EFFECT OF AGE ON THE ACCURACY OF SELECTION AMONG BEEF CALVES FOR GROWTH RATE AND TYPE

by

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INTRODUCTION

It would be desirable and economically valuable if selection of beef calves could be made at an earlier age (three to four months) than the normal weaning age of six to eight months. Bull prospects and steers could be started on their respective treatments at earlier ages. Replacement heifers could be selected earlier and those not to be kept could be handled as feeders, sold as veal, or disposed of as management saw fit.

Selection can be thought of as (1) natural and (2) artificial. Natural selection favors those genetic combinations which can get food, reproduce, and be more or less self sufficient without controls, or restrictions placed on them by man. Under artificial selection, man places controls on those genetic combinations he would like to save by letting only those animals selected by him mate and produce offspring. Artificial selection is the tool which has been effectively used to change populations in the way man has wanted to in order to contribute to his well being.

The earlier methods of selection used have generally been based on phenotype. This is selection based solely on the appearance of a trait or traits of an individual. Gradual progress is made by selecting on phenotype alone; however, many fine looking animals have done little to improve the race or breed.

Selection as practiced today, does not place the mephasis on the individual's phenotype or ancestry alone, although both are usually taken into consideration. Instead, much emphasis is being placed on progeny testing of beef cattle and in this way the genotype becomes a larger part of the basis for selection. When individuals of the desired kind are produced as offspring, their parents are selected for breeders. All of this takes time and the earlier it can be determined which animals produce the most outstanding progeny, the more genetic progress can be realized from their selection as breeding stock.

The heritability of a trait or traits determines the effectiveness of selection in making genetic improvement. The genetic and phenotypic correlation coefficients are necessary to estimate how a change in one trait will affect another trait. The environmental effects are not genetically controlled, passed from parent to offspring and therefore, phenotypic selection can be misleading, causing the retention of animals which do nothing to improve the population. The amount of progress realized from breeding work will depend to a large extent upon the ability to pick for reproduction individuals that are not only phenotypically but also genotypically superior to others in the population.

Selection is one of the most effective and powerful tools available for use by the breeder. By selection, the breeder picks certain individuals which represent a restricted portion of the variance associated with the group from which they came. "The animal is the smallest unit which the breeder can select or reject, therefore, progress by selection is slower than if selection could be gene by gene." (Lush, 1945)

The objectives of this study were:

1. To evaluate growth rate and type of beef calves at 120 days of age (Mid-summer) as predictors of growth rate and type at 210 days of age (weaning).
2. To estimate genetic parameters and relationships among growth rate and grade at different ages in beef calves.
3. To compare the performance of beef calves of different sexes at several ages.

REVIEW OF LITERATURE

The importance of evaluating the breeding potentialities of domestic animals at an early age has long been recognized by livestock breeders.

Most studies on the effectiveness of selection of beef calves have been concerned with selection at weaning with little or no emphasis on its effectiveness at earlier ages. However, using phenotypic resemblances, Rollins and Guilbert (1954) studied the relation between the calf's rate of growth from birth to four months of age and its 240-day weaning weight. They found correlations ranging from 0.62 to 0.91 for these periods and concluded that the early performance of the calf could effectively be used as a part of a system for selecting replacement cows.

Hoover *et al.* (1956) in a cow performance study with 1,110 calves found cow repeatability estimates measured by calf weights at 112 days of age to be 0.29 and 0.35, as determined by intraclass correlation and regression methods, respectively. They found estimates for 210-day weights to be 0.32 by intraclass correlation and 0.34 by regression method. They also found a correlation between weights at 112 days and 210 days of age for calves by the same cow to be 0.86 and concluded that one could effectively cull cows for productivity based on calf performance (observations) at a time earlier than weaning.

High *et al.* (1959) working with daily gain from birth to 120 days, and from birth to weaning, of 744 beef calves from several locations and years, found correlations between daily gain from birth to 120 days and daily gain from birth to weaning for all locations to be consistent and highly significant. The pooled correlation within station, year, age of dam, sex and between the daily gains of calves for these two periods was 0.86 (P<.01). They show the regression of daily gain from birth to weaning on daily gain from birth to 120 days to be 0.73. Their results indicate that gain from birth to 120 days has a relatively high predictive value with respect to daily gain from birth to weaning.

Dawson et al. (1947) studied birth weight as a criterion of selection in beef cattle, using data from 402 calves born as singles. In this study, they found birth weight influencing the time required for animals to attain slaughter weight. They suggest in view of their results, that birth weight should be given some consideration in selection. They found birth weight to be 28.9 per cent heritable calculated by paternal half-sib correlation on uncorrected birth weights of 227 calves. When these same data were corrected for age of dam, and sex of calf, the heritability of birth weight was found to be 11 per cent.

In a beef cow performance study, Taylor (1960) found little difference between repeatability of grade at 120 days and grade at weaning in Hereford and Shorthorn calves. On the other hand, there was a marked difference in the Angus, repeatability of grade at weaning being 0.07 as compared with 0.30 at midsummer. He also reported repeatability estimates for daily gain from birth to 120 days to range from 0.24 to 0.59, and from birth to weaning to be 0.48 for Herefords, 0.44 for Angus and 0.34 for Shorthorns.

A. Environmental Effects

In evaluating the genetic merit of prospective breeding animals, it is often necessary to eliminate, or adjust for, the effects of various fixed environmental factors, such as sex, year, breed, age of dam, and season or month of birth. A number of workers have pointed out the need to evaluate the average effect of these variables in order to show true individual genetic differences.

1. Sex Differences

Marlowe and Gaines (1958) have shown that sex of calf has marked effects on growth rate but little effect on type. Their study indicated that bull calves grew about four per cent faster than steer calves and steer calves about eight per cent faster than heifer calves. Rollins and Guilbert (1954) found that bull calves gained .13 of a pound more per day on the average than heifers from birth to four months of age and were 68 pounds heavier at 240 days. Koch (1951) adjusted calf weights for the effects of year, age of dam, age at weaning, inbreeding of calf, and inbreeding of dam, and found bulls averaged 44 pounds and steers 13 pounds heavier than heifer calves at weaning. Burgess et al. (1954) report an advantage of 29 pounds in favor of bulls at weaning when using weights corrected for year, age of dam, sex of calf, inbreeding of calf and dam, and age of calf at weaning. Koch and Clark (1955) found an advantage of 26 pounds in favor of steers over heifers in a study of a large number of calves over a 25-year period. Gregory et al. (1950) showed that bulls weigh more than heifers by as much as 14 pounds at weaning. Woodfolk and Knapp (1949) showed a difference of 28 pounds between bulls and heifers in favor of bulls. McCormick _et al._ (1956) showed bulls outweighed heifers by 38 pounds at 210 days of age in Polled Hereford cattle.

Pahnish (1958) reported bulls significantly heavier than heifers at a weaning age of 270 days. Nelms (1956) showed no apparent direct effect of sex on rate of suckling gain. This would tend to make average suckling gain equal in bulls and heifers after removal of the birth weight effect. Dawson and co-workers (1947) found that male calves were four to five pounds heavier than female calves at birth.

Dahmen and Bogart (1952) found a significant sex difference in rate of gain. Between 500 and 800 pounds the average daily gain was 2.3 pounds for bulls and 2.0 pounds for heifers.

Smith and Warwick (1953) showed Hereford bulls differed from heifers by 36 pounds and Aberdeen-Angus bulls differed from heifers by 31 pounds. Brown (1958) showed somewhat greater differences between bulls and heifers amounting to near 100 pounds with Herefords and 67 pounds in Angus.

There have been to date, no reports which show any significant difference in weanling type due to sex. Koch and Clark (1955) found that difference in weaning type due to sex was negligible.

2. _Breed Differences_

Gerlaugh _et al._ (1951) found calves from Angus cows averaging as much as 60 pounds more than calves from Hereford cows at weaning with average daily gains of 1.80 pounds for Angus and 1.48 pounds for Herefords. Green and Buric (1953) found no breed difference in gain of calves.

There has been little published on the comparison between pure breeds of cattle for effects due to breed on average daily gain or type score. A few comparisons for breed differences have been made between the pure and crossbreeds for these traits.

3. Year Differences

It has been necessary for research workers, dealing with data covering a number of years, to adjust for year to year differences. Some have corrected for year differences by analyzing the data within years and pooling the resulting estimates. Others have used the method of fitting constants to adjust for the average effects due to years.

Marlowe and Gaines (1958) pooled their data over years and considered year differences to be non-significant. Shelby et al. (1955), working with data collected at the U. S. Range Station, Miles City, Montana, stated that relatively large year differences exist for most production characteristics, and they should be considered when selecting breeding stock. They showed that weaning weight varied greatly between years. Stonaker (1958), working with the calf records at the Beef Cattle Research Station, Fort Lewis, Colorado, reported the effects of year differences on weaning weight to range from -24.10 pounds to +19.71 pounds, expressed as deviations from the mean over a six year period. Burgess et al. (1954) showed years to have a highly significant effect on weaning weight of calves.

