SOME SOURCES OF VARIATION ASSOCIATED WITH BIRTH WEIGHT IN BEEF CATTLE AND ESTIMATES OF HERITABILITY OF BIRTH WEIGHT AND CORRELATIONS BETWEEN BIRTH AND WEANING WEIGHT

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1956

Submitted to the
faculty of the Graduate College of the
Oklahoma State University in partial
fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1967

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ACKNOWLEDGMENTS

The author wishes to express thanks to the following persons for their help in the preparation of this thesis: Dr. J. V. Whiteman, Professor of Animal Science, for his assistance in the analysis of the data and suggestions for improvement; Dr. R. L. Willham and Dr. I. T. Omtvedt, Associate Professors of Animal Science, for their counsel; Dr. R. D. Morrison, Professor of Mathematics and Statistics; Mr. Robert Easterling and Mr. Gary Lance, Graduate Assistants in Mathematics, for their assistance in analysis of the data; fellow graduate students for their counsel and encouragement; and to the author's wife, Pat, for her patience throughout the course of this undertaking.

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INTRODUCTION

Birth weight of beef cattle is one of the earliest measurements that can be taken on a new born animal. It has been reported that birth weight is heritable and related to some other measurements taken later in life. It is known that extreme birth weights, either large or small, contribute to the death loss of calves. Therefore, it becomes important to investigate some of the sources that cause birth weight variation and estimate the heritability of birth weight and its relationship with other traits.

Weaning weight is a measurement to which birth weight has been reported to be related. Since it is common practice for many producers to select the heaviest calves at weaning, it is important to know if this procedure will eventually increase birth weight of beef calves to the point of causing recurring calving difficulties and reproductive loss.

Since there are many sources causing variation in birth weight, it is the purpose of this study to investigate a few of these sources and to adjust birth weight for each source if necessary. The major characteristics evaluated in this study were age of dam and date of birth of calf. The adjusted birth weight was used to estimate the heritability of birth weight and the genetic and phenotypic correlations between birth and weaning weight.

LITERATURE REVIEW

Sex, age of dam, year, date of birth, and breeding are some factors that have been shown to influence birth weight.

Influence of Breed. Burris and Blunn (1952) using 502 calves in Nebraska reported birth weight differences due to breed. In their study Angus calves averaged 64.2 lbs., Hereford calves 67.4 lbs., and Shorthorn calves 64.3 lbs. Data by Flock et al. (1962) found similar averages for Angus and Herefords, but obtained a higher average of 70 lbs. for Shorthorns. Additional average birth weights noted for Herefords were 77.6 lbs. (Brinks et al., 1961), 71.0 lbs. (Gregory et al., 1950), 71.9 lbs. (Lasley et al., 1961), and 68.1 lbs. (Marlowe, 1962). Marlowe (1962) also found a 59.6 lbs. average birth weight for Angus and 66.6 lbs. for Shorthorns, while Foote et al. (1960) reported 56.2 lbs. for Angus and 59.9 lbs. for Shorthorns.

Early work by Eckles (1919) with dairy cattle revealed breed effect to be the most important factor influencing the birth weight of calves. These data showed a range from 55 to 100 lbs. for the average birth weights of the different dairy breeds. Work by Fitch et al. (1924), Everett and Magee (1965), Plum et al. (1965) and Foote et al. (1959) all noted similar averages of birth weight due to breed differences in dairy cattle.

<u>Sex of Calf Influence</u>. Sex of calf is another factor that many researchers have found to influence birth weight. Koch *et al*. (1959) used 1434 bull and 1512 heifer calves of Hereford, Shorthorn, and Angus breeding to evaluate the influence of sex on weight of calf at birth. The bull calves averaged 5.2 lbs. or 1.076 times heavier than the heifer calves at birth.

Dawson *et al*. (1947), using 402 Shorthorn calves also found bull calves to be heavier than heifers by about 4.2 lbs. Burris and Blunn (1952) studied birth weight on 502 calves of Hereford, Angus, and Shorthorn breeding and indicated bull calves were heavier than heifer calves by 5.3 lbs., 4.5 lbs., and 4.9 lbs., respectively. Koch and Clark (1955a) examined the birth weights on a large number of Hereford calves and found males to have a 5.6 lb. birth weight advantage over females. Likewise, Hafez (1963) reported bull calves to be heavier than females at birth, and found the difference to persist throughout life.

Other work done by Asker and Ragab (1953), Botkin and Whatley (1953), and Seebeck and Campion (1964) also showed similar weight advantages of male over female calves at birth.

Birth weight differences also exist between males and females in the dairy breeds. Davis *et al*. (1954) found a 6.4 lb. advantage for male calves while Fitch *et al*. (1924) reported a 4 to 11 lb. weight advantage for bull calves at birth. Everett and Magee (1965) reported a much smaller difference of only 1.6 lbs. between male and female birth weights.

Arunachalam et al. (1952) reported that sex of calf had no significant effect on birth weight. However, this work was done with Indian cattle which also had about a 20 day longer gestation period. The difference of these cattle may account for the dissimilar findings.

Age of Dam Influences. The age of the dam also seems to play an important role in influencing the size of the calf at birth. Data on 402 births of the Shorthorn breed showed that the birth weight of calves increased at the rate of 0.2 lb. per month of increase in age of dam until the dams were six years old (Dawson et al., 1947). Burris and Blunn (1952) found a significant regression of birth weight on age of dam of 1.04 lb. per year increase of age of dam. They found maximum birth weights were reached when the dams were 9 to 10 years of age. Koch and Clark (1955a) using 5952 calves found the largest difference in birth weight to be from cows between 3 and 4 years old. The trend was to increase through 6 years of age and then gradually decline until the cows reached 10 years of age. They used additive correction factors of 4.7, 2.1, 0.2, 0.0, 0.4, 0.4, -0.1, and 1.4 for 3, 4, 5, 6, 7, 8, 9, and 10 year old cows respectively, which indicates that six years of age was the age of maximum production.

A study by Marlowe (1962) using 5067 Angus, 4778 Herefords, and 231 Shorthorn calves indicated there was approximately 2.3 lbs. increase in birth weight for each year increase in age of dam for the Shorthorn breed, but only 1.6 lbs. increase in both the Angus and Hereford breeds. This increase was fairly constant up to 7 years of age; thereafter, birth weight decreased as the cows became older. The exact breaking point could not be determined because all cows over 7 years of age were pooled together. Bennett (1958) found a similar relationship between age of dam and birth weight. In his study, calves from 2 year old dams were 5.9 lbs. lighter and those from 3 year old dams were 4.0 lbs. lighter than those from cows older than 4 years of age.

Dawson et al. (1947) reported correlations between age of dam and birth weight of 0.45 for male calves and 0.35 for females. With 71 male calves that were later fed out as steers, the simple correlation between age of dam and birth weight was 0.53 ($P<.01$). They also computed a multiple correlation on age and weight of dam with birth weight and found a similar figure of 0.56 ($P<.01$).

Some of the early work on the influence of age of dam on birth weight was done by Eckles (1919) using dairy cattle. He noted that calves from 2 year old dams were noticeably smaller than the average for the breed, and that the maximum birth weight was not reached until the dams were about 6 to 8 years of age. Fitch et al. (1924), Everett and Magee (1965), and Donald et al. (1962) also found that as the age of dam increased the birth weight of their calves increased.

Joubert and Bonsma (1959) found no effect of age of dam on birth weight. Their work was done in South Africa on purebred Hereford, Shorthorn, and Africander cattle and crosses between these breeds. The 71.5 to 77.8 lbs. range of average birth weights was similar to the other data, but finding no age of dam effect on birth weight was not in agreement with most other work. No reason for this difference was cited.

Date of Birth Influence. Date of birth or seasonal effect on birth weight was discussed by Koch and Clark (1955a), and they found calves born later in the calving season to be slightly heavier at birth. They indicated this slight difference could be due to better pasture conditions or possibly to the weight difference caused by variation in gestation length of cows. Ellis et al. (1965) found season of calving to have a significant effect on birth weight. They found calves born in November and December to be lighter than calves born later in the season, and contributed this to different pasture conditions during the last third of gestation period when the fetus makes its greatest increase in weight. Other work by Lasley et al. (1961) showed that date of birth had a significant ($P<.01$) effect on birth weight and weaning weight. In this work the length of gestation, birth weight, and weaning weight for all calves were grouped into 2 week periods through the calving season to determine if the date the calves were born was a significant source of variation in these traits. This grouping showed the heaviest calves at birth were dropped during the period from March 1st to 15th.

