PHENOTYPIC RELATIONSHIPS AMONG MATERNAL HALF-SIB WEANING WEIGHTS AND BETWEEN HEIFER GROWTH AND SUBSEQUENT COW PRODUCTIVITY IN BEEF CATTLE

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CHAPTER I

INTRODUCTION

Oklahoma presently has one of the largest beef cow populations of any state. The beef cow via the calf she produces is one of the principle generating sources of income in Oklahoma. There are presently over 2 million beef cows maintained in Oklahoma solely for the production of calves; and approximately 1.5 million of these beef calves are marketed at weaning as feeders or stockers. The weight and grade of the beef calf determines to a large extent its value when marketed at weaning.

To keep the beef cow-calf enterprise important and competitive in Oklahoma, beef cattle producers are constantly searching for ways to increase the productivity of the basic unit of the beef industry, the brood cow. The annual productivity of the beef cow is normally measured by the weaning weight of her calf since this observation occurs at the end of the period over which the cow exerts maximum influence on calf growth. The expanding use of weaning weight production testing programs of various types by beef cow-calf operators has resulted in a rapidly growing interest in techniques to increase the weaning weights of beef calves. It has been found that large differences exist among the standarized production records of contemporary beef cows. Improvement in weaning weights of beef calves is primarily dependent upon increasing the preweaning growth potential of calves and the maternal or mothering ability of cows.

There is opportunity for improving the weaning weight of beef cattle by selection depending upon the degree to which differences in performance observed among animals are genetic and heritable. Differences due to maternal and other environmental variants among beef calves' preweaning performances tend to reduce the effectiveness of selection for genetic improvement. Pertinent to the effective use of genetic variability is a knowledge of the phenotypic, genetic and environmental relationships among traits of concern and among relatives for the same trait. Since the beef cow influences her calf both by the genes transmitted and the maternal environment she provides preweaning, the phenotypic relationship among calves of the same cow includes components due to the genetic likeness of half-sibs and to their common maternal environment.

The response of traits to selection is the combined result of direct selection and indirect selection resulting from the genetic correlations among traits. Thus, selection for increased calf weaning weight results in a complex of direct and indirect selection for maternal and growth ability in the selected animals.

If selection for increased weaning weights in beef calves is to be very effective, the lifetime producing ability of cows must be accurately estimated at a reasonably early age to maximize selection pressure. The accuracy of the heifer's own early growth, characterized by her weaning and yearling weights, as a measure of her subsequent productivity as a cow depends on the correlation or relationship between these weights and the weaning weights of her calves. The accuracy of a cow's first or early calves' weaning weights as a measure of her future productivity depends on the relationship or repeatability of records of maternal half-sibs. Weaning weight occurs only once in an animal's lifetime and is repeatable only when considered as a characteristic of the cow. The repeatability or relationship among calf weaning weights of the same cow determines the number of records necessary to make effective selection among beef cows for increased calf weaning weight.

The objectives of this study were to evaluate and characterize:

1. The phenotypic relationship or repeatability of beef maternal half-sib weaning weights.

2. The phenotypic relationship of a beef heifer's early growth, measured by her weaning and yearling weights, and her subsequent cow productivity as measured by the weaning weights of her calves.

3. The differences between adjusted weights and adjusted weight ratios to the herd-year average for measuring these two phenotypic relationships.

4. The differences between the Angus and Hereford breeds for these two phenotypic relationships.

CHAPTER II

REVIEW OF LITERATURE

Relationship Among Maternal Half-Sibs

The phenotypic relationship among individual or groups of maternal half-sibs can be quantitatively estimated by use of the linear intra- and inter-class correlation and regression coefficients. For this literature review and subsequent study, class refers to the beef cow or dam, and correlation refers to the interclass correlation unless otherwise designated. For clarification it is noted that simple, product-moment and interclass correlation coefficients are synonymous. The following review will cover studies concerned with the phenotypic relationship among both the weaning weights and weaning weight ratios of maternal half-sib beef calves. Ratio refers to the individuals' performance relative to the herd-year or sire-year mean. When possible, the experimental results will be reported by breed.

The previously mentioned statistics and others have all been used to estimate repeatability, a term often used in reference to the phenotypic relationship among maternal half-sib progeny (Taylor et al., 1960; Ronningen, 1970). According to Dickerson (1969), the term "repeatability" was introduced by Dr. J. L. Lush prior to 1937 to imply the intra-class correlation among repeated expressions or measurements of a specific trait for the same individual. Lush (1945, 1948) defined repeatability as "the intra-herd correlation between repeated records of the same individual." This implies that if an individual tends to produce similarly for a particular trait each expression, the first record is a reliable measure of future production, and the trait is considered highly repeatable. Thus, repeatability of calf weaning weights is an estimate or measure of the correlation of maternal half-sib weaning weights and is a permanent characteristic of the beef cow expressed through her calves (Koch and Clark, 1955b).

Knapp et al. (1942) published the first report where researchers attempted to quantify the influence of the differences between beef cows on the weaning weights of their calves. They found in their data that 20% of the variation in weaning weights was due to differences between cows. This study of the effects of various factors on weaning weights of Hereford range cattle in Montana involved records on 770 calves of 112 cows. Sex, sire and age of dam had significant effects on weaning weight. Since their study included a selected population of highly productive cows, the authors concluded that more than 20% of the variation in weaning weights in a randomly selected beef population could be attributed to the differences between cows.

The first known estimate of the repeatability of beef cow productivity was published by Koger and Knox (1947) from their study of the yearly production of range cows which calved first as 3-year-olds. This study was conducted in New Mexico and included 436 Hereford cows and 1,416 of their calves. The analysis of the 205-day weaning weight data was conducted within cow birth year groups. Sums of squares were pooled across groups to obtain correlation and regression estimates. The authors indicated that they followed this procedure in an attempt to remove age of dam and year effects since corresponding records of cows within a group were then made under similar conditions. Correlations and regressions of weaning weights were determined between adjacent and combinations of adjacent calves of the same cow as summarized in Table I. For all cows with five consecutive calves including their first, the results of an analysis of calf weaning weights showed that after the influence of age of dam was removed the permanent differences between cows accounted for 51% of the remaining variance, Table II. The authors concluded that considerable progress could be made by selecting range beef cows on the basis of the weaning weight of their first calf.

TABLE I

RELATIONSHIP OF WEANING WEIGHTS OF CALVES OF RANGE COWS REPORTED BY KOGER AND KNOX (1947)

Calves Compared	df	Correlation	Regression
All Adjacent	909	0.49**	0.50
1st with			
2nd	133	0.66**	0.76
Avg. of 2nd and 3rd	113	0.53**	0.65
Avg. of 2nd, 3rd and 4th	89	0.51**	0.43
Avg. of 2nd, 3rd, 4th and 5th	71	0.53**	0.32
Avg. of 1st and 2nd with			
3rd	113	0.54**	0.69
Avg. of 3rd and 4th	89	0.55**	0.60
Avg. of 3rd, 4th and 5th	71	0.59**	0.52

**$P<.01$.

Gregory, Blunn and Baker (1950) reported a similar study in which repeatability estimates of 200-day weaning weight were calculated as correlation and regression coefficients. The data consisted of 270 Hereford calves from the North Platte, Nebraska Experiment Substation and 69

TABLE II

SUMMARY OF REPORTED INTRACLASS CORRELATION ESTIMATES OF REPEATABILITY OF WEANING WEIGHT AS A CHARACTER OF THE COW

Author and Date	Station	Breed[a]	No. Dams	No. Calves	Repeatability ± St. Error
Koger et al. (1947)	N. Mex.	H	436	1416	0.51
Koch (1951)	Mont.	H	180	745	$(0.44 \leq 0.52 \leq 0.60)$[b]
Botkin et al. (1953)	Okla.	H	151	603	$(0.29 \leq 0.43 \leq 0.55)$[b]
Rollins et al. (1954)	Cal.	H	57	159	$(0.30 \leq 0.48 \leq 0.63)$[b]
Koch et al. (1955b)	Mont.	H	1166	3849	$(0.31 \leq 0.34 \leq 0.38)$[b]
Hoover et al. (1956)	Okla.	A,H[c]	301	1110	0.32±.05
McCormick et al. (1956)	Ga.	PH	95	462	0.42±.06
		PH	90	332	0.38±.06
Rollins et al. (1956)	Cal.	H	97	317	0.51
		H	89	256	0.34
Stonaker (1958)	Colo.	H[d]			0.49
Berg (1961)	Alba.	A[d]		665	0.31
Pratt et al. (1962)	Okla.	A,H,PH[c]	368	680	0.29
Lueker et al. (1963)	Ark.	A,H[c]	80	260	0.45
Sewell et al. (1963)	Mo.	H[d]		1066	0.52
Minyard et al. (1965)	S. Dak.	A[d]			0.52±.13
		H[d]	378	866	0.42±.04
Drewey et al. (1966)	Ia.	A,H[c]	207	384	0.44±.06
		A,H[c]	232	456	0.43±.06
Petty (1966)	Tex.		370	892	0.47
Hohenboken et al. (1969)	Wyo.	A	1501	4722	0.26±.02
Ellicott et al. (1970)	N. Mex.	H	175	655	0.24**
Sellers et al. (1970)	Ia.	A	4785	9907	0.19±.01
		H	4881	10000	0.27±.01
Thompson et al. (1971)	Va.	A[d]		9515	0.31
Hohenboken et al. (1971a)	Col.	H	423	1386	0.33±.03
		H	445	1232	0.40±.03
Kress et al. (1972)	Mont.	H	648	3342	0.44±.02
Averages:					
Unweighted:		All			0.39
		A			0.32
		PH,H			0.41
Weighted[e]: (Calves/Cow = 2.6)		All			0.29
(Calves/Cow = 2.3)		A			0.21
(Calves/Cow = 2.8)		PH,H			0.33

**P<.01.

[a]A = Angus, H = Hereford and PH = Polled Hereford.

[b]95% confidence interval.

[c]Not included in breed averages.

[d]Not included in weighted averages.

[e]Determined by transformation method using the number of dams involved (Fisher, 1958).

Hereford calves from the Valentine, Nebraska Experiment Substation. Some of the cows calved first as 2 and the remainder as 3-year-olds. Since age of dam and year of calving effects were completely confounded, the statistical analysis was conducted on an intra-year, intra-source basis. Sex and sire differences were found to be nonsignificant for weaning weight. The regression and correlation coefficients for the North Platte data between first and second, first and third, and second and third calf weaning weights of the same cow were 0.49 and 0.50 ($P<.01$), 0.41 and 0.35 ($P<.05$), and 0.43 and 0.37 ($P<.01$), respectively. For the Valentine data, the regression and correlation coefficients of first and second calf were 0.33 and 0.43 ($P<.01$), respectively. By both statistical measures, the relationship between the first and second record of a cow was higher than that of the first and third or second and third. The authors suggested that some progress can be made in increasing 200-day weaning weights by culling cows on their first calving record since cows tend to repeat their previous performances.

Koch (1951) in a report of the size of calves at weaning as a permanent characteristic of range Hereford cows indicated that this trait is an important part of the problem of selecting beef cows to improve their productivity. The weaning weights used in this study were adjusted for calf weaning age, sex, year, age of dam, and inbreeding of dam and calf. The author's repeatability estimate of 0.52, Table II, was based on differences between cows which had calves over a ten year period; and according to the author, it may be slightly high for comparing cows born in the same year because the variance among cows in this study included some of the variance among the means of cow birth year groups in addition to the variance among cows born in the same year. The author concluded that weaning weight repeatability is high enough for reasonably accurate selection of beef cows on the basis of their first calf for high lifetime production.

Botkin and Whatley (1953) at the Oklahoma Experiment Station conducted a study on the repeatability of production in range beef cows. The data included 210-day weaning weight records on 603 calves produced in the Stillwater experimental herd by 151 Hereford cows which calved first as 3-year-olds and on 98 calves produced in the Fort Reno experimental herd by 49 Hereford cows which calved first as 2-year-olds. All weaning weights were adjusted for calf weaning age, sex, age of dam and year. Using the Stillwater group, the repeatability of weaning weight estimates were 0.43, 0.51 and 0.49 by the intraclass correlation coefficient, regression of second on first record and of the average of all later records on the first record of a cow, respectively. The authors also calculated an intraclass correlation estimate of repeatability using unadjusted weaning weights. This estimate was 0.22 which was approximately one-half that of their repeatability estimate using adjusted weaning weights. Using the Fort Reno group, the correlation between the weaning weights of first and second calves of a cow was 0.66. The authors noted that these results indicated that considerable progress can be made in increasing 210-day weaning weights by selecting cows on the basis of their first calf since there is little danger of culling good producing cows by this method.

The factors affecting the growth of beef calves during the suckling period were studied by Rollins and Guilbert (1954). The 240-day weaning weight data used in their study was corrected for calf weaning age, sex, age of dam, season of birth and year. The authors suggested that their repeatability estimate of 0.48, Table II, indicated that the 240-day weaning weight of a cow's first calf can be used profitably as a criterion in selecting replacement females.

Dawson et al. (1954) reported on selection for increased weights of 6-month-old beef calves in a Brahman-Angus herd in Louisiana. The data consisted of weaning weights of 446 calves of 111 cows adjusted for year, sex and age of dam. The authors calculated within sire of calf groups the correlation and regression coefficients for the 1949 and 1950 calves' 6-month weights on both the average weight of the dam's previous calves and the weight of their dam's best previous calf. The coefficients were 0.33 and 0.29, respectively, for both cases. The calf sequence number or ages of dam in 1949 and 1950 were not given. The authors concluded that in selecting for 6-month weaning weight one should retain a high percentage of beef heifers for one or two calf crops and then select for future use those demonstrating an ability to wean heavy calves.

As part of a study of the correlation among paternal and maternal half-sibs, Koch and Clark (1955b) reported estimates of the repeatability or maternal half-sib correlation of 182-day weaning weights for various calving patterns of the cow. According to the authors, this was done because calving pattern determines both the years in which a cow calves and ages at which she calves; and it is not possible to separate clearly the effects of cows, years and ages of dam. In order to separate cow differences, the authors divided into groups those cows born in the same year which had identical calving patterns with respect to age of dam at calving. The weaning weights on 3,849 calves of 1,116 Hereford cows which had more than one record at the United States Range Livestock Experiment Station, Miles City, Montana, were used to estimate these correlations. The weaning weights were adjusted for sex, age of dam and calf weaning age. The variance components were estimated for each calving pattern group by an analysis of variance among maternal half-sibs which separated out the effects of cow birth year, lines within cow birth year, cows within lines and calves within cow. The intraclass correlations or repeatabilities of 182-day weaning weight computed from these analyses and their respective calving patterns were 0.39(3-4), 0.50(4-5), 0.47(5-6), 0.30(3-4-5), 0.20(3-4-5-6), 0.34(3-4-5-6-7) and 0.29(3-4-5-6-7-8-9). Pooling of these seven estimates resulted in an overall estimate of repeatability of 0.34, Table II. The downward trend in the correlations as more records were included was contributed to environmental factors and progressive selection of cows. The authors concluded that maternal environment is quite important for the two components of 182-day weaning weight, birth weight and gain from birth to weaning. In an accompanying article on the evaluation of maternal environment, Koch and Clark (1955d) discussed via use of path diagrams the theoretical composition of correlations among maternal half-sibs.

Hoover et al. (1956) used the intraclass correlation and regression of the average of all succeeding calves on the first calf to estimate the repeatability of weaning weight as a means of appraising beef cow productivity. Both Hereford and Angus 210-day weaning weight data were involved in this study which included 1,151 calves of 301 cows which had two or more records in four Oklahoma Experiment Station herds. The weaning weights were adjusted for calf weaning age, sex, age of dam, year and experimental treatment. Analyses were made on an intra-herd basis and then pooled to give an intraclass correlation estimate of 0.32 ±.05 and a regression estimate of 0.34 for the repeatability of weaning weights of calves by the same cow.

McCormick, Southwell and Warwick (1956) analyzed weaning weights of 462 purebred and 332 grade calves of 95 and 90 Polled Hereford cows, respectively, at the Georgia Coastal Plain Experiment Station to estimate the repeatability of 210-day weaning weight. The weaning weights were adjusted for calf weaning age, sex, age of dam and year before being subjected to analyses of variance to estimate the variance components used in calculating the intraclass correlations of 0.42±.06 and 0.38±.06, Table II, for purebreds and grades, respectively. As shown in Table III, the authors also used correlation and regression coefficients to estimate the repeatability of adjacent records of cows calving in successive years by grouping the cows according to cow birth year and then pooling across groups. The authors concluded that cow performance is repeatable enough that culling at relatively young ages after one or at the most two calf crops will be effective in improving weaning weight.

TABLE III

REPEATABILITIES OF ADJACENT COW RECORDS
REPORTED BY McCORMICK *ET AL.* (1956)

Cow Age	Purebred			Grade		
	df	r[a]	b[b]	df	r[a]	b[b]
3-4	39	0.32*	0.25*	27	0.29	0.40
4-5	38	0.58**	0.50**	20	0.66**	0.71**
5-6	30	0.43**	0.35**	14	0.79**	0.78**
6-7	23	0.32	0.29	18	0.75**	1.27**
7-8	24	0.65**	0.57**	16	0.72**	0.67**
8-9	19	0.40	0.58	9	0.54	0.55
9-10	11	-.24	-.30			
Total	184	0.40**	0.35**	104	0.58**	0.68**

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

[a]Correlation coefficient.
[b]Regression coefficient.

Rollins and Wagnon (1956) reported a genetic analysis of the 240-day weaning weights of 573 calves produced in two range Hereford herds at the San Joaquin, California, Experimental Range. One herd of 97 cows was maintained during the fall and winter under an optimum winter nutritional regime; and during the same time period, the other herd of 89 cows was kept under a sub-optimum nutritional regime. The weaning weights were adjusted for differences in pasture, year, sex, calf weaning age and age of dam. Intraclass correlation estimates of repeatability of dam performance for the optimum and sub-optimum herds were reported respectively as 0.51 and 0.34, Table II. The authors did not state confidence intervals for their estimates but did indicate that the two intraclass correlations were not statistically different since their 95% confidence intervals overlapped. Thus, the authors indicated that the two levels of nutrition had no significant effect on estimates of repeatability of beef cow performance.

Stonaker (1958) in a review of the beef cattle breeding research at the Colorado Experiment Station reported the repeatability of weaning weight as 0.49, Table II. This estimate was based on 11 years of data from a herd which varied from 150 to 180 cows per year. The author summarized by suggesting that mothering ability as measured by calf weaning weight is to a considerable extent a permanent cow trait which can be bred for; but the problem is that this type of performance can not be detected early in an animals' life and is limited in expression to one sex. In a report from Canada, Berg (1961) used four years' adjusted weaning weight records of a commercial Angus herd to obtain the repeatability estimate of 0.31, Table II. The data were adjusted for year, sex, calf weaning age and age of dam.

Whatley (1960) used an experimental herd of 120 Hereford cows to investigate the importance of productivity in the beef cow in Oklahoma. He reported that the top eight producing cows in this herd weaned as many pounds of calf in four years as had been weaned by the eight poorest producing cows in five years even though all cows were of the same age, received the same nutritional regime and were bred to the same bulls. The author indicated that the poorest 20 to 30% of a cow herd could be culled on the basis of the weaning weight of the first calf with little danger of culling females that would be above average in real producing ability. Pratt, Whatley and Chambers (1962) in a study of the inheritance of mothering ability in beef cattle used data from three consecutive years from each of two Angus, two Hereford and one Polled Hereford herd in Oklahoma to estimate the repeatability of cow performance as being 0.29, Table II. The data were adjusted for calf weaning age, sex and age of dam. In order to compute the intraclass correlation estimate, the authors computed an analysis of variance of 210-day weaning weights which partitioned out years, ranches, sires in ranches, dams in sires in ranches and calves in dams in sires in ranches.

