HERITABILITY OF WEIGHT AND CERTAIN BODY DIMENSIONS OF BEEF CATTLE AT WEANING

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INTRODUCTION

The differences that exist among beef calves in weight and grade at weaning offer opportunity for improvement by selection. Information concerning procedures designed to locate and select as breeding stock individuals of superior weaning traits is desirable because of the large number of calves that are sold at weaning. It has been estimated that as high as seventy-five per cent of the calf crop in Arkansas is sold as milk fat slaughter calves. The remainder are sold as feeder calves or kept as replacements. Under either plan of production the market value of the calf is determined largely by weight and grade. Weight of the calf determines the number of pounds for which payment is made. Selling price per pound is largely a reflection of grade. Scales provide an objective measure of weight, but grade must be subjectively evaluated by both buyer and seller.

The lack of objective measures of grade has presented problems in the accurate assessment of differences among animals, especially within herds where management and similar bloodlines tend to reduce variability. Tape and caliper measurements of beef cattle have been used to describe certain body dimensions objectively. Such measurements may aid in the assessment of conformation differences, but they give little indication of balance, smoothness, or quality of the animal which must be considered in an over-all score or grade evaluation. Measurements do, however, appear to be useful for the study of variation and relationships of size to other factors among cattle because of the greater accuracy with which certain body parts may be described.

Of particular interest to the breeder is the relative importance of the genetic variation. This portion of the total variation determines the extent to which he may expect to improve weight and dimensions of desirable size and conformation in his cattle. Genetic relationships of weight and various body dimensions are of interest since they indicate to the breeder the effect that he may expect selection for weight to have in changing body dimensions.

The primary objectives of the present study were to obtain estimates of heritability of weight and certain measurements at weaning (which attempt to measure body dimensions stressed in the subjective evaluation of conformation), and to obtain estimates of phenotypic and genetic correlations between these body measurements and weight.

REVIEW OF LITERATURE

Partitioning Genetic Variation

Like most quantitative characters the traits chosen for this study are affected by many pairs of genes and, also, are influenced a great deal by environmental variations. Procedures for the determination of the importance of genetic and environmental causes of differences among individuals have been developed during the past three or four decades. It is only very recently that these procedures have been applied to studies of beef cattle.

Changes in the genetic composition of a population from generation to generation is governed by the accuracy with which either nature or man recognizes genetic differences on the basis of phenotypic differences between individuals or groups of individuals. That early geneticists may have realized this to a certain extent is suggested by statements such as that of Yule (1906) that,

> A complete theory of heredity should take into account, besides germinal processes, the effect of the environment in modifying the soma obtained from any given type of germ-cell, an effect which is hardly likely to be negligible in the case of such a character as stature.

As early as 1910, Weinberg suggested methods of separating genetic and environmental components of total phenotypic variability, but his contribution to the subject was overlooked for many years (see Stern, 1943).

It was several years later that Wright (1917, 1920) and Fisher (1918) independently developed comprehensive techniques dealing with the problem. The first of Wright's papers dealt with a case in which genetic and environmental variation were separated experimentally rather than by statistical means. He developed several highly inbred lines of guinea pigs. The analysis of this experiment not only measured the relative amounts of genetic and environmental variation, but also it separated genetic from environmental correlation between two traits by use of the techniques of covariance (at that time an uncoined term). Subsequent papers by Wright (1918, 1921, 1934) presented and elaborated on his method of path coefficients which allowed statistical separation of genetic and environmental variation in general populations. Simultaneously and independently Fisher (1918) dealt with the same subject, which also was elaborated on later by Fisher, Immer, and Tedin (1932).

The statistical separation of genetic and environmental correlations between different traits was described by Smith (1936) and by Hazel (1943), whose technique was derived from the method of path coefficients combined with the analysis of covariance.

Thus the fraction of the total phenotypic variance due to genetic differences came to be known as heritability, Lush (1945, 1949). Used in a broad sense, this term refers to the functioning of the whole genotype. The genotype, however, is not transmitted as a unit. Instead, its constituent genes segregate and come together in new combinations with each new generation. The genes may interact with each other in non-additive ways so that, in certain combinations, they have effects quite different from their average effects in a population. Those differences between their actual effects in each combination and their average effects in the whole population are called dominance deviations and epistatic deviations and are transmitted only in part, if at all. The narrow definition of heritability includes only the average effects of the genes and is used when the main emphasis is on expressing the fraction of the phenotypic differences between parents that reasonably may be expected to be recovered in their offspring.

All methods of estimating heritability are based in one way or another on measuring the extent to which related individuals are more like each other than unrelated ones. The problem is to measure the extent to which phenotypic likeness parallels genetic likeness. The methods which have been used most widely are the study of isogenic lines, regression of offspring on parental phenotypes, selection in opposite directions from the same initial population, resemblances between full-sibs, resemblances between half-sibs, and regression of variance on relationship.

Discussions of these methods may be found in the publications of Lush (1948, 1949). For illustrations of their use in studies of data from animals other than beef cattle, see Whatley (1942) and Dickerson and Grimes (1947), for swine; Hazel and Terrill (1945, 1946), for sheep; and Laben and Herman (1950), for dairy cattle.

The Heritability of Weaning Weight

There are relatively few studies on heritability of the various measures of beef cattle performance in the literature. The rather recent development of genetical theory, appropriate statistical technique, the long generation interval, and the expense of maintaining experimental herds have contributed to the slow accumulation of data suitable for this type of study.

In 1946, Knapp and Nordskog analyzed the records from 177 steer calves from 23 sires which had been fed on record of performance tests during the period from 1938 through 1944 at the U. S. Range Livestock Experiment Station, Miles City, Montana. These calves were dropped in April and May and weaned in October. Heritability of weaning weight obtained from intra-sire correlation was 12 per cent, and that obtained from a regression of average weight of progeny on weight of sire when adjusted for yearly effects was 30 per cent. A later publication from this station by Knapp and Clark (1950) gave a revised heritability estimate of

28 per cent for weaning weight. This later estimate was based on 110 Hereford sire groups that also included those reported earlier.

From the same station, Shelby, Clark, and Woodward (1955) reported on the analysis of the records of 635 Hereford steers from 88 sires and nine inbred lines fed in the record of performance tests from 1942 to 1951 inclusive. Their heritability estimate of weaning weight of 23 per cent was obtained on components of variance which were adjusted for age at weaning within year and line of breeding. The 95 per cent confidence limits of this estimate were 3 and 41 per cent.

In a study of factors influencing birth and weaning weights of Hereford calves in Nebraska, Gregory, Blunn, and Baker (1950) obtained heritability estimates of 26 and 52 per cent, respectively, from herds maintained at the North Platte and Valentine sub-stations. At the North Platte station the 33 records collected in 1936 and 1937 and the 237 records collected from 1944 through 1947 included progeny of six different sires. These calves were corrected to a standard age of 200 days, while those at the Valentine station were corrected to a standard age of 150 days. At the Valentine station 69 records were available from six different sires during the years 1935 and 1936. Since all cows calving in any one season were the same age, no correction was made for age of dam. Estimates of repeatability in these data ranged from .35 to .50 for weaning weight.

McCormick and Southwell (1954) presented the results of the analysis of 18 years of data collected at the Georgia Experiment Station from a herd of polled Hereford cattle. These records included a total of 491 weaning weights of calves sired by 19 bulls and out of 124 cows. Heritability estimates were determined from paternal half-sib correlations for the 210-day, 210-day sex adjusted, and for the 210-day sex and age of dam adjusted weights. These values were 37, 43, and 3 per cent, respectively. It was thought that age of dam corrections in these data also removed sire differences. A repeatability estimate of 51 per cent was calculated for the sex adjusted weights from differences between cows within seasons and age of dam groups. The repeatability of sire performance determined for yearly average weaning weights for sire groups was 49 per cent.

From an analysis of the relationships among weight gains for five periods of growth of 88 grade and 67 purebred Hereford calves, Kidwell (1954) obtained an estimate of heritability of weaning weight of 100 per cent by the paternal half-sib method. This estimate was based on nineteen degrees of freedom. The calves were purchased in groups in 1946, 1948, and 1950 from four different ranches. It was pointed out that pre-purchase environmental conditions and sex differences could have biased this estimate upward.

Dawson, Vernon, Baker, and Warwick (1954) reported heritability estimates of six-month weights of 446 calves produced during the years 1945 to 1950 in a strain of cattle derived from a Brahman-Angus crossbred foundation at the U. S. Iberia Livestock Experiment Farm, Jeanerette, Louisiana. Heritability of six-month weight was estimated as zero from sire-offspring regressions and paternal half-sib correlations of immediate offspring and from 5 to 15 per cent based on dam-offspring regressions. Paternal half-sib correlations based on weights of calves raised by the daughters of the sires used gave a heritability estimate of 19 per cent.

In a comprehensive study of genetic and environmental relationships among economic characters in beef cattle, Koch and Clark (1955a) analyzed records collected at the U. S. Range Livestock Experiment Station from registered and grade Herefords during the period from 1926 through 1951. These data were adjusted to a heifer basis and corrected for the influence of age of dam. Weaning weights were adjusted to a standard age of 182 days. Year effects and line effects were removed in the analysis. The heritability estimate for weaning weight computed from the 4,553 available records of 137 sires by the paternal half-sib method was 24 per cent with 95 per cent confidence limits of 34 and 17 per cent.

The genetic correlations between birth weight and weaning gain (.46) indicated that many of the same genes affected prenatal and postnatal growth to weaning. Yearling gain was almost independent, genetically, of gain from conception to birth (.06) and from birth to weaning (-.05). In both preweaning and postweaning periods the genetic correlations between gains and scores were quite large. Comparison of maternal (.34) and paternal half-sib (.06) correlations indicated maternal environment to be quite important in the determination of weaning weight. In a companion paper by Koch and Clark (1955b), regression of weaning weight of offspring on that of dam was calculated for 4,234 calves from 1,231 dams on a within year and age of dam classification. Using this method an estimate of 11±6 per cent was obtained for weaning weight. Regression of average offspring on sire also was used to estimate the heritability of weaning weight in this study. From 85 sires and the average of their progeny, an estimate of 25±11 per cent was obtained.