Knapp _et al_. (1940) noted that calves born in the fall months were slightly heavier at birth than calves born in the spring months; however, this difference was not significant.

Tyler _et al_. (1947) found season of calving to have little or no influence on birth weight; however, this work was with dairy cattle and the differences in nutritional management between dairy and beef cattle may account for these results.

Heritability of Birth Weight. Heritability of birth weight has been studied by many workers and the estimates found show considerable variation. Lasley _et al_. (1961) obtained a heritability of birth weight for Hereford calves of 0.67, while Shelby _et al_. (1955) reported an estimate of 0.72. Knapp and Nordskog (1946) determined heritability by two different methods and calculated two different estimates. Using the half-sib correlation method, they obtained a heritability of 0.23, while the sire-offspring regression method gave an estimate of 0.42. Gregory _et al_. (1950) studied the genetic variance of birth weight in Hereford cattle at two locations and found heritability estimates of 0.45 and 1.00.

Other heritability estimates of birth weight showing a moderate range are 0.22 (Burris and Blunn, 1952) on pooled breeds, 0.53 (Knapp and Clark, 1950), 0.11 and 0.29 (Dawson et al., 1947), and 0.41 (Asker and Ragab, 1953).

Legault and Touchberry (1962) found heritability estimates of birth weight to vary from 0.21 to 1.17 in the dairy breeds.

Relationships Between Birth Weight and Weaning Weight. Studies by Gregory et al. (1950) showed that birth weights and weaning weights were related. The phenotypic correlation coefficients between these two weights using data from two stations were 0.27 and 0.60; and 0.07 and 0.44 between gain from birth to weaning and birth weight. The Arizona Agricultural Experiment Station (Annual Report, 1937) reported a phenotypic correlation of 0.60 between birth weight and average daily gain from birth to weaning.

Drewry et al. (1959) also found positive correlations between birth weight and calf weights taken at different ages. The calves were weighed at determined intervals and the phenotypic correlation values between the weights were 0.30, 0.37, and 0.32 for the 1st, 3rd, and 6th month weights, respectively. The magnitude of these values suggest that heavier calves at birth were able to maintain their weight advantage at least through 6 months of age.

Other correlations found between birth weight and weaning weight were 0.62 (phenotypic) by Christian et al. (1965), 0.63 (genetic) and 0.39 (phenotypic) by Koch and Clark (1955b), 0.68 (genetic) and 0.37 (phenotypic) by Shelby et al. (1963), and 0.69 (genetic) and 0.31 (phenotypic) by

Swiger (1961).

Work by Flock *et al.* (1962) indicated there were breed differences in reference to correlations between birth weight and average daily gain. They found these relationships to be 0.30 for Angus, 0.24 for Herefords, and 0.15 for Shorthorns; and concluded that these correlations may justify selecting on the basis of birth weight in Angus and possibly Herefords but not in Shorthorns.

Results by Bennett (1958) from 402 birth and weaning weights with Hereford and Shorthorn calves indicated that weaning weight was not significantly associated with birth weight.

Adjustment Factors. Some difference of opinion exists as to type of adjustment necessary for sex of calf. Brinks *et al.* (1961) suggested a multiplicative factor was more satisfactory than an additive type of adjustment and should be calculated by using the ratio between the average male birth weight and the average female birth weight. However, Koch *et al.* (1959) reported that the variation among bull and variation among heifer birth weights were not significantly different and concluded, that from a practical standpoint the difference between using an additive adjustment factor and a multiplicative factor would be quite small in the case of birth weight, and thought the two types would seldom differ more than 1.5 lb.

Botkin and Whatley (1953) adjusted weights by adding 4 lbs. to the weights of calves from 3 year old dams and

2 lbs. to calves from 4 year old dams, and in this manner removed 62% of the variance in birth weights due to differences in age of dams. Dawson *et al.* (1947) found that birth weights increased as the age of dam increased up to 6 years of age and that this regression did not deviate significantly from linearity. They therefore adjusted birth weight for age of dam influence by adding 0.2 lb. for every month increase in the dam's age until the dam reached 6 years of age, after which there was no further effect. Burris and Blunn (1952) used the same type of adjustment but with a regression coefficient of only 1.043 lbs. for every year increase in age of dam. However, they found that birth weights increased until the cows reached 9 to 10 years of age.

MATERIALS AND METHODS

This study included 612 Angus and 902 Hereford calves born during the 16 year period from 1950 to 1965. All Herefords and part of the Angus were kept at Fort Reno Livestock Research Station at El Reno, Oklahoma. The rest of the Angus were kept at the Lake Carl Blackwell Range. Only records having both birth and weaning weights were used to permit calculation of the relationship between these two traits.

Calves were born in January, February, March, April, and May. Native pastures, consisting primarily of bluestems, sideoats gramma, Indian, and switch grasses, were used throughout the year. During the winter the cattle were fed a protein supplement until about the middle of April. In addition, cattle at Fort Reno had access to wheat pasture when available. These cows were returned to native pasture about March 10th each year. Beginning in 1962, to help decrease calving difficulties, first calf heifers were not given access to wheat pasture after January 1.

The calves were weighed and tattooed within 24 hours after birth. During the first week of April, all calves were vaccinated, ticks were removed from their ears, and the heifers were dehorned. Calves born after the first week of April were vaccinated and dehorned shortly after birth.

When the average age was approximately 205 days the calves were weaned. The adjusted weaning weight was adjusted for age of calf and age of dam by the procedures recommended by the United States Beef Cattle Improvement Committee (1965).

Throughout their productive lives the cows were culled by production records, unsoundnesses, and reproductive failures.

The calf records for each breed were grouped according to the sire of calf, sex of calf, and year born. The major portion of the data was examined by using multiple regression techniques as outlined by Steel and Torrie (1960). The relationship between birth weight and the two variables, age of dam and date of birth (day of year born), was studied by using the following model:

$$Y_{ijkl} = \mu_{ijk} + \beta_{11}(X_{1ijkl} - \bar{X}_{1ijk.}) + \beta_{12}(X^2_{1ijkl} - \overline{X^2}_{1ijk.}) + \beta_{21}(X_{2ijkl} - \bar{X}_{2ijk.}) + \beta_{22}(X^2_{2ijkl} - \overline{X^2}_{2ijk.}) + e_{ijkl}$$

where:

Y_{ijkl} = birth weight of the lth calf in the kth sire, jth sex, and ith year group.

μ_{ijk} = mean for the kth sire, jth sex, and ith year group.

β_{11} = regression coefficient for birth weight on age of dam.

X_{1ijkl} = age of dam of the lth calf in the kth sire, jth sex, and ith year group.

$\bar{X}_{1ijk.}$ = average age of dam for the kth sire, jth sex, and ith year group.

β_{12} = regression coefficient of birth weight on the square of the age of dam.

X^2_{1ijkl} = age of dam squared for the lth calf in the kth sire, jth sex, and ith year group.

$\overline{X^2}_{1ijk.}$ = average of the squared age of dams for the kth sire, jth sex, and ith year group.

β_{21} = regression coefficient for birth weight on date of birth of calf.

X_{2ijkl} = date of birth of the lth calf in the kth sire, jth sex, and ith year group.

$\overline{X}_{2ijk.}$ = average date of birth for the kth sire, jth sex, and ith year group.

β_{22} = regression coefficient of birth weight on the square of the date of birth.

X^2_{2ijkl} = date of birth squared for the lth calf in the kth sire, jth sex, and ith year group.

$\overline{X^2}_{2ijk.}$ = average of the squared date of birth for the kth jth sex, and ith year group.

e_{ijkl} = random error unique for each observation.

The averages for age of dam and date of birth were calculated as follows:

$$\overline{X}_{1ijk.} = \frac{\Sigma X_{1ijkl}}{n_{ijk}}, \text{ and } \overline{X^2}_{1ijk.} = \frac{\Sigma X^2_{1ijkl}}{n_{ijkl}};$$

$$\overline{X}_{2ijk.} = \frac{\Sigma X_{2ijkl}}{n_{ijk}}, \text{ and } \overline{X^2}_{2ijk.} = \frac{\Sigma X^2_{2ijkl}}{n_{ijk}};$$

and where:

n_{ijk} = number of animals in the kth sire, jth sex, and ith year group (ijk=1,2,...,139 in Angus and ijk=1,2,...,164 in Herefords).

The abbreviated Doolittle procedure, as outlined by Steel and Torrie (1960), was used to obtain the sums of squares necessary for an analysis of variance to determine which of the variables had the most effect on birth weight.