Another estimate of the repeatability of cow performance was reported by Lueker Brown and Gifford (1963) as being 0.45, Table II. The data from the Arkansas Experiment Station beef herd included only cows which had produced at least two calves. The authors concluded that repeatability of weaning weight was large enough to enable beef cattle breeders to make improvement by using only one record as a basis for female selection. Sewell _et al_. (1963) reported a repeatability estimate of 0.52, Table II, for weaning weight. The data from a commercial Hereford herd in Missouri were corrected for sex, age of dam, season and year. The authors also calculated an intraclass correlation estimate of repeatability for the same data with adjustments only for the effects of sex, age of dam and season. This resulted in an estimate of 0.38 which indicated that yearly correction factors were effective in removing a significant portion of the variation in the data.

The only estimate of the repeatability of weaning weight ratio found in the literature was reported by Brinks et al. (1964) as part of a study on predicting producing ability in range Hereford cows. The cow's record was expressed as the ratio of her calf's adjusted weaning weight to the adjusted sire-year subclass mean. The data were adjusted for age of calf and of dam. Data on 8,821 calves raised at the United States Range Livestock Experiment Station, Miles City, Montana, from 2,788 cows that calved first as 3-year-olds were used in this study. The repeatability estimate of weaning weight ratio was 0.37. No estimate was given for actual weaning weight. Based on this one study of the repeatability of weaning weight ratio, there is little evidence of a significant difference in the repeatability of weaning weight and of weaning weight ratio as characteristics of the beef cow.

Minyard and Dinkel (1965) investigated the repeatability of the annual production of range beef cows as measured by calf 190-day weaning weight. The data were from 20 private South Dakota purebred Angus and Hereford ranches. The author indicated that 866 calves from 378 cows were analyzed but did not designate the number of animals used from each of the two breeds. The data were adjusted for calf weaning age, sex, age of dam and year differences; also, the data were restricted to the records of cows having produced at least two consecutive calves. Repeatability of weaning weight was estimated as the intraclass correlation of adjacent weaning weight records of the same cow. The nested analysis of variance was calculated with herds, cows and calves as sources of variation. The repeatability estimates were 0.52±.13 and 0.42±.04, Table II, for Angus and Herefords, respectively. The authors also reported a breeds combined estimate of 0.42±.04 for 190-day weaning weight repeatability. The authors suggested that selection for high-producing cows can be practiced early in their productive life and that very low producers can be culled on the basis of their first records with little chance of culling desirable cows.

Fitzhugh (1965) reported a pooled repeatability estimate for weaning weight of 0.44 based on the records of 1,451 straightbred Angus, Brahman, Brangus, Hereford and Santa Gertrudis cows in the Experiment Station herds in Alabama, Florida, Georgia, Louisiana, North Carolina, South Carolina and Texas. The weaning weights were adjusted within location for calf weaning age, age of dam, sex, birth month, previous parity of dam and dam weight at calf weaning. Repeatability of weaning weight was estimated by the regression of later on earlier records of the same cow on a within location basis and then pooled across locations. The author calculated this regression estimate for all possible pairs of weaning weight records of cows up to 12 years of age. Repeatability tended to slightly decrease as dams became older and as the time interval between records became larger. The author indicated that prediction of a cow's future performance on the basis of a single progeny would be only moderately successful since temporary environmental effects tended to account for more, 50 to 75%, of the variation in the progeny weaning weights than did genotypic and permanent environmental differences among beef cows.

In a study of beef calf weights as indicators of cow producing ability, Drewry and Hazel (1966) estimated the repeatability of 205-day weaning weights under two management schemes in four Iowa State University Angus and Hereford herds. The data consisted of weaning weight records of 384 noncreep fed calves of 207 cows in two herds and 456 creep fed calves of 232 cows in the other two herds. The data were adjusted for differences in farm-year, breed, sex, age of calf and dam, and calf and dam inbreeding effects. The repeatability estimates, derived from "among dam" and "within dam" variance components, for the creep and noncreep data were respectively 0.43±.06 and 0.44±.06, Table II. The authors indicated that repeatability estimates were of such magnitude that some culling can safely be practiced after one or at the most two weaning records per cow.

Hohenboken and Brinks (1969) reported estimates of the repeatability of 205-day weaning weight in Angus from data corrected by either adjustment factors deduced from herd data or factors recommended by the beef cattle industry. The data consisted of weaning weight records of 4,722 calves born to 1,501 cows on a commercial Angus ranch in Wyoming. The number of records per cow varied from one to nine. All females were bred to calve first at 2 years of age. Limited culling based on production records was practiced. For the herd adjustment factor method, the weaning weights were adjusted for calf age, sex, cow age, year, cow age x year interaction and sires within years prior to being subjected to an analysis of variance with cows and calves within cows as sources of variation. For the industry adjustment factor method, the weaning weights were adjusted by correction terms cited in the Beef Cattle Records Committee Report (U.S.D.A., 1965) for calf age, sex and cow age.

The industry factor adjusted data was then subjected to an analysis where the variation due to years and sires within years was removed before that of cows and calves within cows. Repeatability of weaning weight was estimated as the intraclass correlation of two calves randomly chosen from a cow and by the same sire. The repeatability estimate from data corrected by herd deduced factors was 0.257±.016, Table II; and from the same data corrected by the industry recommended factors, it was 0.251±.016. According to the authors, these results indicated that "under commercial conditions the additional expense of computing correction terms specific for the herd was not justified." The authors also suggested that their analyses implied that part of the permanent environmental differences among cows resulted from the effect of year of birth of the cow. In their summary, the authors discussed as possible reasons for the low magnitude of repeatability of Angus cow performance the inclusion of cow age x year interaction in the model, non-adjacency of records, a possible breed effect and an effect resulting from behavioral characteristics of Angus cows and calves.

Martin, Srinivasan and Garwood (1970) reported repeatability estimates of 0.53 and 0.62 for non-creep and creep fed Angus calves, respectively, but gave no explanation for this difference. The data were 210-day weaning weights of 831 Angus calves born in the Purdue University herd. The weights were adjusted for age of dam, year and sex. As part of a study of the most probable producing ability of Hereford cows, Ellicott, Holland and Neumann (1970) obtained a repeatability estimate of 0.24, Table II. The 246-day weaning weight data were adjusted for differences due to calf weaning age, sex, age of dam and then expressed as deviations from the year mean.

Sellers, Willham and deBaca (1970) while studying the effects of various factors on the weaning weights of beef calves estimated the repeatability of 205-day weaning weight. The data used in this study consisted of weaning weight records of Angus and Hereford calves collected by the Iowa Beef Improvement Association (IBIA) over a 12 year period from 157 herds. The weaning weights were adjusted for calf age, year, age of dam, management, sex and two-factor interactions. A pooled analysis across herds was used to estimate repeatability. The repeatability estimates calculated from variance components for Angus and Herefords, respectively, were 0.19±.01 and 0.27±.01, Table II. The authors pointed out that the estimates of repeatability of weaning weight obtained in this study were lower than most previous reports probably because the degree of adjacency of calf records may have averaged less than in single herd data since IBIA producers may not always participate every year or even in consecutive years. The authors concluded by stating that "Angus do appear to have slightly lower repeatability than Herefords."

In a study of methods of estimating most probable producing ability (MPPA) of Angus cows, Thompson and Marlowe (1971) estimated the repeatability of 205-day weaning weight to be 0.31, Table II, by pooling intraclass correlations across herds. The data consisted of weaning records from four Angus herds participating in the Virginia Beef Cattle Improvement Association program. These authors also compared two methods of expressing the dam's progeny record for calculating MPPA based on one, two or three records. These methods were as deviations from the herd-year average or as deviations from the sire-year average. The calculated MPPA's for one, two and three weaning weight records based on each of these two methods were correlated with the average of all subsequent records up to six. The MPPA values by the herd-year method for one, two and three records gave correlations of 0.18, 0.10 and 0.04 with the average of subsequent records, respectively; and the sire-year method correlations were 0.23, 0.31 and 0.36, respectively. The differences between the correlation coefficients of the two methods were significant at the levels of P<.10, P<.05 and P<.005, respectively, indicating that the sire-year method was most the accurate of the two.

Hohenboken and Brinks (1971a) estimated the repeatability of 205-day weaning weight for linecross and inbred Herefords at the San Juan Basin Branch of the Colorado Experiment Station. The data consisted of records of 1,386 calves of 423 linecross dams and 1,232 calves of 445 inbred dams. The weaning weights were adjusted for calf age, sex, age of dam and inbreeding of calf and of dam. The maternal half-sib weaning weights were expressed for analytical purposes as deviations from their year-birth year of dam subclass mean plus the overall mean adjusted weaning weight. The respective intraclass correlation estimates of repeatability were 0.33±.03 and 0.40±.03, Table II, for linecross and inbred Herefords.

Using data collected at the Northern Agricultural Research Center, Havre, Montana, during the years 1933 through 1966, Kress and Burfening (1972) calculated an intraclass correlation estimate of 0.44±.02, Table II, for the repeatability of 180-day weaning weight. The data were from three crosslines and four inbred lines of Herefords. Cows born previous to 1950 were bred to calve first as 3-year-olds while those born during 1950 and subsequent years were bred to calve first as 2-year-olds. The weaning weights were adjusted for calf age, year of birth, age of dam, sex and birth date. According to the authors, inbreeding of the calf was not significant enough to justify adjustment for it. Repeatability values were estimated by analyzing the adjusted weaning weights by a nested analyses of variance where sources of variation were cow line, among cows within lines and within cows.

This literature review indicates the following: (1) The relationship or repeatability of weaning weights among maternal half-sibs is large enough to justify selection or culling of beef females after one or at most two weaning records per cow. (2) There is a tendency for repeatability based on the likeness of adjacent records of the same cow to be higher than that based on the likeness of non-adjacent or randomly chosen records of a cow. Repeatability appears to decrease as maternal half-sib records become further apart in time. (3) There is some evidence that Hereford cows have a higher repeatability for weaning weight than Angus.

Relationship Between Heifer Growth and Subsequent Cow Productivity

The phenotypic relationship between dam and offspring traits can be estimated by the use of linear interclass correlation and regression coefficients. The following review covers pertinent published studies of the phenotypic relationships between the weaning and yearling weights of a beef cow and the weaning weights of her calves. No reports were found in the literature on the relationship of the ratios of these weights. Also, some of the pertinent genetic theory of the dam-offspring relationship will be reviewed. When possible, experimental results will be reported by breed.

According to Kempthorne (1969), the theoretical values of the correlations between relatives were first studied in detail by Fisher in 1918. The theory of correlations between parental and offspring traits was further discussed in more detail by Wright (1935). In a discussion of the covariances between relatives, Willham (1963) outlined by use of variance and covariance components how preweaning or suckling period growth of mammals is influenced by the offspring's genotype for growth as measured by his phenotypic value, by the genotype of his dam for maternal characters and by the environments in which the dam developed and in which she expresses her maternal potential. According to Hohenboken and Brinks (1971a), the importance of each of these effects independently has long been known; however, the nature of the joint effects has only recently been investigated. The maternal genetic influence contributes an environmental effect to the offspring which is genetic in that the genotypic differences among dams are expressed in the phenotypic measurements of their progeny (Willham, 1963). According to results of mice studies reviewed by Eisen (1967), the phenotypic expression of quantitative traits such as weaning weight in mammalian species is influenced by the progeny's own genotype, direct genetic effect, and the genes of related individuals, indirect or maternal genetic effects. Mangus and Brinks (1971) implied that these results with mice were applicable to beef cattle when they stated: "Improvement in weaning weights of beef calves is primarily dependent upon increased preweaning growth potential of calves and maternal ability of cows." The relationship between growth potential and maternal ability as reflected, respectively, by the beef heifer's early growth and her subsequent productivity as measured by the weaning weights of her calves has not been reported very extensively in the literature.

The first published quantitative estimate of the beef cow-calf phenotypic relationship was reported from the Jeanerette, Louisiana, Bureau of Animal Industry Station by Dawson et al. (1954). These authors used the weaning weights of 111 Brahman-Angus cows and their 446 calves adjusted for sex, year and age of dam. Their results indicated that the regressions of offspring 6-month weaning weight on that of dam, within sire of offspring, and on that of dam, within sire of dam, were 0.02 and 0.08, respectively. The authors stated: "Maternal ability of the dam apparently exerts a more important influence on calf weight than the inheritance of the calf itself."

Koch and Clark (1955c) reported a study of the correlation between traits in the cow and calf. The data consisted of 182-day weaning weight records of 4,234 Hereford calves and their 1,231 cows and fall yearling weight records of 822 of these cows at the United States Range Livestock Experiment Station, Miles City, Montana. To eliminate the effects of year and age of dam, the data were grouped for analyzing according to the years of cow birth and calf birth and pooled across groups. The phenotypic correlation of cow and calf weaning weights computed from these analyses was 0.06 and that of cow fall yearling weight and calf weaning weight was 0.12. It was indicated that these correlations were not biased by genetic-environmental interactions. The phenotypic regression of calf on cow weaning weight was 0.06. Based on these results, the authors suggested that "negative correlations may exist between the genes affecting maternal environment and the genes directly affecting the growth response of some of the traits of concern." In an accompanying article on the evaluation of maternal environment, Koch and Clark

(1955d) discussed via use of path diagrams the theoretical composition of the genetic and environmental correlations between offspring and dam. The results of this theoretical discussion fully supported the authors' previous article (1955c). They summarized by stating that "selecting cows which produced heavy calves would place greater emphasis on milking ability than on growth response so far as the genic values of the cows are concerned." But, "selecting for weaning gain will increase genic value for growth response and to a slight extent increase genic value for maternal environment."

Rollins and Wagnon (1956) reported regression coefficients for calf on cow 240-day weaning weight of 0.42 and -.06 for optimal and sub-optimal winter nutritional level range herds, respectively, in California. There were records on 47 Hereford cows and their 151 calves in the optimal nutrition herd and on 44 Hereford cows and their 120 calves in the sub-optimal nutrition herd. The weaning weights were adjusted for differences in pasture, year, sex, calf age and age of dam. The authors suggested that in some situations the cow's characteristics which exert a maternal influence on the weaning weight of her calf may be correlated with her own weaning weight.

In a selection index study, Lindholm and Stonaker (1957) calculated a -.01 phenotypic correlation of cow 18-month weight and calf weaning weight. The data consisted of weights of 118 Hereford steer calves and their dams at the Colorado Agricultural Experiment Station. To remove year, type and sire effects the data were subjected to a block within block analysis. A random distribution of ages of dams within the 19 involved sire groups was assumed. The authors implied that weaning weight alone was an accurate basis for selecting for increased net income in range beef cattle. Marchello, Blackmore and Urick (1960) in a similar study reported on the relationship of heifer 18-month weight with the weaning weight of her first calf. The authors used the weights of 631 Hereford heifers, 2 and 3-year-olds, and their first calves in four lines at the North Montana Branch Station. The heifer weights were corrected to 18 months of age, and the effects of age at calving, years and lines were removed by an analysis of variance. Weaning weights were adjusted for sex on a within year basis and for age of calf. The resulting correlation and regression coefficients for 18-month heifer weight and the weaning weight of their first calf were 0.24 ($P<.01$) and 0.18 ($P<.01$). The authors concluded that the weight of heifers at 18 months does not materially influence subsequent milk production as measured by calf weaning weight and that only small increases can be expected in weaning weight by selecting replacement heifers on the basis of their 18-month weight.

Brown (1958) used the intra-sire regression of offspring on dam to investigate the phenotypic relationship of a Hereford cow's weaning weight and that of her calves. The weights of 255 calves were adjusted for differences in weaning age, sex, year, month of birth and age of dam. The author reported regression coefficients calculated within calf sire group of 0.002 and 0.28 ($P<.05$) for cow weaning weight on that of each of her calves individually and on the average of her calves, respectively. There were 154 and 99 degrees of freedom involved in these estimates, respectively. Sewell _et al._ (1963) reported estimates of 0.04 and 0.005 for the intra-sire regression of daughter's on dam's weaning weight and for the gross correlation of daughter and dam weaning weights, respectively. The study involved 208 Hereford daughter-dam pairs from a commercial herd in Missouri. The data were corrected for differences in sex, age of dam, season and year.

Brinks et al. (1964) reported a study of predicting producing ability in 1,608 range Hereford cows at the United States Range Livestock Experiment Station, Miles City, Montana. Each cow averaged 3.2 calves weaned. Producing ability was estimated by the "Most Probable Producing Ability", MPPA, index (Lush, 1945) based on the ratio of a calf's adjusted weaning weight to the adjusted sire-year subclass mean. Weaning weights were adjusted for age of calf and dam. Paternal half-sib correlations between cow producing ability and cow weaning weight, 12-month weight and 18-month weight, respectively, were: phenotypic 0.09, 0.15, and 0.20; genetic 0.00, 0.14 and 0.25; environmental 0.13, 0.15 and 0.15. Standardized partial regressions for the same relationships, respectively, were: phenotypic -.08, 0.01 and 0.31; genetic -.58, -.04 and 0.77; environmental 0.01, -.02 and 0.01. These results indicated to the authors that the best single predictor of producing ability was 18-month weight. They stated that "the zero genetic correlation between dam weaning weight and most probable producing ability suggests a genetic antagonism between genes for preweaning growth and genes for maternal effect or milking ability."

Christian, Hauser and Chapman (1965) at the Madison, Wisconsin, Agricultural Experiment Station investigated preweaning influences on 240-day weaning weight under creep feeding conditions for Hereford cattle. The data consisted of records of 26 sets of identical and fraternal twin heifers and their 88 calves. All animals were kept in drylot. Both members of a twin pair were bred to the same Hereford bull each year. The effects of calf age, sex and age of dam were corrected for by the types of analyses which were done within sires, random split twin-pairs, years and parities and pooled across these subgroups. The simple correlations and standard partial regressions of calf weaning weight and cow milk production 0-60 days, milk production 60-240 days and weaning weight were 0.46 ($P<.01$) and -.10, 0.48 ($P<.01$) and 0.09, 0.07 and 0.12, respectively. The simple correlations of dam 240-day weaning weight and calf average daily gain 0-60 days, dam milk production 0-60 days and milk production 60-240 days were 0.07, -.10 and 0.20, respectively. The authors summarized by stating: "These results suggest a negative genetic or environmental correlation, or both, between weaning performance of the dam and the maternal environment she provides her calf. If this correlation is genetic, selecting heifers superior in weaning weight would result in increased genetic value for growth response, but decreased milk production."

Hill, Legates and Dillard (1966) reported a study at the Raleigh, North Carolina, Agricultural Experiment Station which used the 180-day weaning weights of 717 Hereford calves including 141 cow-calf pairs. Covariances and correlations were computed between paternal and maternal half-sibs, one quarter-sibs and offspring-dam for weaning weight. By equating these covariances to their expected values and assuming that dominance deviations, epistatic deviations and nonmaternal environmental correlations between relatives were negligible, the authors were able to estimate the additive genetic variances for weaning weight and for maternal effects, the genetic covariance between weaning weight and maternal effects and the permanent and the nonmaternal environmental variances. These variance and covariance component estimates indicated: (1) For 180-day weaning weight, the cow's genotypic maternal effects had a greater influence than did the calf's genotype. (2) A negative genetic correlation, covariance, exists between the additive genotypes for maternal effects and calf weaning weight. In very similar studies, Deese and Koger (1967) and Vesely and Robison (1971) presented further evidence of a negative covariance for additive genotype for growth and maternal effects in British type beef cattle. Vogt and Marlowe (1966) reported on a beef cattle study which supplied evidence of a negative genetic and/or environmental relationship between a cow's weaning weight and the maternal environment she provides her calves. In a review publication Cundiff and Gregory (1968) reported that research "results suggest that either a negative genetic or environmental correlation between weaning weight of the dam and maternal environment she provides her calf may exist."