4. Effect of Month of Birth Differences

It was shown by Marlowe et al. (1958) that season of birth was an important source of variation on growth rate. In a study of approximately 4,000 calves of three breeds, they concluded that calves born during August through December grew at about 0.2 of a pound per day slower than those born during February through May. There was little difference in the average type score of calves born during the period November 1 through March 31. They showed a slight decrease in type score of calves born during April and May. Calves born during June through October graded somewhat lower (one third of a Federal grade) than calves born during November through March. They also found that "noncreep-fed" calves born during June through December grew about 0.1 pound per day slower than those born during February through May. In addition, they showed that the season of birth was of little practical importance on type score.

Peacock et al. (1956), at the Florida Station, studied weaning weights from 673 calves and concluded that calves born in winter (December, January, and February) showed a highly significant difference from calves born in the spring (March, April, and May); the adjustment was 14 pounds in favor of winter calves. Koch and Clark (1955) in a study involving a large number of calves, most of which were born during the months of April and May, found that the calves grow at approximately the same rate until weaning time. They showed the regression of average daily gain from birth to weaning on weaning age was -.04 pounds per day. They also found the regression of weaning score on weaning age to be .01±.005 units per day, indicating that early calves tend to score slightly higher than those born later in the season. They used the U.S.D.A. scoring system and .01 units per day for 182 days is almost two thirds of a grade.

5. Differences Due to Age of Dam

Burgess et al. (1954) at Colorado found a peak in calf production was reached when cows were six and seven years old. Cows over ten showed a sharp decline and a wide difference was shown in favor of cows over two years old in their ability to produce a live calf. Stonaker (1958) reported that calves from cows two years old and over nine years old were at a disadvantage to calves from cows three to eight years old.

Koch and Clark (1955), working with data collected at the U. S. Range Station, Miles City, Montana, studied the influence of age of dam on weaning weight and weaning score. They found that both traits increased steadily as age of cow increased from three to six years of age and then declined slightly as the cow grew older. Marlowe and Gaines (1958) found that the cows in the six to ten-year-old age group gave maximum production. Knapp et al. (1942) reported that weaning weights of calves increased with age of cow up to six years and then slowly declined. Knox and Koger (1945) showed that weaning weights of calves increased until cows were seven years old and then began a slight decline.

Brown (1958) indicates that calves from two and three year old dams are distinctly lighter and smaller than calves from older dams. He showed no apparent decline in weight of calves from older cows as has been reported in similar studies. His study included dams from two to ten years of age. Baker and Quesenberry (1944), in contrast to Stonaker, reported little if any trend in calf production with age of cow. Sawyer et al. (1948) reported that two-year-old cows produced calves 75 pounds lighter at 30 weeks of age than those produced by mature cows. Their data indicated that weaning weights increased with the age of dam through eight years. After that age, weaning weights declined with the increased age in dam.

Dawson and coworkers (1947) reported an increase of .2 pound of birth weight for each month increase in age of Shorthorn dams until the dam was six years old. In the report, correlation coefficient of birth weight with age of dam was 0.45 for male calves and 0.36 for female calves.

B. Heritability

Every characteristic is affected, at least to some extent, by both hereditary and environmental factors. The phenotype of the individual is the result of a long chain of interactions of the genes with one another, with the environment, and with the intermediate products at each stage of development. The term heritability expresses the relative importance of heredity and environment in the determination of the phenotype. A number of methods of estimation of heritability have been developed. All methods are based on how much more closely animals with similar genotypes resemble each other than do unrelated animals. The genetic relationship expected between related animals was first shown by Fisher (1918). Under random mating the expected relationship between parent and offspring is one half, between full sibs one half and one quarter between half sibs. The same values were shown by Wright in 1921.

The various methods for the estimation of heritability have been reviewed by Lush (1948). The particular technique used will depend on the nature of the trait and on the data available. Where records are available on the parents and the offspring, regression of the offspring on either parent or on the mid-parental average may be employed. When observations are available only on the offspring the estimate is obtained from full or half sib correlations. In general, the closer the relationship the more accurate will be the estimate of heritability. Estimates based on relationships less than half sibs are of limited value due to the large sampling error of the estimate. (Lush, 1948).

Estimates of a number of traits in beef cattle have been reported in the literature. Those dealing with weaning and preweaning characters are summarized in Table 1.

C. Genetic and Phenotypic Correlations

Genetic and phenotypic correlations among traits prior to weaning and weaning traits of beef calves have been reported in only a few studies. Koch and Clark (1955c) reported an identical genetic and

Table 1

Estimates of Heritabilities of Traits in Beef Calves

Trait	Heritability Estimate	Remarks	Reference
Weaning weight	0.12	Half-sib correlation method Small body of data	Knapp and Nordskog (1946a)
	0.30	Parent offspring regression Analysis of covariance applied	Knapp and Nordskog (1946a)
	0.26, 0.52	Paternal half-sib method Small sire progeny groups	Gregory _et_ _al_. (1950)
	0.28	Paternal half-sib method 110 progeny groups	Knapp and Clark (1950)
	0.28	Paternal half-sib method	Knapp and Woodward (1951)
	0.24	Paternal half-sib analysis	Koch and Clark (1955b)
	0.11 ± 0.06	Regression of offspring on dam	Koch and Clark (1955c)
	0.19	Based on direct genic effects plus genic value of maternal environment	Koch and Clark (1955d)
	0.23	Paternal half-sib method	Shelby _et_ _al_. (1955)
	0.30	Paternal half-sib analysis	Rollins and Wagnon (1956a)

Table 1 (Continued)

Trait	Heritability Estimate	Remarks	Reference
Weaning weight	0.23	Paternal half-sib method	Rollins and Wagnon (1958)
Six months weight	heifers 0.69 steers 0.08	Paternal half-sib method	Carter and Kincaid (1959a)
Gain - birth to weaning	0.00, 0.45	Paternal half-sib method Small sire progeny groups Two estimates, work done at two separate stations	Gregory _et al._ (1950)
	0.21	Paternal half-sib analysis	Koch and Clark (1955b)
	0.07 ± 0.06	Regression of offspring on dam	Koch and Clark (1955c)
	0.12	Based on direct genic effects plus genic value of maternal environment	Koch and Clark (1955d)
Weaning score	0.53	Parent-offspring regression	Knapp and Nordskog (1946b)
	0.24	Paternal half-sib method, 1257 Grade Hereford calves	Koger and Knox (1952)
	0.23	Regression of offspring on dam, 1257 Grade Hereford calves	Koger and Knox (1952)
	0.30	Paternal half-sib method, 715 Angus calves	Koger and Knox (1952)

Trait	Heritability Estimate	Remarks	Reference
Weaning score	0.50	Regression of offspring on dam, 715 Angus calves	Koger and Knox (1952)
	0.18	Paternal half-sib method	Koch and Clark (1955b)
	0.16 ± 0.07	Regression of offspring on dam	Koch and Clark (1955c)
	0.16	Based on direct genic effects plus genic value of maternal environment	Koch and Clark (1955d)
	0.36	Paternal half-sib method	Rollins and Wagnon (1956b)

phenotypic correlation of 0.98 between rate of gain from birth to weaning and weaning weight. They reported genetic and phenotypic correlations to be 0.50 and 0.64, respectively, between weaning weight and type score. Carter and Kincaid (1959b) found a genetic correlation of 0.49 and a phenotypic correlation of 0.37 between weight at 182 days and feeder grade at weaning. Lehmann (1961) obtained a phenotypic correlation of 0.41 for daily gain with type at weaning and a genetic correlation of essentially zero (.007) for these same traits. High et al. (1959) showed a high correlation of 0.73 for average daily gain from birth to 120 days with average daily gain from birth to weaning.

D. Rank Order Correlation

The author is not aware of any published work in which the relative rank of beef calves within groups for a particular trait at different times or periods was compared. If the correlation of rank order at different periods is high, then the within groups, rank at an early age (120 days) might be a good measure of the rank at a later age (weaning). Selections might be made and calves weaned at an earlier age than the usual six to eight months, as was pointed out by Green et al. (1953). If early selection were accurate and early weaning feasible, it might be possible to get a performance test for rate of gain or other characteristics earlier and thus speed up the process of selection of breeding stock.

SOURCE AND DESCRIPTION OF THE DATA

A. Production Data

The data used in this study were collected from the Angus, Hereford, and Shorthorn herds at the Beef Cattle Research Station, Front Royal, Virginia. The station is operated cooperatively by the Virginia Agricultural Experiment Station and the Agricultural Research Service of the United States Department of Agriculture. The data for this study were taken from the calf crops born from 1950 through 1958 and involved 1,682 calves. These included 536 Angus, 556 Hereford, and 590 Shorthorn calves, all purebred.