The F test was used to test for significance.

After determining which of the variables significantly affected birth weight, the Doolittle method was again used to compute the necessary regression coefficients for adjusting the data. Variables after the last significant effect were eliminated. Birth weight was adjusted by the following equation:

$$Y'_{ijkl} = Y_{ijkl} + \beta_{11}(X_{1ijkl}-\overline{X}_1) + \beta_{12}(X^2_{1ijkl}-\overline{X^2_1}) + \beta_{21}(X_{2ijkl}-\overline{X}_2) + \beta_{22}(X^2_{2ijkl}-\overline{X^2_2})$$

where:

Y'_{ijkl} = adjusted birth weight for the lth calf in the kth sire, jth sex, and ith year group.

Y_{ijkl} = actual birth weight for the lth calf in the kth sire, jth sex, and ith year group.

β's = appropriate regression coefficients for each variable.

$\overline{X}_1$ = the average age of dam, and

$\overline{X}_2$ = the average date of birth.

Before adjusting each birth weight for the combined effects of age of dam and date of birth, 157 calves in line four were removed from the Hereford data. This line was a comprest type including known dwarf carriers and it was feared that these calves would contribute to a greater than normal variance in birth weight and cause an abnormal birth weight-weaning weight relationship.

Two paternal half-sib analyses were then run for each breed to obtain the necessary mean squares to calculate estimates of heritability of birth weight and genetic and phenotypic correlations between birth and weaning weight.

The first analysis was run using a weight ratio Y'', hereafter referred to as weight ratio analysis, which was suggested by Dr. R. L. Willham and obtained by:

$$Y'' = \frac{Y'_{ijkl}}{\bar{Y}'_{ij..}}$$

where:

Y'_{ijkl} = the adjusted birth weight for the lth calf in kth sire, jth sex and ith year group and

$\bar{Y}'_{ij..}$ = the average adjusted birth weight for the corresponding jth sex and ith year group.

By using the denominator $\bar{Y}'_{ij..}$, each calf was adjusted for sex and year effects because it was adjusted to the average of its own sex-year group. Since sex and year effects were accounted for by the ratio Y'', the method of analysis of variance for a one-way classification (sire) with unequal subclasses was utilized to obtain the necessary mean squares (Steel and Torrie, 1960).

No previous estimates were found in the literature using the above weight ratio method, so a second analysis was used as a means of comparison.

The second analysis was run using the adjusted birth weight (adjusted for age of dam and date of birth effects) and adjusted weaning weight (adjusted for age of calf), hereafter referred to as adjusted weight analysis. No adjustment was made for sex and year effects in the adjusted weights, so the method of analysis of variance for a nested classification (year and sire) with unequal subclasses was used to account for year effects; a separate analysis was run for each sex to account for sex effects. Due to this type of classification each sire was counted as a different sire with each year change.

The two above mentioned analyses were run to obtain the variances and covariances needed to estimate heritability of birth weight and genetic and phenotypic correlations between birth and weaning weight. The genetic variance plus the environmental variance equals the total observed variance (Lush, 1960). Estimating the genetic and environmental variances and covariances requires estimating the between sire variance (genetic) and within sire variance (environmental) for each trait and the sums of the two (Falconer, 1960). The expected mean squares used to partition the variances and covariances into their component parts are as follows (Munson, 1966):

analysis of variance

between sires $= \sigma^2_w + k\sigma^2_s$

within sires $= \sigma^2_w$

analysis of covariance

between sires $= \sigma^2_{w_a} + \sigma^2_{w_b} + 2\sigma_{w_a w_b} + k(\sigma^2_{s_a} + \sigma^2_{s_b} + 2\sigma_{s_a s_b})$

within sires $= \sigma^2_{w_a} + \sigma^2_{w_b} + 2\sigma_{w_a w_b}$

where:

k = the number of offspring per sire.

σ^2_s = an estimate of ¼ of the additive genetic variance of each trait.

σ_w^2 = an estimate of 3/4 of the genetic variance plus all the environmental variance for each trait.

$\sigma_{s_a s_b}$ = an estimate of ¼ of the genetic covariance between traits a and b.

$\sigma_{w_a w_b}$ = an estimate of 3/4 of the genetic covariance plus all the environmental covariance between traits a and b.

and where:

a = birth weight and

b = weaning weight.

The "k" value was found by the following equation (Steel and Torrie, 1960):

$$k = \frac{n_{..} - \sum_i \left(\sum_j n^2_{ij}/n_{i.} \right)}{\text{df (sires)}}$$

where:

$n_{..}$ = the total number of individuals.

n_{ij} = the number of individuals in the ith group by the jth sire, and

$n_{i.}$ = the total number of individuals in the ith group;

and where:

i and j = any particular pair of traits.

Heritability of birth weight was estimated by the following equation (Knapp and Nordskog, 1946):

$$h^2 = \frac{4(\sigma_s^2)}{\sigma_w^2 + \sigma_s^2}$$

where:

σ_s^2 = the between sire variance component (contains ¼ of the additive genetic variance) and

σ_w^2 = the within sire variance.

The standard error of heritability was calculated by the following formula (Robertson, 1959):

$$(h^2 + \frac{4}{n})\sqrt{\frac{2}{N}}$$

where:

n = the number of offspring per sire and

N = the number of sires.

The genetic and phenotypic correlations between birth and weaning weight were estimated as follows:

$$r_G = \frac{\sigma_{s_a s_b}}{\sqrt{\sigma^2_{s_a}}\sqrt{\sigma^2_{s_b}}}$$

where:

$\sigma_{s_a s_b}$ = the genetic covariance between birth and weaning weight,

$\sigma^2_{s_a}$ = the genetic variance of birth weight, and

$\sigma^2_{s_b}$ = the genetic variance of weaning weight;

$$r_P = \frac{\sigma_{s_a s_b} + \sigma_{w_a w_b}}{\sqrt{\sigma^2_{s_a} + \sigma^2_{w_a}}\sqrt{\sigma^2_{s_b} + \sigma^2_{w_b}}}$$

where:

$\sigma_{s_a s_b} + \sigma_{w_a w_b}$ = the genetic covariance plus the environmental covariance between birth and weaning weight,

$\sigma^2_{s_a} + \sigma^2_{w_a}$ = the genetic variance plus the environmental variance for birth weight, and

$\sigma^2_{s_b} + \sigma^2_{w_b}$ = the genetic variance plus the environmental variance for weaning weight,

as discussed by Hazel _et al._ (1943).

The standard errors for the genetic correlations were calculated by the following equation (Reeve, 1955):

$$\text{S.E. of } r_G \approx \frac{1-r_G^2}{\sqrt{2}} \cdot \sqrt{\frac{\text{S.E. } h_a^2 \cdot \text{S.E. } h_b^2}{h_a^2 \cdot h_b^2}}$$

where:

r_G^2 = the square of the genetic correlation coefficient,

$\text{S.E.}h_a^2$ = the standard error of heritability of birth weight,

$\text{S.E.}h_b^2$ = the standard error of heritability of weaning weight,

h_a^2 = the heritability of birth weight, and

h_b^2 = the heritability of weaning weight.

RESULTS AND DISCUSSION

Because the data were grouped into sire, sex, and year groups, birth weight was not adjusted for these variables. However, since it is generally thought that sex does affect birth weight, averages were calculated in both breeds to determine the magnitude that sex influences birth weight. The differences found between male and female calves at birth were 4.10 lb. for Angus and 5.85 lb. for Herefords, both in favor of males. As shown in Table I, the pooled breed difference between male and female was 5.13 lb. This combined breed figure is in close agreement with Koch et al. (1959) reporting a 5.2 lb. advantage for males while working with Hereford, Angus, and Shorthorn breeds. Botkin and Whatley (1953) found a male advantage in birth weight of 4.4 lb. for Herefords; while Burris and Blunn (1952) reported a 4.5 lb. difference between males and females at birth for Herefords and a difference of 5.3 lb. for Angus.

Even though there is some disagreement as to the magnitude of sex influence on birth weight, most researchers agree that males are larger than females at birth.

Table I also indicates that the variation of birth weight is greater among bulls than heifers.