Koch (1969) reported research which suggested a negative relationship between the environment associated with the early growth of a dam and her offsprings' weaning weights which depend to a large extent on the maternal environment she provides. Records of 613 calves in 115 granddam groups at the Fort Robinson Beef Cattle Research Station in Nebraska were used to estimate these effects via intra-granddam regression of offspring on dam. Calf records were adjusted for known sources of variation, but dam's records were not. Calf sire effect was considered random. The ratio of adjusted calf weaning weight to the average of its sex-year group was regressed on actual average daily gain, birth to weaning, of the dam. The resulting linear regression coefficient was -12.4 ± 9.2. From a study of the performance of 400 Hereford progeny from three topcross sire and dam lines and an outbred line in the San Carlos Apache Indian Tribe herd at Globe, Arizona, Ray _et al._ (1970) reported results which suggested that maternal ability is more important in determining weaning performance than differences in genetic growth potential of the calf and that there exists a negative relationship between maternal ability and growth potential. According to the authors this implied that a different selection criteria should be used for bull calves than for heifer calves of weaning age.

Ellicott et al. (1970) reported the relationship of the weaning traits of 175 purebred Hereford cows with their subsequent producing ability in the New Mexico State University herd. Records of 655 calves of these cows were adjusted for weaning age, age of dam, sex and year. MPPA for weaning weight was used as the measure of subsequent producing ability of these cows. The correlation between the cows' 246-day weaning weight mean and MPPA mean by age in years of the cows' dam, 10 groups, was -.74 (P<.05). This indicated to the authors that heifers out of young or old dams tended to have below average weaning weights but produced calves with above average weaning weights. The correlation between the cows' 246-day weaning weight mean and MPPA mean by cow birth year, 20 groups, was -.52 (P<.05). This suggested to the authors that cows born in high weaning weight years tended to produce calves lighter in weight than cows born in low weaning weight years. A nonsignificant correlation of -.16 was obtained between heifer 246-day weaning weight and MPPA indicating that a heifer's weaning weight is not a good indicator of her subsequent producing ability. The authors suggested "factors of preweaning environment relating to increased nutritive level and growth of a heifer calf adversely affect her subsequent productivity."

Mangus and Brinks (1971) investigated factors influencing the preweaning growth of beef heifers to determine their relationship to her subsequent productivity. The data were 205-day weaning weights of 2,286 Hereford calves and the adjusted weaning weight ratio MPPA values for their 610 dams which were part of an inbreeding study at the Colorado Experiment Station. The weaning weights were adjusted for sex, weaning age and age of dam and then expressed as a ratio of the herd-year mean. Level of inbreeding and line effects were adjusted for by the method of analysis. MPPA values were used to estimate the relative productivity of each cow. The correlations between cow 205-day weaning weight means and MPPA means by cow birth year and by age of cow's dam were -.20 and -.68, respectively; this indicated that for birth year and age of dam classifications in which heifer calf nutrition resulted in higher weaning weights subsequent MPPA values tended to be lower. The partial regression and correlation coefficients of MPPA on cow 205-day weaning weight were 0.03, and 0.14, respectively, indicating that heifer weaning weight is a poor predictor of her subsequent productivity. Using four generations of data, the authors found inverse cyclic trends for cow weaning weight and MPPA means over the four generations. The authors concluded that this study suggested a detrimental effect of relatively high levels of nutrition during the preweaning growth period of the beef heifer upon her subsequent cow productivity and, conversely, a beneficial effect upon cow productivity from relatively low preweaning nutritional levels.

Hohenboken and Brinks (1971a) reported on the genetic and environmental relationships between direct and maternal influences on 205-day weaning weight in Hereford cattle at the Colorado Experiment Station San Juan Basin Branch, Hesperus. The data consisted of weaning weights of 1,386 linecross and 1,232 inbred calves. The weaning weights were adjusted for the effects of weaning age, sex, age of dam, inbreeding of calf and of dam and then expressed as a deviation from their respective year-birth year of dam subclass mean plus the overall mean adjusted weaning weight. The phenotypic regressions of adjusted weaning weights of offspring on dam within sire of calf within line of sire were 0.05 and 0.12 for the linecrosses and inbreds, respectively. The authors demonstrated that the offspring-dam covariance is subject to reduction by a negative environmental covariance between the dam's own preweaning growth and her subsequent maternal performance; they also noted that the daughters of inbred cows are subject to a poorer preweaning maternal, nutritional, environment than those of linecross cows. This could have resulted in the subsequent maternal ability of the inbreds being hindered less than that of the linecrosses. Under these conditions, the authors suggested that the direction of the difference for the regression of offspring on dam found in this study between linecrosses and inbreds was to be expected. The authors most reliable estimate of the additive genetic correlation of direct and maternal effects on 205-day weaning weight was -.28. From these analyses the authors concluded that: (1) Direct effects account for slightly less of the variability in 205-day weaning weight than do maternal effects. (2) A weak genetic antagonism between direct and maternal effects on weaning weight probably exists but does not appear large enough to seriously hamper progress from selection for growth.

As part of a study on cow type and productivity, Frey et al. (1972) calculated least squares prediction equations for cow productivity using her 18-month weight and the 205-day weaning weight of her first calf. The data consisted of records of spring-calving Angus cows under range conditions at the Fort Reno Livestock Research Station, El Reno, Oklahoma. Heifers were bred to calve first at 2-years of age. Weaning weights were corrected for weaning age, year of birth, sex of calf and age of dam. Cow productivity was measured by her "Most Probable Producing Ability" for weaning weight, MPWW. Data on 55 cows which produced from 1 to 5 calves, with an average of 2.81, were used to calculate a prediction equation using 18-month heifer weight. The regression coefficient for 18-month weight alone predicting MPWW was 0.09; the inclusion of 18-month weight along with the mean MPWW resulted in dropping the standard error of estimate only from 20.4 to 19.9 pounds. The correlation coefficient for 18-month adjusted weight and MPWW was 0.24 ($P<.05$). The regression coefficient for first calf 205-day weaning weight of 51 cows alone predicting MPWW was 0.32 ($P<.01$); the inclusion of first calf weaning weight along with the mean MPWW reduced the standard error of estimate from 18.3 to 14.0 pounds. Based on these analyses, the authors suggested that a heifer's 18-month adjusted weight offers only limited means of selection for increased cow productivity and that final selection should probably be made after a cow has weaned her first calf. As part of this same study, Frey (1971) reported the following correlations: first calf weaning weight with second calf weaning weight, average weaning weight and MPWW as 0.29, 0.79 and 0.71, respectively; second calf weaning weight with average weaning weight and MPWW as 0.72 and 0.73, respectively; average weaning weight with MPWW as 0.94; first calf weaning weight ratio with second calf weaning weight ratio, average weaning weight ratio and MPWW as 0.35, 0.81 and 0.69, respectively; second calf weaning weight ratio with average weaning weight ratio and MPWW as 0.74 and 0.72, respectively; and average weaning weight ratio with MPWW as

0.89. All of these correlations were statistically significant at the 0.01 level.

In a study of the selection of dams for planned matings, Inbau (1972) reported correlation coefficients of 0.06 and 0.13 between a cow's breeding value based on her own 205-day weaning weight and that based on the 205-day weaning weight of her first calf and of her progeny average, respectively. The correlation of a cow's breeding value based her own yearling weight and that based on the weaning weight of her first calf was 0.14. The data consisted of records on 529 Hereford cows that each had at least four calves at the United States Range Livestock Experiment Station, Miles City, Montana. The results of this study suggested to the author that: (1) Selection of cow's with superior weaning weight genotypes would best be accomplished by using their yearling weight since the heritability for yearling weight is higher than for weaning weight and since these two traits are highly correlated genetically. (2) A cow's own weaning weight is a poor indicator of her calves' weaning weights or her true breeding value for weaning weight.

Kress and Burfening (1972) reported the phenotypic relationship between measures of early heifer growth rate and subsequent cow MPPA for 180-day weaning weight in range Herefords at the Northern Agricultural Research Center, Havre, Montana. Data on 3,342 calves and their 648 Hereford dams from four inbred lines and three crosslines, crosses between specific lines, were used. Heifers were fed to gain approximately 0.8 pounds per day from weaning to 1 year of age. Some cows were bred to calve first as 2-year-olds while others as 3-year-olds. Weaning weights were adjusted for differences due to weaning age, year, age of dam, sex and birth date. Inbreeding of calf was not found to be a significant source of variation. MPPA was used as a measure of cow productivity. The average number of cow records used in calculating MPPA ranged from 1.0 to 5.4 depending on cow line. The overall phenotypic correlations of heifer 180-day weaning and yearling weights with subsequent MPPA were 0.15 ($P<.01$) and 0.12 ($P<.01$), respectively. The correlation and regression of cow MPPA birth year least squares effects on those of her weaning weight year of birth effects were -.11 and $-.03\pm.06$, respectively, indicating that as cow weaning weight increased her MPPA tended to decrease and vice versa when both traits were classified by year of cow birth. The correlation and regression of cow MPPA age of dam least squares effects on those of her weaning weight age of dam effects were -.19 and $.05\pm.08$, respectively, when both traits were classified by age of dam of the cow. According to the authors, these data indicated that at least a part of the environmental portion of the phenotypic relationship between a heifer's weaning weight and her subsequent MPPA for weaning weight is negative and that to maximize cow producing ability heifer growth rates may need to be controlled.

In an evaluation of the effect of three levels (high, medium, low) of preweaning nutrition on subsequent cow productivity, Holloway and Totusek (1972) used records of 203 Angus and Hereford range females born over a 4 year period. The heifers were bred to calve first at 2-years of age and were allowed to produce three calf crops. Weaning weights were adjusted for weaning age and sex. Overall, preweaning treatment of the cow did not significantly affect calf 205-day weaning weight. The high level females, however, weaned the lightest calves each year and for two of three calf crops produced the least milk. The results of this experiment suggested to the authors that a medium plane of preweaning nutrition, weaning at 240 days with no creep feed in this experiment, was preferable for replacement heifers which calved first as 2-year-olds. In a similar experiment, Martin et al. (1970) found that treatment of the dam, creep or no-creep feed, influenced the response of the calf to creep feed. Creep-fed calves weighed 451 and 458 pounds while no-creep calves weighed 440 and 418 pounds, respectively, from no-creep and creep fed dams. The 210-day weaning weights of the calves were significantly ($P<.01$) influenced by treatment of calf, treatment of dam and the interaction of these two factors. The data were 210-day weaning weights of 831 Angus calves born in the Purdue University herd. The weights were adjusted for age of dam, year and sex.

This literature review indicates the following: (1) A detrimental effect upon subsequent cow productivity usually results from environmental factors resulting in high or excessive levels of preweaning nutrition and growth of the beef heifer; and, conversely, relatively low levels of preweaning nutrition may result in relatively higher beef cow productivity. (2) A low relationship exists between a beef heifer's weaning weight and her subsequent cow productivity indicating that heifer weaning weight is a poor selection criterion for increasing cow productivity as measured by the weaning weights of her calves. (3) Heifer yearling or 18-month weight appears to be a more reliable predictor of her subsequent calves' weaning weights than does her own weaning weight. (4) There is evidence suggesting that a negative genetic covariance exists between a dam's own weaning weight and her subsequent maternal ability resulting in a genetic antagonism between direct preweaning growth and maternal effects in beef cattle. (5) There is evidence that the maternal ability of the cow exerts a more significant influence on her calves' weaning weights than does the calves' direct inheritance for growth. (6) No evidence was found in the literature that there is a difference between the Angus and Hereford breeds for the relationship between heifer growth and subsequent cow productivity.

CHAPTER III

MATERIAL AND METHODS

Data

The data considered for this study were the weaning and yearling weights collected from 1958 through 1971 as part of the beef cattle breeding projects 670 and 1256 at the Oklahoma Agricultural Experiment Station (OAES), Stillwater. From these 14 calf crops, the weaning weights of 2,664 and 634 calves from 680 and 183 Angus and Hereford cows, respectively, were used in this study. These 863 cows were born from 1956 through 1969; and weaning and yearling weights were available on 573 and 427 Angus and 162 and 144 Hereford cows, respectively, which were as heifers part of the 1958 through 1969 calf crops. Weaning and yearling weight data were not available on 17 Angus and 21 Hereford cows which were born in 1956 or 1957 and neither were these data available on 90 Angus purchased cows born from 1957 through 1962. The animals used in this study are classified in Table IV by year of birth, breed and traits studied.

A heifer's and her subsequent calves' records were included in this study if she met all of the following criteria:

1. She was born from 1956 through 1969 as part of the beef cattle breeding projects 670 or 1256 at the OAES; she was born from 1957 through 1962 and was purchased from private commercial herds to be one of project 1256's foundation Angus females; or she was born in 1959 or 1960 out of

project 670 bulls and cows owned by the El Reno Federal Reformatory (ERFR), El Reno, Oklahoma. Cows from various other sources were incorporated into project 1256 at various times prior to 1965; however, because these cows were transferred to project 1256 in small groups of various ages and because heifer growth data was usually not available on them, they were not included in this study.

2. She was a purebred or grade straightbred Angus or purebred Hereford. Crossbreds were incorporated into project 1256 during the later 1960's but were not used in this study because of their small numbers and few progeny.

3. She was born between January and June, inclusively. Most of the heifers used in this study were born from February through April. Some cows used in projects 670 and 1256 and which were born prior to approximately 1963 were born in the fall. Since these fall born cows had varying types of calving patterns of spring and fall born calves, they had a different type of heifer growth and lifetime productivity record than those spring born females used in this study; thus, they were not included.

4. She was bred to calve first in the spring as a 2-year-old. A few females used in these two projects during the early part of the time period of concern were bred to calve first as a 3-year-old. All heifers calving first after they were 28 months old were not included in this study.

5. She weaned at least one calf as a 2 or 3-year-old. Any cow which failed to wean at least one calf during these years was not included in this study.

6. She always calved in the spring. For this study, a cow's

calving record was terminated just prior to any fall calvings. All fall calves and subsequent calf records of a cow were not included in this study.

7. She weaned at least two calves whose records met the necessary criteria for use in this study, or her own weaning weight record was available as well as that for at least one of her calves.

8. She had a unique identification number or code. Since this study involved data from two different decades, a few cow identification numbers were duplicated. From such duplicate pairs, the cow with the largest number of useable calves was included in this study.

TABLE IV

NUMBER OF OBSERVATIONS CLASSIFIED AS TO YEAR OF BIRTH, BREED AND TRAIT

	Angus				Hereford			
	Cows			Calves	Cows			Calves
Birth Year	Total	WW[a]	YW[b]	WW[a]	Total	WW[a]	YW[b]	WW[a]
1956	7				11			
1957	12				10			
1958	18	11		6	3	3		10
1959	72	69	49	14	5	5	5	21
1960	67	64	20	32	5	5	5	13
1961	69	42	42	84	8	8	8	15
1962	61	13		140	15	15		17
1963	36	36	36	170	20	20	20	29
1964	47	47	47	199	13	13	13	23
1965	51	51	32	245	14	14	14	58
1966	53	53	33	272	21	21	21	58
1967	79	79	60	290	22	22	22	60
1968	39	39	39	288	19	19	19	68
1969	69	69	69	310	17	17	17	76
1970				313				96
1971				301				90
Total	680	573	427	2664	183	162	144	634

[a]Weaning weight in pounds.

[b]Yearling weight in pounds.

Assuming that a calf's dam met all of the previously discussed qualifications, a calf's weaning weight record was included in this study if the calf itself met the following criteria:

1. Its dam was known.

2. Its weaning weight record was available. The records of any calves which died prior to weaning were excluded and considered as a missing record as far as their dam was concerned.

3. It was not a twin. Calves raised as a twin were not included in this study and were considered as a missing record as far as their dam was concerned.

4. It was not born after its dam had failed to wean a calf for any reason for 2 years in a row. The records of all calves born to a cow after she had failed to wean a calf in each of two successive years were excluded from this study.

5. It was born to a 11-year-old or younger dam. All calves born to 12-year-old and older cows were excluded from this study.

6. It was a straightbred Angus or Hereford calf. The records of the few crossbred calves involved in project 1256 were excluded from this study.

7. A few project 1256 Angus and Hereford cows were transferred from the selection lines herd at Fort Reno to the progeny test herd at Stillwater and thus had calves born in both herds. All such progeny test herd calves were excluded from this study.

Source of Data

Since data from two different research projects with somewhat different objectives and years are involved in this study, the objectives, the project outlines, the genetic material and locations of the animals will be described separately for each project. Also discussed will be the transition from projects 670 to 1256 since data from this time period has been included in this study.

Project 670

The 22 Angus and 75 Hereford foundation females for this project which was located at the Fort Reno Livestock Research Station (FRLRS), El Reno, Oklahoma, were purchased in 1949 from six Angus commercial herds (six different sires) and five Hereford commercial herds (17 different sires). These animals were assigned to four unrelated lines of breeding designed to study via selection, mild inbreeding and comparison of small and large types the inheritance and improvement of economically important traits in range beef cattle. The only Angus line was maintained as a semi-closed line with mild inbreeding, level not found in the literature. Expansion of this line at various times kept it from being permanently closed. Of the three Hereford lines, one was maintained with mild inbreeding, level not found in the literature; another was developed as a large or conventional type outbred line; and the third was maintained as a small or comprest type line. All animals used in these four lines were purebred. Males and females of similar type were used in each line. Kieffer (1959) indicated that very little selection of females had occurred in these four lines through 1956 due to expansion of cow numbers. For the present study, no distinction was made between these three lines of Herefords. The comprest line of Herefords was removed from the project during 1958; thus, very few records from this line were involved in the present study.

Approximately 100 head of 1959 and 1960 heifer calves born to project 670 bulls and grade mature Angus cows owned by the ERFR were purchased at weaning by the OAES to be part of project 670 and later project 1256 (Cundiff, 1964). The present study includes records of 92 of these females. These and other grade Angus cows in project 670 were transferred from the FRLRS to the Lake Carl Blackwell Range (LCBR) area west of Stillwater, Oklahoma, prior to calving in 1962 (Cundiff, 1964). These cows were the first project 670 cows located at the LCBR.

Project 670 served as a source of part of the foundation females for project 1256. The Angus and large-type Hereford lines were the main sources of these foundation animals selected from project 670. The large-type Hereford line eventually was more influential as a source of foundation females for project 1256 than was the Angus line. The mildly inbred Hereford line and other cattle in project 670 not suitable because of their type and/or age as project 1256 foundation animals were culled during 1960 and 1961. Additional foundation cattle for project 1256 were purchased from various commercial sources during 1960 through 1962. During 1961 the foundation animals were assigned to lines for the initial matings under the project 1256 design.

The records used in the present study that were made prior to 1964 were part of project 670; even though beginning in 1961, the lines for project 1256 were being formed within project 670. The 1960 calf crop was the last data to be collected under the project 670 basic structure. The transition from project 670 to 1256 took about 5 years.