In a third paper of this series Koch and Clark (1955c) obtained an estimate of the influence of maternal environment on several traits related to beef production. The procedure used by these workers was to compare calculated values with the theoretical composition of paternal half-sib correlations, maternal half-sib correlations, correlations between offspring and dam, and correlations between offspring and sire. These comparisons suggest that maternal environment from conception to birth and from birth to weaning had a large influence on birth weight, gain from birth to weaning, and weaning score, but there was very little influence on yearling gain and yearling score. The results further suggest a negative correlation between maternal environment from birth to weaning and the traits weaning gain and score. Heritability of weaning weight, taking maternal environment into account, was .19. These workers point out that for traits that are influenced by genetic differences in maternal environment a clarification of genic value affecting the trait is needed. The total genic value affecting the trait is the genic value for direct response in that trait plus the genic value for maternal environment as it affects the traits. Following their notation, let G_i be the calf's genic value for direct response of the i^{th} trait and G_j be the calf's genic value for maternal environment affecting the i^{th} trait. The regression of $(G_i + G_j)$ on P_i is

$$_{GiPi} \frac{\sqrt{G_i}}{\sqrt{P_i}} + r_{GjPi} \frac{\sqrt{G_j}}{\sqrt{P_i}} .$$

If epistasis is negligible the following relationships exist: The paternal half-sib correlation estimates $.25 g_i^2$. The regression of offspring on dam estimates $.5\ g_i^2 + .5\ g_j^2\ m_i^2 + 1.25\ g_i g_j m_i\ r_{GiGj}$, provided the environmental factors affecting P_1 of the dam are not correlated with the environmental factors affecting her maternal environment. Estimation of the genetic correlations between traits, by the reciprocal correlation of one trait in the dam with another in the offspring, was shown to be complicated where maternal environment has a direct influence. It was shown that where maternal environment has a direct influence, the conditions necessary for the use of the formula given by Hazel (1943) are not met and that valid estimates of genetic correlations could be obtained only from paternal half-sib analysis.

Rollings and Wagnon (1956) analyzed the 577 weaning weight records collected from 1936 through 1946 from two experimental range herds of similar breeding at the San Joaquin Experimental Range. One herd was fed supplementary feed during the fall and winter when range was nutritionally deficient while the other herd was not supplemented. Data were standardized for differential effects of pasture, year, sex, age of calf at weaning, and age of dam. Heritability of weaning weight in the supplemented herd by the paternal half-sib method was 9 per cent and by regression of offspring on dam was 84 per cent. In the unsupplemented herd, heritability by the paternal half-sib method was 54 per cent and -15 per cent by regression of offspring on dam. These workers were in agreement with Koch and Clark (1955c) in the opinion that the characteristics of the dam which exert a maternal effect on the weaning weight of her calf may be correlated with her weaning weight to such an extent as to seriously bias the heritability estimate based on the offspring-dam regression. Since there was no evidence of an effect of nutritional level on the heritability of weaning weight, it was concluded that the average of the two half-sib estimates, which was 30 per cent, was the best estimate of heritability. Repeatability was estimated to be .51 in the supplemented herd and .34 in the unsupplemented herd.

Repeatability of Weaning Weight

Correlation between different records of the same individual has been referred to by Lush (1948) as repeatability. He has pointed out that repeatability should be at least as large as heritability in the broad sense because neither the genes nor the dominance and epistatic deviations change during an individual's lifetime. Repeatability can, however, be larger than heritability because it includes the permanent effects of environment. In studying weaning weight of calves as a characteristic of cows, the maternal influence would be determined, in part, by genetic difference between cows; whereas, in studying heritability of weaning weight from likeness between related groups of calves, the maternal influence would be environmental in so far as the calf was concerned.

Knapp et al. (1942) estimated that 20 per cent of the variance in weaning weight was due to differences between dams. This estimate was somewhat lower than later estimates. This was due most likely to the fact that this estimate was derived from a highly select group of purebred Hereford cows. The records analyzed were those of 112 cows that had remained in the herd at the U. S. Range Livestock Experiment Station for at least nine years during the period between 1926 and 1940.

Koger and Knox (1947) used the records collected between 1935 and 1945 at the New Mexico Station, which provided 909 degrees of freedom between cows, to obtain an estimate of repeatability of weaning weight. On data that were corrected for age and sex, and analyzed on a within year and age of dam basis, they obtained an average correlation of .49 between all adjacent calves by the same cow.

Koch (1951) studied the records of 745 calves from 180 cows having two or more calves during the period 1938 to 1948 in Line 1 at the U. S. Range Livestock Experiment Station, Miles City, Montana. Adjustments were made for year, age of dam, and inbreeding of calf. Differences between cows accounted for 52 per cent of the variance in the corrected weaning weight of calves.

Botkin and Whatley (1953) studied the repeatability of weaning weights of 603 calves from 151 cows at Stillwater, Oklahoma, and 98 calves produced by 49 cows at Fort Reno, Oklahoma. Corrections were made for age of calf, sex, age of dam, and year. Estimates were obtained by two methods for the Stillwater data. Intraclass correlation between calves by the same cow was .43. Regression of subsequent records on earlier records by the same cow yielded an estimate of .49. Correlations between the first and second record for the Fort Reno data was .66.

Heritability of Body Measurements

Dawson, Yao, and Cook (1955) estimated the heritability of eight beef production performance traits and nineteen 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 through 1949 and were offspring of nine bulls and 51 cows. Paternal half-sib correlations were used to estimate heritability. The twenty-seven characters were put arbitrarily into four groups as follows:

High heritability group (above 40 per cent) - Dressing percentage, 69 per cent; carcass grade, 66 per cent; height of withers, 65 per cent; width between the eyes, 63 per cent; slaughter grade, 58 per cent; days to final weight, 56 per cent; birth weight, 50 per cent; width of muzzle, 50 per cent; days to weaning, 45 per cent; depth of chest, 40 per cent.

Medium heritability group (20 per cent to 40 per cent) - circumference of shin bone, 33 per cent; height of floor of chest, 33 per cent; circumference at foreflank, 33 per cent.

Low heritability group (1 per cent to 20 per cent) - daily gain, 18 per cent; width at last rib, 15 per cent; width at chest, 9 per cent; height at flank, 4 per cent; width at loin, 4 per cent; efficiency, 3 per cent.

No heritability group (less than 1 per cent) - width at hips, 0.5 per cent; length of body, 0 per cent; length of rump, 0 per cent; length of coupling, 0 per cent; length of nose, 0 per cent; width at shoulder, 0 per cent; circumference at navel, 0 per cent; circumference at rear flank, 0 per cent.

Three of the five growth characters--average daily gain, efficiency of feed utilization, and days to final weight--previously had been reported on by Kohli, Cook, and Dawson (1952). Heritability of these three characters differed slightly because of a slight difference in the procedure of calculations and the inclusion of four other steers in the earlier paper.

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 .60 for weight, .60 for height of withers, .61 for depth at withers, .65 for heart girth, .81 for width of hips, and .68 for body length.

Touchberry (1950) derived estimates of heritability and the genetic and phenotypic correlations between weight and five body measurements from 187 Holstein daughter-dam pairs available 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 twenty-two 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, respectively, .73, .80, .58, .61, .26, and .37. The genetic correlations between weight and the body measurements were high positive values ranging from .70 to .88. Corresponding phenotypic correlations ranged from .53 to .84.

Schutte (1935) reported heritability estimates of body measurements from the Messina Experiment Station in Northern Transvaal. These data were collected from 176 crossbred offspring of 200 cows of unimproved native breeding and two average type bulls of each of the Hereford, Shorthorn, Sussex, Aberdeen-Angus, and Afrikander breeds. He observed that width measurements showed greater seasonal variation than height, length, and depth measurements. Dam-offspring correlations were used to estimate heritability. Estimates of 76 per cent for height at withers, 20 per cent for depth of chest, 48 per cent for body length, 62 per cent of width at hooks, and 35 per cent for heart girth were obtained.

Interrelationships of Weight and Body Measurements

Most of the available data which indicate the relationship of weight and body measurements were taken from cattle at maturity or during the post-weaning development period. Black and Knapp (1937) state that growth of a beef animal takes place in two ways--increases in skeletal structure and development of muscular and fat tissues. Skeletal development may be associated with increase in flesh, but flesh development can be independent of skeletal growth. Such considerations indicate that the relationships between weight and body measurements would be different during different periods of development. Growth curves and silhouettes presented by Brody (1945) for dairy cattle, rabbits, and man lend support to this assumption.

Several studies have made use of measurement data to describe changes which normally take place during some particular period of growth and development. The studies of Severson, Gerlaugh, and Bentley (1917), Hultz (1927), Hultz and Wheeler (1927), and Lush (1928) were concerned primarily with the changes in body measurements of steers during fattening. These studies indicated that, during fattening, steers increase most in body width, next in body length, next in height of top line from ground, and least in head measurements. While the steers became broader, slightly taller, and somewhat lower set, and their bones grew slightly during the fattening process, the fat steers were shorter and smaller boned, as well as broader and lower set, than thin steers of the same weight.

