of pounds of bone with circumference of cannon bone is surprising as it would seem that as the circumference of this measurement increased the weight of the bone would also increase. The environmental correlation of circumference of cannon bone with estimated pounds of carcass bone was positive and the gross correlation indicated a low but positive relationship.

Relationships of Measurements and Scores With Carcass Grade

Carcass grade as established by the U.S.D.A. standards is determined by the conformation of the carcass, intramuscular fat in the rib eye and the maturity of the carcass at slaughter time. Maturity is estimated principally by the amount of red bone marrow in the thoracic vertebrae and the amount of connective tissue between the lumbar vertebrae. The correlation between carcass grade and marbling as given in Table 8 was .77, indicating that major emphasis is placed on marbling in determining carcass grade. As shown in Table 21 the correlation between carcass grade and carcass conformation was .30.

Table 21. Genetic, Environmental and Phenotypic Correlations Between Carcass Grade and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.19	.10	-.14
Circumference of foreflank	.94	- .19	.27
Circumference of single round patella	- .76	.77	-.12
Length from shoulder point to pins	- .11	- .14	-.12
Width of shoulder	- .56	.88	.13
Width of loin	3.14	- .57	.02
Width of hooks	.14	- .06	.00
Length from hooks to bottom of round	--	.24	-.14
Length from pins to bottom of round	- .38	.19	-.06
Length of rump	--	- .42	.06
Height at withers	.51	-1.07	-.08
Depth of chest	--	- .23	.13
Quarter width at patella	1.84	- .49	-.06
Circumference of cannon bone	-1.13	1.24	-.19
Thickness of hide	- .94	1.02	-.08
Head width	.13	- .04	.03
Fat thickness	1.03	-1.62	.18
Initial type	.22	- .06	.13
Final condition	.13	.11	.13
Plumpness of forearm	- .03	.02	-.01
Plumpness of shoulder muscle	.02	.25	.14
Fullness of crops	.35	.30	.29
Fullness of loin	.53	.06	.26
Fullness of rump	--	.04	.19
Width of pins	.28	.13	.18
Fullness of outside round	.43	.05	.19
Depth of round	.17	.12	.15
Fullness of twist	.34	- .36	.13
Carcass conformation	.61	.06	.30
Market grade	- .09	.34	.06

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

The phenotypic correlations indicate that steers with more depth of the foreflank and width of shoulder and consequently, more circumference of the heart girth appear to have a favorable influence on carcass grade. Negative phenotypic correlations were found between carcass grade and the bulk of the other measurements. Cook et al. (1951) calculated positive phenotypic correlations of .09 and .16 for carcass grade with circumference of foreflank and width of shoulder, respectively. Correlations of carcass grade with height at withers and length of body in their study were -.42 and -.21, respectively. Yao et al. (1953) found that carcass grade was positively correlated with width and circumference of body.

With the exception of plumpness of forearm (this correlation was virtually zero, but the sign was negative) all scores were positively correlated with carcass grade phenotypically. The correlation between carcass grade and slaughter grade was .06. This is considerably below the correlations of .69, .36 and .60 reported by Cook et al. (1951), Durham and Knox (1953) and Carter and Kincaid (1959b), respectively. Their correlations were not adjusted for differences in weight.

Selection for carcass grade will develop a shorter bodied, narrower shouldered, smaller boned, thinner skinned animal as indicated by the negative genetic correlations which were calculated between carcass grade and these measurements. With the exception of plumpness of forearm and market grade, the genetic correlations between carcass grade and the scores were positive. The negative correlation between carcass grade and market grade is unexpected but is too low to be of

much consequence, the negative sign may be due to sampling error.

Relationships of Measurements and Scores With Marbling Score

Marbling, or the amount of intramuscular fat in the lean, is one of the primary factors used to determine carcass grade. It has been commonly associated with quality of the lean, i.e., tenderness, juiciness and flavor. As noted in Table 8, the phenotypic correlation between marbling and tenderness was -.01. Other workers have also found low relationships between marbling and meat qualities. Cover et al. (1956) computed the correlation between estimated marbling and shear value to be -.21. Correlations of marbling with juiciness were .37 and .13 for broiled and braised steaks, respectively. Palmer et al. (1958) reported that same conclusions. Consequently, marbling appears to have little value as a quality measurement.