Project 1256

This long term beef cattle selection study was designed to measure the direct and correlated genetic responses to selection based solely on weaning or yearling weights (Frahm, 1971). Initially this project was also designed to compare responses of lines selected on the basis of individual performance as measured by weaning and yearling weights with those selected for on both individual and progeny test performance. The initial project 1256 outline is given in Table V. This outline was modified slightly in 1969 (Frahm, 1971) when the Angus yearling weight progeny testing line was transformed into a random control line for the purpose of estimating selection response. As shown in the initial project outline the six selection lines were maintained at the FRLRS while the progeny test herd was kept at the LCBR.

TABLE V

INITIAL DESIGN OF BEEF CATTLE SELECTION PROJECT 1256[a]

	Line						
	5	6	7	8	9[b]	10[b]	11[c]
Breed[d]	H	H	A	A	A	A	A
Number Cows Per Line	50	50	50	50	50	50	200
Selection Procedure:							
Weight[e]	WW	YW	WW	YW	YW	WW	WW,YW
Criteria[f]	I	I	I	I	I/P	I/P	P
Number Males Selected Per Year	2	2	2	2	5/2[g]	5/2[g]	
Number Years Selected Males Used	2	2	2	2	2	2	1
Number Females Selected Per Year	10	10	10	10	10	10	40[h]
Generation Interval in Years	4.5	4.5	4	4	5	5	

[a]Frahm and Whiteman (1968).

[b]Progeny test lines.

[c]Progeny test herd.

[d]H = Hereford; A = Angus.

[e]WW = Weaning weight; YW = Yearling weight.

[f]I = Individual; P = Progeny.

[g]Five selected on own performance, two of these selected on progeny performance.

[h]This number is approximate and varied.

The time table for the transition from project 670 to project 1256 has been partially outlined here in the discussion of project 670. The discussion will be continued here beginning with the 1962 calf crop which was the first born into the six lines of project 1256. The frequency of the longhead dwarf gene was found to be high enough in the foundation Angus females to jeopardize the 1256 selection project. The suspected carrier females were transferred to the progeny test herd prior to their 1963 calf crop. Replacement foundation females for these carrier cows were purchased during 1962 from several sire groups owned by midwestern Angus breeders. The ultimate foundation Angus females in this study were the progeny of over 30 different sires in several herds in several states. The foundation Hereford females, some of which were purchased from various commercial sources, did not appear to have as broad a genetic base as did the foundation Angus females. Foundation bulls of both breeds were purchased, approximately four or five annually, from 1960 through 1963; and Angus foundation bulls were purchased through 1965. Due to the occurrence of the dwarf gene in the original foundation Angus cows, foundation matings were made again in 1963. Replacement bulls and heifers were first selected within the Hereford lines from the 1963 calf crop and within the Angus lines from the 1964 and 1965 calf crops. The 1964 calf crop marked the official beginning of project 1256. The last purchased sires were used in 1965 in the Hereford lines, in 1966 in Angus lines 7 and 8 and in 1967 in Angus lines 8 and 9. The first calf crop in the progeny test herd from bulls produced within project 1256 was born in 1966.

According to Frahm et al. (1972), the six selection lines in project 1256 have in general shown little difference in response of total growth performance within breed due to selection for either weaning or yearling weight. Thus, the genetic changes for weaning or yearling weight to date have been similar within breed regardless of which selection trait was used in a line. Selection has not been practiced long enough within these lines to have shown much change from foundation animals. Therefore, in the present study, no distinction or differentiation was made between these six lines within breed.

The cattle previously described in projects 670 and 1256 and used in the present study were considered to be a fairly representative random sample of both breeds, probably more so for the Angus than the Herefords. Consequently, it was hoped that the genetic base was broad enough in both breeds that the results of this study would be as applicable to the respective breeds as is experimentally possible.

Breeding and Management

Because projects 670 and 1256 involved different years, management practices and geographical locations, the management is described separately for each project.

Project 670

The cow herd was located at the FRLRS and was managed under native range conditions typical of central Oklahoma. The native range consisted primarily of bluestems, sideoats grama, Indian and switch grasses. During the winter the cattle normally were fed approximately 1 to 2 pounds of cottonseed cake per head daily and alfalfa hay as needed. Wheat pasture, when available, was grazed during the winter. The cows were returned to native pasture during March of each year (Turvey, 1967).

Depending upon condition and age of the female, some were fed in the winter up to 4 pounds of ground milo and some silage daily during the early 1960's (Pherigo, 1967). The post-weaning treatment up to about a year of age for the replacement females was slightly variable from year to year; however, the treatment was the same for all heifers in any one season. None of the calves were fed creep.

The majority of the cows in this project were bred to calve first as 2-year-olds in the spring of the year with most of the calves being born in February, March and April. The calves were weighed and identified within 24 hours of birth. The male calves were normally left intact through weaning which was at an average age of between 205 and 210 days during late September or early October. The calves were weighed and scored at weaning. The replacement heifers were weighed after post-weaning treatment at approximately 1 to 1.5 years of age. The cows were culled because of poor production records, unsoundness and reproductive failures. More detailed descriptions of project 670 were given by Ray (1959), Kieffer (1959), Cundiff (1964), Pherigo (1967) and Turvey (1967).

The ERFR herd was a source of some of the 670 cows. This herd was managed similar to the FRLRS project 670 herd except that the calves were fed creep from approximately 100-days of age until weaning (Kieffer, 1959).

Project 1256

Two cow herds were involved in this project. The six selection lines were located at the FRLRS. The progeny test herd for bulls from selection lines 9 and 10 was located at the LCBR. The management of these two herds will be discussed separately because differences in location and purpose dictated some different management procedures.

Selection Lines Herd. The six selection lines at the FRLRS were managed as one herd except during the 90-day breeding season from May 1 to July 31 when they were run in their respective breeding groups. When circumstances such as pasture size and available grass dictated that all six lines could not be handled as one group, the lines were managed as near alike as possible. Special effort was made at all times to obtain as uniform environmental conditions as possible for all cows and calves in this herd. The cow herd was managed similarly to most progressive commercial beef herds in central Oklahoma. The cows were pastured on native range very similar to and in many instances the same range as that previously described for project 670. When available, the cows and replacement heifers were run on wheat pasture during the late fall and winter and supplemented with alfalfa hay and cottonseed meal cake when necessary. The replacement heifers were fed to gain approximately 0.75 to 1.0 pound per day their first winter. Management of the replacement heifers varied some from year to year, but it was consistent for all heifers in any one year. The nursing calves were run with their dams on native pasture without creep feed. Following weaning, the bull calves were placed on a 160-day feedlot performance test.

The breeding age females were assigned to sires within line by stratified randomization to obtain equal distribution of cow age-groups within sires and to avoid mating half-sibs or more closely related animals to minimize any inbreeding. Four sires were used per line per year and each sire was used just two years with two new sires used each year. The heifers were bred to calve first as 2-year-olds in the spring. Most of the calves were born during February, March and April. The calves were weighed and identified within 24 hours of birth. None of the male calves were castrated. The calves were weaned, weighed and scored at an average age of 205 days. The replacement heifers were weighed for long yearling weights at approximately 14 months of age. All exposed females were pregnancy checked in the fall following weaning of their calves. Open, unsound and aged cows were normally culled from the herd.

Selections within these six lines of breeding were made based on 205-day weaning weights adjusted to a mature dam basis or on yearling weights for bulls adjusted to 365 days and long yearling weights for heifers adjusted to 425 days (U.S.D.A., 1970). The amount of actual selection practiced was much greater for the bulls than the heifers.

Progeny Test Herd. The progeny test herd of grade and purebred Angus females at the LCBR was managed to provide as uniform as possible environmental conditions for all animals at all times. The cow herd was managed similar to local progressive commercial operations under typical range conditions with only native grass, mainly bluestems, for grazing the year around. The cow herd was managed in groups as large as pasture conditions would permit except during the 90-day breeding season from May 1 to July 31 when the breeding groups were randomly assigned to pastures. The cows were wintered on dry native grass and received from 1 to 3 pounds per head daily of cottonseed meal cake from November until April, depending upon the season and condition of the cows and heifers. Heifers sometimes received more supplemental feed than the mature cows. Prairie hay was fed during inclement weather and from some time after January 1, depending on the year, until new grass was available, usually in April. Replacement heifers were normally fed to gain from 0.5 to 1.0

pound per day their first winter. The nursing calves were maintained with their dams on native pasture without creep feed. All calves at weaning except the replacement females were trucked from the LCBR area approximately 100 miles to the FRLRS for 160 to 170-day feeding trials.

The breeding age females were assigned within cow age groups to sires by use of a stratified randomization scheme. There were rare exceptions to this procedure such as when a certain sire was bred primarily to known heterozygous dwarf carrier cows (Tanner, 1969). Eight to ten registered Angus bulls produced in selection lines 9 and 10 were used each year, four to five from each line, until the project design was changed in 1970. During the formative years of project 1256, outside purebred Angus bulls were used in this herd. The heifers were bred to calve first as 2-year-olds in the spring. Most of the calves were born during February, March and April. Within 24 hours of birth the calves were weighed and identified. The male calves were normally surgically castrated at about 3-months of age near the end of April. During 1964 through 1966 another study was superimposed on this progeny test herd such that a random one-half of the male calves of each sire were left intact (Tanner, 1969). The calves were weaned, weighed and scored at an average age of 205 days, normally late September. The replacement heifers were usually weighed for long yearling weights just prior to being placed in the breeding pastures as yearlings, approximately 14 months. All exposed females were pregnancy checked in the fall following weaning of their calves. Open, unsound and aged cows were normally culled from the herd. Due to herd expansion little selection was practiced among the adult cows in this herd, and the replacement heifers were sometimes not highly selected.

Herd Designation

Because the cattle whose growth records were used in this study were part of two different experimental projects, of two breeds, of different sources, located in different geographical areas at varying times and subjected to somewhat different management schemes, the statistical analyses were made on an intra-herd basis (Dickerson, 1940; Gregory et al., 1950; Kieffer, 1959; Brown, 1960; Swiger et al., 1962; Drewry, 1964; Thompson and Marlowe, 1971). This was done to circumvent the need for the use of herd correction factors. According to Swiger et al. (1962), varying environmental conditions for cows of different sources including movement of the cows might bias certain effects such as year. The effects which might be attributable to herds as defined in this study were not directly analyzed and specified. If the variances within the different herds were homogeneous, the "within herd analyses" was legitimately pooled for an overall analysis.

The use of the intra-herd analysis method tends to create groups of contemporary animals, especially when the animals within a group are all of the same sex, all born in the same year at the same location or are of the same source, and all have been maintained in the same location at the same times during their lives. This study involved the analyses of two kinds of contemporary groups of animals, cows and calves. For this reason, the data were designated into cow herds and calf herds. Previous use of the word herd in this manuscript should not be confused with its use here and in the remainder of this paper.

Cow Herds

The cow herd designation was used to describe those cows which when classified by year of their birth could have been called contemporaries. In this sense, contemporaries were those cows of one breed born in the same year at the same location or which were from the same source that were managed, maintained, bred and calved throughout their productive lives in a uniform manner. Thus, the differences of environmental influences on contemporary cows should have been as minimal as was experimentally possible under the existing conditions.

The 863 cows in this study were classified into one of the six cow herds as shown in Table VI by the year of their birth. The number of calves of each contemporary group of cows is also given in Table VI. Table VII shows the heifer weaning and yearling weight means and standard deviations for the contemporary cow groups. No growth data was available on the purchased females in cow herd five. The bases for classifying a cow into a herd were mainly breed, source and where she spent her productive life. These six cow herd designations will be used mainly in that part of this study concerned with the relationship between the dam and her offspring. The cow herd classification along with cow birth year created 45 contemporary cow groups.

Cow Herd One. These Angus cows were born to project 670 or 1256 dams in the selection lines at the FRLRS and spent their entire productive life at that station as part of project 1256 or its foundation females.

Cow Herd Two. All Hereford cows were classified into this single herd because all were born to project 670 dams or 1256 dams in the selection lines at the FRLRS; and they spent their entire productive life at that station as part of project 670 and/or 1256.

TABLE VI

NUMBER OF OBSERVATIONS OF COWS AND THEIR CALVES CLASSIFIED BY COW HERD AND COW BIRTH YEAR

Cow Birth Year	Cow Herd: 1-Angus Cows	1-Angus Calves	2-Hereford Cows	2-Hereford Calves	3-Angus Cows	3-Angus Calves	4-Angus Cows	4-Angus Calves	5-Angus Cows	5-Angus Calves	6-Angus Cows	6-Angus Calves
1956			11	31	7	48						
1957			10	55	10	63			2	12		
1958			3	17	11	63			7	50		
1959			5	40	21	120			3	23	48	112
1960	2	12	5	20			18	111	3	8	44	323
1961			8	44	35	234	7	51	27	142		
1962	13	51	15	63					48	259		
1963	18	67	20	86	18	93						
1964	36	136	13	54			11	36				
1965	32	113	14	50	19	63						
1966	33	105	21	66	20	58						
1967	41	99	22	57	38	78						
1968	39	65	19	34								
1969	35	35	17	17	27	27	7	7				
Total	249	683	183	634	206	847	43	205	90	494	92	435

TABLE VII

CONTEMPORARY COW HERD-BIRTH YEAR GROUP MEANS AND STANDARD DEVIATIONS FOR HEIFER WEANING AND YEARLING WEIGHTS

Cow Birth Year	Cow Herd 1-Angus No.	Mean	S.D.	2-Hereford No.	Mean	S.D.	3-Angus No.	Mean	S.D.	4-Angus No.	Mean	S.D.	6-Angus No.	Mean	S.D.
	Weaning Weight (lbs.)														
1958				3	439	43	11	442	36						
1959				5	419	55	21	437	46				48	438	51
1960	3	377	20	5	454	36				18	425	41	44	412	45
1961				8	445	31	35	434	39	7	443	39			
1962	13	398	47	15	460	51									
1963	18	421	39	20	461	36	18	400	38						
1964	36	424	33	13	453	40				11	387	32			
1965	32	452	33	14	453	39	19	455	34						
1966	33	449	25	21	439	29	20	453	27						
1967	41	440	24	22	437	26	38	450	28						
1968	39	461	27	19	476	27									
1969	35	416	30	17	442	32	27	435	27	7	394	13			
Total	249	436	36	162	450	37	189	439	37	43	414	40	92	426	50
	Yearling Weight (lbs.)														
1959				5	604	56	21	630	47				28	607	74
1960	2	589	0	5	661	50				18	628	38			
1961				8	684	40	35	687	47	7	677	25			
1962															
1963	18	617	41	20	660	44	18	620	48						
1964	36	631	40	13	699	50				11	588	25			
1965	31	564	36	14	582	52	1	718	0						
1966	33	534	39	21	536	25									
1967	41	626	31	22	649	39	19	514	57						
1968	39	586	33	19	614	33									
1969	35	600	40	17	594	40	27	556	30	7	587	19			
Total	235	594	49	144	522	64	121	611	78	43	619	44	28	607	74

Cow Herd Three. These Angus cows were born to project 670 or 1256 dams at either the FRLRS or the LCBR and spent their entire productive lives as part of project 670 and/or the 1256 progeny test line. Many of these cows did not spend their entire productive life at one location, only those born at the LCBR after the early 1960's were never moved. The project 670 cows which were transferred to the LCBR may have produced up to approximately five calves prior to being moved. However, all cows born in the same year were moved such that they all had their calves in the same location each year. Thus, the contemporary groups of cows were treated alike.

Cow Herd Four. These Angus cows were born to project 670 or 1256 dams at the FRLRS; however, for various reasons, these cows were transferred to the progeny test line at the LCBR prior to having their first calf. They spent their entire productive life at the LCBR.

Cow Herd Five. These Angus cows were purchased prior to being bred the first time from various commercial sources as part of the foundation female group for project 1256. Therefore, no growth data were available on these cows. These cows were always bred to project 670 or 1256 bulls and spent their entire productive life at the FRLRS as part of project 1256 or its foundation females.

Cow Herd Six. These Angus cows were sired by project 670 Angus bulls and born in 1959 and 1960 to grade mature Angus cows owned by the ERFR. After weaning, these females were transferred to the FRLRS where those born in 1959 had their first calf as part of Project 670. Prior to the 1962 calving season, all of these females were transferred to the LCBR where they spent the rest of their productive lives as part of the progeny test line of project 1256.

Calf Herds

The calf herd designation was used to describe those calves which when classified by year of their birth could have been called contemporaries. In this sense, contemporaries were those calves of one breed born and weaned in the same year at the same location and managed as a uniform group prior to weaning. Thus, the differences of non-maternal environmental influences on contemporary calves should have been as minimal as was experimentally possible under the existing conditions.

The 3,298 calves in this study were classified into one of the three calf herds as shown in Table VIII by the year of their birth. Table VIII also gives the 205-day, age of dam and sex adjusted weaning weight means and standard deviations of each of the 40 calf herd-birth year contemporary groups. These three calf herd designations were used mainly in that part of this study concerned with the relationship among maternal half-sibs. The bases for classifying a calf into a herd were mainly breed and where it was born.

Calf Herd One. These Angus calves were born to project 670 or 1256 dams at the FRLS. These calves were the progeny of the dams previously classified into cow herds one and five.

Calf Herd Two. All Hereford calves were classified into this single herd because all were born to project 670 or 1256 dams at the FRLRS. These calves were the progeny of the dams previously classified into cow herd two.

Calf Herd Three. These Angus calves were born to project 670 or

1256 dams at either the FRLRS or the LCBR. These calves were the progeny of the dams previously classified into cow herds three, four and six.

TABLE VIII

NUMBER OF OBSERVATIONS, MEANS AND STANDARD DEVIATIONS FOR CALF WEANING WEIGHTS CLASSIFIED BY CALF HERD AND BIRTH YEAR

Calf Birth Year	Calf Herd: 1-Angus No.	Mean (lbs.)	S.D. (lbs.)	2-Hereford No.	Mean (lbs.)	S.D. (lbs.)	3-Angus No.	Mean (lbs.)	S.D. (lbs.)
1958				10	452	26.0	6	468	40.2
1959				21	456	50.9	14	450	47.4
1960	10	416	30.4	13	414	55.4	23	412	55.1
1961	10	465	47.5	15	462	20.6	74	432	42.2
1962	16	420	44.8	17	443	48.6	124	423	42.4
1963	30	407	42.6	29	428	43.3	140	404	39.2
1964	80	417	34.6	23	427	54.4	119	408	46.7
1965	115	426	35.5	58	437	41.5	130	433	40.0
1966	128	418	31.9	58	430	41.2	144	439	38.9
1967	145	428	34.3	61	417	40.7	145	440	35.9
1968	142	442	37.9	67	460	40.2	146	440	46.5
1969	157	400	38.2	76	417	41.2	153	417	40.0
1970	172	403	38.7	96	411	48.7	140	427	37.4
1971	172	451	45.7	90	467	54.6	129	451	34.9
Total	1177	423	41.8	634	435	49.4	1487	429	43.0

Adjustment of Weaning Weights

The observed or measured differences in growth of beef animals are due to two major causes, genetic and environmental. When cattle are kept under nearly equal conditions and their growth records are adjusted for known environmental differences, true differences or relationships (mostly genetic) between animals can be more accurately estimated and evaluated. Random or chance environmental variables such as fill at time of weighing contribute to errors in estimating differences or relationships based on the animals' own performance and can be appreciably reduced by following appropriate and uniform experimental procedures. Such was done, within reasonable limits, for the animals used in this study.

Weaning weight of beef calves is a complex trait subject to influences of growth ability of the calf, maternal ability of the dam, weaning age of the calf, sex of the calf, age of dam and year of calf birth (Sellers et al., 1970). The data adjustments used in this study for the last four of these influences on calf weaning weight are discussed in some detail.