Since the average birth weight and the difference between sexes were not similar for the two breeds, age of dam

TABLE I

BIRTH WEIGHT AVERAGES, VARIANCES, AND COEFFICIENTS OF VARIATION FOR ANGUS, HEREFORD, AND POOLED BREEDS

Sex	Number of Calves	Ave. B.W.	$\hat{\sigma}^2$	CV	Difference
Angus:					
Bulls	318	63.45	66.59	12.86	+4.10
Heifers	294	59.35	58.37	12.87	
Breed Ave.		61.48			
Hereford:					
Bulls	468	75.73	100.38	13.23	+5.85
Heifers	434	69.88	91.66	13.70	
Breed Ave.		72.91			
Pooled Breeds:					
Bulls	786	70.76	86.72	13.16	+5.13
Heifers	728	65.63	78.23	13.48	

and date of birth effects on birth weight were studied separately for each breed to see if these two traits reacted the same in Angus and Herefords. Tables II and III show the analyses of variance that disclose which variables have a significant effect on birth weight. Both age of dam and date of birth showed only linear significance in the Angus herd; while in the Hereford herd, age of dam showed significance due to linear and quadratic effects and date of birth showed quadratic effects. Since these variables influencing birth weight did not follow a similar pattern for two breeds, the Angus and Hereford data were analyzed separately.

Age of Dam. Swiger (1961) noted that the effect of age of dam on birth weight was curvilinear.

Figure 1 shows the regression of birth weight on age of dam from 2 to 10 years of age. The regression equation used for plotting the regression line was:

$$Y = \overline{Y} + \beta_1 x_1 + \beta_2 x^2_1$$

where:

x_1 = the deviation between the age of dam and the average age of dam.

x_2 = the deviation between the age of dam squared and the average of the squared age of dams.

These regression lines indicate the Angus dams continue to give birth to heavier calves through 10 years of age, while Hereford dams produced the heaviest calves at about 8 years of age. Burris and Blunn (1952) working with Hereford, Angus, and Shorthorns found that maximum birth weights were reached when dams were 9 to 10 years old. However,

TABLE II

ANALYSIS OF VARIANCE OF BIRTH WEIGHT OF ANGUS CALVES

(Regression Analysis Showing Reduction in Sum of Squares Removed by one Variable After Adjusting for the Preceeding Variables.)

Source	df	Sum of Squares	Mean Squares
Total (Cor.)	473	25971.683	54.9084
$R(\hat{\beta}_{11})^a$	1	1993.3319	1933.3319 **
$R(\hat{\beta}_{12}/\hat{\beta}_{11})$	1	134.8242	134.8242
$R(\hat{\beta}_{21}/\hat{\beta}_{11},\hat{\beta}_{12})$	1	1013.3604	1013.3604 **
$R(\hat{\beta}_{22}/\hat{\beta}_{11},\hat{\beta}_{12},\hat{\beta}_{21})$	1	91.3998	91.3998
Error	469	22798.766	48.6114

** $P<.01$.

[a] $R(\hat{\beta}_{11})$ = reduction in sum of squares due to fitting $\hat{\beta}_{11}$ after fitting $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{12}/\hat{\beta}_{11})$ = reduction in sum of squares due to fitting $\hat{\beta}_{12}$ after fitting $\hat{\beta}_{11}$ and $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{21}/\hat{\beta}_{11},\hat{\beta}_{12})$ = reduction in sum of squares due to fitting $\hat{\beta}_{21}$ after fittimg $\hat{\beta}_{11}$, $\hat{\beta}_{12}$, and $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{22}/\hat{\beta}_{11},\hat{\beta}_{12},\hat{\beta}_{21})$ = reduction in sum of squares due to fitting $\hat{\beta}_{22}$ after fitting $\hat{\beta}_{11}$, $\hat{\beta}_{12}$, $\hat{\beta}_{21}$, and $\hat{\mu}_{ijk}$.

TABLE III

ANALYSIS OF VARIANCE OF BIRTH WEIGHT OF HEREFORD CALVES

(Regression Analysis Showing Reduction in Sum of Squares Removed by one Variable After Adjusting for the Preceeding Variables.)

Source	df	Sum of Squares	Mean Squares
Total (Cor.)	738	53999.239	73.1697
$R(\hat{\beta}_{11})$[a]	1	2018.7156	2018.7156 **
$R(\hat{\beta}_{12}/\hat{\beta}_{11})$	1	1533.5055	1533.5055 **
$R(\hat{\beta}_{21}/\hat{\beta}_{11},\hat{\beta}_{12})$	1	76.2922	76.2922
$R(\hat{\beta}_{22}/\hat{\beta}_{11},\hat{\beta}_{12},\hat{\beta}_{21})$	1	610.5847	610.5847 **
Error	734	49760.141	67.7931

** $P<.01$

[a]$R(\hat{\beta}_{11})$ = reduction in sum of squares due to fitting $\hat{\beta}_{11}$ after fitting $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{12}/\hat{\beta}_{11})$ = reduction in sum of squares due to fitting $\hat{\beta}_{12}$ after fitting $\hat{\beta}_{11}$ and $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{21}/\hat{\beta}_{11},\hat{\beta}_{12})$ = reduction in sum of squares due to fitting $\hat{\beta}_{21}$ after fitting $\hat{\beta}_{11}$, $\hat{\beta}_{12}$, and $\hat{\mu}_{ijk}$.

$R(\hat{\beta}_{22}/\hat{\beta}_{11},\hat{\beta}_{12},\hat{\beta}_{21})$ = reduction in sum of squares due to fitting $\hat{\beta}_{22}$ after fitting $\hat{\beta}_{11}$, $\hat{\beta}_{12}$, $\hat{\beta}_{21}$, and $\hat{\mu}_{ijk}$.

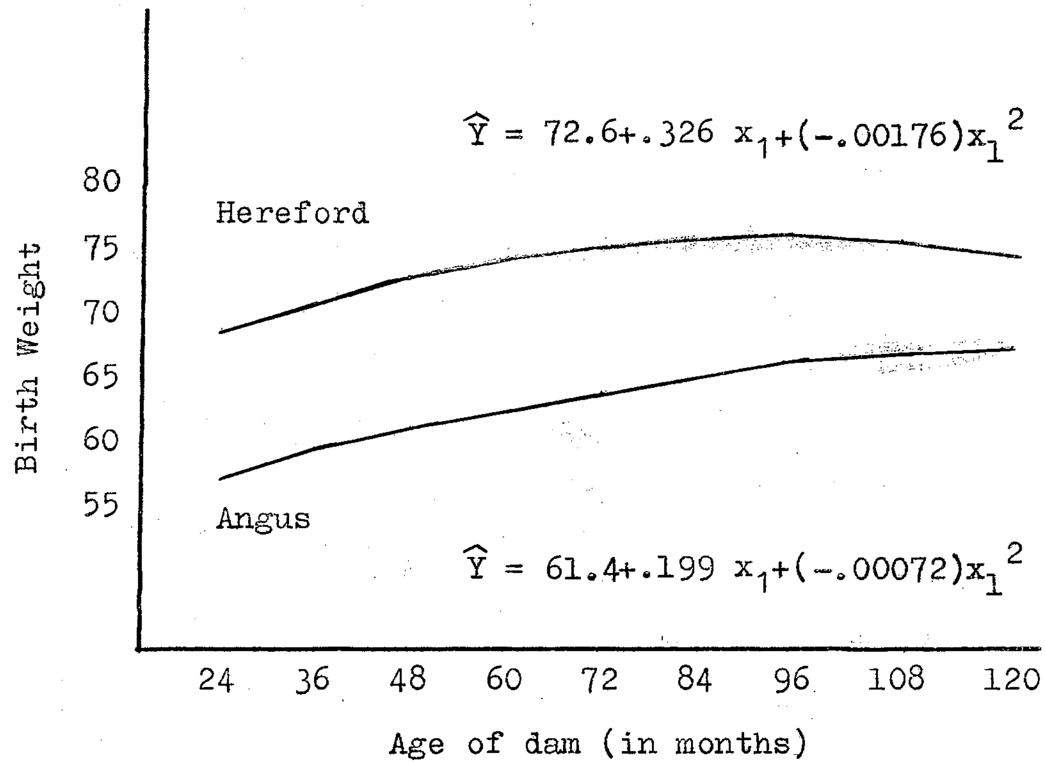

Figure 1. Regression of Birth Weight on Age of Dam.

Koch and Clark (1955b) reported 6 year old Hereford dams calved the heaviest calves.

Even though the regression lines shown in Figure 1 are not exactly the same for the two breeds, there may not be much actual difference from one breed to the other. Since relatively few dams over 9 years of age are included in this study, the reliability of the information on older cows may be questionable. Therefore, the effects of age of dam (beyond 8 or 9 years of age) on birth weight might be looked at with caution. The frequency distributions on ages of dams are shown in Figure 2 and 3.