The Shorthorn herd at the Front Royal Station was established by transferring the herd of beef Shorthorns, about 100 cows, from the United States Department of Agriculture Research Center at Beltsville, Maryland, to Front Royal in the winter 1948-49. This herd had been maintained at Beltsville since the early 1930's and was bred as a closed herd with two partially separate lines. This herd was therefore rather uniform in breeding. The Angus and Hereford herds were assembled from a variety of sources during the years following 1948. They were much more variable in blood lines than the Shorthorns.

During the early years at Front Royal, the principle problem was to obtain sufficient numbers of cattle to stock the station which contains more than 4,000 acres. Most of the heifer calves were retained for breeding, and the cows kept as long as they were serviceable. There was, therefore, little selection practiced which would affect this study.

The experimental breeding plan for the Front Royal station is designed to compare the progress to be made from mass selection with that made from developing inbred lines with eventual crossing among them. It is planned that one-half of the animals will be in herds on which mass selection is practiced and one-half in inbred lines or families. Four inbred lines of about sixteen cows in each of the three breeds are planned, for a total of twelve lines. Two selection herds of about thirty-two cows each will be established in each of the breeds. Mass selection will be practiced for growth rate in one of these herds and for type in the other herd of each breed.

The inbred lines and the selection lines are established as random samples from the same populations. Four bulls of each breed that have been found to be superior on performance and progeny tests are designated as foundation sires. These bulls are bred to random samples of outbred cows of the same breed until 32 or more of his daughters are available. A random one-half (16) of these daughters are assigned at random, eight to the type selection herd and eight to the growth rate selection herd. Thus, in each breed, there are four inbred lines of 16 cows each and two selection herds of 32 cows each.

The foundation sires are used as herd sires in the inbred lines, being mated to their daughters and granddaughters as long as they are serviceable. When found unserviceable, a foundation sire is replaced by an inbred son. Both male and female replacements are chosen from within the inbred herd. Selection of replacements in the inbred lines is made on the basis of an index in which 50 per cent of the emphasis is on growth rate and 50 per cent is on type score.

In the selection herds, female replacements come from within the herd. Selection is on the basis of type score alone in the type herd, and growth rate alone in the growth rate herd. Sires are replaced annually in these herds; usually the replacement sires come from within the herds at Front Royal. Each year from 40 to 50 bull calves, selected from all the lines and herds on the station along with some additional bulls purchased from purebred breeders, are placed on a feeding test at the time of weaning. The bulls are full fed a fattening ration for 168 days. The bull with the highest type score within each breed is selected as the type herd sire and the bull with the fastest growth rate is selected as the herd sire for the growth rate herd. Each is bred to approximately half of the females in the herd each year for two years and is then replaced.

Several herds and lines are completely established, and some are still in the process of becoming established. Progress was faster in establishing the inbred and selection herds in the Shorthorn breed. This was because the herd transferred from Beltsville had been maintained as a closed herd for several years. It was possible to divide this herd into two groups of 32 cows each with any pair within a group of 32 being the equivalent of half sisters or closer in relationship, but the two groups relatively unrelated. Thus, it was possible to start the experimental project with two inbred lines and the initial contributions to the two mass selection herds were made much earlier in the Shorthorn breed than in the Hereford or Angus breeds.

Except for the Shorthorn lines, most of the breeding activity during the years covered by this study was directed toward performance and progeny testing of bulls, the selection of foundation sires, and the raising of 32 daughters of each of the foundation sires. In 1957 and 1958, the Shorthorn and Angus inbred and selection herds were completed. These herds have not yet been established in the Hereford breed. During the years, 1950-1958, with the exception of the two Shorthorn lines, relatively little inbreeding was done. Random mating can be assumed in this study except in the Shorthorns. The slight deviations from random mating in the other breeds are believed to be relatively unimportant and should not invalidate results obtained under this assumption.

In general, all three breeds were handled in the same manner within a given year. Each year the calves were maintained on pasture and milk from their dams, without supplemental or creep feeding. All the calves in this study were purebred.

All calves were weighed and graded at mid-summer (July) and again at weaning time (September). Data were available on calves ranging in age from 40 days at mid-summer to 250 days at weaning; however, no calf less than 80 days old at mid-summer was included in the analysis. Federal-State standards for grades of feeder cattle were used as the basis of the grading except that each standard grade was subdivided into thirds. Each calf was classified as being the upper, middle or lower third of the grade. The grading was done by a committee consisting of from five to seven representatives of the Animal Husbandry Department of the Virginia Agricultural Experiment Station and the Animal and Poultry Research Division of the United States Department of Agriculture. Each grader worked independently in scoring the calves and these scores were averaged to obtain the grade of an individual calf.

METHODS USED IN ANALYSIS OF THE DATA

A. Environmental Effects

The effects due to breed, sex, age of dam at birth of calf, year and month of birth were considered fixed environmental effects. Since the data had unequal sub-class numbers (non-orthogonal), estimates of the environmental effects were obtained, for the two traits studied, by least squares analysis for multiple classification with disproportionate sub-class numbers. The method was developed by Yates (1934).

Each calf was classified in five different ways, according to its sex, breed, year born, month of birth, and age of dam. It was assumed that no appreciable interaction existed between these effects; therefore, they were considered to be zero. Therefore, the mathematical model was assumed to be:

$$Y_{ijklmn} = \mu + a_i + b_j + c_k + d_l + s_m + e_{ijklmn}$$

where:

Y_{ijklmn} is a type score or average daily gain of a particular calf

μ is the general mean of type score or average daily gain for all calves

a_i is the year effect and $i = 1.....9$

b_j is the effect due to breed and $j = 1.....3$

c_k is the effect due to month of birth and $k = 1.....6$

d_l is the effect due to age of dam and $l = 2.....14$

s_m is the effect due to sex and m = 1.....2

e_{ijklmn} is the effect due to an individual calf.

It was assumned that the e_{ijklmn}'s summed to zero and had a like variance (σ^2), and were not correlated. With these assumptions least squares analysis could be applied.

The general multiple regression system designed for the IBM "Type 650" digital computer, as outlined by the Statistical Laboratory, North Carolina State College, was used to invert the matrix and estimate the parameters. In this procedure, one variable from each classification is omitted in the original matrix and thus becomes the base from which the remaining variables are expressed as deviations. The original matrix is shown in Appendix A.

In this study, Shorthorn bull calves from three year old dams, born in February, 1955, were chosen as the base and all calves were adjusted to this mean. This base was selected on the basis of numbers in the classification and its position in relation to the unadjusted means for each classification.

B. Estimation of Heritability

Lush (1948) defined heritability in both a broad and a narrow sense. The functioning of the whole genotype is meant when heritability is used in the broad sense. It is used in this manner when contrasting hereditary with environmental effects. The narrow definition of heritability includes as hereditary only the average (additive) effects of the genes in a particular population.

Heritability in the broad sense includes the non-linear gene effects associated with dominance, epistasis, and interactions of heredity and environment. In the narrow sense, these effects are excluded form the fraction. Thus the two definitions are the same only if the effects of dominance, epistasis, and hereditary-environmental interactions equal zero.

Depending on the method used, an actual numerical estimate of heritability is usually between the narrow and broad definitions, almost always including a little of the epistatic variance and sometimes a little of the dominance variance. It may include all, part,or none of the variance caused by the non-linear or joint effects of heredity and environment. (Lush, 1948)

Heritability in the broad and narrow senses may be expressed as shown below:

Broad sense:

$$h^2 = \frac{H}{P} = \frac{G + D + I}{G + D + I + E + EH}$$

Narrow Sense:

$$h^2g^2 = \frac{G}{P} = \frac{G}{G + D + I + E + EH}$$

where:

P is the observed phenotypic variance

H is the total hereditary variance

G is the genic or additive variance

D is the variance due to dominance

I is the variance due to epistasis

EH is the variance due to the interaction between heredity and environment

E is the environmental portion of the variance.

Heritability estimates could not be calculated by the regression of offspring on parent because observations comparable to those taken on the calves at midsummer and at weaning were not available on many of the sires and dams. The method most suitable for the data available seemed to be the correlation of paternal half sibs. The estimate is obtained as:

$$h^2g^2 = \frac{4\ \sigma s^2}{\sigma s^2 + \sigma^2} \qquad (1)$$

where:

σs^2 is the component of variance for "between sires"

σ^2 is the component of variance for "between calves within sires."

The estimates of σs^2 and σ^2 were obtained from analysis of the adjusted data. The theoretical relationship was shown by Fisher (1936) and Snedecor (1946) and is shown below:

	Expected M.S.
Between sire progenies	$\sigma^2 + k_o \sigma s^2$
Among calves within sire progenies	σ^2
Difference	$k_o \sigma s^2$

Here, σ^2, the component of variance among calves within sire progenies, is expected to contain three-fourths of the additive genetic variance, all of the non-additive heritable variance, and the environmental variance. The sire component, σs^2, is expected to contain one-fourth of the additive genetic variance. Thus the additive genetic variance, σG^2, is estimated as four times the sire component ($4\ \sigma s^2$) and the total phenotypic variance by the within sire progeny variance plus the sire component ($\sigma^2 + \sigma s^2$). The coefficient of the sire component, k_o, is the average number of offspring per sire.