Age of Calf

Differences in age of beef calves at weaning was an important source of variation in weaning weight because each year the calves were born over approximately a 3-month period with the majority being born within the first 60 days and because they were normally all weaned on the same day in each calf herd at an average of 205 days. Each calf weaning weight was adjusted linearly to a constant age of 205 days by multiplying each calf's preweaning average daily gain by 205 days and then adding in its actual birth weight (U.S.D.A., 1970). Adjustment in this manner assumes a linear growth rate from birth to weaning (Koch and Clark, 1955a). Reports in the literature indicate that this method might bias the adjusted weights of older calves downward (Johnson and Dinkel, 1951; Koch and Clark, 1955a; Hoover et al., 1956; Marlowe, 1962; Swiger et al., 1962; Kress and Burfening, 1972). However since the range in weaning age each year of calves used in this study was within 205 ± 45 days with the majority being within 205 ± 30, the nature of this bias should have been small according to Koch and Clark (1955a) and Swiger et al. (1962). This method of adjustment tends to rank calves in nearly the same order as more refined procedures according to Swiger et al. (1962).

The day of calf birth was not considered a significant source of variation in the weaning weights used in this study. Using a subset of the data used in the present study, Pherigo et al. (1969) concluded that under most conditions when the calving interval is relatively small adjustment of calf weaning weights for day of birth is of little practical value since their results indicated that the amount of variation in adjusted weaning weights associated with birth date was small and depended upon the year.

Age of Dam

Changes in cow size, weight, condition and physiological function which accompany aging might be expected to influence maternal environment and consequently weaning weight (Koch and Clark, 1955a). It is normally impossible to control these age of dam sources of variation through management. Many researchers have shown that age of dam has a significant effect on the age adjusted weaning weights of beef calves (Koch and Clark, 1955a; Keiffer, 1959; Cundiff, Willham and Pratt, 1966a; Hohenboken and Brinks, 1969; Sellers et al., 1970; Cardellino and Frahm, 1971; Kress and Burfening, 1972). Using a subset of the data used in the present study, Cardellino and Frahm (1971) found a highly significant ($P<.01$) breed by age of dam interaction but a nonsignificant sex by age of dam interaction indicating that age of dam adjustment factors are probably different for the two breeds of concern, Angus and Hereford, but that the same correction factors could be used for all sexes. A significant breed x age of dam interaction was also reported by Brown (1960) and Sellers et al. (1970); however, Cundiff et al. (1966a) did not find such an interaction. A nonsignificant sex by age of dam interaction was also found by Koch and Clark (1955a), Cundiff et al. (1966a) and Harwin, Brinks and Stonaker (1966).

Additive and multiplicative correction factors have both been used to adjust weaning weights for the effect of age of dam. Both tend to equalize means between adjusted groups; but, the latter raises or lowers the variance within the adjusted groups (Brinks et al., 1961). Cundiff, Willham and Pratt (1966b) concluded that additive adjustments were more appropriate than multiplicative factors in adjusting weaning weights for the effects of age of dam. Additive factors are favored over multiplicative when variances are homogeneous among groups but not when a scaler effect causes the variances to be similar (Koch et al., 1959; Brinks et al., 1961).

The 205-day weaning weight correction factors for age of dam used in this study were those calculated by Cardellino and Frahm (1971) on a large subset of the data used in the present study. These additive factors are presented in Table IX along with the number of weaning weight observations in the present study at each age of dam. When converted to multiplicative factors, these are similar to the industry correction factors (U.S.D.A., 1970) except for 2-year-old Hereford heifers. Cundiff et al. (1966b) and Hohenboken and Brinks (1969) also reported a similar discrepancy for 2 year old dams. No adjustment was made for the progeny of 11-year-old cows even though it is normally recommended (U.S.D.A., 1970). This was done because of the small number of observations in this group and because these calves were probably out of highly selected and productive dams (Cundiff, 1966b; Sellers et al., 1970).

Since some cows were culled based on productivity in the cow herds of concern to this study, the age of dam correction factors used may have been biased because age of dam effects were confounded somewhat with the effects of selection. The records of younger cows may have been overcorrected while the records of older cows may have been under-corrected (Lush and Shrode, 1950). However, Botkin and Whatley (1953), Brown (1958), Kieffer (1959), Koch and Clark (1955a) and Cundiff et al. (1966b) all indicated that in their data such a bias was small. Therefore, no attempt was made to adjust the age of dam estimates used in the present study for the effects of selection.

TABLE IX

NUMBERS OF OBSERVATIONS AND ADDITIVE ADJUSTMENT FACTORS FOR AGE OF DAM EFFECTS ON 205-DAY WEANING WEIGHT

Age of Dam		Angus		Hereford	
Years	Months	No.	Factor (lbs.)	No.	Factor (lbs.)
2	17-28	539	59	160	84
3	29-40	510	33	138	37
4	41-52	420	9	101	5
5	53-64	323	0	74	0
6	65-76	267	0	58	0
7	77-88	214	0	43	0
8	89-100	166	0	35	0
9	101-112	113	0	16	0
10	113-124	76	0	8	0
11	125-136	36	0	1	0

Sex

Sex is another factor influencing calf weaning weights which can not be controlled by management. Only when one sex is involved such as for cows or replacement heifers are sex corrections not needed. The heifer weaning and yearling weights used in this study were thus not adjusted for sex. However, the weaning weights of all calves used in this study were adjusted for sex differences since disproportionate distributions of sexes in dam group averages or in calf to calf relationship comparisons could have easily biased the results of this study.

Sex differences for weaning weights of bulls, steers and heifers reported in the literature have shown considerable variation due to the weaning age of the calves and to the confounding of the sex effect with selective castration based on size (Koch and Clark, 1955a; Kieffer, 1959; Brinks et al., 1961; Cundiff et al., 1966a; Hohenboken and Brinks, 1969; Tanner et al., 1970; Sellers et al., 1970; Kress and Burfening, 1972). Various researchers have studied the sex differences for calf weaning weights using subsets of the data used in the present study (Kieffer, 1959; Tanner et al., 1970; Cardellino and Frahm, 1971; Frey et al., 1972). All found a significant influence of calf sex on 205-day weaning weights. In a study where random castration was practiced, Tanner et al. (1970) found a nonsignificant difference for bull and steer calves. Cardellino and Frahm (1971) found nonsignificant interactions for sex with year, breed or age of dam. Multiplicative correction factors for sex differences in calves have been found to be more appropriate than additive factors since they more nearly equalize the variances and means among sexes (Koch et al., 1959; Brinks et al., 1961; Cundiff et al., 1966b).

The 205-day, age of dam adjusted weights used in this study were corrected for sex differences by the multiplicative factors shown in

Table X along with the number of calves of each sex of each breed. These factors were derived from those calculated by Tanner et al. (1970), Cardellino (1970) and Frey et al. (1972). These factors are similar to those recommended for industry use (U.S.D.A., 1970) and to the average of several studies reported by Petty and Cartwright (1966). As can be seen in Table X, the sex adjustments used in this study corrected all sexes to a heifer basis. This was done because there were more heifers than any other sex in this study. This method also simplified the study of the relationship between dam and offspring weaning weights since both were on the same sex basis.

TABLE X

NUMBER OF OBSERVATIONS AND MULTIPLICATIVE ADJUSTMENT FACTORS FOR SEX EFFECTS ON 205-DAY, AGE OF DAM ADJUSTED CALF WEANING WEIGHT

Sex	Multiplicative Adjustment	Number Observations	
		Angus	Hereford
Heifer	1.00	1307	325
Steer	0.94	589	
Bull	0.92	768	309

Year

The effect of year was the fourth known factor or influence on preweaning calf growth for which the calf weaning weights were adjusted. Most year effects are uncontrollable by management; and thus, this environmental effect must be removed by statistical means. In this study, dam weaning and yearling weights were not adjusted for year effects since all analyses involving these traits were done on an intra-year of dam birth basis. This method makes adjustment for year unnecessary as it tends to minimize year effects (Koch and Clark, 1955b) and any partial confounding of year with sire effects due to half-sib groups of replacement heifers entering the herd contemporaneously (Hohenboken and Brinks, 1969). However, the weaning weights of all calves used in this study were adjusted for year effects. This was done to minimize the bias due to year effect when studying the relationships among calves born in different years of the same cow and when studying relationships involving averages of calf records over years. The year bias in average records would be due mostly to disproportionate numbers of calf records and varying years involved in each average. A bias of this nature would be relatively small if the number of records per average was not small and highly variable (Kieffer, 1959).

Pherigo et al. (1969), Tanner et al. (1970), Cardellino and Frahm (1971) and Frey (1971) all found highly significant year effects on 205-day calf weaning weights when studying subsets of the data used in the present study. Cardellino and Frahm (1971) reported a highly significant ($P<.01$) year by breed but nonsignificant year by sex and year by age of dam interactions. However, Frey (1971) reported a significant ($P<.05$) year by sex but nonsignificant year by age of dam interaction. Tanner et al. (1970) did not find a significant year by sex interaction.

Based on these previous studies and a knowledge of the yearly environmental, location and management differences that existed, the decision was made to adjust the 205-day, age of dam and sex adjusted calf weaning weights used in this study for the effects of calf birth year within calf herd. This decision was confirmed by the analyses of variance reported in Table XI. This adjustment for calf birth year was done by two methods which resulted in the two calf traits of concern in this study, adjusted weaning weight and adjusted weaning weight ratio. These traits will be specifically defined in a later section of this manuscript as will how the weaning weight ratio was calculated.

The year adjustment factors used in calculating the adjusted calf weaning weights were obtained by the least squares method of fitting constants for data with disproportionate subclass numbers (Harvey, 1960). For the analysis procedure by Harvey (1960), the restriction imposed was that the sum of the least squares constants for year must be equal to zero. This procedure estimated the effects of the independent variable year within calf herd on calf weaning weight adjusted for age of calf, age of dam and sex. A separate analysis was conducted for each of the three calf herds.

TABLE XI

ANALYSES OF VARIANCE OF AGE OF CALF, AGE OF DAM AND SEX ADJUSTED CALF WEANING WEIGHT FOR YEAR WITHIN EACH CALF HERD

Source of Variation	Herd: 1-Angus df	Herd: 1-Angus Mean Square	Herd: 2-Hereford df	Herd: 2-Hereford Mean Square	Herd: 3-Angus df	Herd: 3-Angus Mean Square
Total	1176		633		1486	
Year	11	31313.17***	13	20627.98***	13	23458.29***
Residual	1165	1452.41	620	2055.89	1473	1657.22

***P<.005.

The linear and additive mathematical model utilized for each calf herd in these analyses was:

$$W_{ij} = \mu + Y_i + e_{ij}$$

where:

W_{ij} = is the 205-day, age of dam and sex adjusted weaning weight of the jth calf in the ith year.

μ = is the overall mean, an effect common to all observations.

Y_i = is the effect of the ith year,

$i = 1, \cdots, 12$ for calf herds two and three,

$i = 1, \cdots, 10$ for calf herd one.

e_{ij} = is the random error associated with each observation.

Year was assumed to be a fixed factor in this model; and random error was assumed to be normally and independently distributed with a mean of zero and a common variance of σ_e^2.

The least squares constants obtained from these analyses were used to formulate correction factors for year effects. Additive corrective factors for years were obtained by changing the sign of the least squares constants for each year. The standard errors of the least squares constants and of the correction factors as well, were obtained by:

$$S_{b_i} = [C_{ii} \cdot \hat{\sigma}_e^2]^{\frac{1}{2}}$$

where C_{ii} is the diagonal element in the inverse matrix corresponding to the partial regression coefficient (b_i) under consideration, $i = 1, \cdots, 14$; and $\hat{\sigma}_e^2$ is the error mean square obtained from the analysis of variance. Table XI presents the analysis of variance for each calf herd for year effect. The least squares year constants and their standard errors in pounds for the 205-day, age of dam and sex adjusted calf weaning weights are given in Table XII for each calf herd.

TABLE XII

LEAST SQUARES YEAR CONSTANTS (b) AND STANDARD ERRORS FOR EACH CALF HERD FOR 205-DAY, AGE OF DAM AND SEX ADJUSTED CALF WEANING WEIGHT IN POUNDS

Calf Birth Year	Calf Herd 1-Angus No.	b	S.E.	2-Hereford No.	b	S.E.	3-Angus No.	b	S.E.
$\hat{\mu}$	1177	424.34	1.90	634	437.30	2.35	1487	431.62	1.77
1958				10	14.80	13.48	6	36.22	15.49
1959				21	18.56	9.46	14	17.96	10.23
1960	10	-8.74	11.16	13	-22.84	11.88	23	-19.92	8.05
1961	10	40.76	11.16	15	24.30	11.09	74	0.15	4.72
1962	16	-3.96	8.90	17	5.88	10.45	124	-8.51	3.82
1963	30	-17.11	6.63	29	-9.13	8.14	140	-27.31	3.64
1964	80	-7.71	4.33	23	-10.65	9.06	119	-23.93	3.88
1965	115	1.27	3.75	58	-0.27	5.99	130	1.21	3.75
1966	128	-6.77	3.61	58	-6.94	5.99	144	7.72	3.60
1967	145	3.92	3.46	61	-20.56	5.87	145	7.92	3.59
1968	142	17.35	3.48	67	23.19	5.64	146	8.25	3.58
1969	157	-23.89	3.36	76	-20.02	5.36	153	-14.76	3.52
1970	172	-21.34	3.26	96	-26.07	4.89	140	-4.86	3.64
1971	172	26.21	3.26	90	29.76	5.01	129	19.86	3.76

The four sources of variation (age of calf, age of dam, sex and year) adjusted for in this study put calf weaning weights on as nearly an equal and comparable basis as was possible with the statistical methods used. Quantifying the average influence of these four identifiable sources of variation and adjusting the observations for them amounted to statistically controlling a portion of the data. Since the environmental effect probably varied from one observation to the next, only the average effect was removed by statistical control; however, the resulting adjusted weaning weights were standardized as much as was reasonably possible. Not all environmental variation can be removed by statistical adjustment factors; however, the most important biologically significant sources have been in the most part removed from the calf weaning weights used in this study. Any environmental variation removed increases the accuracy with which real differences between animals can be assessed.

Many studies have considered sire as an important source of variation in calf weaning weight. The data used in this study came from selection research projects where dams and sires were both allotted at random to breeding groups within line, and sires were not normally used more than two years. Hence, the chance of a dam having any full-sib offspring was not very large. Therefore in this study concerned with relationships among maternal half-sibs and between dam and offspring, sire was considered a random source of variation. Thus, no adjustment in calf weaning weight was made for sire effect, and sire was not considered in any analyses as a source of variation.

Traits Studied

Calf Traits

Adjusted Weaning Weight. The raw calf weaning weights used in this study were adjusted for differences due to weaning age, age of dam, sex and year of birth as previously described. The adjustments were applied in the order in which they were discussed in this manuscript. This trait henceforth in this study will be referred to as adjusted calf weaning weight (CaWW).

Adjusted Weaning Weight Ratio. Prior to converting to ratios, the raw calf weaning weights used in this study were adjusted for differences due to weaning age, age of dam and sex in this order as previously described. Thompson and Marlowe (1971) indicated that weight ratios based on sire-year means are more accurate than those based on herd-year means when estimating correlations between cow and calf traits. Brinks *et al.* (1964) used the sire-year mean for calculating weaning weight ratios; however, Clark *et al.* (1958) and Mangus and Brinks (1971) expressed their weaning weight data as ratios to the respective herd-year mean. The herd-year mean method was chosen for the data in this study because sires were considered a random factor and the number of calves in some sire-year subclasses was too small for an accurate estimate of the subclass mean since the confidence we put in such means is dependent upon the number of observations used in calculating them. The adjusted calf weaning weight ratios, henceforth referred to in this study as CaWWR, were calculated by the following formula using the calf herd-year means shown in Table VIII:

$$CaWWR_{ijk} = \frac{WW_{ijk}}{\overline{WW}_{ij}}$$

where,

$CaWWR_{ijk}$ = is the 205-day, age of dam and sex adjusted weaning weight ratio of kth calf in the jth calf herd in the ith year.

WW_{ijk} = is the 205-day, age of dam and sex adjusted weaning weight of the kth calf in the jth calf herd in the ith year,

$k = 1,\cdots, 1177$ for calf herd one,

$k = 1,\cdots, 634$ for calf herd two,

$k = 1,\cdots, 1487$ for calf herd three.

$\overline{WW}_{ij}$ = is the mean 205-day, age of dam and sex adjusted calf weaning weight for corresponding jth calf herd and ith year subclass,

$j = 1,2,3,$

$i = 1,\cdots, 10$ for calf herd one,

$i = 1,\cdots, 12$ for calf herds two and three.

By using the denominator $\overline{WW}_{ij}$, each calf's weaning weight was adjusted for herd and year effects since it was adjusted to the average of its contemporary calf herd-year subclass (Turvey, 1967; Richey, 1971). The mean of each calf herd-year subclass CaWWR is always one.

Richey (1971), while studying the statistical properties of ratios, found that ratios to subclass means effectively equalize the variances and means of calf weaning weights for effects common to the subclass means under the assumption that the subclass means have been measured without error. When the coefficients of variation are equal, the most appropriate adjustment method for beef cattle growth data is the ratio method using subclass means (Richey, 1971).

Arithmetic means of various groupings of both CaWW and CaWWR within cow were also used in this study. For example, the average of the CaWWs of a cow's calves when she was a 2,3 and 4-year-old will be expressed as CaWW (2-4). When necessary to distinguish between calves of the same cow, the number in parenthesis following CaWW will indicate the age of dam when that calf was born. For example, the CaWW of a cow's calf when she was a 6-year-old will be designated CaWW (6).

Cow Traits

Adjusted Weaning Weight. The actual heifer weaning weights used in this study were adjusted for differences due to weaning age and age of dam in this order as previously described. No adjustments were made for sex or year of birth. This trait henceforth in this study will be referred to as adjusted cow weaning weight (CoWW).

Adjusted Weaning Weight Ratio. The CoWWs were converted to ratios using the herd-year method previously discussed and the cow herd-year subclass means given in Table VII. This trait henceforth in this study will be referred to as adjusted cow weaning weight ratio (CoWWR).

Adjusted Yearling Weight. This trait is more appropriately referred to as an adjusted long yearling weight since it actually refers to a 14 month weight. Each heifer's long yearling weight was adjusted linearly to a constant age of 425 days by multiplying each heifer's average daily gain from weaning to 14 months by 220 days and then adding in its CoWW (U.S.D.A., 1970). This trait henceforth in this study will be referred to as adjusted cow yearling weight (CoYW).

Adjusted Yearling Weight Ratio. The CoYWs were converted to ratios using the herd-year method previously discussed and the cow herd-year subclass means given in Table VII. This trait henceforth in this study will be referred to as adjusted cow yearling weight ratio (CoYWR). Since nonreplacement female calves were normally culled at weaning, yearling weight ratios of the selected replacement heifers were lower in magnitude than they would have been if the entire heifer calf crop had been retained until yearling age because culling raised the yearling weight group means. Emsley et al. (1972) discussed the amount of and methods of avoiding the bias in yearling weight ratio due to culling at weaning age. However, it does seem that the ranking of the ratios of the replacement heifers would be the same regardless of the mean used.

Most Probable Producing Ability. Using the CaWW or CaWWRs a "Most Probable Producing Ability" index (MPPA) was used in this study to measure the productivity of each cow (Lush, 1945, 1948). The MPPA values based on CaWW will henceforth in this study be referred to as MPWW, and those based on CaWWR will be referred to as MPWWR. The MPWWs were calculated according to the formula suggested by Lush (1945, 1948):

$$\mathrm{MPWW} = \mathrm{HA} + \left[\frac{nr}{1 + (n-1)r} (\overline{\mathrm{CaWW}} - \mathrm{HA})\right]$$

where,

MPWW = is the most probable producing ability index for CaWW for the cow of concern.