The pattern of normal growth from birth to maturity has been investigated by Lush, Jones, Dameron, and Carpenter (1930) for Hereford range cattle in Southwest Texas and by Guilbert and McDonald (1933) and Guilbert and Gregory (1952) for purebred Hereford, Shorthorn, and Aberdeen-Angus at the University of California. Similar studies are reported by Brody (1945) from the Missouri Experiment Station for cattle and many other species of animals. These studies point out that growth involves increases in weight and also changes in body shape. It is evident from these reports that skeletal growth is much more regular than growth in weight. Similar reports have been submitted for publication by Brown et al. (1956a, 1956b) on the growth of Hereford and Aberdeen-Angus cattle from birth to maturity at the Arkansas station. The calves in the present study were a part of those included in the reports above. Maturity for dimensions of height, depth, width, length, and heart girth were reached at an earlier age than maturity for weight. At eight months of age Hereford calves had attained 35 per cent of their mature weight and from 69 to 81 per cent of their mature size, as indicated by body measurements. Aberdeen-Angus calves at the same age had attained 41 per cent of their mature weight and from 71 to 83 per cent of their mature size, as indicated by body measurements.

Other studies in which measurements of cattle were taken have been aimed at objectively describing a group or breed of cattle. Ashton (1930) described the Lombardy, Brown Swiss, Brittany, Dairy Shorthorn, and Beef Shorthorn breeds through the use of body measurements. Historical and geographical differences in the development of these breeds that may have contributed to differences in size were pointed out. He cites a number of German studies of similar nature. Other studies in which measurements have been used primarily for descriptive purposes were those of Ragsdale and Regan (1930) and Knapp and Cook (1933). These workers demonstrated that between beef and dual purpose Shorthorns certain differences exist in body measurements and in ratios of body measurements. In the data of Knapp and Cook (1933) steers slaughtered at 900 pounds with the lowest height at withers were of the better beef type. They also noted a significant difference between beef and dual purpose cattle in the ratio of height of withers to heart girth.

A study was conducted by Wanderstock and Salisbury (1946) of the relationship between the heart girth measurement and body weight of 100 Aberdeen-Angus and 45 Hereford good to choice fat yearling steers shown at the New York

State Fair in 1941 through 1943. They ranged in weight from 640 to 1,150 pounds. Data also were obtained on height at withers, circumference of round, and body length for 36 of the Aberdeen-Angus and 30 of the Hereford steers. In addition, heart girth and weights were obtained on 27 Aberdeen-Angus heifers and cows of the Cornell University herd ranging in age from two to twelve years. Interrelationships among these measurements were all highly significant except that between height of withers and circumference of round. Correlations between heart girth and weight were the highest observed. These correlations were as follows: .91 for Hereford steers, .99 for Aberdeen-Angus steers, .91 for all steers, and .93 for heifers and cows.

Studies by Kohli et al. (1951) and Cook et al. (1951) gave the relationships among various body measurements and certain performance and carcass characters of 157 Milking Shorthorn steers fed in the record of performance project between 1932 and 1949 at the Agricultural Research Center, Beltsville, Maryland. These steers were from 125 different dams and 29 different sires. There were slight changes in the testing procedure over the years; however, 62 of the steers were fed under uniform procedures, and the two groups of data were analyzed separately. Quite close agreement between the two groups of data was observed. These steers tended to vary independently with regard to body dimensions, as shown by the lack of high correlation between them, except for a fairly high association between height of withers and height of chest floor (.75). Steers which were shorter in height and length of body and smaller in circumference of fore-flank were slightly superior in average daily gain and efficiency. They also tended to have slightly higher slaughter and carcass grades and a higher dressing per cent than more rangy steers. Length tended to be associated positively with height and heart girth measurements. Width of shoulders tended to be associated positively with heart girth and negatively with height of chest floor and tended to indicate slightly higher slaughter and carcass grades.

Data of eight meat production characters and nineteen body measurements from 101 beef Shorthorn steers and 62 Milking Shorthorn steers raised at the Beltsville Agricultural Research Center were used by Yao, Dawson, and Cook (1953) to study relationships between these characters and measurements. These steers were the offspring of 18 and 10 sires, respectively, and were raised between 1940 and 1950. All animals were nursed until they reached 500 pounds and then fed individually to a live weight of 900 pounds on a standard ration. Measurements were taken on foot immediately before slaughter. Variance and covariance caused by breed differences were calculated and were subtracted from the total variance and covariances. The eight meat production characters and nineteen body measurements were divided into eight main groups and two sub-groups. Each body measurement group could be represented fairly well by one measurement which was highly correlated with all the other measurements within the group. The measurements considered best were as follows: height at withers for the height measurement group, length of body for the length measurements, width of muzzle for the head measurements, width at chest for the width measurements, and circumference at navel for the circumference measurements. Depth of chest was well correlated with all the circumference measurements and could be included in the circumference group instead of the height group. All the width and circumference measurements were correlated positively with slaughter grade, carcass grade, and dressing percentage and were referred to as fleshing measurements. All height and length measurements were correlated negatively with slaughter grade and were called skeletal measurements. Measurements of head, width, and circumference had negative correlations with efficiency of feed utilization and average daily gain.

Correlations among several body measurements, live grade and slaughter grades, were computed by Kidwell (1955) from data collected shortly before slaughter of 64 fat Hereford steer calves exhibited at the 1954 Nevada Junior Livestock Show. These calves varied in age from 10 to 16 months and had been fed from 180 to 240 days. Because of the high correlation (.90) between weight and heart girth and the much lower coefficient of variation of heart girth, it was concluded that heart girth was a more suitable measure of total size than weight for studies of growth and form. It was concluded further that much of the observed correlation among the various measurements arises from their general relation to size. The relationship between several ratios of measurements of carcass traits was studied. Chest width (.55, .72) was the single measurement, and the ratio of height at withers to heart girth (-.55, -.68) was the ratio most closely related to live and carcass grades. These data support the work of earlier investigators that steers of widely different form may have equal carcass value and dressing per cent and vice versa.

Green (1954) and White and Green (1952) used multiple correlations to study the predictability of the weights of wholesale cuts of beef carcasses from live weight and grade and twenty-four body measurements taken on 50 steers prior to slaughter. The steers ranged in weight from 800 to 1,445 pounds and ranged in grade from medium to choice. Live weight was the single measure most closely associated with the weight of the cuts. Width of shoulders and hooks and depth of twist were correlated more highly with weight of round, trimmed loin, rib, and crosscut than other linear measurements. Width of shoulders was the only measurement significantly correlated with dressing per cent. The greatest accuracy of prediction was found for the crosscut where 98.6 per cent of the total variation in the weights of cuts was accounted for by use of nine measurements. Lowest predictability was in connection with short loin and round where only 87.0 per cent of the variation in cuts could be associated with variation in measurements.

MATERIALS AND METHODS

Source of Data

The data that were summarized in this study were collected from the purebred Hereford and Aberdeen-Angus herds maintained on the Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas, during the period between 1940 and 1953. These records include the weaning weight and measurements at weaning time of all calves during this period, except a very few on which measurement data were incomplete.

In 1940, a group of 29 Hereford females were selected to establish a herd of cattle for the study of performance records of beef cattle. This group consisted of six cows and twenty-three weaned heifer calves. Since the herd was established, the only female additions were made in 1951 and 1952 when seven bred heifers and two cows were added. Seven different sires were used, and inbreeding was avoided. All of the sires except one sired calves in three different years. Of the original twenty-nine foundation females, only seven were found in the pedigrees of the last calf crop. The relationship among animals in the herd increased slightly because of the several groups of half sisters that were kept for replacements. By 1953, there were seventy-two producing females. From these animals there was a total of 134 heifers, 62 steers, and 59 bull calves with weaning weights and measurements available for study.

In 1940, when studies on beef cattle performance were initiated, only four Aberdeen-Angus cows were available with which to establish a herd. The offspring of these four cows and their daughters which were retained for breeding purposes comprised the animals on which data were available until 1949. In 1949, the University purchased a herd of approximately 100 animals. There were approximately sixty mature cows in this group of cattle. From these animals there was a total of 105 heifers, 40 steers, and 67 bull calves with weaning weight and measurements available for study.

During the thirteen year period of this study, the management of these cattle varied somewhat more than might be expected under normal farm conditions. The Hereford cattle and the initial group of Aberdeen-Angus cattle occasionally were limited severely for space and grazing area. Labor shortage and restrictions on feed supplies during the war years, no doubt, affected management to some extent. After the purchase of the Aberdeen-Angus cattle in 1949, the Hereford and Aberdeen-Angus herds were maintained on separate farms until 1952, when both were moved to a new location and managed as a single herd. Changes in personnel caring for and supervising the cattle also have been a contributing factor to variations in management. Three different herdsmen and five different staff members have been associated with the management during this period.

These cattle were kept on pasture during the seasons when forage was available. During the remainder of the year, hay or silage and protein supplement were fed to maintain growth and to hold production at a level which was comparable to that of other purebred cattle in the area.

Calves were born in all months of the year, but most of the calving dates were during the fall, winter, and spring months. Those born in the fall received grain in a creep while running with their dams in years when fall grazing was scanty.

Method of Taking Measurements

Weights and measurements were taken at weaning near the middle of the month in which the calves became eight months of age. Weights were recorded to the nearest pound, and measurements were recorded to the nearest tenth of an inch, as read from a steel tape or wooden caliper drawn snugly against the hide. The measurements taken were height of withers, height of hips, depth of chest, depth of rear flank, width of shoulders, width of hips, length of body, and heart girth. Each animal, after being weighed, was haltered and tied or held in as nearly a normal standing position as possible. The following reference points were used in taking the measurements:

Height of withers--the vertical distance from the floor to the top of the withers, as measured with the caliper.

Height of hips--the vertical distance from the floor to the highest point in the region of the hooks, as measured with a caliper.

Depth of chest--the vertical distance from the chest floor just behind the fore legs to the top of the withers, as measured with the caliper.

Depth of flank--the vertical distance from the flank just in front of the rear legs to the top of the back, as measured with the caliper.

Width of shoulders--the horizontal distance across the widest point of the shoulders, as measured with the caliper.