As previously mentioned, the older cows had continually been selected by their production records due to the culling practice. This may account for part of the reason that older cows produced heavier calves at birth.

<u>Date</u> <u>of</u> <u>Birth</u>. Date of birth was also a significant variable affecting birth weight so regression coefficients were computed and regression lines plotted (Figure 4). The Angus herd did not deviate significantly from linearity, therefore their calves increased in birth weight as the calving season progressed. The study by Ellis <u>et</u> <u>al</u>. (1965) also showed calves born later in the calving season to be heavier than early calves. They reported May and June calves were 8.74 lb. heavier than calves dropped in November and December. Koch and Clark (1955a) also found calves born later in the calving season to be slightly heavier at birth.

Date of birth effects on birth weight in the Hereford

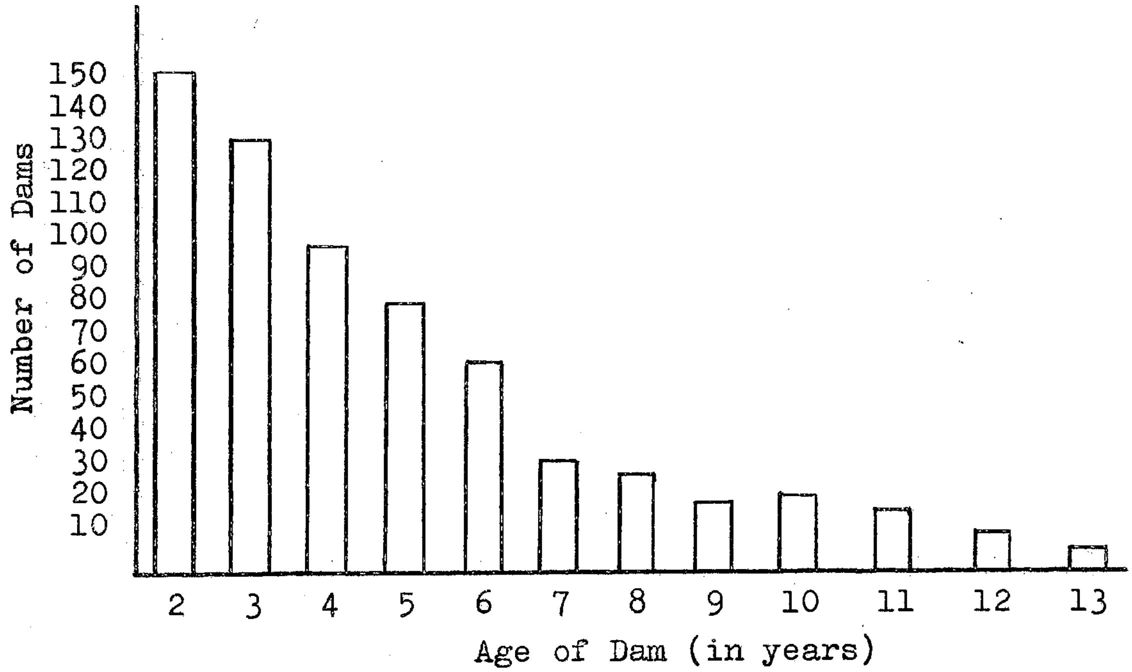

Figure 2. Angus Age of Dam Frequency Distribution.

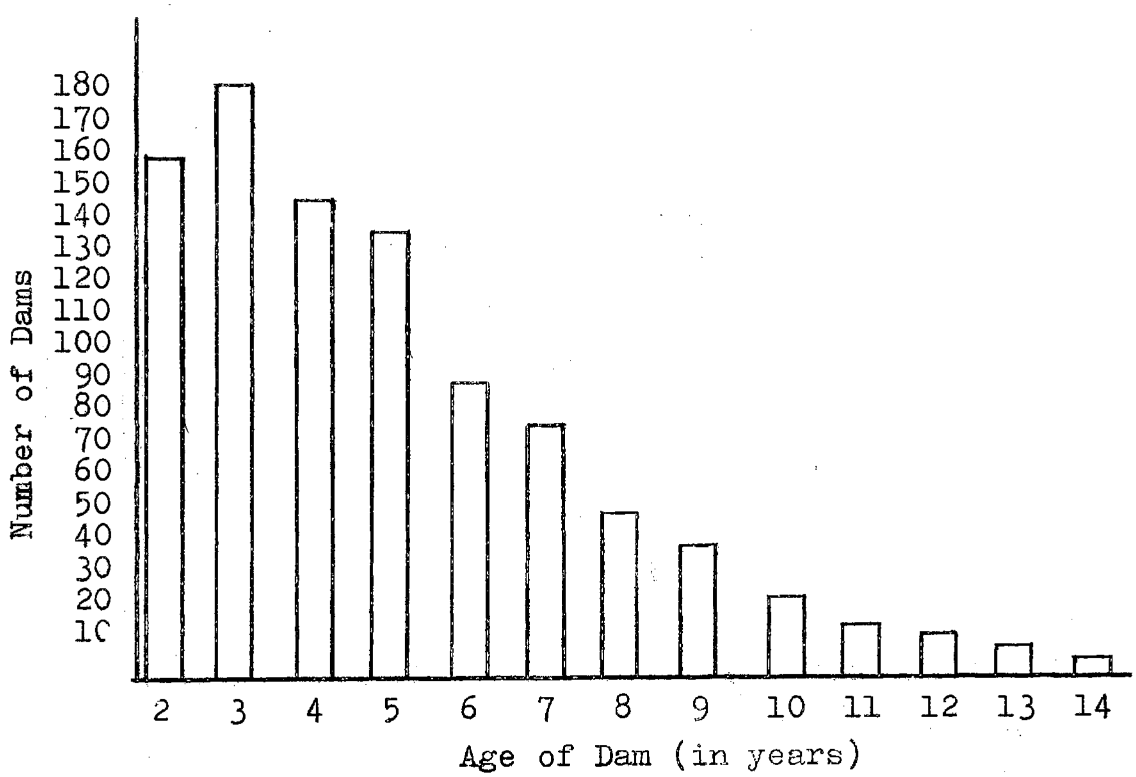

Figure 3. Hereford Age of Dam Frequency Distribution.