$\overline{\mathrm{CaWW}}$ = is the adjusted calf (progeny) weaning weight mean for the cow of concern.

n = is the number of calf records, CaWW, that the MPWW is based on, $n = 1, \cdots, 10$.

r = is the repeatability of the calf trait of concern, CaWW.

HA = is the population true mean which in this case is estimated by the herd averages.

The MPWWR values were calculated by this same general formula except that CaWWR was used instead of CaWW and the appropriate values of r and HA were used. The HA values used to calculate the MPWW values were 424.34, 437.30 and 431.62 pounds, respectively, for calf herds 1, 2 and 3. The

HA value used to calculate the MPWWR values was 1.0 for each of the 3 calf herds. The estimates of repeatability (r) for both CaWW and CaWWR were calculated from the data used in this study and are given in Table XIV.

The term $nr/[1 + (n-1)r]$ is the regression (b) of the performance potential on averages of n observations (Pirchner, 1969); and it weights the MPWW or MPWWR values by the inverse of the variance of averages based upon different numbers of observations as a proportion of the variance of single observations (Hohenboken and Brinks, 1971b). With repeated observations, the denominator variance of this weighting term decreases; and the size of b increases such that performance potential may be estimated more accurately (Pirchner, 1969). The number of observations, size of n, needed for accurate prediction of performance is inversely related to the size of r, the repeatability of the trait of concern. According to Ronningen (1970), the validity of this weighting factor depends on the assumption that the repeated observations are measurements of what is genetically the same trait. This is assumed in this study of calf weaning weights of the same cow. This weighting term times an animal's average phenotypic deviation from the population mean performance, if known, is the best predictor of its true genetic deviation (Kempthorne, 1969). Therefore, MPWW and MPWWR are the most accurate available estimates of a cow's true producing ability for CaWW and CaWWR, respectively. Kempthorne (1969) and Pirchner (1969) have discussed and statistically developed in detail this "Most Probable Producing Ability" index. The accuracy of MPWW and MPWWR as predictors of cow productivity should have been enhanced due to use of the previously discussed weaning weight adjustments for non-genetic or environmental sources of variation.

Statistical Analyses

The objective of the analysis of these data was to estimate the relationships outlined in the introduction of this manuscript. To accomplish this objective the data were analyzed using linear phenotypic inter- and intra-class correlation and regression techniques. The computer programs of Barr and Goodnight (1971) were used to calculate these statistics throughout this entire statistical analysis. For this analysis, it was assumed that the data were a random sample and that all variables were normally and independently distributed.

Relationship Among Maternal Half-Sibs

This relationship, repeatability, was evaluated by the use of the linear phenotypic inter- and intra-class correlation and regression coefficients. All three of these statistics are estimates of the repeatability of CaWW when it is considered as a characteristic of the cow (Taylor *et al*., 1960; Ronningen, 1970). Henderson *et al*. (1959), Butcher and Freeman (1969) and Ronningen (1970) indicated that these methods of estimating repeatability yield almost the same results as the more complicated maximum likelihood procedure.

For this study, CaWW and CaWWR were both studied separately by the same statistical techniques; for simplicity and expediency, this discussion of statistical procedures will use only CaWW. Richey (1971), in a statistical study of the use of ratios of beef cattle growth data, concluded that "current estimate procedures for repeatability and most probable producing ability (MPPA) are appropriate when using records expressed as ratios to a group average."

It is reasonable to assume that the observed calf phenotype is determined additively by genetic and environmental effects and may be partitioned into a genetic component (normally including additive, dominance and epistatic genetic effects), a component due to environmental effects which are permanent in the sense that they are common to all records on the same animal and a component due to temporary environmental effects which vary from calf to calf of the same cow. Since CaWW is a function of the cow expressed through the calf, the genetic component includes (a) the genetic maternal ability of the cow, (b) the genetic effects common in calves of the same cow (which comprise a sample half of the cow's own additive genotype for CaWW and a small fraction of the cow's epistatic effects) and (c) such interactions as exist between (a) and (b) (Hazel, 1943; Cunningham and Henderson, 1965b). The phenotype (CaWW) is in model form:

$$p_i = g_i + pe_i + te_i$$

where,

p_i = is the phenotype of the ith calf of a cow, $i = 1, \cdots, 10$.

g_i = is the genetic component of the ith calf phenotype.

pe_i = is the permanent environmental component of the ith calf phenotype.

te_i = is the temporary environmental component of the ith calf phenotype.

It was assumed that these three components were uncorrelated. Thus, the phenotypic variance and covariance are:

$$V(p) = V(g) + V(pe) + V(te),$$

$$COV(p_i p_j) = COV(g_i g_i) + COV(pe_i pe_j) + COV(te_i te_j),$$

$$i = 1, \cdots, 10,$$

$$j = 1, \cdots, 10.$$

Intraclass Correlation. Since temporary environmental effects are independent from calf to calf of the same cow they are as likely to be positive as negative and should tend to average near zero over several calves; therefore, the variance of temporary factors should be reduced as the number of calves per cow increases. The permanent environmental and genetic effects determine the cow's constant performance during its whole life since these effects do not change over time or space. The repeatability of cow performance was estimated by the intraclass correlation (r) which measures the proportion of variation among calves caused by permanent or real differences among cows (Pirchner, 1969):

$$r = \frac{V(g_i) + V(pe_i)}{V(p_i)} = \frac{V(P)}{V(P) + V(T)}$$

where,

V(P) = the variance among permanent differences of cows.

V(T) = the variance among temporary differences in cow performance.

Repeatability is then defined as the ratio of permanent differences among cows to total differences among cows. Since the variation between repeated measures of CaWW for the same cow may be largely attributed to temporary environmental variation, r can be redefined using variance components as:

$$r = \frac{\hat{\sigma}_c^2}{\hat{\sigma}_c^2 + \hat{\sigma}_w^2},$$

where $\hat{\sigma}_c^2$ and $\hat{\sigma}_w^2$ are estimated variance components among average calf weights of different cows and calf weights within the same cow, respectively (Lush et al., 1934; Hazel, 1943). Repeatability calculated in this manner expresses the proportion of the variance of a single CaWW that is due to permanent differences among cows, both hereditary and environmental. This method assumes that there is no interaction or correlation between cow effects and the factors used in adjusting the data.

For this study, a nested analysis of variance was calculated for each trait, CaWW and CaWWR, for each breed, Angus and Hereford, to obtain estimates of the corresponding variance components $\hat{\sigma}_c^2$ and $\hat{\sigma}_w^2$. The sources of variation considered were cow herd, cows within cow herds and calves within cows. This analysis assumed that the repeatability was the same or homogeneous among cow herds (Henderson et al., 1959; Lee and Henderson, 1971). The k values or coefficients of variance components in the expected mean squares that are needed for calculating the individual variance components were obtained according to Method II of Henderson (1953) and Cunningham and Henderson (1965a) for unequal subsample numbers.

The standard errors of the intraclass correlation estimate of repeatability were calculated by the formula

$$\text{S.E. }(r) = \frac{(1-r)\ [1 + (K-1)\ r]}{[\frac{1}{2}\ K\ (K-1)\ (d-1)]^{\frac{1}{2}}}, \text{ (Fisher, 1958)},$$

where r is the intraclass correlation, d is the total number of cows and K is the average number of calves per cow. According to Fisher (1958), this formula is not completely applicable to the correlations obtained in this study; but its use should indicate the magnitude of the standard error. The formula is probably less accurate than theoretically possible because not all of its assumptions are met such as an equal number of progeny per dam. However, no other reasonably applicable standard error formula is available.

Effective selection of cows will decrease the intraclass correlation estimate of repeatability numerator proportionately more than the denominator; however, only greater precision in experimental technique would decrease the size of the denominator (Morley, 1951). It has been demonstrated that a slightly downward bias is introduced into the intraclass correlation when computed from an analysis where unequal subclass numbers are caused by systematic truncation selection (Koch and Clark, 1955b; Henderson et al., 1959; Curnow, 1961; Wadell, 1961; Swiger et al., 1964; Butcher and Freeman, 1969). This bias varies with the culling intensity and is greater for low than high repeatability parameters (Wadell, 1961). It has been indicated rather conclusively that the records of all cows including those with only a single record should be involved in any intraclass correlation estimate of repeatability since exclusion of single record cows tends to underestimate cow differences when some of the poorer producing cows are culled after having only one calf (Koch and Clark, 1955b; Henderson et al., 1959; Curnow, 1961; Swiger et al., 1964; Butcher and Freeman, 1969). Koch and Clark (1955b) showed that even if the cow differences are underestimated by excluding single record cows, the intraclass correlation would not be altered greatly since for the case of calf weaning weight an increase in the cow component of variance by 25% only increases the intraclass correlation by 0.05.

There were 136 Angus and 37 Hereford cows in this study which had only one record; of these, 69 and 17, respectively, had only one calving opportunity. Thus, the amount of early culling based on production in these data should not have biased the results of this study to any appreciable extent. To study this bias, intraclass correlation estimates of repeatability were calculated for both traits for both breeds using two sets of data, one using the records of all dams and one using only the records of those dams which had two or more records.

Tests for significant differences between the obtained intraclass correlation estimates of repeatability were conducted according to Fisher (1958). Tests were conducted using both sets of estimates between traits within breed, between breeds for each trait and between data sets.

Interclass Correlation. Repeatability also can be defined as the correlation or degree of association between calves randomly chosen from a cow's progeny (Taylor *et al.*, 1960; Hohenboken and Brinks, 1969; Ronningen, 1970). The phenotypic correlation between two randomly chosen calves of a cow is equal to the ratio of the phenotypic covariance of the two calves to the geometric mean of their variances. This allows for repeatability to be computed by the simple or interclass correlation coefficient which was discussed by Dickerson (1969).

In this study, the correlation coefficient was calculated on a within calf herd basis; and then the appropriate sums of squares and cross products were pooled across calf herds to obtain a breed pooled estimate. This was done assuming that the simple linear correlation estimate of repeatability of CaWW did not vary significantly between the two Angus calf herds. No pooling was necessary for the Herefords since there was only one calf herd.

For this study, all CaWWs were classified by age of dam; and correlation coefficients were computed separately for each possible pairwise combination of ages of dam, i.e., for all pairs of records made by the same cow at ages 2 and 3, 2 and 4, etc. This amounts to 45 possible pairwise combinations in this study. Thus, estimates were obtained for each degree of adjacency of CaWW of the same cow. The degree of adjacency infers number of years between calf records. Such correlation estimates of repeatability were obtained for each breed for both calf traits. Pooled estimates were also obtained for each breed and trait at each level of adjacency under the assumption that the various estimates at the same degree of adjacency were homogeneous. Only those subclasses with two or more paired observations contributed to the pooled estimate.

For any given pair of records of the same cow, the pair was included in the analysis only if both members of the pair were present. This tends to bias the results since not all of the data is used. Culling that has occurred on earlier records biases downward correlation estimates of relationship compared to estimates in unselected populations (Lush, 1940; Curnow, 1961; Searle, 1961; Dickerson, 1969; Ronningen, 1970). According to Dickerson (1969), interpretation errors can also be associated with correlation estimates if unrecognized factors contribute to the association between two variables.

The simple linear correlation coefficient (r) is an estimate of ρ (rho), the population parameter. Assuming the CaWWs are a random sample from a joint bivariate normal distribution, tests for $\rho = 0$ were made for each estimate using the appropriate table and (n-2) degrees of freedom as outlined in Snedecor and Cochran (1967). To test the hypothesis that the two breed sample values of "r_p", pooled, were drawn from the same population, each "r_p" was converted to its corresponding "Z" value; and the appropriate "t" test was conducted as outlined by Snedecor and Cochran (1967). Pooled sample size was decreased one for each estimate pooled.

<u>Regression</u>. With the assumption that $V(p_1) = V(p_2)$, then $r_{p_1p_2} = b_{p_2p_1}$ where $b_{p_2p_1}$ is the phenotypic linear regression of the later (p_2) on the earlier calf (p_1) of the same cow (Hazel, 1943; Lush, 1945; Cunningham and Henderson, 1965b). If we further assume that the temporary environments for the two calf records are uncorrelated, then referring back to the discussion at the beginning of this section $COV(p_1p_2) = V(g) + V(pe)$. And thus, repeatability may be estimated by the regression of later calf records (dependent variables) on earlier ones (independent variables) of the same cow (Searle, 1962; Cunningham and Henderson, 1965b). In these calculations, $b_{p_2p_1}$ was estimated on a within calf herd basis; and the appropriate sums of squares and cross products were pooled across calf herds to obtain a breed pooled estimate, as was done for the correlation estimates. This was done assuming that the linear regression estimate of repeatability of CaWW did not vary significantly between the calf herds.

As was done for the simple correlation estimates, all CaWWs were classified by age of dam; and regression coefficients were computed separately for each possible pairwise combination of ages of dam so that estimates were obtained at each degree of record adjacency. Estimates were obtained for each breed for each trait. Pooled estimates were also obtained for each breed and trait at each level of adjacency under the assumption that the various estimates at each level of adjacency were homogeneous. Pooling tends to cancel out high estimates with low ones resulting in a weighted average. Hopefully sampling errors operate randomly and on the average cancel out. The influence of any single estimate on the pooled statistic is proportional to the number of pairs of observations involved in the unpooled estimate (Fitzhugh, 1965).

The regression coefficient as an estimator of repeatability has the advantage over the correlation coefficient of being unbiased by truncation selection or culling that has occurred based on earlier records (Eisenhart, 1939; Curnow, 1961; Searle, 1961; Butcher and Freeman, 1969; Kempthorne, 1969; Lee and Henderson, 1971). The regression estimator is less efficient than a maximum likelihood estimator which uses information on all first records whether or not there is a corresponding second record; however, the maximum likelihood estimator may contain biases (Curnow, 1961; Ronningen, 1970). In the present study considering the large amount of data used, it seemed more reasonable to avoid bias than to extract a maximum amount of information from the data.

A basic assumption for the estimation of repeatability from the regression of later on earlier records is that the phenotypic variances are similar or homogeneous for both covariates or groups (Curnow, 1961). To test this assumption, the variances at each age of dam for each trait for each breed in this study were computed by pooling appropriate sums of squares and degrees of freedom over calf herds. Within each breed, the variances, Table XIII, of the calf records used in the maternal half-sib relationship study and classified by age of dam were quite similar and were considered homogeneous based on a test for the comparison of

TABLE XIII

MEANS AND VARIANCES AT EACH AGE OF DAM FOR CaWW AND CaWWR BY BREED

Age of Dam	No. of Records	CaWW		CaWWR	
		Mean[a]	Variance[b]	Mean	Variance
	Angus				
2	419	427	1445	99.8	81.10
3	492	428	1604	99.9	89.58
4	418	424	1616	99.1	91.64
5	325	424	1569	99.1	86.09
6	267	430	1414	100.5	76.07
7	214	431	1525	100.4	82.22
8	166	435	1986	101.4	108.15
9	113	440	1228	102.2	67.45
10	77	438	1316	101.4	68.83
11	36	428	1001	99.3	51.71
	Hereford				
2	129	445	2076	102.0	112.91
3	132	430	2295	98.4	124.58
4	101	425	1902	97.1	99.53
5	74	428	1535	98.0	79.56
6	58	444	1517	101.6	81.81
7	43	443	1786	101.4	94.72
8	35	444	1417	101.7	69.92
9	16	453	1654	103.6	84.12
10	8	461	1629	105.8	91.35

[a]Pounds.

[b](Pounds)^2.

correlated variances (Snedecor and Cochran, 1967). The results of this comparison of correlated variances test appeared to justify on the whole the use of the regression coefficient as an estimator of the repeatability of these traits in these breeds. Cunningham and Henderson (1965b), Fitzhugh (1965) and Smith and Fitzhugh (1968) also found no significant heterogeneity of variances for calf weaning weight among age of dam subclasses. If selection on the earlier record determined which cows had a second record, there is a tendency for the variances of the two sets of records to be unequal (Searle, 1962); however, rarely will culling be sufficiently highly correlated with future cow productivity as to seriously affect the normality of variance distribution over a herd (Curnow, 1961).

The slight tendency for the variation in both traits to decrease with increasing age of dam, Table XIII, may indicate that cows in the older age groups are genetically more alike than those in the herd as a whole. This result could have been brought about by selection for these traits at younger ages. This tendency is somewhat more pronounced in the Angus than in the Herefords.

The simple regression coefficient (b) is an estimate of β (beta) the population parameter. Assuming that the CaWWs were a random sample, tests for $\beta = 0$ were made for each estimate using the appropriate "t" test and table as outlined by Snedecor and Cochran (1967) utilizing (n-2) degrees of freedom. Standard errors for the b values were calculated by the usual procedures given by Searle (1962). Such "t" tests were run on only the adjacency pooled regression coefficients where pooled sample size was decreased one for each estimate pooled. To test the hypothesis that the two breed sample values of "b_p", pooled, for each degree of adjacency were drawn from the same population, tests for $b_{p_1} \neq b_{p_2}$ were made by calculating an "F" ratio value for comparing regression slopes as outlined by Snedecor and Cochran (1967) and then comparing this calculated value with the appropriate "F" table.

Relationship Between Heifer Growth and Subsequent Cow Productivity

This relationship was evaluated by the use of the linear phenotypic interclass correlation and regression coefficients which were discussed in detail in the previous section. Within each breed, each of a cow's CaWW, her CaWW average and her MPWW was correlated with and regressed on both of her growth traits individually, CoWW and CoYW. Likewise, each of a cow's CaWWRs, her CaWWR average and her MPWWR was correlated with and regressed on both of her ratio growth traits individually, CoWWR and CoYWR. The correlation coefficient estimates of these relationships were obtained by the "Cross Product Analysis Program" of Barr and Goodnight (1971) with cow herds, cow birth years in cow herds and cows in cow birth years in cow herds as sources of variation.

The tests for statistically significant correlations and differences between correlation values were conducted as outlined by Snedecor and Cochran (1967). The regression coefficient estimates of the heifer growth (independent variable)-subsequent productivity (dependent variable) relationship were obtained by the "Regression Procedure Program" of Barr and Goodnight (1971) with cow herds and cow birth years as "dummy" variables in the regression model (Draper and Smith, 1966). Therefore, the coefficients obtained were actually partial rather than simple regression coefficients. This computer program also calculated the standard errors for the regression coefficients, stated at what probability the coefficients were significantly different from zero and gave the coefficient of determination (R^2) for each regression model. The standard error of estimate for each model was obtained by taking the square root of the corresponding error mean square (Draper and Smith, 1966).

The correlation and regression coefficients obtained by these computer programs were essentially the same as would have been calculated by pooling sums of squares and cross products across cow birth year-herd subclasses or contemporary cow groups. Therefore, these estimates will be discussed as pooled coefficients. Means and variances by breed of all animals involved for each trait of concern in this heifer growth-subsequent cow performance relationship study are given in Appendix Table XXVII.