Width of hips--the horizontal distance across the widest part of the top in the region of the hooks, as measured with a caliper.

Length of body--the distance from the shoulder point to the point of the pin bone, as measured with a steel tape.

Heart girth--the distance along a steel tape drawn snugly around the body just behind the fore legs.

Standardization of Data for Non-Hereditary Factors

a. Age of calf at weaning time

A standard age of eight months, or 240 days, was selected as being most representative of the weaning age since all calves were weaned on the regular weigh-day during the month in which they were eight months old. The daily gain of each calf was computed from birth to weaning and was multiplied by the deviation in age from 240 days. This correction was added then to the actual weaning weight. Correction in this manner assumes linear growth from birth to weaning. Examination of data accumulated on growth patterns at the Arkansas station which include these data supports this assumption.

No attempt was made to standardize the measurements for differences in age at weaning because of the lack of measurement data at birth. The large percentage of mature size of body measurements attained by weaning time would suggest less need for correction of the measurements for age.

b. Influence of sex

The sex influence was evaluated from the average difference over all years and ages of dam. The average unadjusted weights and measurements and the correction factors applied are listed in Table I for Hereford calves and in Table II for Aberdeen-Angus calves.

TABLE I

AVERAGE 240-DAY WEIGHT AND BODY MEASUREMENTS
OF 255 HEREFORD CALVES ACCORDING TO SEX

Number Measurement	134 Heifers	62 Steers	59 Bulls	Factor used to standardize to female basis Steers	 Bulls
240-Day Weight	403	428	510	-25	-107
Height Withers	36.8	37.8	38.3	- 1.0	- 1.5
Height Hips	39.3	39.8	38.3	- .5	- 1.5
Depth Chest	18.7	19.0	19.7	- .3	- 1.3
Depth Rear Flank	16.1	16.1	16.8	0	- .7
Width Shoulders	12.5	12.8	13.8	- .3	- 1.3
Width Hips	13.2	13.1	14.5	- .1	- 1.4
Length Body	44.6	45.0	46.8	- .4	- 2.2
Heart Girth	51.8	52.1	55.7	- .3	- 3.9

TABLE II

AVERAGE 240-DAY WEIGHT AND BODY MEASUREMENTS OF 212 ABERDEEN-ANGUS CALVES ACCORDING TO SEX

Number	105	40	67	Factor used to standardize to female basis	
Measurement	Heifers	Steers	Bulls	Steers	Bulls
240-Day Weight	433	456	500	-23	-67
Height Withers	37.2	38.0	37.7	- .8	- .5
Height Hips	39.0	40.1	39.6	- 1.1	- .6
Depth Chest	19.2	19.5	19.7	- .3	- .5
Depth Rear Flank	17.0	16.5	16.9	- .5	- .1
Width Shoulders	12.7	13.2	13.8	- .5	- 1.1
Width Hips	13.7	14.3	14.5	- .6	- .8
Length Body	45.8	46.1	47.3	- .3	- 1.5
Heart Girth	53.3	53.4	55.5	- .1	- 2.2

Separate averages were computed for the bull and steer calves even though it would not be possible to separate the physiological effects of castration from selection for size in a comparison of bulls and steers. The calves were weaned at approximately eight months, which would allow time for considerably more sex differentiation than has been observed among calves of other studies that were weaned at younger ages. In a summary by Smith and Warwick (1953), Hereford bulls differed from heifers by 36 pounds, and Aberdeen-Angus bulls differed from heifers by 31 pounds. Comparison of the sex differences shown in Table I and Table II indicate that the difference between bulls and heifers was considerably greater in these data. However, differences between steer and heifer calves agree rather closely with the 23 pound difference observed between Hereford steers and heifers in this summary. In addition to the effects of age and physiological effects of castration, any management which would favor bull calves or be unfavorable to heifers and steers would tend to increase this difference. Selection of bull calves primarily from cows that previously had weaned heavy calves would tend to increase this sex difference.

The data were adjusted to a heifer basis by subtraction of the appropriate correction factors listed in Table I and Table II from the weight and measurement record of each steer and bull calf. Twenty-five and 107 pounds, respectively, were subtracted from the 240-day weight of Hereford steers and bulls. Twenty-three and 67 pounds, respectively, were subtracted from the 240-day weight of Aberdeen-Angus steers and bulls.

c. Year and month of birth of calf

Many of the factors which influence the weight or size of calves at weaning are peculiar to the particular year or season of the year in which they are born. Most commonly cited as reasons for yearly and seasonal variation are the effects of temperature and rainfall. These exert their influence directly on the comfort and well being of cattle and indirectly through the feed and forage supply available for production. In Table III are listed the annual maximum, minimum, and mean temperature along with total annual rainfall recorded at the Arkansas Agricultural Experiment Station Weather Station. The average weight and body measurements of 255 Hereford calves are classified according to year of birth in Table IV. The average weight and body measurements of the 212 Aberdeen-Angus calves are classified according to year of birth in Table V. Only a few animals were available in several of the earlier years of the study. The years 1946 through 1951, inclusive, appear to differ from the other years in that the weights of calves were considerably heavier during this period. Preliminary analysis indicated that this difference was sufficiently large to create high negative heritability estimates from a regression analysis on a within sire-year basis.

TABLE III

CLIMATOLOGICAL DATA DURING PERIOD OF PRESENT STUDY

	Temperature (degrees F.)			Rainfall (inches)
Year	Highest	Lowest	Annual Mean	Annual Total
1940	97	- 7	56.0	40.48
1941	100	10	59.9	50.48
1942	97	-11	58.6	56.88
1943	105	- 6	59.2	40.74
1944	99	- 7	58.7	47.97
1945	97	- 2	57.8	64.23
1946	102	6	59.8	52.62
1947	105	- 1	57.8	40.01
1948	97	-11	58.0	48.28
1949	98	4	57.7	47.03
1950	96	- 4	56.9	50.71
1951	102	- 8	57.4	48.13
1952	100	10	59.1	34.83
1953	102	5	59.7	35.63

TABLE IV

AVERAGE WEIGHT AND BODY MEASUREMENTS OF 255 HEREFORD CALVES
ACCORDING TO YEAR OF BIRTH

Year	40	41	42	43	44	45	46	47	48	49	50	51	52	53
No. Calves	4	6	15	13	18	19	19	16	13	17	21	25	29	40
240-Day Weight	358	383	350	381	384	359	414	444	467	477	453	415	369	372
Height Withers	36.4	37.3	36.7	36.5	36.6	36.2	37.0	37.5	38.0	38.2	37.5	36.6	35.2	36.6
Height Hips	38.3	39.2	39.1	38.8	39.2	39.0	39.1	40.0	40.6	40.4	40.4	39.1	37.9	38.8
Depth Chest	18.2	19.0	18.7	18.7	18.9	18.6	18.9	19.0	18.7	19.6	19.4	18.4	17.8	18.5
Depth Rear Flank	15.7	16.1	16.6	15.7	16.0	16.0	16.4	16.4	16.0	17.2	16.9	16.0	15.2	15.8
Width Shoulders	11.9	12.0	12.0	12.5	13.1	12.5	12.9	12.6	12.5	13.6	13.6	15.3	11.3	12.1
Width Hips	12.1	12.3	11.8	12.6	12.9	12.8	13.6	13.8	13.5	14.6	14.6	13.4	12.2	13.1
Length Body	42.2	43.9	44.4	43.6	44.8	43.8	44.2	45.8	45.4	46.1	44.8	45.3	44.4	43.9
Heart Girth	48.9	51.0	49.8	50.1	50.6	49.8	53.2	52.9	53.3	53.3	54.3	53.3	50.5	51.0

TABLE V

AVERAGE WEIGHT AND BODY MEASUREMENTS OF 212 ABERDEEN-ANGUS CALVES ACCORDING TO YEAR OF BIRTH

Year No. Calves	40 2	41 1	42 2	43 5	44 6	45 3	46 3	47 3	48 1	49 24	50 36	51 38	52 37	53 51
240-Day Weight	394	403	384	343	450	437	418	529	444	483	498	453	376	402
Height Withers	38.4	36.2	35.6	35.6	38.2	37.7	36.9	39.4	39.1	38.5	37.7	36.9	36.0	37.2
Height Hips	39.5	38.0	39.3	37.5	40.3	39.1	39.0	41.4	40.8	39.8	39.8	38.9	38.2	38.6
Depth Chest	19.7	19.7	19.6	18.3	19.9	19.4	18.1	20.9	20.1	20.0	19.6	19.3	18.4	18.9
Depth Rear Flank	17.2	18.0	18.2	16.8	17.3	17.4	17.8	18.2	18.6	18.3	17.7	17.0	15.9	16.2
Width Shoulders	11.5	12.7	13.0	12.2	14.0	13.5	12.3	13.7	12.3	12.9	13.8	12.4	11.3	12.2
Width Hips	12.7	12.6	13.5	12.2	13.1	13.0	12.8	14.9	14.4	15.1	14.9	13.5	12.5	13.3
Length Body	44.7	46.3	44.9	42.9	46.4	46.3	44.7	46.1	46.2	46.7	45.7	46.9	44.7	45.4
Heart Girth	51.6	52.0	51.9	49.0	53.4	52.8	51.4	57.9	54.6	55.5	55.4	54.4	50.7	52.0

The negative relationship between the size of a cow and her offspring appeared to arise because cows which were born in the early years when weaning weights were low tended to produce calves in years when weaning weights were high. Also, cows born in the years when weaning weights were high, 1946 through 1951, tended to produce calves in the years when weaning weights were low, 1952 and 1953.