Width and length measurements seem to be positively and phenotypically correlated with marbling while circumference measurements tended to be negative. Harwin et al. (1961) found that width of body, circumference of heart girth, circumference of hind quarter and wither height were negatively correlated with marbling (-.04, -.48, -.19 and -.62, respectively). The scores in this study, except for initial type, plumpness of forearm and market grade were positively correlated with marbling.

Negative genetic correlations were computed for marbling with circumference of single round at patella, length from shoulder point to pins, width of shoulder, length from pins to bottom of round, circumference of cannon bone and thickness of hide.

Table 22. Genetic, Environmental and Phenotypic Correlations Between Marbling and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	.50	- .78	-.09
Circumference of foreflank	.58	.08	.26
Circumference of single round patella	- .30	.16	-.10
Length from shoulder point to pins	- .25	.14	-.13
Width of shoulder	- .51	.70	.07
Width of loin	3.23	.53	.05
Width of hooks	.90	- .20	.10
Length from hooks to bottom of round	--	.18	-.06
Length from pins to bottom of round	- .22	.21	.02
Length of rump	--	- .36	.13
Height at withers	.39	- .76	-.04
Depth of chest	--	.43	-.00
Quarter width at patella	2.36	- .54	-.03
Circumference of cannon bone	- .79	.83	-.15
Thickness of hide	- .54	.76	.03
Head width	.11	.03	.02
Fat thickness	.85	-1.48	.11
Initial type	- .15	.23	-.03
Final condition	.61	-1.05	.10
Plumpness of forearm	.14	- .30	-.07
Plumpness of shoulder muscle	.15	.04	.07
Fullness of crops	.20	.14	.15
Fullness of loin	.40	- .06	.14
Fullness of rump	--	.02	.11
Width of pins	.53	- .05	.19
Fullness of outside round	.53	- .27	.06
Depth of round	.25	- .20	.10
Fullness of twist	.38	- .82	.03
Carcass conformation	.70	- .28	.17
Market grade	- .18	.26	-.02

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

The genetic correlations for marbling with initial type and market grade were negative; however, the remainder of the scores were positive. Environmental correlations varied a great deal. The negative environmental correlations for marbling with fat thickness and final condition were confusing as it indicates that conditions favorable for the expression of one trait (marbling) are not favorable for the others.

Relationships of Measurements and Scores With Color of Lean

The value of color of lean is reflected in consumer preferences, as the purchaser of beef prefers a light colored cut. The heritability of color of lean was low (.26), but does indicate that the genes of the sire and dam have an effect. Consequently, if a predictor of color of lean could be found in the live animal, selection could bring about improvement in this trait.

The phenotypic correlations of color of lean with the scores were too low to be of any practical significance. The environmental correlations were generally low; however, all the scores had positive environmental correlations with color of lean. Genetically, it appears selection for such traits as length of body, width of shoulder, width of loin, height at withers and width through the lower round could be a means of producing lighter colored lean. If selection were based on scores, fullness of loin appears to have the only promise of improvement. The animals used in this study may limit the usefulness of the above observations as very little variation existed between sire groups, the greater source of differences being due to environment.

Table 23. Genetic, Environmental and Phenotypic Correlations Between Color of Lean and Measurements and Scores

	Genetic	Environ-mental	Pheno-typic
Circumference of forearm	-1.07	- .64	-.07
Circumference of foreflank	- .30	.03	-.05
Circumference of single round patella	- .46	.22	-.04
Length from shoulder point to pins	.45	- .20	.12
Width of shoulder	.07	- .30	-.18
Width of loin	1.66	.03	.13
Width of hooks	-1.44	.18	.07
Length from hooks to bottom of round	--	- .09	.03
Length from pins to bottom of round	.71	- .17	.06
Length of rump	--	- .42	.00
Height at withers	1.32	- .76	.10
Depth of chest	--	- .14	-.02
Quarter width at patella	4.89	- .46	-.01
Circumference of cannon bone	.33	.04	-.10
Thickness of hide	-1.16	.45	-.12
Head width	.02	- .05	-.04
Fat thickness	.46	- .19	.11
Initial type	- .78	.38	-.16
Final condition	- .22	.14	-.03
Plumpness of forearm	- .23	.13	.01
Plumpness of shoulder muscle	-1.29	.37	.02
Fullness of crops	-1.08	.40	.04
Fullness of loin	.78	.28	-.01
Fullness of rump	--	.13	.02
Width of pins	- .44	.11	.04
Fullness of outside round	-1.21	.33	-.04
Depth of round	- .23	.27	.03
Fullness of twist	- .05	.05	.00
Carcass conformation	- .28	.17	.04
Market grade	- .65	.58	.04

Correlation greater than .19 is significant at 1 percent level of probability.