Also evaluated were multiple regression models with (a) CoWW and CoYW, separately and jointly, as the independent and CaWW (2-11) and MPWW (2-11) as the dependent variables, (b) CoWW, CoYW and CaWW (2) as the independent and CaWW (3-11) as the dependent variables, (c) CoWW, CoYW, CaWW (2) and CaWW (3) as the independent and CaWW (4-11) as the dependent variables, and (d) CoWW, CoYW, CaWW (2), CaWW (3) and CaWW (4) as the independent and CaWW (5-11) as the dependent variables. These models were analyzed by the Barr and Goodnight (1971) "Regression Procedure Program" with cow herds and cow birth years as "dummy" variables. As described previously, standard errors of the regression coefficients and the probability that the coefficients were significantly different from zero were supplied by the computer program. Standard errors of estimate were also calculated as previously described. If any of the necessary variables for one of these regression models was missing for a dam-offspring family, that families' data was excluded from the analysis of that model but not necessarily from the analyses of all models. Means and variances by breed for each variable involved for each of these model are given in Appendix Table XXVIII. This series of models was not analyzed using the corresponding ratio variables because the similarities in results obtained previously in this study for the actual and ratio variables indicated that such would be redundant.

In all of the analyses in this study concerned with the growth traits of the heifer as indicators of her future productivity, year of heifer birth was assumed to be a significant source of variation and thus was included in all statistical analysis models. This assumption was based on the work of other researchers who in similar studies found cow birth year a significant source of variation in calf weaning weights (Koch and Clark, 1955c; Fitzhugh, 1965; Mangus and Brinks, 1971; Kress and Burfening, 1972). The data analyses results of the present experiment also justified this assumption since cow birth year was usually found to be a significant source of variation in calf records. Mangus and Brinks (1971) and Kress and Burfening (1972) both indicated that the year of cow birth effect reflects an inverse relationship between environmental factors available to the heifer calf and her dam and the subsequent productivity of the heifer.

The CaWW and CaWWR averages involved in calculating some of the statistics discussed in this section were used under the assumption that the lack of constantly equal numbers in every average would not seriously bias or complicate the interpretation of the results of this study. The lack of unequal numbers tends to result in unequal variances for averages of varying numbers of observations. Therefore in calculating correlation and regression coefficients as was done in this study, the variance of "averages" tends to vary from observation pair to pair creating a difficult to interpret statistic. However, if the "averaged" variable, regardless of the number of observations it contains, is considered the best and only available estimate of a trait, then it seems logical that the results of this study should be valid and interpretable. The amount of variation in number of observations per given average would influence the validity of this assumption. A measure of this variation of number of observations per average would be the number of calves per cow. The range was from 1 to 10 in both breeds with an average of 3.91 and 3.46 calves per cow in the Angus and Hereford breeds, respectively. Berry (1945), while studying the reliability of averages of different numbers of lactation records for comparing dairy cows, concluded that averages were a fair but slightly biased basis for comparing productiveness of dairy cows with varying numbers of records. Several researchers have implied that the available lifetime average performance of an animal is the "best or ideal" measure of relative merit since averages are effective for correcting automatically the errors resulting from unrecorded temporary variations in the environment (Dickerson, 1940; Lush, Norton and Arnold, 1941; Marlowe, Kincaid and Litton, 1958). MPWW and MPWWR were used in this study as measures of lifetime cow productivity in an effort to avoid the bias of varying numbers of records per cow and to compare the results obtained using these measures of cow lifetime productivity with those of CaWW and CaWWR averages. Lush *et al*. (1941), Lush (1945, 1948) and Berry (1945) have all shown that the "Most Probable Producing Ability" index is an unbiased basis for comparing cows with different numbers of production records since the weighting factor, $nr/[1 + r\ (n-1)]$, corrects for the different numbers of observations involved.

According to Lush (1940) and Kempthorne (1969), in populations where the parents are a selected group, but the offspring are unselected, the regression of offspring on parent is a more reliable estimate of the relationship than the actual correlation observed and that selection of the parents does not affect or bias the estimation of the regression of offspring on parent. Kempthorne (1969) also indicated that this would be true only if the regression of offspring on parent is linear throughout the range of parent values and if there are no dominance deviations involved. Therefore even though cow selection was a factor in the data used in this study, the effect of this selection was not considered as a serious source of bias in interpretation of the results obtained in this study of the cow-calf relationship since both the correlation and regression estimates were obtained.

CHAPTER IV

RESULTS AND DISCUSSIONS

A primary goal of large animal breeding research has been to develope methods of accurately predicting the breeding value or future animal performance from that of the past. This would greatly facilitate formulation of optimum breeding plans. To do this requires a knowledge and understanding of the phenotypic relationships among various measurements of performance in an animals life. Since the phenotypic relationships among animal performances are the sum of the corresponding genetic and environmental relationships, a knowledge of these latter two types of relationships helps us to understand the phenotypic relationship and how to use it for animal improvement. Since the genetic and environmental relationships are extremely difficult to estimate with precision and since the phenotypic relationship is the actual information that researchers and livestock producers have to work with, the phenotypic relationship has been studied and discussed the most but perhaps least truly understood, probably because of its many components. The results of the present phenotypic relationship study will be given and discussed using the knowledge of the corresponding genetic and environmental relationships gleaned from the works of other reserachers to help explain, when it seems appropriate, the results of this study.

A common technique used in improving the accuracy of predicting future animal performance has been the identification of environmental sources of variation for a trait and adjustment of the data for these sources using the "best" methods available. This technique was applied to the data used in the present study as discussed in Chapter III. Since the objectives of this study were basically twofold, the results will be discussed in two sections, relationship among maternal half-sibs and relationship between heifer growth and subsequent cow productivity.

Relationship Among Maternal Half-Sibs

The two calf weaning weight traits of adjusted calf weaning weight (CaWW) and adjusted calf weaning weight ratio (CaWWR) were used to evaluate the relationship among maternal half-sibs. The phenotypic relationship among maternal half-sib weaning weights will be referred to by the term repeatability. When calf traits are considered as permanent characteristics of the beef cow expressed through her calves, repeatability of cow performance can be estimated. This implies the workable definition of repeatability for this study as being the relationship or correlation between calf weaning weight records of the same cow (Lush, 1945, 1948). A cow's influence on her calves' weaning weights is attributable to components from the additive genotype of the cow for growth potential and to her genotype for milk production and maternal ability. Repeatability has been estimated by many different methods (Taylor et al., 1960; Ronningen, 1970); however, only three of these were used in the present study.

Intraclass Correlation

Repeatability of calf weaning weight is that proportion of the variance among CaWW or CaWWRs attributable to permanent differences among cows, genetic and environmental. Thus according to Lush et al.

(1934), repeatability of these traits can be estimated by the intraclass correlation among CaWWs or CaWWRs for the same cow where cow is the class.

The data in the present study were subjected to nested analyses of variance for estimation of the variance components "between cows" and "within cows" from which intraclass correlation estimates of repeatability were computed for CaWW and CaWWR for Angus and Hereford, separately, from two subsets of the data. One subset was composed of the calf records of all cows regardless of their number of calves, and the other was composed of only those calf records of cows which had two or more calves. The results of the analyses of these two data subsets by breed by trait are given in Tables XIV and XV, respectively. Each of these tables gives for each trait for each breed the analysis of variance, size of the variance components, percent of total variation accounted for by each variance component, the repeatability estimate and its standard error and the average number of calves per cow involved in that respective analysis. In each of the eight analyses of cow influence on calf weaning weight traits, a highly significant difference was found between cows within herd.

As can be seen by comparing each of the four repeatability estimates in Table XIV with the corresponding estimate in Table XV, there is very little evidence for a significant difference between any of the four pairs of estimates. There was a slight but insignificant tendency for a decrease in the size of the repeatability estimates for the Hereford but not necessarily so for the Angus breed when the records of all cows having only one calf were excluded from these analyses. This slight decrease was probably due to a small bias resulting from underestimating the "between cows" variance component for this sample of cows. This

TABLE XIV

ESTIMATES OF COMPONENTS OF VARIANCE, REPEATABILITY (INTRACLASS CORRELATION) AND STANDARD ERRORS BY BREED BY TRAIT USING ALL RECORDS OF ALL COWS[a,b]

Source	df	Mean Square	Component of Variance	Percent of Variation
			Angus-CaWW	
Between cow herds	4	12841***	18.01	1.15
Between cows within herds	675	2777***	422.57	26.91
Within cows	1984	1129	1129.45	71.94
Repeatability = 0.272±.021				
			Angus-CaWWR	
Between cow herds	4	0.0227	0.00001	0.06
Between cows within herds	675	0.0153***	0.00231	27.00
Within cows	1984	0.0063	0.00625	72.94
Repeatability = 0.270±.021				
			Hereford-CaWW	
Between cows	182	4512***	1014.22	50.22
Within cows	451	1005	1005.46	49.78
Repeatability = 0.502±.040				
			Hereford-CaWWR	
Between cows	182	0.0239***	0.00537	50.20
Within cows	451	0.0053	0.00533	49.80
Repeatability = 0.502±.040				

***P<.005.

[a]Repeatabilities not significantly different within breed but are significantly different (P<.001) between breeds within trait.

[b]Average number of calves per cow was 3.91 and 3.46 for Angus and Hereford, respectively.

TABLE XV

ESTIMATES OF COMPONENTS OF VARIANCE, REPEATABILITY (INTRACLASS CORRELATION) AND STANDARD ERRORS BY BREED BY TRAIT USING ONLY RECORDS OF COWS WITH TWO OR MORE RECORDS[a,b]

Source	df	Mean Square	Component of Variance	Percent of Variation
		Angus-CaWW		
Between cow herds	4	12937***	19.00	1.21
Between cows within herds	539	3070***	418.88	26.73
Within cows	1984	1129	1129.44	72.06
Repeatability = 0.271±0.021				
		Angus-CaWWR		
Between cow herds	4	0.0253	0.00001	0.11
Between cows within herds	539	0.0170***	0.00232	27.03
Within cows	1984	0.0063	0.00625	72.86
Repeatability = 0.271±0.021				
		Hereford-CaWW		
Between cows	145	4915***	957.55	48.78
Within cows	451	1005	1005.46	51.22
Repeatability = 0.483±0.043				
		Hereford-CaWWR		
Between cows	145	0.0263***	0.0051	49.12
Within cows	451	0.0053	0.0053	50.88
Repeatability = 0.491±0.042				

***P<.005.

[a]Repeatabilities not significantly different within breed but are significantly different (P<.001) between breed within trait.

[b]Average number of calves per cow was 4.68 and 4.09 for Angus and Hereford, respectively.

could have resulted from excluding some of the cows with the poorest records which were culled after having only one calf (Koch and Clark, 1955b) or from excluding all cows which had only one calving opportunity. It seems reasonable to assume that cows at both extremes, very high or low producers, would contribute more to the variance between cows than those cows near the average. The results, Table XIII, of the present study agree in general with those of Smith and Fitzhugh (1968) who indicated that the progeny weaning weights of first calf cows tended to be more variable on the average than those of more mature cows. Smaller sample size and chance may account for most of the larger decrease in the estimated repeatability for Herefords than Angus since as sample size decreases it is normally expected that the variance of variance component estimates would increase resulting in a less precise estimate. However, this comparison indicates that if sample size is large enough, like that for the Angus in this study, it makes very little difference which type of data set is used to estimate repeatability by the intraclass correlation since none of these four comparisons were significantly different at the P<.05 level. Koch and Clark (1955b) postulated that this would be the result of such a comparison. Regardless of the lack of difference in their size, the repeatabilities in Table XIV are considered, as discussed previously in this paper, the more accurate and unbiased estimates of the repeatability of calf weaning weight.

No significant differences were found at the P<.05 level between the intraclass correlation repeatability estimates for CaWW and CaWWR within breed within data set, Tables XIV and XV. This indicates that the repeatability of calf weaning weight does not change significantly when the weights are converted to ratios and that intraclass correlation repeatability estimates calculated using either variable are applicable to both variables. No precedent for this comparison was found in the literature.

For both data subsets and within both traits, there was a highly significant difference (P<.001) between the Angus and Hereford intraclass correlation estimates of the repeatability of calf weaning weight, Tables XIV and XV. The estimated repeatabilities were 0.272±.021 and 0.270±.021 for Angus and 0.502±.040 and 0.502±.040 for Herefords for CaWW and CaWWR, respectively, from Table XIV.

It is interesting to note in Table XIV that the percent of total variation accounted for by cows and the magnitude of the variance component estimates for between cow variation are both about twice as large in Herefords than in Angus. The 140% larger Hereford between cow variance component estimate indicates that there is more true variation among the measured average performance of Hereford than Angus cows; or some factor such as cross-nursing or robbing by calves tends to camouflage the true differences and thus decrease the variation among Angus cows. However, comparison of the size of estimated variance components for calves within cows indicates that there is only slightly more variation from calf to calf of the same cow in Angus than in Herefords. The magnitude of these variance components as reflected in the corresponding repeatability estimates indicates that there is apparently more variation in the productivity of Hereford than Angus cows and that Hereford cows are more consistent in their productivity than Angus.

Only two reports were found in the literature where these two or any two breeds were compared for the repeatability of calf weaning weight, and neither report stated if the differences obtained between breeds had been tested for significance. Minyard and Dinkel (1965) reported estimates of 0.52±.13 and 0.42±.04 for Angus and Hereford, respectively. However using approximately 4.6 times as many observations, Sellers *et al.* (1970) reported estimates of 0.19±.01 and 0.27±.01 for Angus and Hereford, respectively, and indicated that repeatability appears to be slightly lower in Angus than Herefords. The results of the present study agree in conclusion with but indicate a larger breed difference than that reported by Sellers *et al.* (1970).

The intraclass correlation repeatability estimates reported in Tables XIV and XV agree fairly well with those found in the literature for Angus but are slightly higher on the average than most literature reports for Herefords, Table II. The five reported estimates found in the literature for Angus were 0.31 (Berg, 1961), 0.52 (Minyard and Dinkel, 1965), 0.26 (Hohenboken and Brinks, 1969), 0.19 (Sellers *et al.*, 1970) and 0.31 (Thompson and Marlowe, 1971). Unweighted and weighted averages of the many reports in the literature for Herefords were 0.41 and 0.33, respectively from Table II. Possible reasons for the significant difference found in this study for the repeatability of calf weaning weight traits, CaWW and CaWWR, between the Angus and Hereford breeds will be discussed later in this section after the other two estimators of repeatability have been presented.

Interclass Correlation and Regression

The estimates of repeatability obtained in this study by the correlation and regression coefficients for later on earlier calves of the same cow will be discussed together because of the similarity of results from these two methods. For these types of estimators, repeatability of calf weaning weight, CaWW or CaWWR, can be thought of as the degree of association between pairs of randomly chosen calves of the same cow. The use of these two statistics to estimate the repeatability of calf weaning traits has been well documented in the literature (Taylor et al., 1960; Fitzhugh, 1965; Cunningham and Henderson, 1965b; Ronningen, 1970).

The correlation estimates of repeatability are presented in Tables XVI and XVII for Angus and Herefords, respectively, by trait, CaWW and CaWWR, and by degree of adjacency for each age of dam. In the same manner, the regression estimates of repeatability are presented in Tables XVIII and XIX. These four tables also give the number of pairs of records involved in the computation of each individual estimate and the level of significance of each correlation estimate. All calf records used were classified by age of dam, and repeatability was computed separately for each pairwise combination of ages of dam, i.e., for all pairs of records made by the same dam at ages 2 and 3, 2 and 4, etc. In each of these four tables, the values on the main diagonal were computed from records made at adjacent ages of dam, i.e., in adjacent years. On the next diagonal going up and to the right the two records in each pair are separated by two years, on the next by three years, and so on. Thus, the values on successive diagonals in these tables were computed from records with 1,···,9 and 1,···, 8 degrees of adjacency for the Angus and Herefords, respectively.

This analysis system resulted in 45 and 36 separate repeatability estimates in each of the two Angus and Hereford tables, respectively. Differences between CaWW and CaWWR and between the two breeds for these 81 separate estimates within each estimator type were not tested for statistical significance.

TABLE XVI

CORRELATION ESTIMATES OF REPEATABILITY OF ANGUS CaWW AND CaWWR COMPUTED FROM GROUPS OF PAIRS OF RECORDS AT DIFFERENT AGES OF DAM AND DIFFERENT DEGREES OF ADJACENCY

Age of Dam (1st Record)	Trait	Age of Dam (2nd Record) 3	4	5	6	7	8	9	10	11
2	CaWW	0.25**	0.22**	0.21**	0.27**	0.28**	0.20*	0.12	0.13	0.27
	CaWWR	0.24**	0.22**	0.21**	0.28**	0.28**	0.20*	0.12	0.13	0.26
	No.[a]	368	307	235	189	144	112	73	43	23
3	CaWW		0.31**	0.26**	0.23**	0.29**	0.25**	0.21*	0.18	0.27
	CaWWR		0.30**	0.26**	0.23**	0.29**	0.25**	0.20*	0.18	0.27
	No.[a]		368	291	243	195	150	101	70	29
4	CaWW			0.30**	0.28**	0.21**	0.24**	0.24*	-.05	0.12
	CaWWR			0.29**	0.28**	0.20**	0.23**	0.25*	-.07	0.11
	No.[a]			290	240	192	148	100	62	29
5	CaWW				0.31**	0.32**	0.24**	0.10	0.28*	-.10
	CaWWR				0.31**	0.32**	0.24**	0.10	0.29*	-.08
	No.[a]				254	204	157	109	75	34
6	CaWW					0.25**	0.21**	0.32**	0.30*	0.29
	CaWWR					0.25**	0.21**	0.33**	0.30*	0.29
	No.[a]					206	159	109	74	32
7	CaWW						0.23**	0.27**	0.26*	-.06
	CaWWR						0.23**	0.27**	0.26*	-.05
	No.[a]						159	109	74	33
8	CaWW							0.36**	0.26*	0.30
	CaWWR							0.37**	0.26*	0.29
	No.[a]							108	74	33
9	CaWW								0.30*	0.20
	CaWWR								0.31**	0.20
	No.[a]								73	33
10	CaWW									0.00
	CaWWR									0.00
	No.[a]									33

**P<.01.

*P<.05.

[a]Number of pairs of records.

TABLE XVII

CORRELATION ESTIMATES OF REPEATABILITY OF HEREFORD CaWW AND CaWWR COMPUTED FROM GROUPS OF PAIRS OF RECORDS AT DIFFERENT AGES OF DAM AND DIFFERENT DEGREES OF ADJACENCY

Age of Dam (1st Record)	Trait	Age of Dam (2nd Record)							
		3	4	5	6	7	8	9	10
2	CaWW	0.42**	0.55**	0.51**	0.41**	0.52**	0.26	0.03	0.17
	CaWWR	0.43**	0.56**	0.51**	0.43**	0.53**	0.27	0.03	0.19
	No.[a]	115	86	62	51	33	29	13	7
3	CaWW		0.59**	0.14	0.25	0.43**	0.34	0.21	0.09
	CaWWR		0.59**	0.14	0.23	0.44**	0.34	0.18	0.06
	No.[a]		87	61	50	37	29	13	6
4	CaWW			0.48**	0.36*	0.55**	0.47**	-.19	-.16
	CaWWR			0.49**	0.38**	0.53**	0.48**	-.17	-.16
	No.[a]			64	50	38	30	13	6
5	CaWW				0.47**	0.32	0.47**	0.33	0.28
	CaWWR				0.45**	0.31	0.45*	0.33	0.27
	No.[a]				49	36	29	11	7
6	CaWW					0.69**	0.69**	0.43	0.35
	CaWWR					0.69**	0.70**	0.44	0.34
	No.[a]					39	31	14	8
7	CaWW						0.71**	0.39	0.97*
	CaWWR						0.70**	0.43	0.98*
	No.[a]						31	12	4
8	CaWW							-.08	-.42
	CaWWR							-.08	-.41
	No.[a]							15	7
9	CaWW								0.65
	CaWWR								0.62
	No.[a]								8

**P<.01.

*P<.05.