The reason for the weaning weight and body measurements being lower prior to 1946 is not clear. These years were during World War II. Available records on management during this period and discussion with personnel who were at the Arkansas Station at that time indicated that space limitations, short supplies of feed and forage, and labor shortage were prevalent and could have contributed to the lower records made in these years. The average weights and measurements shown in Tables IV and V for the years 1946 through 1951, inclusive, appear to be made in years with approximately normal rainfall and temperature records for the area. Normal feed and forage were available. The average weights and measurements shown in Tables IV and V for the years of 1952 and 1953 are considerably lower than those of the 1946 through 1951 period. The rainfall in these two years was approximately two-thirds that of normal and reduced the available forage considerably during the grazing season. The records made in 1952 and 1953 also were made at a different location under a more extensive type of management than those of previous years since all cattle were moved to a new beef cattle area in 1952.

In Table VI are shown the average weights and body measurements of the 255 Hereford calves classified according to the month in which they were born. In Table VII are shown the average weights of the 212 Aberdeen-Angus calves classified in a similar manner. The number of calves born in each month also is listed in the tables. It will be noted that most of the calves were born between September and May which will include the fall, winter, and spring seasons. The practice of calving over such a long period of the year would tend to increase the seasonal variation in calf weight and size as compared to data collected on the usual 60 to 90 day period of calving.

The pattern of seasonal temperature and rainfall varies with each year, but usually in the spring temperatures are mild and rainfall is heavy. During July and August, day temperatures usually rise above 90 degrees, and rainfall is very light. Mild temperature and moderate rainfall in the fall usually are followed in the winter months by colder temperatures and less rainfall or snow. This seasonal pattern of weather usually allows a period of ample forage from early April until July followed by a short period of scarcity after native grasses and legumes have matured.

TABLE VI

AVERAGE WEIGHT AND BODY MEASUREMENT OF 255 HEREFORD CALVES ACCORDING TO MONTH OF BIRTH

Month No. Calves	July 4	Aug. 7	Sept. 60	Oct. 32	Nov. 26	Dec. 16	Jan. 15	Feb. 15	Mar. 41	Apr. 20	May 13	June 6
240-Day Weight	312	390	379	387	373	395	371	428	462	439	360	407
Height Withers	35.3	35.3	36.3	35.8	36.4	36.2	36.6	38.0	37.8	37.7	36.8	37.6
Height Hips	38.1	39.0	38.7	38.8	38.8	38.4	39.1	39.7	40.4	40.3	38.9	39.7
Depth Chest	17.4	18.3	18.3	18.5	18.7	18.5	18.5	19.3	19.3	19.0	18.3	18.7
Depth Rear Flank	14.6	15.8	15.6	15.8	16.1	15.5	15.9	17.5	17.1	16.4	16.0	15.6
Width Shoulders	10.9	12.3	13.3	12.2	12.8	12.2	12.0	13.0	13.4	12.8	11.7	12.4
Width Hips	12.0	13.4	12.8	12.8	13.1	12.6	12.7	13.7	14.2	13.6	12.4	13.4
Length Body	42.6	43.9	44.2	44.7	43.7	43.7	44.1	45.4	45.6	45.8	43.9	45.1
Heart Girth	48.0	50.6	51.3	51.0	50.6	51.2	50.5	52.9	54.1	52.9	50.3	52.6

TABLE VII

AVERAGE WEIGHT AND BODY MEASUREMENT OF 212 ABERDEEN-ANGUS CALVES ACCORDING TO MONTH OF BIRTH

Month No. Calves	July 5	Aug. 5	Sept. 30	Oct. 29	Nov. 12	Dec. 16	Jan. 14	Feb. 13	Mar. 33	Apr. 20	May 16	June 11
240-Day Weight	503	470	420	415	456	407	418	459	432	416	447	445
Height Withers	39.5	37.9	36.9	36.5	37.0	36.6	36.9	37.6	37.6	37.3	37.7	37.8
Height Hips	41.6	40.3	38.8	38.1	38.5	38.5	38.5	39.1	39.3	39.0	39.8	39.5
Depth Chest	20.1	19.6	19.1	19.0	19.5	19.0	19.1	19.4	19.1	19.1	19.1	19.5
Depth Rear Flank	18.0	17.3	16.7	16.8	17.3	17.0	16.8	16.9	17.0	16.8	17.0	17.3
Width Shoulders	13.2	11.5	13.1	12.5	13.4	12.2	12.3	12.9	12.7	12.5	12.5	13.1
Width Hips	14.8	14.1	13.4	13.5	14.3	13.4	13.4	13.6	13.6	13.4	13.8	14.3
Length Body	45.3	46.3	45.9	45.2	44.2	45.2	45.6	46.3	46.0	46.3	46.1	46.0
Heart Girth	56.3	54.4	52.7	52.3	53.8	52.5	54.1	54.4	53.2	52.9	53.3	54.4

Fall rains usually bring a new growth of forage which, along with aftermath, provides an ample feed supply from pastures until some time in December when wintering rations must be supplied. Thus, each of the seasons provide different nutritional levels for the dams of calves and for calves themselves after they have developed enough to utilize feed or forages.

Table VI shows that the heaviest Hereford calves were born in February, March, and April. It was thought that these weights reflected the effect that spring grass had on increasing milk flow in the dams and in providing a tender, succulent, high protein pasturage for the calves when they were large enough to graze. In Table VII the weight records of the Aberdeen-Angus calves for February, March, and April do not show such a distinct advantage. One reason for this may have been due to the effect that the offspring of a very large type bull may have had on these averages. Most of the offspring of this bull were born in June, July, and August. They weaned at sufficiently heavy weights to make the averages of these months, which include only a few records, appear much heavier than they would have if the offspring of the bull had been omitted.

The data were standardized for variations due to year and month of birth in the following manner. The records of each breed for each of the items studied were listed in a two-way table according to year and month of birth. On the basis of the marginal means, the years of 1946 to 1951, inclusive, were designated as high years, and the months of February, March, and April were designated as high months. All other years or months were designated as low years or low months. Designation of years and months in this manner allowed the data to be classified into three groups according to date of birth of the calf.

Calves born in low years and low months were classified in group I; calves born either in low years and high months or high years and low months were classified in group II; and calves born in high years and high months were classified in group III. The only exception to this procedure was in placing the high months of 1952 and 1953 with group I. The average weight and body measurements of each of the groups and the factors used for standardization are given for the Hereford calves in Table VIII and for the Aberdeen-Angus calves in Table IX. Each breed was standardized to low month and a low year basis (group I) by subtracting the appropriate factor from Table VIII or Table IX from the individual records of animals classified in group II or group III on the basis of birth date. The choice of low month and low year was made because fewer records would need correction by this procedure.

TABLE VIII

AVERAGE WEIGHT AND BODY MEASUREMENTS OF 255 HEREFORD CALVES ACCORDING TO GROUPING BY YEAR AND SEASON USED TO STANDARDIZE RECORDS

No. / Measurement	127	78	50	Factor used to standardize to Gp. 1	
	Gp. I	Gp. II	Gp. III	Gp. II	Gp. III
240-Day Weight	366	407	482	-41	-107
Height Withers	36.2	37.3	38.2	- 1.1	- 2.0
Height Hips	38.6	39.5	40.7	- .9	- 2.1
Depth Chest	18.2	18.9	19.4	- .7	- 1.2
Depth Rear Flank	15.7	16.3	17.2	- .6	- 1.5
Width Shoulders	11.9	13.0	13.4	- 1.1	- 1.5
Width Hips	12.5	13.2	14.5	- .7	- 2.0
Length Body	43.9	44.8	46.1	- .9	- 2.2
Heart Girth	49.9	52.3	54.8	- 2.5	- 4.9

TABLE IX

AVERAGE WEIGHT AND BODY MEASUREMENTS OF 212 ABERDEEN-ANGUS CALVES ACCORDING TO GROUPING BY YEAR AND SEASON USED TO STANDARDIZE RECORDS

No.	102	84	26	Factor used to standardize to Gp. I	
Measurement					
	Gp. I	Gp. II	Gp. III	Gp. II	Gp. III
240-Day Weight	392	467	488	-75	-96
Height Withers	37.0	37.5	37.6	- .5	- .6
Height Hips	38.8	39.1	39.7	- .3	- .9
Depth Chest	18.8	19.4	19.6	- .6	- .8
Depth Rear Flank	16.4	17.4	17.7	- 1.0	- 1.3
Width Shoulders	12.2	12.9	13.5	- .7	- 1.3
Width Hips	13.0	13.6	14.3	- .6	- 1.3
Length Body	45.3	45.7	47.0	- .4	- 1.7
Heart Girth	51.7	53.4	55.6	- 1.7	- 3.9

d. Age of dam

In order to evaluate the influence of age of dam, the age of the cow when each calf was born was calculated in months. Using the weights and measurements that had been corrected for age, sex, year and month of birth, the data were then sorted into groups with six-month age of dam intervals to see if the effect of age within lactations was similar. There appeared to be very little difference between adjacent groups within lactations, so these were pooled. Thus the correction factors were calculated from a comparison of all records made at each age. It has been pointed out by Lush and Shrode (1950) that this method may be biased somewhat by selection. Comparison of the average of the same cows calving in adjacent age groups, however, showed that there was very little of the difference associated with age of dam due to selection in these data.

In Table X are shown the average weight and body measurements for each age of dam group for the Hereford calves. Similar classification of the data for Aberdeen-Angus calves is shown in Table XI. These averages indicate that the calves from two and three-year-old dams are distinctly lighter and smaller than calves from older dams. There was no apparent decline in weight of calves from the older dams as has been reported in similar studies. Several such studies were summarized by Warwick and Smith (1953).