Correlation greater than .14 is significant at 5 percent level of probability.

APPLICATION

Improvement of livestock can be accomplished more efficiently and accurately with the knowledge and use of genetic parameters. It should be remembered that the parameters calculated were from a particular population taken at a specific time and will not necessarily be the same for another population. Genetic parameters may not remain constant for any length of time, i.e., over four or five generations.

Dickerson and Hazel (1943), Lush (1948) and Falconer (1960) have discussed methods by which response to selection can be estimated for several different situations. The most effective selection program for the breeder is the system that produces the most improvement per unit of time. The change in the population mean brought about by selection is influenced by the heritability of the trait and the amount of selection applied as measured by the "selection differential." Of these factors the commercial producer has the most control of the selection differential as this is influenced by the proportion of the population the breeder saves for breeding stock. In addition the selection differential is affected by the standard deviation of the trait under consideration.

The most common method for improvement of livestock is mass selection. This is the method by which individuals of the population are selected only on their own phenotypic values. Of the major economic traits listed in Table 4, it is obvious that only the three production traits can actually have direct selection applied to them. Consequently, some other system must be used, such as sib selection, to make the most rapid improvement. Sib selection is the method by which individuals are

selected on the merits of relatives, i.e., half or full sibs. Another alternative presents itself in this study. It may be that selection for a measurement or score may influence the rate of improvement of an important trait to a larger degree than selection by the sib method. This utilizes the principles of correlated response, the details of which are given by Falconer (1960).

Data involving the comparisons of actual correlated responses versus theoretical responses are limited. Research in this area has been restricted to Drosophila and mice. Falconer (1954) and Reeve and Robertson (1953) found excellent agreement between expected and observed responses of correlated variables with traits related to body size. Clayton et al. (1957) found low relationships between expected and observed response when studying characteristics in Drosophila which were not directly associated with the size of the body.

The formulae used to calculate the expected response for mass selection (Rm), sib selection (Rs) and correlated response to selection of a measurement (CRy) are, respectively,

$$Rm = i \; \sigma ph^2$$

$$Rs = i \; \sigma ph^2 \cdot \frac{nr}{\sqrt{n\,[1 + (n - 1)t]}}$$

$$\text{and } CRy = i \; h_x h_y \; r_a \; \sigma p_y$$

where i = selection differential (assumed to be equal for all methods)

σp = standard deviation

h^2 = heritability estimate

r = genic correlation, for half sibs $r = \frac{1}{4}$

t = correlation of phenotypic values of members of the families

n = number of individuals in the families

r_a = genetic correlation between traits x and y.

Using the above formulae the expected annual improvement for the major economic traits were calculated and presented in Table 24. The heritability estimates, genetic correlations and standard deviations calculated in this study were utilized. The gain from correlated response was computed using circumference of forearm as the selected variable. The assumptions for the calculation of the expected gain were: 1) all selection takes place at one stage of development in each generation and 2) fifty percent of the heifers and five percent of the bulls were saved for breeding. In the situation of mass selection, it was also assumed that direct selection could be applied to each trait.

Selection for circumference of forearm would cause more rapid improvement than sib selection for pounds of round, rib eye area and tenderness. The heritability estimates for circumference of forearm, pounds of round, rib eye area and tenderness were .39, .05, .36 and .005, respectively. The genetic correlations of circumference of forearm with pounds of round, rib eye area and tenderness were 1.0, .60 and 1.0, respectively. All the other major traits listed in Table 24 had either a lower heritability than circumference of forearm or the genetic correlation between the trait and the measurement was negative. It appears from this brief illustration that correlated response would be expected to be superior to either mass or sib selection when the heritability of the secondary characteristic, i.e., circumference of forearm, is substantially higher than the estimate of the primary trait

Table 24. Expected Response of Major Traits to Three Selection Systems1/

Trait	Mass selection	Sib selection	Correlated2/ response
Adjusted weaning weight	7.58	4.59	3.64
Rate of gain	.03	.02	.03
Final type	.52	.25	.10
Pounds of round	.10	.09	.27
Pounds of loin	0	0	- .28
Pounds of rib	.36	.22	- .18
Pounds of chuck	1.08	.63	.49
Pounds of round + rib + loin	.75	.53	- .33
Pounds of wholesale cuts	2.40	1.51	.62
Rib eye area	.12	.08	.09
Estimated pounds of carcass fat	-3.70	-2.00	-2.44
Estimated pounds of carcass lean	0	0	-3.46
Estimated pounds of carcass bone	3.37	1.58	1.24
Carcass grade	.19	.10	.02
Color of lean	- .07	- .05	- .07
Marbling score	.18	.10	.07
Tenderness	- .0003	- .0003	- .0018

1/ Expressed in units per year.