In estimating heritability, the underlying principle is that the observed correlation among relatives is divided by the known genetic relationship among them. Under random mating the relationship among half-sibs is one-fourth. (This is accomplished by multiplying the numerator by four in [1] above). In the present data, however, random mating cannot be assumed in the two inbred Shorthorn lines established from the Beltsville herd, hereafter referred to as lines A and B. Greater relationship than would be expected under random mating also existed in the selection herds since they were established with groups of half sisters.

An attempt was made to estimate the average relationship among the Shorthorn calves in the study, as a measure of the deviation from random mating. A complete covariance chart (Hazel) was constructed for calves in the inbred A line. The average half-sib relationship was estimated to be .41 in this line. The average relationship in the B line was estimated as .33, using a random sample of calves in the line. It was estimated that calves by the same bulls in the selection herds had a relationship of about .28; the estimate being based on the number of half sisters in the foundation sets used to establish these lines. The Angus and Hereford herd were assumed to be randomly mating populations since they had only recently been established from a fairly diverse foundation. Finally a weighted average estimate of the relationship of all the calves across breeds of .28 was obtained. This provides a value of 3.57 as the coefficient of the sire component $\frac{(1.00)}{.28}$ in the numerator of (1) above. Heritability was therefore estimated as:

$$h^2g^2 = \frac{3.57\sigma s^2}{\sigma s^2 + \sigma^2} \qquad (2)$$

The number of calves per sire progeny, k_o, was calculated after Snedecor (1946) as:

$$k_o = \frac{1}{n - 1}\left(\Sigma k_i - \frac{\Sigma k_i^2}{\Sigma k_i}\right) \qquad (3)$$

where:

n is the number of sires

k_i is the number of the offspring for the ith sire.

Heritability is computed in the following way: the difference between the two mean squares (between sires minus within sires) divided by k_o and multiplied by four (in this study 3.57) gives the numerator of the paternal half-sib formula. The expected mean square for between sires plus the expected mean square for within sires ($\sigma^2 + \sigma s^2$) forms the denominator.

The standard error of heritability as defined by Fisher (1936) and extended by Hazel and Terril (1945) to apply to estimates from paternal half-sib analysis was computed by the following formula:

$$\sigma_{herit.} = 4\left[\frac{\sigma^2(\sigma^2 + k_o\sigma_s^2)}{(\sigma^2 + \sigma_s^2)^2\sqrt{(1/2)(k_o - 1)k_o n}}\right] \qquad (4)$$

where:

$\sigma_{herit.}$ is the standard error of the heritability estimate

σ^2, σ_s^2, k_o, and n are previously described.

Except, as before, 3.57 was used instead of 4 as shown in the above formula based on the average relationship as calculated for use in estimating the heritabilities.

C. Phenotypic Correlations

The degree of association among two or more variates may be measured by the product moment correlation (Ostle, 1956).

The phenotypic correlations calculated in this study follow the exact principles of product moment correlations. They were expected to measure the extent to which any two traits studied vary in the same or opposite directions.

The equation

$$rGx_ix_j = \frac{\Sigma Gx_ix_j}{\sqrt{x^2_i x^2_j}} \qquad (5)$$

will give the degree of association where:

x_i is the sum for trait i

x_j is the sum for trait j

x^2_i is the corrected sum of squares for trait i

x^2_j is the corrected sum of squares for trait j

rx_ix_j is the phenotypic correlation.

The theoretical limits of the correlation coefficient are -1 and 1. A negative coefficient shows variation in opposite direction between the two traits and a positive one shows variation in the same direction. The relative size of the coefficient indicates the magnitude of variation in like or opposite directions.

D. Genetic Correlations

Genetic correlations measure the joint variation of two variates due to additive or genic causes. In this study a genetic correlation measures the tendency of any of the five traits taken two at a time to vary in the same or opposite direction due to the same genes or combination of genes.

The genetic correlation may be expressed as the ratio of genic covariance between the two traits and the square root of the product of their genic variances. The formula may be written:

$$rx_1x_2 = \frac{Cov.x_1x_2}{\sqrt{\sigma x_1{}^2 \sigma x_2{}^2}} \qquad (6)$$

where:

$Cov.x_1x_2$ is the genetic covariance between the two traits

$\sigma x_1{}^2 \sigma x_2{}^2$ is the product of the genetic variance for the two traits.

It was shown by Hazel et al. (1943) that estimates of genetic correlations could be obtained from paternal half-sib data by using the sire components of variance and covariance.

E. Rank Order Correlations

It is desirable to rank animals at various ages by some method to determine their relative standing compared to other animals in that classification. To date, no good method of ranking for unequal numbers in sire groups has been used.

In this study, it was decided to rank beef calves at various ages on type score and on average daily gain.

Spearman (1904) gives a formula for rank order correlations as follows:

$$r_s = 1 - \frac{6\Sigma d_i^2}{n^3 - n} \qquad (7)$$

where:

d_i is the difference in rank of the ith individual at the two periods

n is the number of individuals per group to be correlated.

In this study, rank order correlations of average daily gain at mid-summer and at weaning were calculated on individual sire groups of five or more calves. Also rank correlations for type at mid-summer and weaning were calculated. An example of rank correlations appears in Appendix C.

The rank correlation varies from -1 to +1 where -1 signifies perfect disagreement and +1 signifies perfect agreement between the two rankings.

RESULTS AND DISCUSSION

A. Adjustment of the Data Using Least Squares Analysis

Estimates of the effects of the various environmental factors on growth rate and type score at mid-summer and at weaning, obtained from multiple regression analysis, are shown in Tables 2 and 3. These estimates, with the signs reversed, may be used to adjust the individual records to a common environmental basis. For example, from Table 2, male calves gained 0.18 pounds per day more than females. The estimates of the effects of the various environmental influences at weaning are similar to, or within the range of, those reported by a number of other investigators. No reports of environmental effects on daily gain or type at mid-summer are available.

The majority of the estimates of the environmental constants were statistically significant; therefore, it was decided to use all of them as adjustments. When all the constants are used to adjust the data, some calculation difficulties are eliminated and the question of level of significance by-passed. All the data were adjusted to the nearest one hundredth of a grade point, or of a pound of daily gain, for all effects, and the final value rounded to the desired number of decimal places.

The constants computed for effects due to breed were significant in all five traits studied. Most studies reported to date have been analyzed within breed and the data pooled, or the study was concerned with only one breed. Marlowe and Gaines (1958) analyzed pooled data

Table 2

Estimates of Constants for Fixed Effects from Least Squares Analysis

Effect	Number Calves	M.S. Average Daily Gain	Weaning Average Daily Gain	M.S. to Weaning Aug. Daily Gain
Deviation from base due to:				
Breed:				
Angus	536	0.20±0.02**	0.22±0.01**	0.26±0.02**
Hereford	556	0.04±0.02**	0.04±0.01**	0.05±0.02**
Shorthorn	590	0.00	0.00	0.00
Sex				
Bulls	762	0.00	0.00	0.00
Heifers	920	-0.18±0.01**	-0.23±0.01**	-0.30±0.02**
Age of Cow:				
2-year old	55	-0.05±0.04	-0.06±0.03	-0.04±0.05
3-year old	321	0.00	0.00	0.00
4-year old	294	0.12±0.02**	0.11±0.02**	0.09±0.03**
5-year old	265	0.20±0.02**	0.16±0.02**	0.11±0.03**
6-year old	213	0.23±0.02**	0.18±0.02**	0.12±0.03**
7-year old	151	0.20±0.03**	0.17±0.02**	0.11±0.03**
8-year old	128	0.20±0.03**	0.14±0.02**	0.05±0.03
9-year old	93	0.17±0.03**	0.14±0.03**	0.10±0.04**
10-year old	45	0.16±0.04**	0.11±0.04**	0.00±0.05
11-year old	44	0.13±0.04**	0.10±0.04**	0.06±0.05
12-year old	33	0.05±0.05	0.01±0.04	-0.08±0.06
13-year old	17	0.05±0.06	0.03±0.06	0.02±0.08
14-year old	23	0.01±0.06	0.01±0.05	0.01±0.07
Month born:				
December	4	0.07±0.13	0.11±0.11	0.08±0.17
January	281	-0.06±0.02**	-0.08±0.02**	-0.08±0.02**
February	752	0.00	0.00	0.00
March	415	0.03±0.02*	0.04±0.01**	0.07±0.02**
April	182	0.01±0.02	0.03±0.02	0.12±0.03**
May	48	0.02±0.04	0.06±0.04	0.16±0.05**

Table 2 (Continued)