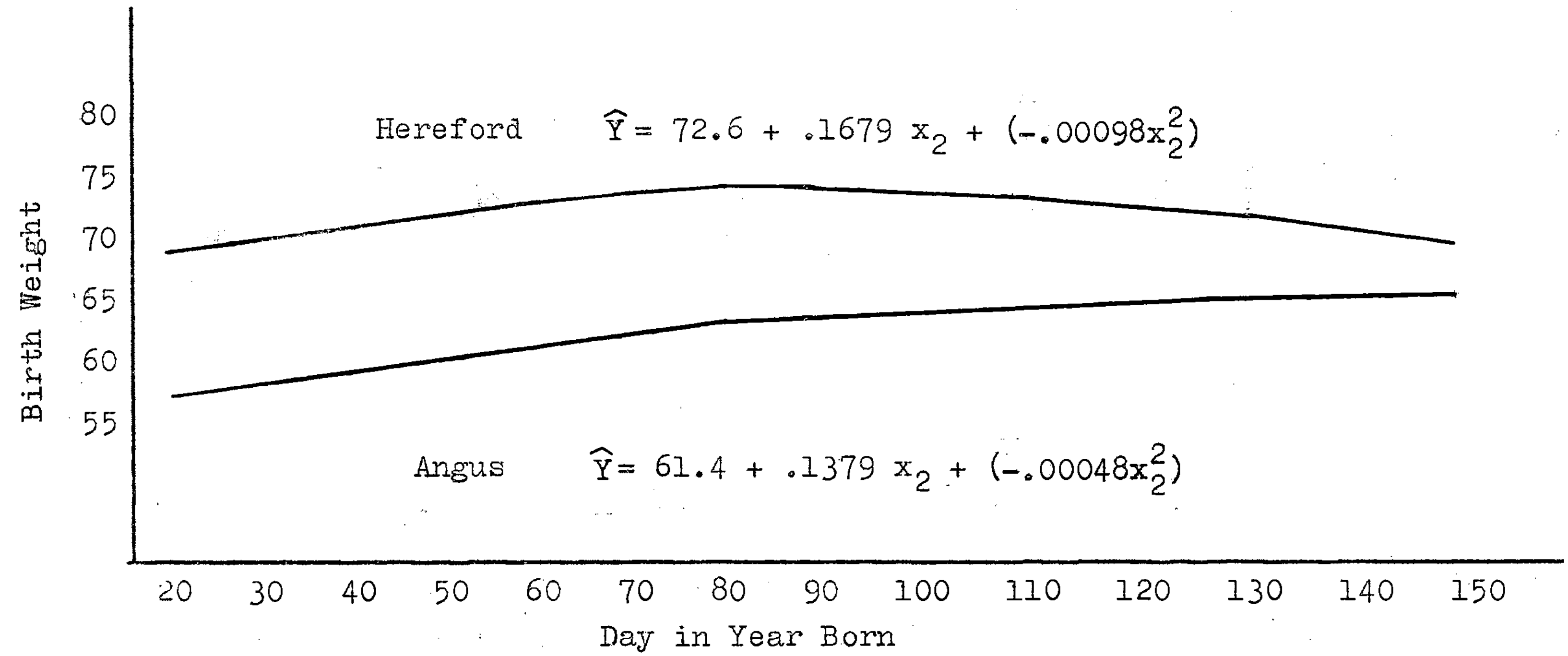

Figure 4. Regression of Birth Weight on Date of Birth

herd had a dissimilar pattern than the Angus. The heaviest calves at birth were produced from about March 20 to April 10, after which the birth weights gradually decreased through May. Lasley _et al_. (1961) found a similar pattern when they reported the heaviest calves were born between March 1 and 15.

The regression lines of birth weight on date of birth show marked differences between Angus and Hereford cattle. However, the frequency distributions showing the number of calves born each week of the calving season (Figures 5 and 6) indicate that the majority of the calves were born in a 10 to 12 week period, and there were relatively few calves born the last 40 to 50 days of the calving season. This last part of the calving season is where most of the difference is between the two breeds, so the few calves born at this time could account for most of these differences.

Adjustments. After determining the significant variables influencing birth weight in both breeds, birth weights were adjusted for age of dam and date of birth effects as follows:

Angus: $$Y'_{ijkl} = Y_{ijkl} + \beta_{11}(X_{1ijkl} - \bar{X}_1) + \beta_{12}(X^2_{1ijkl} - \overline{X^2_1}) + \beta_{21}(X_{2ijkl} - \bar{X}_2)$$

Hereford: $$Y'_{ijkl} = Y_{ijkl} + \beta_{11}(X_{1ijkl} - \bar{X}_1) + \beta_{12}(X^2_{1ijkl} - \overline{X^2_1}) + \beta_{21}(X_{2ijkl} - \bar{X}_2) + \beta_{22}(X^2_{2ijkl} - \overline{X^2_2})$$

where:

X_1 = age of dam and

X_2 = date of birth.

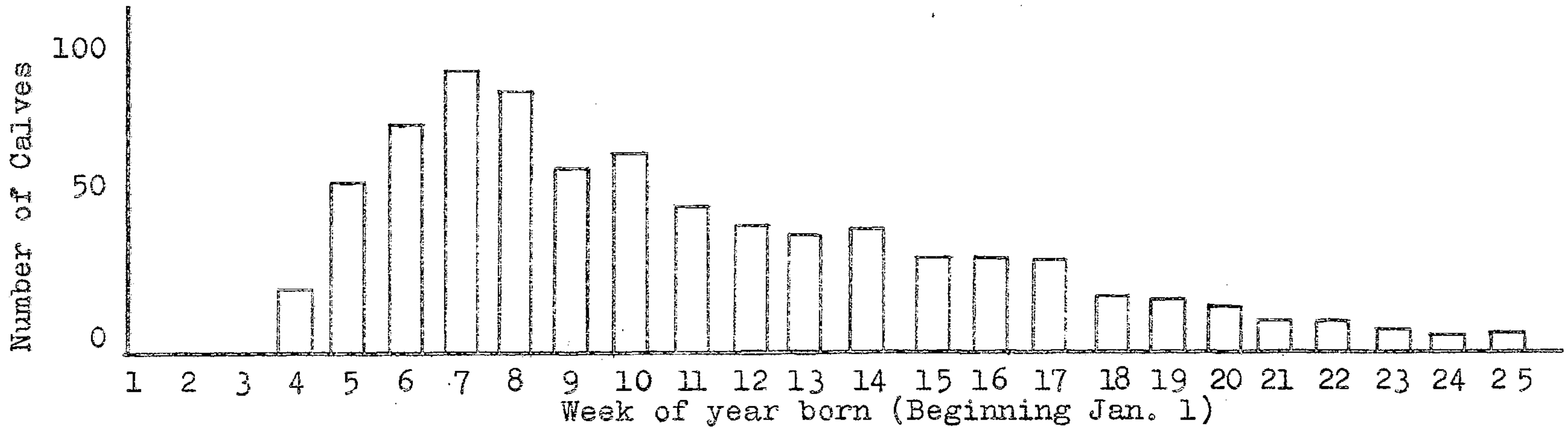

Figure 5. Angus Date of Birth Frequency Distribution.

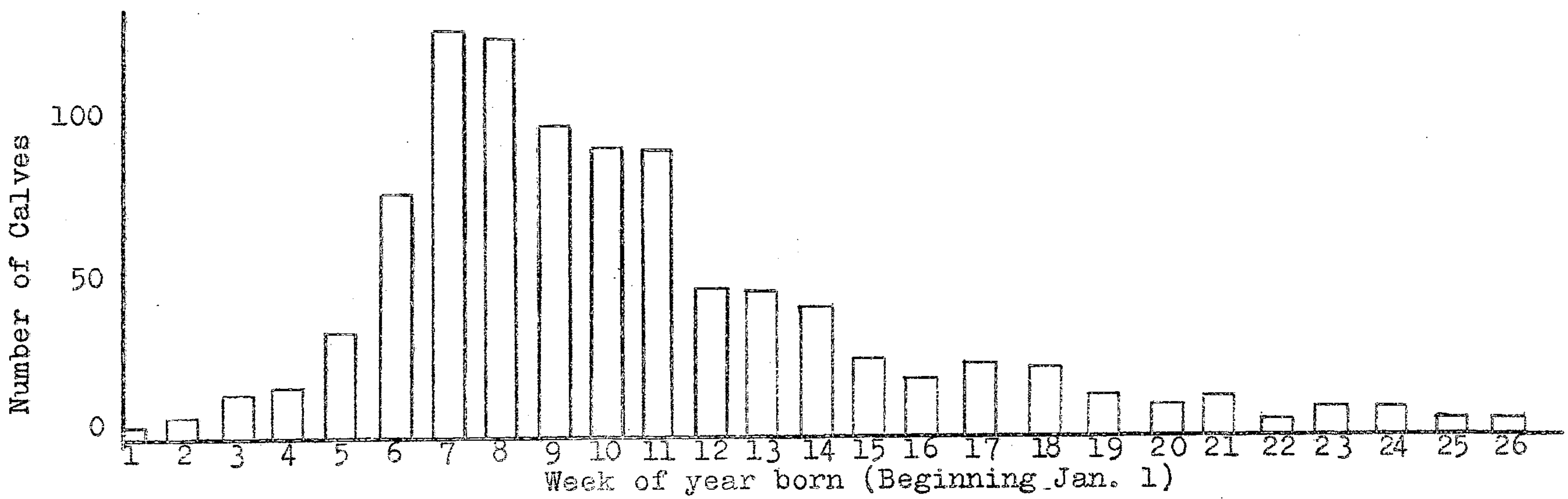

Figure 6. Hereford Date of Birth Frequency Distribution.

The adjustment coefficients and the computed averages of age of dam and date of birth used in the above adjustment equations are presented in Tables IV and V, respectively.

Heritability of Birth Weight. Heritability is estimated for use as a guide for predicting the reliability of the observed value of a trait as a measure of the breeding value. This is based on heritability being the ratio of genetic variance to phenotypic variance, or that proportion of the total variance (phenotypic) accounted for by genic effects.

It was the intent of this paper to estimate heritabilities of birth weight for use to help determine the importance of birth weight in selection programs.

The mean squares used to obtain the variance components for computing heritability estimates are shown in Tables VI and VII. The heritability estimates (Table VIII), calculated from the weight ratio analysis, of 0.43 (Angus) and 0.47 (Hereford) were between the 0.45 found by Gregory et al. (1950) and the 0.53 reported by Knapp and Clark (1950).