TABLE X

EFFECT OF AGE OF DAM ON WEIGHT AND BODY MEASUREMENTS OF 255 HEREFORD CALVES - CORRECTED FOR SEX, YEAR, AND MONTH OF BIRTH

Age of Dam	2	3	4	5	6	7	8	9	10	Average size of calf from mature dam	Deviation from calf size of mature dam by	
No. of Calves	67	47	44	29	22	15	11	9	13	(over 4 yr.)	2 yr. dam	3 yr. dam
240-Day Weight	340	347	375	388	390	399	426	390	410	391	51	44
Height Withers	35.6	35.7	36.2	36.3	36.1	36.9	36.5	36.6	36.7	36.4	.8	.7
Height Hips	38.1	38.1	38.5	39.0	39.0	39.0	39.1	39.4	39.2	38.9	.8	.8
Depth Chest	17.8	18.1	18.4	18.6	18.3	18.6	18.5	18.7	18.8	18.5	.7	.4
Depth Rear Flank	15.6	15.3	15.5	16.0	15.8	15.7	15.6	16.0	15.9	15.8	.2	.5
Width Shoulders	11.3	11.6	11.9	12.5	12.0	12.4	12.8	11.9	12.4	12.2	.9	.6
Width Hips	12.2	12.2	12.7	12.9	12.6	13.5	13.0	12.9	13.0	12.9	.7	.7
Length Body	43.2	42.9	44.5	44.4	44.5	44.2	44.0	44.2	44.2	44.4	1.2	1.5
Heart Girth	49.1	49.0	50.2	50.7	50.1	50.6	51.7	51.3	51.4	50.6	1.5	1.6

TABLE XI

EFFECT OF AGE OF DAM ON WEIGHT AND BODY MEASUREMENTS OF 212 ABERDEEN-ANGUS CALVES - CORRECTED FOR SEX, YEAR, AND MONTH OF BIRTH

Age of Dam	2	3	4	5	6	7	8	9	10	Average size of calf from mature dam	Deviation from calf size of mature dam by	
No. of Calves	26	32	27	27	23	26	17	9	25	(over 4 yr.)	2 yr. dam	3 yr. dam
240-Day Weight	342	391	396	399	408	385	408	436	394	399	57	8
Height Withers	35.7	36.5	36.9	37.7	37.6	36.7	37.2	38.3	37.3	37.3	1.6	.8
Height Hips	37.3	38.4	38.9	39.2	39.4	38.6	38.6	39.7	39.2	39.0	1.7	.6
Depth Chest	18.0	18.8	19.0	19.1	18.9	18.9	18.9	19.5	19.0	19.0	1.0	.2
Depth Rear Flank	15.4	16.2	16.4	16.9	16.5	16.5	16.5	17.1	16.8	16.6	1.2	.4
Width Shoulders	11.1	12.2	12.6	12.5	12.5	12.5	12.4	12.8	11.9	12.4	1.3	.2
Width Hips	12.1	13.2	13.3	13.9	13.4	13.2	13.3	14.5	13.2	13.5	1.4	.3
Length Body	43.9	45.6	45.3	45.4	46.1	43.5	46.0	46.6	45.2	45.6	1.7	.0
Heart Girth	49.3	51.9	52.5	52.7	52.6	52.4	52.6	53.6	52.5	52.6	3.3	.7

The reason for this is not clear. It may have been due to the small number of older dams available for study. A similar phenomena, however, was observed in the data of Botkin and Whatley (1953) from the Oklahoma Station which was explained on the basis of a less rigorous environment and more ample forage supply in areas of higher rainfall, as compared with the more arid range areas of the west where most of the correction factors for age of dam have been computed.

The correction factors for age of dam used in this study were calculated by averaging all records from cows four years and older to obtain what was considered a mature record. The difference between a mature record and the two-year-old and three-year-old records was used to standardize these groups to a mature equivalent. Correction factors were calculated for each of the breeds for weight and each of the body measurements. The appropriate corrections, as indicated in Tables X and XI, were added to the record of each calf dropped by two and three-year-old dams.

Statistical Procedures

a. Estimates from analysis of variance

The method of least squares for estimation in a nested classification with disproportionate sub-class numbers has been described by Kempthorne (1952) and by Anderson and Bancroft (1952). This pattern of analysis was followed for the estimation of variance components associated with sires, dams, and error, using the data which had been standardized for non-hereditary factors listed in the previous section on materials and methods. The following linear model was considered to be representative of the biological situation:

$$Y_{ijk} = u + s_i + d_{ij} + e_{ijk} \quad (1)$$

where for Herefords,

$i = 1 \ldots\ldots 7$

$j = 1 \ldots\ldots 36$

$k = 1,2,3,4$

and for Aberdeen-Angus,

$i = 1 \ldots\ldots 8$

$j = 1 \ldots\ldots 40$

$k = 1,2$

In both breeds,

Y_{ijk} - is the observed phenotypic value for a record from the k^{th} calf belonging to the j^{th} dam and sired by the i^{th} sire.

u - is the effect common to all calves. It is the population mean if all other effects were zero.

s_i - is the effect common to all calves sired by the i^{th} sire.

d_{ij} - is the effect common to all calves of the j^{th} dam and sired by the i^{th} sire.

e_{ijk} - is the effect associated with k^{th} calf of the j^{th} dam and sired by the i^{th} sire. It includes those environmental effects which would cause full-sibs to differ from one another. Also, this term would include those genetic differences which exist between full-sibs because of Mendelian segregation.

It was assumed that u is a constant, that s_i, d_{ij}, and e_{ijk} are uncorrelated random variables with means zero and variances σ_S^2, σ_D^2, and σ_E^2, respectively.

Variance components for sires, dams, and error were obtained by equating expected mean squares to computed mean squares and substituting in the known elements of the equation. An outline of the analysis of variance is shown in Table XII. Lush (1948) has outlined procedures for the use of these variance components to provide estimates of heritability. One of the estimates can be obtained from the paternal half-sib correlation as

$$\frac{4S}{S + D + E} . \qquad (2)$$

The reliability of this estimate depends upon the number of degrees of freedom available for the estimation of (S), the contribution made to the sire component of variance by epistasis, the validity of the assumption concerning random mating, and the magnitude of environmental correlations between paternal half-sibs.

TABLE XII

THEORETICAL ANALYSIS OF VARIANCE FOR COMPUTATION OF VARIANCE COMPONENTS

Source of Variation	d.f.	Mean Square	Variance Components
Total	N - 1		
Between Sires	s - 1	V 3	E - k_1D - K_2S
Between Dams in Sires	d - s	V 2	E - k_1D
Between Full-Sibs	N - d - s	V 1	E

N is the total number of calves

s is the number of sires

d is the number of dams

V is the computed mean square or variance

k_1 is approximately the average number of calves produced by each dam. It would be exactly that number if all dams produced the same number of calves.

k_2 is approximately the average number of offspring per sire

E is the variance between full-sibs

D is the extra variance within groups of paternal half-sibs. That is, E + D is the average variance between calves having the same sire but different dams. D is, therefore, a measure of the dams' contribution to the likeness of full-sibs since the variance between paternal half-sibs is that much larger than the variance between full-sibs.

S is a measure of the paternal contribution since S is the excess variance between non-sibs as compared with paternal half-sibs.

E + D + S is the individual variance which would be found if one computed it by studying the differences between calves which had neither the same dam nor the same sire using all such pairings possible within this population.

Another estimate of heritability may be obtained from the maternal half-sib correlation as

$$\frac{4D}{S + D + E} \quad (3)$$

This estimate of heritability differs from the paternal half-sib estimate according to the magnitude of the maternal influence. The magnitude of the maternal effect may be estimated by the difference between the dam and sire components of variance.

b. Estimates from regression of offspring on dam

Using only the records of calves which had dams with corresponding records, the model

$$Y = u + BX + E$$

was assumed to be descriptive of the biological situation. In this model Y is the phenotypic observation on the offspring, X is the phenotypic observation on the dam, u and B are population parameters, and E represents the true errors which are assumed to be distributed independently with zero mean and variance of σ^2. This model also assumes that the X's are measured without error (selected), and the corresponding Y's (unselected) are then measured. It has been shown by Bancroft and Anderson (1952) that the method of least squares will produce unbiased and minimum variance estimates of B. In terms of X and Y the regression coefficient b is an estimate of B and is obtained by the formula,

$$b_{yx} = \frac{\sum xy}{\sum x^2} \qquad (5)$$

where

$$\sum xy = \sum XY - \frac{(\sum X)(\sum Y)}{N} \text{ and } \sum x^2 = \sum X^2 - \frac{(\sum X)^2}{N}$$

Here X is the observation recorded from the dam, Y is the observation recorded from the offspring, and N is the number of daughter-dam pairs. An estimate of heritability, Lush (1940), may be obtained from this method of analysis by doubling b_{yx} (the regression coefficient). Such an estimate from a random breeding population would be expected to include half the additive genetic variance and less than one-fourth of the epistatic variance. No variance due to dominance deviations would be included. This estimate would include the effect of maternal influence but would be free of the effects of permanent environmental differences.

Since there were different numbers of offspring for different dams, two different estimates of the intra-sire regression of offspring on dam were computed. In the first case the record of the dam was repeated with the record of each offspring. In the second case all the offspring of a dam were averaged within each sire group and regressed on the dam's record. It has been pointed out by Kempthorne and Tandon (1953) that the first case would be valid if the correlation among offspring of a parent were zero while the second case would be valid if the correlation among members of a progeny group were one. The real situation, most likely, is intermediate between these two extremes, although probably nearer to the situation in the first case.

<u>c. Correlations between weight and body measurements</u>

Phenotypic correlations between weight and body measurements were estimated from intra-sire variances and covariances. The formula given by Snedecor (1946) is

$$r_{xy} = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \qquad (6)$$

where notation is the same as that used for equation 5.

Genetic correlations were estimated according to the formula derived by Hazel (1943) which, in terms of regression coefficients, was

$$r_{G_w G_m} = \sqrt{\frac{(b_{O_w D_m})\,(b_{O_m D_w})}{(b_{O_w D_w})\,(b_{O_m D_m})}}\ . \qquad (7)$$

Here O refers to the offspring's record, D to the dam's record, w to weight, m to body measurement, and G to the pertinent genes.