Effect	Number Calves	M.S. Average Daily Gain	Weaning Average Daily Gain	M.S. to Weaning Aug. Daily Gain
Year of birth:				
1950	89	0.06±0.03	0.08±0.03**	0.06±0.04
1951	137	0.01±0.03	-0.08±0.03**	-0.27±0.04**
1952	167	-0.01±0.03	-0.08±0.02**	-0.15±0.04**
1953	205	-0.04±0.03	-0.07±0.02**	-0.21±0.03**
1954	192	0.00	0.00	0.00
1955	233	-0.07±0.03**	0.02±0.02	0.20±0.03**
1956	236	0.01±0.03	0.17±0.02**	0.46±0.03**
1957	242	-0.04±0.03	-0.00±0.02	0.14±0.03**
1958	181	-0.21±0.03**	-0.05±0.02	0.35±0.04**

1 Base effect
* Significant $P<0.05$
** Significant $P<0.01$

Table 3

Estimates of Constants for Fixed Effects from Least Squares Analysis

Effect	Number Calves	Mid-summer Type	Weaning Type
Deviation from base due to:			
Breed:			
Angus	536	0.73±0.09**	0.66±0.09**
Hereford	556	0.54±0.09**	0.22±0.09
Shorthorn	590	0.00	0.00
Sex:			
Bulls	762	0.00	0.00
Heifers	920	-0.07±0.07	0.26±0.07**
Age of Cow:			
2-year old	55	-0.53±0.22*	-0.56±0.22**
3-year old	321	0.00	0.00
4-year old	294	0.28±0.12*	0.21±0.12
5-year old	265	0.46±0.12**	0.39±0.12**
6-year old	213	0.42±0.10**	0.39±0.13**
7-year old	151	0.38±0.14**	0.30±0.14*
8-year old	128	0.41±0.15**	0.32±0.15*
9-year old	93	0.25±0.17	0.20±0.18
10-year old	45	0.09±0.23	0.01±0.23
11-year old	44	0.17±0.24	-0.21±0.24
12-year old	33	-0.69±0.26**	-0.81±0.27**
13-year old	17	-0.95±0.36**	-0.80±0.36
14-year old	23	-0.34±0.31	-0.49±0.31
Month born:			
December	4	-0.62±0.72	-0.35±0.73
January	281	0.13±0.10	0.02±0.10
February	752	0.00	0.00
March	415	-0.41±0.09**	-0.13±0.09
April	182	-0.99±0.13**	-0.56±0.13**
May	48	-1.50±0.22**	-0.50±0.23*

Table 3 (Continued)

Effect	Number Calves	Mid-summer Type	Weaning Type
Year of birth:			
1950	89	0.04±0.19	0.61±0.19**
1951	137	0.29±0.17	0.40±0.17*
1952	167	0.32±0.15*	-0.10+0.16
1953	205	0.11±0.15	-0.08±0.15
1954	192	0.00	0.00
1955	233	-0.33±0.14*	0.21±0.14
1956	236	-0.40±0.14**	0.16±0.15
1957	242	-0.41±0.14**	-0.45±0.15**
1958	181	-0.99±0.15**	-0.52±0.15**

1 Base effect
* Significant $P<0.05$
** Significant $P<0.01$

and disregarded breed. Thornton (1960) analyzed within breed in a study of pre- and post-weaning gains of beef heifers. Lehmann (1961) found the effects due to breed to be significant for daily gain and type at weaning.

Constants computed for sex were highly significant for all traits studied except type at 120 days. The estimates show that heifers gained 0.24 pound per day less on the average than bulls; however, they graded only slightly lower at mid-summer and significantly higher at weaning than bulls. These estimates are in agreement with those found by Lehmann (1961) and by Marlowe et al. (1958). They are slightly lower than those found for weaning weight by Koch and Clark (1954). Various authors have reported male calves to be 22, 23, 32, 28, and 2 to 14 pounds heavier at weaning than females (Knapp et al., 1942; Koch, 1951; Koger and Knox, 1945; Woolfolk and Knapp, 1949; and Gregory, Blunn, and Baker, 1950, respectively).

Differences due to age of dam show calves from two year old dams gaining less and grading lower in all cases than calves from dams three to eleven years old. In general, calf daily gains gradually increased with age of dam until approximately nine years, and then gradually decreased. The effect on type score of calves due to age of dam was very similar. This same trend was shown by Marlowe et al. (1958); however, the magnitude of the effect varied. In addition, they grouped all dams over 9.5 years of age. Koch and Clark (1955), in a study involving cows from three to ten years of age, state that .23,

.10, and .13 pound per day should be added to calves out of 3, 4, and 10 year old cows, respectively.

Differences due to month or season of birth were not large in their effect on daily gain; however, the earlier born calves generally gained slower and graded higher. These trends were true for each trait both at mid-summer and weaning. Koch and Clark (1955) found little difference in daily gain of calves born during the months of April and May, but earlier calves tended to score slightly higher than those born later in the season. This study is in agreement with their findings.

Year constants computed in this study show that the greatest effect is in the period from mid-summer to weaning. At this time the milk production of the dam is declining and the calf must get an increasing proportion of its nutrition from pasture; thus making it more susceptible to seasonal climatic variation. It has been pointed out by various researchers that years are a large source of variation for which adjustment should be made for studies covering more than one year. For example, Stonaker (1958) expressed the effect due to year as deviations from the overall mean, with adjustments for six years ranging from -24.10 to +19.79 pounds above or below the average in its effect on weaning weight.

It appears from reviewing the literature and from results obtained in this study that adjustments should be made for year of birth, age of dam, and sex of calf. Breed differences are quite important, and should be considered by the research worker.

The reduction in variation of the various traits, as a result of fitting the constants, is shown in Table 4 for daily gain at the different periods, and in Table 5 for type score. The R^2 values shown in these tables represent the fraction of the total corrected sum of squares that was removed by holding the environmental effects constant. There was a substantial reduction in variation of daily gain, the R^2 values ranging from 0.30 for gain from birth to mid-summer to 0.46 for mid-summer to weaning. There was much less reduction in variation of type scores; R^2 values were 0.15 for type at mid-summer and 0.11 for type at weaning. Lehmann (1961), in a similar study, found an R^2 of 0.35 for daily gain from birth to weaning, and one of 0.43 for type at weaning. He did not work with mid-summer traits.

B. Heritability Estimates

Estimates of heritability, calculated by the paternal half-sib method, and their standard errors are shown in Table 8. Analysis and sire components of variance and covariance for the traits studied are shown in Tables 6 and 7. The estimate of 0.22 for daily gain for the entire period birth to weaning is intermediate between the 0.18 for birth to mid-summer and 0.25 for the period mid-summer to weaning. This might indicate some advantage in selecting for daily gain during the period mid-summer to weaning rather than gain during the earlier period or from birth to weaning, but this statement is vulnerable to challenge, because the standard errors are of such magnitude that the

Table 4

Analysis of Variance

A. Average daily gain: Birth to Mid-summer

Source	D.F.	S.S.	M.S.	F
Regression	28	45.054	1.609	25.140**
Error	1655	106.974	0.064	
Total	1681	151.848		

$R^2 = 0.30$

B. Average daily gain: Birth to Weaning

Source	D.F.	S.S.	M.S.	F
Regression	28	57.772	2.063	42.102**
Error	1655	138.061	0.049	
Total	1681	138.061		

$R^2 = 0.42$

C. Average daily gain: Mid-summer to Weaning

Source	D.F.	S.S.	M.S.	F
Regression	28	155.771	5.563	51.036**
Error	1655	179.866	0.109	
Total	1681	335.637		

$R^2 = 0.46$

Table 5

Analysis of Variance

A. Mid-summer Type:

Source	D.F.	S.S.	M.S.	F
Regression	28	603.192	21.543	10.644**
Error	1655	3349.012	2.024	
Total	1681	3952.204		

$R^2 = 0.15$

B. Weaning Type:

Source	D.F.	S.S.	M.S.	F
Regression	28	451.320	116.119	55.639**
Error	1655	3453.245	2.087	
Total	1681	3904.566		

$R^2 = 0.11$

Table 6

Analysis of Variance for Daily Gain

Source	D.F.	Birth to Mid-summer M.S.	Mid-summer to weaning M.S.	Birth to weaning M.S.
Between Sires	84	0.1214	0.2660	0.1014
Within Sires	1571	0.0611	0.1091	0.0454
Total	1655			
Difference		0.0603	0.1578	0.0560
Sire Component		0.0031	0.0081	0.0029

Analysis of Variance for Type Score

Source	D.F.	Mid-summer M.S.	Weaning M.S.
Between Sires	84	4.7991	4.2386
Within Sires	1571	1.8805	1.9418
Total	1655		
Difference		2.9186	2.2968
Sire Component		0.1500	0.1182