The estimates of 0.84 (bulls), 1.05 (heifers) and 0.72 (bulls), 1.06 (heifers) for Angus and Herefords respectively, obtained from the adjusted weight analysis, were considerably higher than those from the weight ratio analysis. However, other high heritability estimates of birth weight of 0.72 by Shelby et al. (1955), 1.00 by Gregory et al. (1950), and 1.17 by Legault and Touchberry (1962) have been reported.

TABLE IV

REGRESSION COEFFICIENTS USED FOR ADJUSTING BIRTH WEIGHT

	Angus	Hereford
β_{11}[a]	1.41364040	0.32649028
β_{12}	-0.00829057	-0.00176862
β_{21}	0.21730615	0.16792040
β_{22}		-0.00097770

[a]Regression coefficients for the appropriate variables (β_{11} for age of dam, β_{12} for age of dam squared, β_{21} for date of birth and β_{22} for date of birth squared).

TABLE V

COMPUTED AVERAGES OF AGE OF DAM AND DATE OF BIRTH USED FOR ADJUSTING BIRTH WEIGHT IN THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES

Analysis		Angus	Hereford
Weight Ratio Analysis			
$\overline{X}_1$[a]		53.861	56.615
$\overline{X_1^2}$		3764.065	3983.809
$\overline{X}_2$		67.306	66.016
$\overline{X_2^2}$		5474.483	5220.121
Adjusted Weight Analysis			
$\overline{X}_1$	Bulls	54.035	57.805
	Heifers	53.609	55.271
$\overline{X_1^2}$	Bulls	3806.764	4099.365
	Heifers	3715.357	3853.397
$\overline{X}_2$	Bulls	68.028	65.114
	Heifers	65.782	67.034
$\overline{X_2^2}$	Bulls	5592.997	5068.370
	Heifers	5218.776	5391.382

[a] X_1 = age of dam and X_2 = date of birth.

TABLE VI

ANGUS ANALYSES OF VARIANCE SHOWING THE MEAN SQUARES AND THE K VALUE FOR THE WEIGHT RATIO AND THE ADJUSTED WEIGHT ANALYSES

Source	df	Mean Squares[c] a	b	a + b
Weight Ratio Analysis				
between sires	55	0.06621510	0.01785500	0.09173307
within sires	556	0.02920881	0.01217789	0.05532782
			k^d = 10.607	
Adjusted Weight Analysis				
Bulls				
groups (year)	14	802.59151459	12920.57141113	13767.21423340
between sires	55	264.32045364	4704.69085693	5546.19995117
within sires	248	125.92937183	2663.23989868	3274.65319824
			k = 4.139	
Heifers				
groups (year)	14	457.56863785	12720.14282227	13818.07141113
between sires	54	208.82175827	2256.50924683	2723.68518066
within sires	225	85.64930534	2224.71997070	2599.49777222
			k = 4.031	

[c]a = birth weight.
b = weaning weight.
a + b = birth weight + weaning weight
[d]k = number of offspring per sire.

TABLE VII

HEREFORD ANALYSES OF VARIANCE SHOWING THE MEAN SQUARES AND THE K VALUE FOR THE WEIGHT RATIO AND THE ADJUSTED WEIGHT ANALYSES

Source	df	Mean Squares[c] a	b	a + b
Weight Ratio Analysis				
between sires	47	0.03826401	0.05138105	0.14366702
within sires	697	0.01273488	0.01361462	0.03809246
			k^d = 15.187	
Adjusted Weight Analysis				
Bulls				
groups (year)	15	134.24791527	17560.46655273	17870.39990234
between sires	50	165.00749969	6680.71997070	7892.11999512
within sires	329	74.65776920	2609.04861450	3078.69906616
			k = 5.516	
Heifers				
groups (year)	15	141.87812424	16979.93310547	17916.73315430
between sires	47	169.95611572	7495.10632324	8986.76586914
within sires	287	60.07257175	2588.89196777	3003.76654053
			k = 5.086	

[c]a = birth weight.
b = weaning weight.
a + b = birth weight + weaning weight
[d]k = number of offspring per sire.

TABLE VIII

HERITABILITY ESTIMATES OF BIRTH WEIGHT AND STANDARD ERRORS OF HERITABILITY ESTIMATES FROM THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES

Analysis	Angus	Hereford
Weight Ratio	0.43 ± 0.15	0.47 ± 0.15
Adjusted Weight		
Bulls	0.84 ± 0.34	0.72 ± 0.29
Heifers	1.05 ± 0.39	1.06 ± 0.38

The heifer heritability estimates are greater than the bull estimates in both breeds. This might be explained by the fact that bulls had a greater variance than heifers for both Angus and Herefords and that more of this variance must be getting into the within sire variance than the sire component of the between sire variance. In the formula for calculating heritability σ_s^2 (the resemblance between relatives due to the sire) should be fairly constant for bulls and heifers since a sire produces approximately the same number of each sex. Therefore, a greater portion of the bulls variance must be getting into the within sire variance, thus decreasing the proportion of genetic variance to total phenotypic variance and decreasing heritability of birth weight for bulls.

Heritability estimates were found to be considerably lower for the weight ratio method of analysis than for either sex in the adjusted weight method of analysis. This difference may be due to the sire selection procedures followed and methods of classification of the data. Sires were selected to be used from one year to another on the basis of their productive performance. The birth weight of the offspring from a few of these selected sires deviated from the average of the year they were used more than other sires used only a year or two, as shown in Table XIII in the Appendix. Therefore, a few of these exceptional sires, having more offspring per sire, contributed to a greater birth weight variance than did the offspring from the average sires.

When the data were classified for the adjusted weight analysis a sire was counted as a new sire for each year change, thus counting a sire repeated from one year to the next as a separate sire for each year he produced any offspring. By this means of classification a selected sire's contribution to the variance between sires (which was normally greater than that of the average sire) was magnified by the fact that he was counted as a new sire each year he was selected for use. Therefore, the sire component of variance was increased, in turn causing the heritability estimates obtained from the adjusted weight analyses to be biased upward and should be regarded as such.

Since the estimates of heritability of birth weight obtained from the weight ratio analysis do not show the above mentioned bias, they should be considered the more accurate estimates of the two methods of analyses.

Relationship of Birth Weight and Weaning Weight. The correlation coefficients between birth and weaning weights as shown in Table IX were calculated from the necessary variances and covariances obtained from the two analyses of variance shown in Tables VI and VII.

From the weight ratio analysis genetic correlations between birth and weaning weights of -0.22 (Angus) and 0.68 (Hereford) were obtained. This suggests that the same genes do not affect both traits in the Angus but to some degree do affect both traits in the Hereford data. The standard errors of these genetic correlation estimates indicate there

TABLE IX

GENETIC AND PHENOTYPIC CORRELATIONS BETWEEN BIRTH AND WEANING WEIGHTS AND STANDARD ERRORS OF GENETIC CORRELATIONS FROM THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES

Analysis		Angus	Hereford
Weight Ratio			
	G[a]	-0.22±0.31	0.68±0.12
	P	0.33	0.48
Adjusted Weight			
Bulls	G	0.09±0.31	0.54±0.19
	P	0.36	0.46
Heifers	G	-0.25±1.76	0.66±0.14
	P	0.28	0.51

[a] G = Genetic and P = Phenotypic.

is probably a true difference between the breeds involved. The Hereford estimate is very close to the genetic correlations of 0.63 reported by Koch and Clark (1955b) and 0.68 by Shelby et al. (1963), both of which were obtained from Hereford data.

The negative genetic correlation estimate obtained from the Angus data was not in accordance with the literature reviewed. However, no estimates were found which had been obtained only from Angus data. This might suggest the need for additional work to help determine if there is a difference between breeds in other populations in regard to the relationship between birth and weaning weight.

The phenotypic correlations of 0.33 (Angus) and 0.48 (Hereford) obtained from the weight ratio analysis are in much closer agreement between breeds than the genetic correlations, and indicate that heavier than average calves at birth will tend to be heavier than average at weaning for both breeds. These phenotypic relationships fall within the range of the coefficients reported by Gregory et al. (1950) of 0.27 and 0.60 obtained from data from two stations.

The adjusted weight analysis indicated essentially the same trend as did the weight ratio analysis. The 0.09 (bulls) and -0.25 (heifers) genetic correlations for Angus suggests that birth weight and weaning weight are not being affected by the same genes, while the 0.54 (bulls) and 0.66 (heifers) estimates from the Hereford data suggests that birth and weaning weights are genetically related. However, the standard errors of these estimates from this method of analysis do not indicate a significant difference between breeds as did the standard errors obtained from the weight ratio analysis.