Koch (1955c) has shown that this formula is not strictly valid for traits influenced by maternal environment.

RESULTS AND DISCUSSION

Mean and Variability of Traits

The average weight and body measurements of both the Hereford and Aberdeen-Angus calves are presented in Table XIII along with the standard deviations and coefficients of variation. The average weights of the two groups of calves are quite similar, differing by only 8 pounds in favor of the Aberdeen-Angus calves. Differences in the body measurements of the two groups were also quite similar, but in all cases they were in favor of the Aberdeen-Angus and consistent with the difference in weight which was observed. Since the corrections of the data and the analysis were carried out separately for each breed, it was not possible to test the significance of the difference between these means. If such a difference were real it would suggest that the dams of the Aberdeen-Angus calves were better mothers than the dams of the Hereford calves. During the latter three years of this study, the author has had an opportunity to observe that it was necessary to milk cows from the Aberdeen-Angus group much more frequently than cows from the Hereford group in order to prevent damage to the udder when calves were young and unable to take all of the milk produced.

TABLE XIII

MEAN AND VARIABILITY OF TRAITS[1]

Trait	From 212 Aberdeen-Angus Calves			From 255 Hereford Calves		
	Mean	Standard Dev.	Coeff. Var.	Mean	Standard Dev.	Coeff. Var.
Weight	399	59.8	14.9	391	57.6	14.7
Height of Withers	37.3	1.9	5.1	36.4	1.6	4.4
Height of Hips	39.0	1.7	4.3	38.9	1.5	3.8
Depth of Chest	19.0	.9	4.7	18.5	1.0	5.4
Depth of Rear Flank	16.6	1.1	6.6	15.8	1.1	7.0
Width of Shoulders	12.4	1.3	10.6	12.2	1.2	9.8
Width of Hips	13.5	1.2	9.0	12.9	1.1	8.5
Length	45.6	2.3	5.1	44.4	2.1	4.7
Heart Girth	52.6	2.8	5.4	50.6	2.9	5.7

1 Data corrected to 240 days of age, female, mature dam basis.

The variability of the data, as indicated by the standard deviation of each of the traits, agreed quite closely with those reported in other studies. This would seem to indicate that there were no gross errors in the method of taking the measurements or in recording the data. Also, it was determined visually by classification of the corrected data into classes which were one-twentieth of the range that the data were distributed approximately normally over a range from 184 to 623 pounds.

Probably all research workers who have studied the interrelationship of age, weight, and linear measurements have realized that weight is only an approximate measure of growth. Condition or fleshing may vary widely; thus animals of similar weights may have measurements which differ considerably. Similarly it is recognized by most workers that variation in fill at weighing time and environmental conditions of growing animals have a much greater effect on weight than on body dimensions. These factors may have been responsible for the considerably greater variability of weight in these data as compared to that noted for the body measurements in Table XIII. The coefficients of variation for weight of the Hereford and Aberdeen-Angus, which were in rather close agreement, were 14.7 and 14.9 per cent, respectively. This would indicate quite similar variations in weight for the two groups of cattle. These statistics may be compared with the coefficients of variation of the measurements which range from 3.8 to 10.6 per cent.

A comparison of the coefficients of variation among the measurements studied indicated that in both groups of cattle width measurements were more variable. This was thought to be a reflection of the effect of differences in condition or fatness.

A similar comparison of the coefficients of variation for depth of rear flank with those for the other measurements would suggest a slightly greater variation in this measurement. Such an observation would be consistent with the effect of differences due to fill.

Heritability of Traits

The magnitude of the heritability estimate would influence the decision of the cattle breeder in the choice of a selection and breeding plan. It would determine the relative amount of emphasis to be given to a trait in the selection of replacements and in estimating the breeding value of individual animals. In order to estimate the rate of progress in a selection program, it would be necessary to know the approximate heritability of the traits in question. Under the usual plans of beef cattle production, the initial selection of females is made at weaning time. Many times most of the conscious selection practiced is made at this time.

In Table XIV are presented the heritability estimates calculated from the variance components obtained by analysis of variance. Two different estimates were obtained from each set of data. The paternal half-sib estimates were derived using the sire components of variance, and the maternal half-sib estimates were derived using the dam components of variance as outlined in Table XII. Under the conditions of random mating the sire component would be expected to contain one-fourth of the variance due to additive effects of genes, none of the effects of dominance deviations, and a small but undetermined amount of the epistatic variance. According to Koch (1955a), the expectation that an epistatic effect requiring n non-allelic genes would be correlated between half-sibs would be $(\frac{1}{4})^n$. The dam component of variance would be expected to be influenced in the same way as the sire component by the additive effects of genes, dominance, and epistasis, but in addition it would contain an extra contribution due to the maternal influence of the dam.

A comparison of the values shown in Table XIV, which were derived by the two methods for each set of data, is surprisingly inconsistent with that which might be expected from the theoretical composition of such estimates. It might be expected that the maternal half-sib estimates would be larger values because of the extra variance due to the maternal influence which they would contain.

TABLE XIV

HERITABILITY OF WEIGHT AND BODY MEASUREMENTS
ESTIMATED FROM VARIANCE COMPONENTS

Measurement	Hereford		Aberdeen-Angus	
	Paternal half-sib d/f = 6	Maternal half-sib d/f = 152	Paternal half-sib d/f = 7	Maternal half-sib d/f = 168
Weight	.26	.52	.11	1.10
Wither height	.29	-.30	.38	.63
Hip height	.21	-.83	.22	.64
Chest depth	.33	-.65	.17	-.39
Flank depth	.15	.06	.40	.40
Shoulder width	.12	-.37	.78	- .04
Hip width	.15	-.20	.32	- .04
Body length	.10	.64	.00	.49
Heart girth	.44	.63	.06	-1.03

Such was the case in only about one-half of the comparisons. In fact, a number of the dam components for the measurements were negative values and, as a consequence, yielded high negative heritability estimates by the maternal half-sib method. Such estimates would appear to be erroneous and to have no biological meaning. Because all the maternal half-sib estimates were calculated in the same manner, the validity of the other estimates obtained by the maternal half-sib method would appear to be questionable. One explanation as to how such negative dam components might arise would be that the similarity of calves due to their having the same dam was removed or obscured in the correction of the data. In the present study the data on each calf are completely confounded with sex, year, season, and age of dam effects. Corrections for these effects that failed to remove differences completely among calves due to them would tend to increase within dam variability and thus obscure the similarity of calves because they were by the same dam. The manner in which corrections for sex, year, season, and age of dam were derived in the present study would appear to provide only approximate values. McCormick and Southwell (1954) noted a situation in which sire differences were removed by age of dam corrections.

The heritability estimates derived from these data by the paternal half-sib method appear to be more reliable than those derived by the maternal half-sib method even though the sire component is based on a small number of sires. The large number of offspring per sire and the fact that many of the sires were used over a two or three-year period would tend to average out many of the environmental effects in the data. The small number of sires from which to estimate the sire component, however, would tend to increase the likelihood of the occurrence of sampling errors.

Taking the paternal half-sib estimates from Table XIV at their face value, the heritability of weight was 26 per cent in the Hereford data and 11 per cent in the Aberdeen-Angus data. These estimates agree fairly well with those obtained by other workers studying populations of beef cattle. Most of the estimates reviewed were between 20 and 30 per cent.

The estimates obtained for heritability of the body measurements were not in as close agreement with those reviewed. Estimates derived in the present study tended to be lower than those reported by other workers. It is possible that this discrepancy may have arisen because of differences in the variability of these body measurements in different breeds and types of animals. Heritability of body measurements available for comparison were taken from animals of dairy type and from animals of more advanced age.

Sixty-six per cent of the variation in wither height was attributed to additive genetic differences in the group of Milking Shorthorn steers studied by Dawson et al. (1955).

Gowen (1933) obtained a heritability estimate of 52 per cent in a large Jersey population. Touchberry (1951) obtained an estimate of 73 per cent in an experimental Holstein herd, and Schutte (1935) obtained 76 per cent in a herd of cross-bred cattle. In the present study the heritability of wither height was 29 per cent, and height at hooks was 21 per cent from the Hereford data and 38 per cent and 22 per cent for these respective measurements of the Aberdeen-Angus calves by the paternal half-sib method.

Chest depth was 40 per cent heritable as reported by Dawson et al. (1955), 59 per cent as reported by Gowen (1933), 80 per cent as reported by Touchberry (1951), and 20 per cent as reported by Schutte (1935). In these data the paternal half-sib estimates of heritability of chest depth were 33 per cent and 17 per cent for the Hereford and Aberdeen-Angus calves, respectively. Depth of flank was 15 and 40 per cent heritable, respectively, in the Hereford and Aberdeen-Angus data. No comparable estimates of the heritability of depth of flank were found in the literature. In the present study heritability of depth, although somewhat lower than reported estimates, was more nearly in agreement than were the estimates of height.

Heritability of width was estimated as 12 per cent and 15 per cent at shoulders and hips among the Hereford calves. The corresponding measurements on the Aberdeen-Angus calves yielded estimates of 78 and 32 per cent for these respective measurements. Five width measurements studied by Dawson et al. (1955) yielded estimates ranging from zero to 15 per cent for width at hips, and Schutte (1935) obtained 62 per cent for the heritability of this measurement.

Estimates of heritability of body length were 10 per cent from the Hereford and zero from the Aberdeen-Angus data. These are similar to the zero estimate obtained by Dawson et al. (1955) for length of body. These estimates, however, differ considerably from the 58 per cent reported by Gowen (1933) and Touchberry (1951) and the 48 per cent reported by Schutte (1935).