2/ Response if selection were for circumference of forearm

and when the genetic correlation between the two traits is high. Furthermore, it illustrates the practical use which measurements and scores may have in selecting for traits which cannot be measured on the live animal.

Due to the large sampling errors apparent in the genetic correlations the method of attaining genetic gain by correlated response is intended only as an example. Recommendations are restricted until further data is compiled and analyzed.

SUMMARY

Data collected on 184 grade Hereford steers in 1959 and 1960 were analyzed. Heritability estimates of production traits, objective measurements, subjective scores and carcass characteristics were computed. The genetic, environmental and phenotypic correlations of production and carcass traits with the measurements and the scores were calculated. Data were analyzed on an intra-ranch, intra-year basis.

The heritability estimates computed from this study show considerable variation but indicate that genetic improvement could be expected for the major portion of the traits if selection were practiced. The heritability estimates for the three production factors (weaning weight, rate of gain and final type) were large enough to expect improvement in these traits with mass selection.

The reliability of the heritability estimates for the four wholesale cuts depends on the influence of fat deposition on the weights of the wholesale cuts. It is suggested that this problem receive more detailed study. The heritability estimate for estimated pounds of carcass lean was zero in this study. This may indicate that the production of leaner cattle may more effectively be brought about by decreasing fat content instead of attempting to produce more lean. The important consideration in a selection program of this type would be that marbling score be maintained at its present level as marbling is the most important criterion in grading beef carcasses. The heritability estimate of marbling score in this study was high enough to warrant investigation of such a program.

The magnitude of the heritability estimates of the measurements indicates that changes in body dimensions may be brought about by selection. Attempts to change body dimensions by selection may be limited by the relative fitness of the selected animals and this factor may slow progress. Robertson (1955) and Falconer (1960) have discussed the effects of selection on metric characteristics and its relationship to fitness. Most of the discussions presented by Robertson and Falconer are largely assumptions and no evidence at the present time can be offered. The heritability estimates of the scores show considerable variation and may also prove to be effective in changing body structure.

Phenotypically no high correlations were noted among the production and carcass traits in Table 7. The single exception was the relationship between carcass grade and marbling, marbling accounting for approximately 59 percent of the variation in carcass grade. Very few negative genetic correlations were found among the major economic traits, indicating no gross antagonisms would be expected to result from selection of these metric traits at the same time.

Phenotypically the prediction of carcass merit of the live animal appears somewhat limited, as most of the phenotypic correlations in this study were quite low and accounted for little of the variation expressed by the major traits. It is suggested that combinations or ratios of these measurements may have some promise in a future study. The measurements of fat thickness appear to have some value in estimating the amount of carcass fat and perhaps a study relative to this particular trait may yield useful information in the selection of leaner animals.

Genetically the measurements may have some use in improving beef cattle. While some of the measurements were negatively associated with some of the economic traits, certain of the measurements, notably circumference of forearm, circumference of foreflank, quarter width at patella, head width and fat thickness were positively associated with the major traits. The genetic correlations indicate that selection for these measurements may cause improvement in such traits as pounds of round, rib eye area, carcass grade and marbling score.

Width of shoulder and width of loin seem to hold special emphasis for development of livestock for leanness or meatiness, as these two measurements were positively related with the wholesale cuts on the genotypic scale. However, these measurements were negatively correlated with the production traits.

These steers were subjected to a different environment than bulls and heifers might receive. The influence of sex relative to the measurements and scores should be studied before any recommendation can be made for breeding stock.

The component scoring appears unnecessary in light of the high phenotypic and genetic correlations between final type and the scores of the live animal. The correlations in Table 10 indicate that a final subjective score would give as much information on a beef animal as the breakdown scoring. It is further recommended that more emphasis should be given to width of hooks, length from hooks to bottom of round, length of rump and depth of chest when placing a final type score on a beef animal. The phenotypic correlations between these measurements and the

wholesale cuts were positive. The correlations between final type and the measurements indicate that these portions of the animal were discriminated against in arriving at a score for final type.

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