Table 7

Analysis of Covariance Between Traits

		A.D.G.[a] Birth to M.S.[b] with A.D.G. M.S. to weaning	A.D.G. Birth to M.S. A.D.G. Birth to weaning	A.D.G. Birth to M.S. Type at M.S.
Source	D.F.	M.C.P.	M.C.P.	M.C.P.
Between Sires	84	.0547	.0945	.1647
Within Sires	1571	.0186	.0429	.1756
Total	1655			
Difference		.0316	.0516	-.0109
Sire Components of Covariance		.0019	.0027	-.0005

		A.D.G. Birth to M.S. with Type at weaning	A.D.G. M.S. to weaning with A.D.G. Birth to weaning	A.D.G. M.S. to weaning with Type at M.S.
Source	D.F.	M.C.P.	M.C.P.	M.C.P.
Between Sires	84	.1382	.1136	.1700
Within Sires	1571	.1546	.0446	.0243
Total	1655			
Difference		-.0164	.0690	.1457
Sire Components		-.0008	.0035	.0075

Table 7 (Continued)

Source	D.F.	A.D.G. M.S. to weaning with Type at weaning M.C.P.	A.D.G. Birth to weaning with Type at M.S. M.C.P.	A.D.G. Birth to weaning with Type at weaning M.C.P.
Between Sires	84	.2987	.1397	.1742
Within Sires	1571	.1216	.1213	.1416
Total	1655			
Difference		.1771	.0184	.0326
Sire Components		.0091	.0010	.0017

Source	D.F.	Type Score at M.S. with Type Score at weaning M.C.P.
Between Sires	84	4.2386
Within Sires	1571	1.3177
Total	1655	
Difference		2.9209
Sire Component		.1280

[a] A.D.G. is the Average Daily Gain
[b] M.S. is Mid-summer
[c] M.C.P. is Mean Cross Product

Table 8

Heritability Estimates and Standard Errors

Trait	Heritability
A.D.G. Birth to Mid-summer	.18±.05
A.D.G. Mid-summer to weaning	.25±.06
A.D.G. Birth to weaning	.22±.06
Type at Mid-summer	.27±.06
Type at weaning	.21±.06

A.D.G. is the Average Daily Gain
M.S. is Mid-summer

Table 9

Phenotypic and Genetic Correlations Among Traits in Beef Calves

		M.S. to Weaning	Birth to Weaning	Type M.S.	Type Weaning
A.D.G. Birth to M.S.	Pheno.	.21	.82	.49	.42
	Genetic	.37	.92	.39	.04
A.D.G. M.S. to Weaning	Pheno.		.69	.05	.26
	Genetic		.73	.21	.29
A.D.G. Birth to Weaning	Pheno.			.39	.46
	Genetic			.15	.09
Type M.S.	Pheno.				.71
	Genetic				.74

true values of the three heritabilities could all be the same. The estimate of 0.22 for daily gain found in this study is very close to the estimate of 0.21 shown by Koch and Clark (1956b), but lower than 0.45 for daily gain to weaning shown by Gregory et al. (1950).

The heritability point estimate for type at mid-summer of 0.27 is higher than that for type at weaning of 0.21. This may indicate that selection at mid-summer would be more effective than at weaning, but again this is open to challenge, because the standard errors are such that there might be no real difference between the true heritabilities. The estimate of 0.21 for type at weaning in this study is slightly higher than those shown by Koch and Clark (1956b) of 0.18 and 0.16 and somewhat lower than 0.53 found for type at weaning by Knapp and Nordskog (1946b). Carter and Kincaid (1959a) reported higher estimates for grade at weaning of 0.41 (heifers) and 0.51 (steers), than found in this study. No other estimates for heritability of traits at mid-summer, or for growth from mid-summer to weaning, are available.

C. Estimates of Correlations Among Traits

1. Phenotypic and Genetic Correlations

Phenotypic and genetic correlations for all combinations among the five traits appear in Table 9. Correlations for growth rate between the two periods, birth to mid-summer and mid-summer to weaning, were positive and moderately high, 0.21 phenotypically and 0.37 genotypically. Correlations for growth rate between the first period and the whole period were positive and high, 0.82 and 0.92, as were those between the second and the whole period, 0.69 and 0.73 respectively for the phenotypic and genetic correlations. Both are, of course, part-whole relationships.

Positive correlations for gain in a particular period with type at the end of the period were found. Phenotypic correlations were moderately high, 0.26 to 0.49. When type was correlated with later daily gain in a later period, the correlation was essentially zero, 0.05. Genetic correlations were generally low to moderate, 0.04 to 0.39. Here again, type at mid-summer with previous gain from birth to mid-summer was moderately high, 0.39.

Both phenotypic and genetic correlations were high when type at mid-summer was correlated with type at weaning, 0.71 and 0.74.

These phenotypic correlation estimates are within the range of those found by Koch and Clark (1955b) and by Carter and Kincaid (1959a) for weanling traits. High et al. (1959) obtained a part-whole phenotypic correlation of 0.82 for daily gain from birth to 120 days with daily gain from birth to weaning. No other information has been published on the correlation of data taken prior to weaning with data taken at weaning.

2. Rank Order Correlations

Correlations obtained by this method appear in Table 10. The correlation 0.82, between daily gain from birth to weaning and daily gain from birth to mid-summer is positive and high, and identical to the phenotypic product-moment correlation estimate for the two periods.

A moderately high estimate, 0.41, almost double the product-moment estimate, was found between daily gains from birth to mid-summer and mid-summer to weaning. Type at mid-summer was highly correlated, 0.69, with type at weaning being only slightly less than the phenotypic and genetic correlations for these same traits.

Table 10

Rank Order Correlations

A.D.G. Birth to M.S. with Birth to weaning	0.82
A.D.G. Birth to M.S. with M.S. to weaning	0.41
Type at M.S. with Type at weaning	0.69

D. Discussion

Studies involving large animals are usually based on rather small numbers due to economic and other reasons. In this study, the numbers were comparatively large, and there were no location differences.

It appears that selection based on the individual calf's daily gain could best be made using the period from mid-summer to weaning. At this period the heritability appears to be highest indicating that the genotype of the calf is showing its effect to a greater extent than earlier. If selection is to be made on an individuals type, more progress could be made at mid-summer when the heritability is 0.27±.06 as compared to 0.21±.06 at weaning.

Possibly a creep feeding scheme might enable the heritable differences between calves to be measured earlier in the animals life and therefore enable progress from selection to be realized and utilized sooner.

A cow culling program based on mid-summer observations would be as effective as when based on weaning observations as shown by the maternal effects present then that are relatively reduced at weaning. Taylor (1960) showed repeatability of cow performance to be as high or higher than at weaning for gain from birth to mid-summer. He indicated that cow selection could accurately be made on the growth rate and grade of their calves at a time prior to weaning. Repeatability estimates were not calculated in this study, however heritability is usually a fairly large fraction of repeatability as shown by Lush and Arnold (1937), where heritability was about two-thirds of repeatability.

Correlations, both phenotypic and genetic found in the present study indicate that 120 day observations are good predictors of the performance, which can be expected up to weaning age. It can be seen that gain and grade are essentially genetically independent in this study, therefore selection can be practiced on either without affecting the other genetically.

CONCLUSIONS AND SUMMARY

A. Conclusions

The following conclusions were obtained from these data:

1. The fixed environmental effects, in this case breed, sex, age of dam, and year of birth, had large influences on variation. Adjustment for these effects should be made before estimating genetic relationships.

2. The correlations, both genetic and phenotypic, indicate that 120-day observations are good predictors of the performance which can be expected up to weaning age.

3. The correlations point out that gain and grade are genetically independent when grade is correlated with future daily gain but not when grade is correlated with previous daily gain.

4. The rank order correlations found in this tudy indicate that a positive degree of association exists between ranks at 120 days (mid-summer) and 210 days (weaning) for both average daily gain and type score.

5. Selection based on the individual's daily gain can be best made on the period of growth from mid-summer to weaning and selection based on type can be best made at mid-summer.

6. Cow selection based on calf performance to mid-summer would be more effective than calf performance from birth to weaning or calf performance from mid-summer to weaning, because the maternal influences

are more evident when measured at mid-summer than they are later in the growth of the individual calf.

B. Summary

The data for this study were taken from the calf crops born from 1950 through 1958 at the Beef Cattle Research Station, Front Royal, Virginia. These included 536 Angus, 556 Hereford, and 590 Shorthorn calves.

Least squares analysis was used to adjust the daily gains and type scores for the fixed effects of: breed, sex, age of dam, month born, year born. All the least squares constants were used to adjust the data even though all were not statistically significant. The fixed environmental effects had more influence on daily gain than on type at both mid-summer and weaning.

Paternal half-sib analysis was used to calculate heritability estimates for the traits at both mid-summer and at weaning. The heritability estimates were $0.18 \pm .05$, $0.25 \pm .06$, and $0.22 \pm .06$ for daily gain from birth to mid-summer, mid-summer to weaning, and birth to weaning, respectively. They were $0.27 \pm .06$, and $0.21 \pm .06$ for type score at mid-summer and at weaning.