Dawson et al. (1955) obtained 32 per cent; Gowen (1933) obtained 57 per cent; Touchberry (1951) obtained 26 per cent; and Schutte (1935) obtained 35 per cent for heritability of heart girth. Estimates in the present study were 44 per cent from Hereford calves and 6 per cent from Aberdeen-Angus calves by the paternal half-sib method.

In Table XV are presented the heritability estimates obtained from the Hereford data by doubling the regression coefficient of the offspring's measurement on the dam's measurement taken from the corrected data. Heritability estimates obtained in this manner, according to Lush (1940), would be expected to be free of the effects of mating system and to dodge many of the difficulties in the correction for environment because the members of a set of paternal half-sibs are nearly contemporary and raised in the same herd.

TABLE XV

HERITABILITY OF WEIGHT AND BODY MEASUREMENTS ESTIMATED FROM INTRA-SIRE REGRESSION OF OFFSPRING ON DAM COMBINATIONS AMONG HEREFORD CALVES

Measurement	Dams repeated with each offspring d/f = 154	Offspring of each dam averaged d/f = 99
Weight	.04 ± .19	.55** ± .19
Wither Height	-.14 ± .18	-.10 ± .20
Hip Height	.48* ± .20	.40 ± .21
Chest Depth	.36** ± .17	.24 ± .16
Flank Depth	-.05 ± .16	-.01 ± .16
Shoulder Width	-.01 ± .12	.01 ± .13
Hip Width	-.02 ± .17	-.01 ± .17
Body Length	.37** ± .16	.35** ± .16
Heart Girth	.03 ± .20	.31 ± .20

* Heritability based on regression coefficients that differed significantly from zero, $P < .05$.

** Heritability based on regression coefficients that were highly significantly different from zero, $P < .01$.

In the present study, however, many of the sires were used in more than one year and thus would contain any variance due to effects of years which was not removed in the correction of the data. Estimates obtained by this method should contain, in addition to the additive genetic variance, a contribution due to the maternal influence and slightly more of the epistatic variance than the paternal half-sib estimate. A problem of interpretation arises, however, in the evaluation of the selection practiced among parents. This is particularly true in the present study where the selection practiced was largely on factors other than weight and body measurements. The extent to which other things were considered in the selections and the real correlation between those other things and the actual breeding value of the parents would determine the bias from this source. The reports of Koch and Clark (1955) and Rollins and Wagnon (1956) indicate that the genetic correlation between maternal environment and weaning gain and weaning score are sufficiently large to seriously bias heritability estimates computed by this method.

The two heritability values shown in Table XV were obtained, first, by repeating the dam's measurement with each of her offspring, and, second, by averaging the offspring of each dam within each sire group. Thus the difference between the two estimates might be due to the accuracy with which the offspring's measurement indicates the breeding value of the parent or due to the effect that repeating measurements of the dam might have on the variance and covariance of the trait. It may be noted that, except in the case of weight and heart girth, the values obtained by the two analyses are very similar. By both methods several negative values for heritability were obtained although in no case were they based on regression coefficients which differed significantly from zero. In the first case where dams were repeated with each offspring, positive heritability estimates based on regression coefficients differing significantly from zero were obtained only for hip height (.48 ± .20), chest depth (.36 ± .17), and body length (.37 ± .16). In the second case where offspring of each dam was averaged, only weight (.55 ± .19), and body length (.35 ± .16) were based on regression coefficients differing significantly from zero. The negative estimates were obtained from regression coefficients which did not differ significantly from zero and might be interpreted as indicating a zero heritability. Such an interpretation, however, would not be consistent with positive values obtained by the paternal half-sib analysis of data from the same source, Table XIV, or with the rather high positive values obtained by Dawson et al. (1955), Gowen (1933), Touchberry (1951), or Schutte (1935). Several negative values of heritability were obtained from the computations which made use of the dam component of variance, Table XIV, but these are not necessarily the same body measurements for which negative estimates were obtained by regression of offspring on dam, Table XV. For example, heritability of height of top line from the ground was estimated by the maternal half-sib method at the shoulders to be -.30 and at the hips to be -.83, while by regression of offspring on dam the heritability estimate of height at shoulders was -.14 and height at hips was .43. Similar discrepancies are noted in the estimates for depth of body. Thus it would appear that either the group of dams used in the regression analysis was not representative of all the dams in this herd, all of which were used in the analysis of variance, or that there was more than one factor acting which would tend to increase the variability among the offspring of a dam. The possibility of such an effect arising from the correction of the data, or from genetic correlations between the traits studied and maternal environment, has been pointed out.

Another explanation of the negative values and the inconsistencies between the heritability values obtained by regression and from the analysis of variance would appear to be associated with the errors of measurements. If the errors made in taking the measurements were relatively large in proportion to the real differences between animals and were random in nature, they would tend to average out over a large group of animals, such as the large paternal half-sib groups in this study, and the sire differences would be fairly accurately approximated. However, when estimates were based on small numbers per group, such as maternal half-sibs, the real difference between dams might vary quite widely due to the lack of opportunity for the positive errors in measurements to compensate for those in the opposite direction. This effect would be independent of the question of how representative of the general population that the sires or dams were. A description of the errors which influence body measurements has been given by Lush (1928) and Touchberry and Lush (1950).

Correlations between Weight and Measurements

The relationship of weight and body measurements is of interest since many cattlemen are concerned over the effects that selection for weight might have on the conformation of their cattle. The measurements used in this study define some of the dimensions considered in the evaluation of conformation. Correlations between weight and these measurements are presented in Table XVI. The phenotypic correlations were computed from the pooled sum of squares and cross products of each sire group and, therefore, would be on an intra-sire basis. These correlations are all positive and significant with fairly small standard errors.

TABLE XVI

CORRELATIONS BETWEEN WEIGHT AND BODY MEASUREMENTS OF HEREFORD CALVES AT WEANING TIME

Measurement	Phenotypic d/f = 99	Genetic d/f = 99
Withers Height	.49	.12
Hip Height	.50	.30
Chest Depth	.76	.00
Flank Depth	.44	.00
Shoulder Width	.91	.43
Hip Width	.58	.35
Body Length	.67	.27
Heart Girth	.71	.13

Phenotypic correlations in Table XVI are slightly smaller values than have been reported by other workers, but the fact that these correlations represent the degree of association within paternal half-sib groups would appear to account for this difference. For example, the correlation between heart girth and weight was .71 in these data while Wanderstock and Salisbury (1946) obtained .91 and .93, respectively, for this correlation in a quite variable group of steers and females, and Kidwell (1955) obtained .90 in a group of fat show calves. The highest of the correlations obtained from these data was that between weight and shoulder width, .91. These fairly high positive phenotypic relationships would appear to arise from the fact that increases in weight of the growing calf are accompanied by a general increase in size. The higher association of weight with the measurements in the shoulder region (i.e., shoulder width, .91; chest depth, .76; heart girth, .71) would appear to be consistent with the fact that a large proportion of the weight of cattle is carried on the fore legs.

Genetic correlations between weight and body measurements should give an indication of the extent to which the genes that are associated with weight differences also are associated with differences in body dimensions. The genetic correlations between weight and measurements presented in Table XVI were calculated according to the formula (eq. 7) derived by Hazel (1943). Only Hereford offspring and dam combinations were used for this analysis. Koch (1955) has shown for weanling traits which may be influenced by maternal effects that this formula is not strictly valid because of the genetic relationship between maternal effect and the trait.

In the present study, the weights and measurements were taken at weaning and should contain the cumulative effects of any maternal influence. Thus the genetic correlations reported here should be interpreted with caution. A partial check is provided, however, since genetic correlations were computed for two independent measures of height, depth, and width. These pairs of measurements show surprisingly close agreement. The highest genetic correlation observed was that between weight and width which at the shoulders was .43 and at the hips was .35. The lowest genetic correlation observed was that between weight and depth of body which was zero at both chest and flank. The greatest difference in estimates between any of the paired measurements and weight was the .12 and .30 between height at withers and height at hips. The genetic correlation between weight and body length was .27, and that between weight and heart girth was .13. Estimates of genetic correlations from .70 to .88 between weight and these measurements were obtained by Touchberry (1950) by the same method from a group of three-year-old Holstein cows. Age, breed differences, and bias from maternal effect would explain, no doubt, a considerable amount of the discrepancy in genetic correlations from data of such widely divergent sources.

SUMMARY AND CONCLUSIONS

Weaning weight and body measurement data available from 255 purebred Hereford and 212 purebred Aberdeen-Angus calves born in the University of Arkansas Experiment Station herds during the period between 1940 and 1953 were studied to determine heritability estimates and the relationship between body measurements and weight. The body measurements studied were wither height, hip height, chest depth, flank depth, shoulder width, hip width, body length, and heart girth. In the standardization of the data for non-hereditary sources of variation the effect of sex, year and season of birth, and age of dam on each of the variables studied were estimated. A time trend in the data created problems pertinent to the reliability and interpretation of estimates of heritability.

The most reliable estimates of heritability appeared to have been obtained from paternal half-sibs. From Hereford and Aberdeen-Angus, respectively, the estimates computed were for weight, 26 and 11 per cent; for wither height, 29 and 38 per cent; for hip height, 21 and 22 per cent; for chest depth, 33 and 11 per cent; for flank depth, 15 and 40 per cent; for shoulder width, 15 and 32 per cent; for body length, 10 and 0 per cent; and for heart girth, 44 and 6 per cent.

The relationship between weight and the body measurements within sire groups was shown by phenotypic and genetic correlations, although the formula used for the calculation of the genetic correlations may not have been strictly valid because of the maternal influence. The phenotypic and genetic correlations computed from the Hereford data were, respectively, for wither height, .49 and .12; for hip height, .50 and .30; for chest depth, .76 and .00; for flank depth, .44 and .00; for shoulder width, .91 and .43; for hip width, .58 and .35; for body length, .67 and .27; and for heart girth, .71 and .13.

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