The phenotypic correlations calculated from the adjusted weight analysis of 0.36 (bulls), 0.28 (heifers) and 0.46 (bulls), 0.51 (heifers) for Angus and Herefords respectively, again indicate a moderately strong observable relationship between these two traits. The Hereford estimates suggest a slightly stronger relationship than do the Angus estimates.

Based upon these phenotypic correlation estimates it may be concluded that birth weight might be an indicator as to a calf's subsequent weaning weight. However, since most all calves are kept at least through weaning time anyway, this becomes of secondary importance.

The genetic correlation estimates between birth weight and weaning weight found in this study seem to be of primary importance. When some of the same genes affect two traits, selection for one trait may result in some change in the other. The amount of change would depend upon the magnitude of the genetic correlation between the two traits involved. Since birth weight and weaning weight are shown to have a moderately high genetic correlation in the Hereford data, it should be expected that as weaning weight is continually increased by selection, birth weight will be indirectly increased. This would not become economically important until the larger birth weights would cause increased calving difficulties and reproductive losses.

The negative, or very low, genetic correlation estimates found from the Angus data suggest that selecting for heavier weaning weight will not simultaneously increase birth weight.

SUMMARY

Records involving 1514 calves of purebred Angus and Hereford cattle were used in this study. The records were collected over a 16 year period beginning in 1950. The cattle were kept at either Fort Reno or Lake Carl Blackwell Range. Each record had both birth weight and adjusted 205 day weaning weight.

Age of dam, date of birth (day of year born), and sex of calf were studied for their influences on birth weight. Angus and Herefords were analyzed separately because the variables affected birth weight differently in each breed.

Male calves were 4.10 lb. heavier in the Angus and 5.85 lb. heavier in the Herefords. Birth weight was regressed on age of dam and date of birth. In the Angus herd age of dam and date of birth associations with birth weight did not deviate significantly from linearity, indicating that as the age of dam increased and as the calving season progressed birth weights increased. In the Hereford herd birth weight responded in a linear and quadratic manner to age of dam and in a quadratic manner to date of birth. The Hereford data implies that birth weights are steadily increased by increases in age of dam until the dams reach about 8 years of age, thereafter declining as age of dam

increases. It also indicates that birth weight responds in a curvilinear manner to date of birth, reaching a peak at about the middle of the calving season.

After adjusting birth weight for age of dam and date of birth effects, two paternal half-sib analyses were run to estimate the heritability of birth weight and the genetic and phenotypic correlations between birth and weaning weight. The weight ratio used in the first analysis was obtained by dividing the adjusted birth weight of each calf by the average adjusted birth weight of the sex and year group to which it belonged. The data were then sorted in sire groups and the analysis of variance was run using a one-way classification (sires).

The adjusted weights used in the second analysis were the birth weights adjusted for age of dam and date of birth effects. The data were sorted into year and sire groups and the analysis of variance using a nested classification (years and sires) was run.

The heritability estimates for birth weight were 0.43 and 0.47, for Angus and Herefords respectively, from the weight ratio analysis. The heritabilities obtained from the adjusted weight analysis of 0.84 (bulls), 1.05 (heifers) and 0.72 (bulls), 1.06 (heifers) for Angus and Herefords respectively, were considerably higher than the weight ratio analysis. These estimates from the adjusted weight analysis were biased upward because a few exceptional sires used for several years produced offspring with birth weights that deviated from the average more than the average sires offspring did. Due to the method of classification all sires were counted as new sires for each year they appeared in the data, which magnified the deviations that these exceptional sires contributed.

The genetic correlations obtained between birth and weaning weight for the weight ratio analysis of -0.22 (Angus) and 0.68 (Hereford) and the adjusted weight analysis of 0.09 (Angus bulls), -0.25 (Angus heifers), 0.54 (Hereford bulls), and 0.66 (Hereford heifers) suggest there might be a breed difference with regard to this relationship. However, the standard errors of the genetic correlations indicated a significant difference between breeds only for the estimates obtained from the weight ratio analysis.

The phenotypic correlations between birth and weaning weight for the weight ratio analysis of 0.33 (Angus) and 0.48 (Hereford) and the adjusted weight analysis of 0.36 (Angus bulls), 0.28 (Angus heifers), 0.46 (Hereford bulls) and 0.51 (Hereford heifers) imply that calves with above average birth weights will hold this advantage at least through weaning weight in both breeds; Herefords showing a somewhat stronger relationship between these two traits than did Angus.

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APPENDIX

TABLE X

BIRTH WEIGHT COMPONENTS OF VARIANCE USED FOR CALCULATING HERITABILITY AND CORRELATION ESTIMATES FROM THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES FOR ANGUS AND HEREFORDS

Analysis	$\hat{\sigma}_s^2$ [a]	$\hat{\sigma}_w^2$ [b]
<u>Weight Ratio</u>		
Angus	0.00348883	0.02920881
Hereford	0.00168099	0.01273488
<u>Adjusted Weight</u>		
Angus		
Bulls	33.43174635	125.92937183
Heifers	30.55216350	85.64930534
Hereford		
Bulls	16.38011154	74.65776920
Heifers	21.60212364	60.07257175

a $\hat{\sigma}_s^2$ = (between sire mean square—within sire mean square)/k.

b $\hat{\sigma}_w^2$ = within sire mean square.

TABLE XI

WEANING WEIGHT COMPONENTS OF VARIANCE USED FOR CALCULATING HERITABILITY AND CORRELATION ESTIMATES FROM THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES FOR ANGUS AND HEREFORDS

Analysis	$\hat{\sigma}_s^2$ [a]	$\hat{\sigma}_w^2$ [b]
Weight Ratio		
Angus	0.00053522	0.01217789
Hereford	0.00248677	0.01361462
Adjusted Weight		
Angus		
Bulls	493.16234600	2663.23989868
Heifers	7.88513293	2224.71997070
Hereford		
Bulls	738.18074000	2609.04861450
Heifers	964.51793700	2588.89196777

[a] $\hat{\sigma}_s^2$ = (between sire mean square–within sire mean square)/k.

[b] $\hat{\sigma}_w^2$ = within sire mean square.

TABLE XII

COMPONENTS OF COVARIANCE USED FOR CALCULATING CORRELATIONS BETWEEN BIRTH AND WEANING WEIGHT FROM THE WEIGHT RATIO AND ADJUSTED WEIGHT ANALYSES FOR ANGUS AND HEREFORDS

Analysis	$\hat{\sigma}_{s_a s_b}$ [c]	$\hat{\sigma}_{w_a w_b}$ [d]
Weight Ratio		
Angus	-0.00029594	0.00697056
Hereford	0.00139196	0.00587148
Adjusted Weight		
Angus		
Bulls	11.07675682	242.74196386
Heifers	-3.81668971	144.56424809
Hereford		
Bulls	59.04833375	197.49634123
Heifers	95.04209350	177.40100050

[c] $\hat{\sigma}_{s_a s_b} = \left[(\text{between sire mean square}-\text{within mean square})/k-(\sigma^2_{s_a}+\sigma^2_{s_b})\right]/2$

[d] $\hat{\sigma}_{w_a w_b} = \left[\text{within sire mean square}-(\sigma^2_{w_a}+\sigma^2_{w_b})\right]/2$

TABLE XIII

AVERAGE BIRTH WEIGHT DEVIATIONS ON A WITHIN YEAR BASIS FOR ANGUS AND HEREFORD SIRES

Number of Years Sires Used	Sex of Calf	Within Year Average Deviation[a]	Number of Calves	Number of Sires
<u>Angus</u>				
More Than Three Years	B	3.76	46	1
	H	3.05	44	
Three Years	B	8.58	35	2
	H	6.72	33	
Two Years	B	3.94	138	13
	H	4.33	104	
One Year	B	5.55	99	40
	H	5.76	113	
<u>Hereford</u>				
More Than Three Years	B	4.09	40	1
	H	5.79	43	
Three Years	B	4.31	42	3
	H	2.15	42	
Two Years	B	3.31	193	15
	H	3.38	144	
One Year	B	3.09	120	29
	H	3.87	121	

[a] Within Year Average Deviation = Σ[(Sires average birth weight for the year - birth weight average for the year) X number of calves by the sire].

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Master of Science

Thesis: SOME SOURCES OF VARIATION ASSOCIATED WITH BIRTH WEIGHT IN BEEF CATTLE AND ESTIMATES OF HERITABILITY OF BIRTH WEIGHT AND CORRELATIONS BETWEEN BIRTH AND WEANING WEIGHT

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