Phenotypic correlations were calculated for each trait with every other trait in the study. These correlations were moderately high to high, ranging from 0.21 to 0.82, for daily gain. When type was correlated with previous daily gain, the estimates were moderately high, 0.26 to 0.49. They were essentially zero (0.05) for future daily gain from mid-summer to weaning with type at mid-summer. The correlation for mid-summer type with weaning type was high, (0.71).

Genetic correlations were calculated from paternal half-sib variance and covariance component analysis. They were moderately high to high ranging from 0.37 to 0.92 for daily gain in one period with daily gain in another period, but considerably lower for type at mid-summer and type at weaning with daily gain from birth to weaning (0.15 and 0.09). The genetic correlations were moderate between type at mid-summer and daily gain from birth to mid-summer, and between type at weaning and daily gain from mid-summer to weaning, (0.39 and 0.29).

Rank order correlations were computed within sire groups of five or more calves using Spearman's formula. These correlations were 0.82, 0.41, and 0.69, for daily gain from birth to mid-summer with daily gain birth to weaning, daily gain birth to mid-summer with daily gain mid-summer to weaning, and type at mid-summer with type at weaning,respectively.

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APPENDIX A

GENERAL MATRIX

		Total	a_1	a_2	a_3	a_4	a_5^*	a_6	a_7	a_8	a_9	b_1	b_2	b_3^*	c_1	c_2	c_3^*	c_4	c_5	c_6	d_1	d_2^*	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}	d_{13}	s_1^*	s_2	M.S. Sum of Gain	M.S. Sum of Type	Weaning Sum of Gain	Weaning Sum of Type	M.S. to W. Sum of Gain
Total		1682	89	137	167	205	192	233	236	242	181	536	556	590	4	281	752	415	182	48	55	321	294	265	213	151	128	93	45	44	33	17	23	762	920	2847.95	18213.0	2787.18	18937.8	2649.50
Year	a_1	89	89	0	0	0	0	0	0	0	0	13	24	52	0	3	11	41	24	10	9	19	13	7	6	4	18	3	8	1	0	0	1	37	52	155.47	931.3	150.24	1029.1	135.03
	a_2	137		137	0	0	0	0	0	0	0	36	60	41	0	0	35	44	41	17	20	20	18	16	5	4	4	25	4	12	5	2	2	67	70	237.23	1480.2	215.81	1552.2	171.21
	a_3	167			167	0	0	0	0	0	0	47	55	65	2	5	80	49	21	10	11	38	29	23	18	10	9	2	13	6	5	2	1	83	84	286.70	1861.4	262.78	1843.6	224.80
	a_4	205				205	0	0	0	0	0	67	79	59	1	10	82	72	29	11	5	38	52	32	23	14	6	6	3	18	6	2	0	90	115	347.67	2261.5	327.90	2286.4	266.98
	a_5	192					192	0	0	0	0	49	78	65	1	33	72	44	42	0	1	35	34	39	30	13	9	6	1	2	12	3	7	87	105	330.56	2101.1	315.57	2149.2	283.84
	a_6	233						233	0	0	0	73	70	90	0	64	96	58	15	0	3	53	31	36	50	25	12	6	3	1	2	8	3	102	131	386.01	2511.8	387.58	2690.6	387.84
	a_7	236							236	0	0	86	69	81	0	70	116	44	6	0	2	35	50	45	26	34	25	12	3	1	1	0	2	94	142	412.14	2567.5	430.40	2745.6	454.32
	a_8	242								242	0	94	68	80	0	69	146	27	0	0	4	41	37	38	38	26	29	16	8	1	1	0	3	111	131	412.22	2641.6	401.43	2687.2	388.89
	a_9	181									181	71	53	57	0	27	114	36	4	0	0	42	30	29	17	21	16	17	2	2	1	0	4	91	90	279.95	1856.6	295.47	1973.9	336.59
Breed	b_1	536										536	0	0	4	103	272	107	44	6	15	105	103	101	81	53	34	14	4	7	6	3	10	245	291	969.27	5999.1	963.57	6241.6	942.56
	b_2	556											556	0	0	60	242	140	82	32	20	107	85	66	55	36	43	45	23	30	22	13	11	248	308	920.04	6030.8	891.19	6176.9	834.69
	b_3	590												590	0	118	238	168	56	10	20	109	106	98	77	62	51	34	18	7	5	1	2	269	321	958.64	6183.1	932.42	6519.3	872.25
Month Born	c_1	4													4	0	0	0	0	0	1	2	0	0	1	0	0	0	0	0	0	0	0	2	2	7.34	43.6	7.11	44.5	6.17
	c_2	281														281	0	0	0	0	2	63	43	43	41	30	23	22	5	1	4	1	3	127	154	458.32	3099.9	456.64	3199.0	453.80
	c_3	752															752	0	0	0	7	158	123	135	99	76	67	31	18	12	12	5	9	337	415	1274.43	8302.9	1254.92	8531.6	1204.68
	c_4	415																415	0	0	14	73	86	57	52	35	22	20	12	20	8	7	9	185	230	713.84	4430.0	692.32	4665.6	643.64
	c_5	182																	182	0	22	21	31	27	19	9	12	11	5	11	8	4	2	86	96	311.08	1862.7	298.27	1972.8	272.65
	c_6	48																		48	9	4	11	3	1	1	4	9	5	0	1	0	0	25	23	82.94	473.9	77.92	524.3	68.56
Age of Dam	d_1	55																			55	0	0	0	0	0	0	0	0	0	0	0	0	29	26	86.42	542.7	81.85	576.6	74.50
	d_2	321																				321	0	0	0	0	0	0	0	0	0	0	0	152	169	499.94	3430.0	496.15	3571.8	483.57
	d_3	294																					294	0	0	0	0	0	0	0	0	0	0	126	168	496.79	3195.9	489.94	3327.5	470.15
	d_4	265																						265	0	0	0	0	0	0	0	0	0	108	157	465.94	2939.9	455.24	3055.3	431.64
	d_5	213																							213	0	0	0	0	0	0	0	0	100	113	382.45	2357.2	372.97	2451.8	355.16
	d_6	151																								151	0	0	0	0	0	0	0	82	69	267.30	1652.7	265.86	1718.2	259.71
	d_7	128																									128	0	0	0	0	0	0	57	71	223.85	1400.8	218.12	1460.0	205.94
	d_8	93																										93	0	0	0	0	0	38	55	156.41	944.9	152.23	1042.8	144.02
	d_9	45																											45	0	0	0	0	20	25	77.04	479.4	72.34	495.5	62.95
	d_{10}	44																												44	0	0	0	22	22	75.19	482.0	70.53	476.5	60.07
	d_{11}	33																													33	0	0	12	21	52.84	333.2	49.22	338.8	41.32
	d_{12}	17																														17	0	7	10	27.32	165.8	26.45	176.5	24.81
	d_{13}	23																															23	9	14	36.46	238.5	36.28	246.5	35.66
Sex	s_1	762																																762	0	1363.45	8269.9	1355.21	8456.6	1323.10
	s_2	920																																	920	1484.50	9943.1	1432.29	10481.2	1326.40

* - Base Effect

Appendix B

Unadjusted and Adjusted Means

Classification	Number Calves	Mid-summer daily gain unadjusted	Mid-summer daily gain adjusted	Mid-summer Type unadjusted	Mid-summer Type adjusted
Breed:					
Angus	536	1.81	1.62	11.2	10.7
Hereford	556	1.65	1.62	10.9	10.6
Shorthorn	590	1.62	1.62	10.5	10.7
Sex:					
Bulls	762	1.79	1.62	10.9	10.6
Heifers	920	1.61	1.62	10.9	10.6
Age of Cow:					
2-year old	55	1.57	1.62	9.8	10.5
3-year old	321	1.56	1.62	10.7	10.7
4-year old	294	1.72	1.63	11.0	10.6
5-year old	265	1.75	1.62	11.1	10.7
6-year old	213	1.79	1.62	11.1	10.7
7-year old	151	1.77	1.62	10.9	10.7
8-year old	128	1.75	1.62	10.9	10.6
9-year old	93	1.68	1.62	10.7	10.6
10-year old	45	1.71	1.62	10.7	10.5
11-year old	44	1.71	1.62	11.0	10.7
12-year old	33	1.60	1.62	10.1	10.6
13-year old	17	1.61	1.62	9.8	10.7
14-year old	23	1.46	1.62	10.0	10.7
Month Born:					
December	4	1.84	1.63	10.9	10.7
January	281	1.63	1.61	11.0	10.7
February	752	1.69	1.62	11.0	10.7
March	415	1.72	1.63	10.7	10.7
April	182	1.71	1.62	10.3	10.7
May	48	1.72	1.63	9.9	10.0
Year of Birth:					
1950	89	1.75	1.62	10.5	10.6
1951	137	1.73	1.63	10.8	10.5
1952	167	1.72	1.62	11.2	10.6
1953	205	1.69	1.62	11.0	10.6
1954	192	1.72	1.62	10.9	10.7

Appendix B (Continued)

Classification	Number Calves	Mid-summer daily gain unadjusted	Mid-summer daily gain adjusted	Mid-summer Type unadjusted	Mid-summer Type adjusted
Year of Birth:					
1955	233	1.66	1.62	10.8	10.7
1956	236	1.75	1.62	10.9	10.7
1957	242	1.70	1.62	10.9	10.7
1958	181	1.55	1.62	10.3	10.7
Grand Mean		1.69	1.62	11.0	10.5

Classification	Number Calves	Weaning Average daily gain unadjusted	Weaning Average daily gain adjusted	Weaning Type unadjusted	Weaning Type adjusted
Breed:					
Angus	536	1.80	1.59	11.6	10.8
Hereford	556	1.44	1.59	11.0	10.8
Shorthorn	590	1.58	1.59	11.1	10.8
Sex:					
Bulls	762	1.78	1.59	11.0	10.8
Heifers	920	1.56	1.59	11.4	10.8
Age of Cow:					
2-year old	55	1.49	1.58	10.5	10.8
3-year old	321	1.55	1.59	11.1	10.8
4-year old	294	1.69	1.59	11.6	10.8
5-year old	265	1.72	1.59	11.5	10.8
6-year old	213	1.75	1.59	11.5	10.8
7-year old	151	1.76	1.59	11.4	10.8
8-year old	128	1.70	1.60	11.4	10.8
9-year old	93	1.61	1.59	11.2	10.8
10-year old	45	1.61	1.58	11.0	10.8
11-year old	44	1.60	1.59	10.8	10.8
12-year old	33	1.49	1.58	10.3	10.8
13-year old	17	1.55	1.58	10.4	10.8
14-year old	23	1.54	1.58	10.1	10.8

Appendix B (Continued)

Classification	Number Calves	Weaning Average daily gain unadjusted	adjusted	Weaning Type unadjusted	adjusted
Month Born:					
December	4	1.77	1.59	11.1	10.8
January	281	1.63	1.59	11.4	10.8
February	752	1.67	1.59	11.4	10.8
March	415	1.67	1.59	11.2	10.8
April	182	1.64	1.59	10.8	10.8
May	48	1.62	1.58	10.9	10.8
Year of Birth:					
1950	89	1.69	1.59	11.6	10.8
1951	137	1.58	1.59	11.3	10.7
1952	167	1.57	1.59	11.0	10.8
1953	205	1.60	1.59	11.2	10.8
1954	192	1.65	1.59	11.2	10.8
1955	233	1.66	1.59	11.6	10.8
1956	236	1.82	1.59	11.6	10.8
1957	242	1.66	1.44	11.0	10.8
1958	181	1.63	1.59	10.9	10.9
Grand Mean		1.64	1.58	11.1	10.8

Classification	Number Calves	Average Daily Gain M.S. to Weaning* unadjusted	adjusted
Breed:			
Angus	536	1.75	1.47
Hereford	556	1.50	1.47
Shorthorn	590	1.48	1.46
Sex:			
Bulls	762	1.73	1.47
Heifers	920	1.44	1.46

Appendix B (Continued)

Classification	Number Calves	Average Daily Gain M.S. to Weaning* unadjusted	adjusted
Age of Cow:			
2-year old	55	1.36	1.46
3-year old	321	1.51	1.46
4-year old	294	1.58	1.47
5-year old	265	1.63	1.46
6-year old	213	1.67	1.47
7-year old	151	1.72	1.46
8-year old	128	1.61	1.47
9-year old	93	1.55	1.47
10-year old	45	1.40	1.46
11-year old	44	1.37	1.46
12-year old	33	1.25	1.46
13-year old	17	1.46	1.45
14-year old	23	1.54	1.44
Month Born:			
December	4	1.54	1.46
January	281	1.61	1.46
February	752	1.60	1.47
March	415	1.55	1.47
April	182	1.49	1.46
May	48	1.36	1.49
Year of Birth:			
1950	89	1.48	1.48
1951	137	1.25	1.45
1952	167	1.35	1.46
1953	205	1.30	1.46
1954	192	1.48	1.46
1955	233	1.66	1.46
1956	236	1.93	1.47
1957	242	1.61	1.46
1958	181	1.86	1.47
Grand Mean		1.53	1.46

*M.S. is Mid-summer

Appendix C

Example of Rank Order Correlation

Sire 82

Calf number	1st Rank	2nd Rank	d_i	d_i^2
1310	1	1	0	0
1317	2	6	4	16
1305	3	2	1	1
1328	4	5	1	1
1256	5	7	2	4
1333	6	4	2	4
1279	7	8	1	1
1331	8	13	5	25
1291	9	3	6	36
1251	10	9	1	1
1306	11	10	1	1
1324	12	11	1	1
1277	13	14	1	1
1276	14	12	2	4
				$\Sigma d_i^2 = 96$

$N = 14$

$N^3 - N = 2730$

$$1 - \frac{6(96)}{2730} = 1 - \frac{576}{2730} = 1 - .21$$

Rank Correlation = .79

Appendix D

Outline of I.B.M. Procedure

The available International Business Machines, Card Punch Type 26, Card Sorter Type 75, Accounting Machine Type 402, and the Digital Computer Type 650 were used in punching, sorting, listing and in making the computations. The I.B.M. equipment was used for the major portion of the calculations, e.g., sums of squares and sums of products, adjusting the data, and for summing the observations for calculation of the means. The remainder of the computations were made on an automatic desk calculator.

The data were punched into standard 80 column I.B.M. cards as follows:

1-4 calf number
5 breed
6 sex
7-12 date of birth
13-16 dam number
17-18 age of dam
19-22 sire number
23-25 birth weight of calf
26-28 mid-summer weight of calf
29-31 mid-summer type of calf, unadjusted
32-34 unadjusted mid-summer average daily gain
35-37 age of calf (in days) at mid-summer
38-40 age of calf (in days) at weaning
41-43 age of calf (in days) at weaning minus (age in days) at mid-summer
44-46 weaning weight of calf
47-49 weaning type of calf
50-52 average daily gain birth to weaning, unadjusted
53-55 average daily gain from mid-summer to weaning, unadjusted
58-60 mid-summer average daily gain, adjusted
61-63 mid-summer to weaning average daily gain, adjusted
64-66 birth to weaning average daily gain, adjusted
67-70 mid-summer type, adjusted
71-74 weaning type, adjusted

ABSTRACT OF THESIS

Submitted in Candidacy for Degree of

MASTER OF SCIENCE

in

ANIMAL HUSBANDRY

EFFECT OF AGE ON THE ACCURACY OF SELECTION AMONG BEEF CALVES

by

David C. Meyerhoeffer

This study was undertaken to investigate the possibility of selecting beef calves at 120 days of age instead of 210 days of age using growth rate (average daily gain) and type score.

There were 1682 calves of the three British breeds (Angus, Hereford, and Shorthorn) used in the study. The data on these calves were taken from the records of the Beef Cattle Research Station, Front Royal, Virginia, and covered nine years, 1950 through 1958.

The data were corrected for environmental effects (breed, sex, age of dam, year born, and month born) by fitting constants.

Adjusted data were then used to compute correlations (genetic, phenotypic, and rank). The product-moment correlation method was used to arrive at phenotypic correlations. The paternal half-sib variance and covariance components were used to estimate genetic correlations. In addition, heritability estimates were calculated using the paternal half-sib variances.

The traits studied were average daily gains from birth to mid-summer (Y_1), mid-summer to weaning (Y_2) and birth to weaning (Y_3) and type scores at mid-summer (Y_4) and at weaning (Y_5). Heritability estimates obtained for these traits were 0.18, 0.25, 0.22, 0.27 and 0.21, respectively. Similar estimates appear in the literature for traits at weaning, but few have been reported for traits measured prior to weaning.

Positive genetic correlations between 0.2 and 0.4 were obtained between $Y_1 Y_2$, $Y_1 Y_4$, $Y_2 Y_4$, $Y_2 Y_5$; they were greater than 0.7 for $Y_1 Y_3$, $Y_2 Y_3$, $Y_4 Y_5$. Positive genetic correlations less than 0.2 were found between $Y_1 Y_5$, $Y_3 Y_4$, and $Y_3 Y_5$.

Phenotypic correlations were generally higher than the genetic correlations, but not in all cases.

Three rank order correlations were obtained within sire groups containing five or more calves. The average rank correlation for daily gain from birth to mid-summer with daily gain from mid-summer to weaning was 0.41; for daily gain from birth to mid-summer with daily gain from birth to weaning it was 0.82; and for type at mid-summer with type at weaning it was 0.69.