[a]Number of pairs of records.

TABLE XVIII

REGRESSION ESTIMATES OF REPEATABILITY OF ANGUS CaWW AND CaWWR COMPUTED FROM GROUPS OF PAIRS OF RECORDS AT DIFFERENT AGES OF DAM AND DIFFERENT DEGREES OF ADJACENCY

Age of Dam (1st Record)	Trait	Age of Dam (2nd Record)								
		3	4	5	6	7	8	9	10	11
2	CaWW	0.27	0.23	0.21	0.27	0.28	0.21	0.10	0.10	0.21
	CaWWR	0.26	0.23	0.22	0.27	0.27	0.21	0.10	0.10	0.19
	No.[a]	368	307	235	189	114	112	73	43	23
3	CaWW		0.32	0.27	0.23	0.29	0.29	0.17	0.19	0.23
	CaWWR		0.32	0.26	0.22	0.28	0.28	0.16	0.17	0.22
	No.[a]		368	291	243	195	150	101	70	29
4	CaWW			0.31	0.30	0.23	0.28	0.22	-.05	0.12
	CaWWR			0.30	0.29	0.21	0.27	0.22	-.06	0.10
	No.[a]			290	240	192	148	100	62	29
5	CaWW				0.30	0.33	0.28	0.09	0.25	-.08
	CaWWR				0.30	0.32	0.27	0.09	0.25	-.06
	No.[a]				254	204	157	109	75	34
6	CaWW					0.28	0.26	0.32	0.31	0.24
	CaWWR					0.27	0.27	0.33	0.30	0.23
	No.[a]					206	159	109	74	32
7	CaWW						0.28	0.25	0.24	-.04
	CaWWR						0.29	0.25	0.24	-.04
	No.[a]						159	109	74	33
8	CaWW							0.30	0.20	0.21
	CaWWR							0.31	0.20	0.20
	No.[a]							108	74	33
9	CaWW								0.35	0.16
	CaWWR								0.35	0.16
	No.[a]								73	33
10	CaWW									0.00
	CaWWR									0.00
	No.[a]									33

[a]Number of pairs of records.

TABLE XIX

REGRESSION ESTIMATES OF REPEATABILITY OF HEREFORD CaWW AND CaWWR COMPUTED FROM GROUPS OF PAIRS OF RECORDS AT DIFFERENT AGES OF DAM AND DIFFERENT DEGREES OF ADJACENCY

Age of Dam (1st Record)	Trait	Age of Dam (2nd Record)							
		3	4	5	6	7	8	9	10
2	CaWW	0.45	0.63	0.53	0.39	0.56	0.24	0.03	0.12
	CaWWR	0.45	0.63	0.53	0.41	0.57	0.24	0.03	0.15
	No.[a]	115	86	62	51	33	29	13	7
3	CaWW		0.56	0.13	0.21	0.42	0.25	0.17	0.06
	CaWWR		0.54	0.13	0.19	0.43	0.23	0.13	0.04
	No.[a]		87	61	50	37	29	13	6
4	CaWW			0.52	0.38	0.66	0.46	-.19	-.18
	CaWWR			0.51	0.40	0.63	0.44	-.16	-.19
	No.[a]			64	50	38	30	13	6
5	CaWW				0.53	0.45	0.57	0.42	0.40
	CaWWR				0.51	0.44	0.54	0.41	0.40
	No.[a]				49	36	29	11	7
6	CaWW					0.70	0.77	0.65	0.60
	CaWWR					0.70	0.74	0.64	0.61
	No.[a]					39	31	14	8
7	CaWW						0.78	0.68	1.78
	CaWWR						0.71	0.74	1.83
	No.[a]						31	12	4
8	CaWW							-.14	-.49
	CaWWR							-.14	-.50
	No.[a]							15	7
9	CaWW								0.63
	CaWWR								0.65
	No.[a]								8

[a]Number of pairs of records.

A previously discussed basic assumption necessary for use of the regression of later on earlier records as an estimator of repeatability is that the phenotypic variance of both groups be the same. The results of this study substantiate on the whole that this assumption has basically valid for these data since the corresponding correlation and regression estimates reported in Tables XVI, XVII, XVIII and XIX are very similar in sign and magnitude within trait within breed. If the variance of the later group would have been much larger than that of the earlier group, the regression coefficient would have been much larger than the corresponding correlation coefficient and vice versa. Therefore, the amount of bias in these correlation estimates of repeatability due to culling on the earlier record is small and insignificant for both traits within both breeds.

Referring to Tables XVI and XVII, it is of interest to note that 69 and 47% of the Angus and Hereford, respectively, correlation estimates of repeatability for both traits are significantly different from zero at the $P<.05$ level. The estimates that are not significant tend to be those for the larger degrees of adjacency or those which involve calves from older dams. For both cases, the number of observation pairs per estimate is usually comparatively low. The comparatively fewer observation pairs involved in the Hereford than Angus estimates also seems to be a plausible explanation for fewer Hereford than Angus estimates being significant; this seems especially so since the Hereford estimates were usually larger than those of the Angus. Nevertheless, it is encouraging to note that the majority of these estimates are positive and significant even though a few are close to zero. Only 7 and 11% of the estimates are negative for Angus and Hereford, respectively. No general pattern is apparent across both breeds for negative values. Similar results of sign were obtained from the regression estimates, Table XVIII and XIX, since both corresponding estimators were calculated using the same covariance terms for their numerators. Even though tests for significant differences from zero were not conducted for the regression estimates, these can crudely be implied from the corresponding correlation estimates.

As the degree of adjacency increases or becomes larger, the number of pairs of records involved in each estimate decreases leading to an expected increase in the variance of the estimates reported in Tables XVI, XVII, XVIII and XIX. Therefore, it is questionable whether estimates obtained in this study from pairs of records with degree of adjacency 8 and 6 or above for the Angus and Herefords, respectively, are of much practical value. Because of the differences shown in each of these four tables for the values of the estimates at different degrees of adjacency, all estimates were not pooled for each breed, trait or estimator type. However since within the same degree of adjacency the estimates appeared quite consistent, pooled estimates were computed at each level of adjacency for each breed for each trait. These were calculated as weighted averages of the values on separate diagonals, Tables XVI, XVII, XVIII and XIX. The resulting pooled correlation and regression estimates of repeatability are given in Tables XX and XXI, respectively, by breed and by degree of adjacency for CaWW and CaWWR. Tables XX and XXI also give the number of pairs of observations represented by each pooled estimate, the level of significance of each estimate and the level of significance for the differences between the Angus and Hereford breed estimates of the same type, of the same degree of adjacency and for the same trait. The regression of later on earlier CaWW is also plotted in Figure 1 by breed for the first 8 degrees of adjacency. Because graphs of the corresponding CaWWR values and correlation estimates would have been very similar in shape to that shown in Figure 1, plots were not constructed for these repeatability estimates.

TABLE XX

CORRELATION ESTIMATES OF REPEATABILITY (r) OF CaWW AND CaWWR COMPUTED BY BREED FROM GROUPS OF PAIRS OF RECORDS OF DIFFERENT DEGREES OF ADJACENCY

	Angus			Hereford		
Degree of	No. of	r		No. of	r	
Adjacency	Pairs	CaWW	CaWWR	Pairs	CaWW	CaWWR
1	1859	0.28**,[a]	0.27**,[a]	408	0.51**,[b]	0.51**,[b]
2	1417	0.25**,[c]	0.25**,[c]	283	0.40**,[d]	0.40**,[d]
3	1043	0.24**,[a]	0.23**,[a]	197	0.44**,[b]	0.43**,[b]
4	748	0.23**,[c]	0.24**,[c]	137	0.42**,[d]	0.43**,[d]
5	501	0.26**	0.26**	82	0.30**	0.31**
6	309	0.13*	0.13*	48	0.19	0.18
7	172	0.14	0.14	19	0.05	0.04
8	72	0.17	0.17	7	0.17	0.19
9	23	0.27	0.26			

**$P<.01$.

*$P<.05$.

[a,b]Coefficients of each trait in the same line bearing different superscript letters are significantly ($P<.01$) different.

[c,d]Coefficients of each trait in the same line bearing different superscript letters are significantly ($P<.05$) different.

No significant differences were found at the $P<.05$ level between any of the pooled corresponding estimates of repeatability for CaWW and CaWWR within breed within estimator type, Tables XX and XXI. This

TABLE XXI

REGRESSION ESTIMATES OF REPEATABILITY (b) AND STANDARD ERRORS FOR CaWW AND CaWWR COMPUTED BY BREED FROM GROUPS OF PAIRS OF RECORDS OF DIFFERENT DEGREES OF ADJACENCY

	Angus			Hereford		
Degree of Adjacency	No. of Pairs	b	S.E.	No. of Pairs	b	S.E.
			CaWW			
1	1859	0.29***,a	0.02	408	0.53***,b	0.04
2	1417	0.26***,a	0.03	283	0.44***,b	0.06
3	1043	0.24***,a	0.03	197	0.47***,b	0.07
4	748	0.24***,c	0.04	137	0.42***,d	0.08
5	501	0.27***	0.04	82	0.28**	0.10
6	309	0.12*	0.05	48	0.17	0.13
7	172	0.13	0.07	19	0.04	0.22
8	72	0.14	0.10	7	0.12	0.30
9	23	0.21	0.16			
			CaWWR			
1	1859	0.29***,a	0.02	408	0.52***,b	0.04
2	1417	0.26***,a	0.02	283	0.44***,b	0.06
3	1043	0.24***,a	0.03	197	0.45***,b	0.07
4	748	0.24***,c	0.03	137	0.43***,d	0.08
5	501	0.26***	0.04	82	0.28**	0.10
6	309	0.11*	0.05	48	0.16	0.13
7	172	0.12	0.07	19	0.03	0.22
8	72	0.13	0.09	7	0.15	0.33
9	23	0.19	0.16			

*** P<.001.

** P<.01.

* P<.05.

[a,b] Coefficients in same line bearing different superscript letters are significantly (P<.01) different.

[c,d] Coefficients in same line bearing different superscript letters are significantly (P<.05) different.

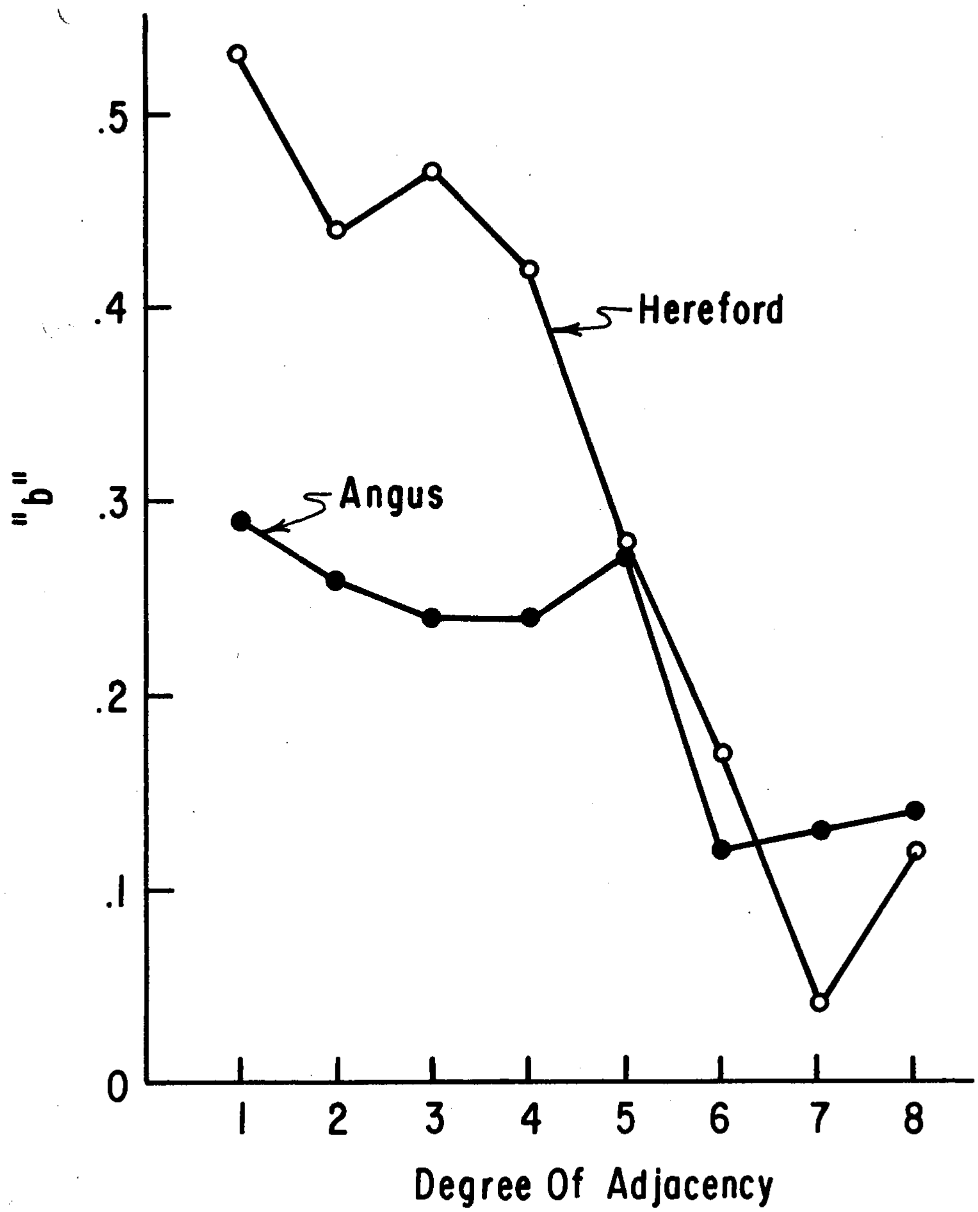

Figure 1. Regression Coefficients (b) for Later on Earlier Calf of Pairs of CaWW Records of Different Degrees of Adjacency by Breed

agrees with the previously discussed results of the present study for similar comparisons using the intraclass correlation estimates of repeatability.

As shown in Tables XX and XXI, tests were conducted for both the pooled regression and correlation estimates of repeatability at each degree of adjacency to gain evidence as to whether the estimate was estimating zero or not. For both types of estimators and both traits, the estimates were significantly different from zero at least at the $P<.05$ level through the first 6 and 5 degrees of adjacency for the Angus and Herefords, respectively. These pooled results agree very closely with the respective pairwise individual estimates, Tables XVI, XVII, XVIII and XIX.

Tables XVI through XXI and Figure 1 all demonstrate that as the degree of adjacency increases or becomes larger, the value of the weaning weight repeatability estimate tends to decrease. Also, the relationship between consecutive records tends to increase gradually as the cows get older. Fitzhugh (1965) reported the same general trends in repeatabilities of weaning weight pooled over many breeds but did not find as drastic a decline in repeatability with larger degrees of adjacency. Using average daily gain from birth to weaning data pooled across Angus and Herefords, Cunningham and Henderson (1965b) reported declines in repeatability with increasing, larger, degrees of adjacency very similar to those of the present study. These were the only two directly comparable studies found in the literature. Koger and Knox (1947), Gregory et al. (1950) and Koch and Clark (1955b) have all suggested with their results from beef studies that there is a tendency for a decrease in the repeatability of calf weaning weights as the calf records become further apart in time.

In Tables XX and XXI and in Figure 1, the adjacency effect is particularly noticeable in the declining value of the repeatability estimates as the level of separation of the records increases. This effect may be due to positively correlated temporary environmental effects among adjacent or closely adjacent records (e.g., common sire or those similar in genetic make up, management practices, weather conditions, undefinable similar age of dam effects, or similar effects of changes in the nutritional level of the herd), to slight changes in the nature of the permanent environmental effects contributable to the cow as the observations become further apart in time (Cunningham and Henderson, 1965b) or to progressive selection of cows (Koch and Clark, 1955b; Fitzhugh, 1965).

The effect of sire is usually considered random in most repeatability of cow performance studies; however in the present study involving data from selection studies, this assumption may not be completely valid, especially when studying nonadjacent records. If selection was effective over time for increasing the genetic merit of the sires of the calves in the present study, this would tend to reduce the degree of genetic relationship between non-adjacent and especially distantly adjacent calves.

The permanent environmental effects contributable to the cow are largely attributable to her year of birth (Hohenboken and Brinks, 1969). Possible examples of changes in the nature of such effects are the varying rates of physiological aging including time to maturity and onset of the old age productive decline (Brown, Brown and Butts, 1972) and partial recovery of the cow over time from an adverse environment while she was a calf or heifer.

Progressive selection, based on calf performance, of cows over time would tend to reduce the variation among remaining cows and probably within cows such that repeatability estimates based on records far apart in adjacency would probably be lower than if selection was not practiced. Some selection was practiced which might have slightly affected the repeatability estimates, especially the distantly adjacent estimates, obtained in the present study.

No reason is apparent to explain the marked downward break in the size of the repeatability estimates after 5 degrees of adjacency in the Angus as compared to the more constant and consistent decline in the Hereford data, Tables XX and XXI and Figure 1. Cunningham and Henderson (1955b) reported remarkedly similar trends in their data. The adjacency effect found in the data of the present study and that of similar studies indicates that early cow performance records are probably at best a poor basis for prediction of her performance more than 4 or 5 years removed.

The pooled repeatability estimates, Tables XX and XXI, for the first four to five degrees of adjacency agree fairly well within breed with the intraclass correlation estimates reported earlier in this paper, Tables XIV and XV. The Hereford repeatability estimates, Tables XX and XXI, based on closely adjacent records, those of degree four or less, are in close agreement with similarly calculated estimates reported in the literature. Some reported estimates for closely adjacent Hereford weaning weight records are 0.50 (Koger and Knox, 1947), 0.49, 0.43 and 0.33 (Gregory et al., 1950), 0.51 (Botkin and Whatley, 1953), 0.66, 0.39 and 0.47 (Koch and Clark, 1955b) and 0.35 and 0.68 (McCormick et al., 1956). The only Angus repeatability estimates found in literature based on adjacency of records were calculated on average daily gain birth to weaning data and reported by Cunningham and Henderson (1955b). Their estimates for degrees of adjacency of 1, 2, 3 and 4 were 0.47, 0.29, 0.24 and 0.25, respectively, which are in moderate agreement with those of the present study through 5 degrees of adjacency, Tables XX and XXI.

Tables XX and XXI provide significant (P<.05) evidence of breed differences within trait within type of estimator for the repeatability of weaning weight estimates at the first four degrees of adjacency. This evidence agrees with that generated by the intraclass correlation estimates discussed previously in this paper. However, this evidence of a Angus-Hereford breed difference in repeatability estimates of calf weaning weights at different degrees of adjacency is in some disagreement with that of Taylor et al. (1960) and Cunningham and Henderson (1965b) who both used average daily gain from birth to weaning data of these same two breeds and reported that their estimates for the two breeds were in close agreement with Herefords having slightly higher values. No other breed comparisons of a similar type were found in the literature. And as reviewed earlier in the intraclass correlation discussion, very few comparisons between breeds for the repeatability of calf weaning weight traits were found in the literature.

Assuming the breed difference observed in the present study is real, there are probably many reasons for it in these calf weaning weight traits; but due to lack of research effort in this area, few have been postulated. Hohenboken and Brinks (1969) in a discussion of possible reasons for low repeatability in the Angus breed hypothesized that any thing which limited growth potential would impose a phenotypic ceiling on calf weaning weights which would not permit cow differences for maternal ability to be expressed. If maternal ability, basically milk production, in the Angus breed is on the average higher than that for Herefords, growth potential of Angus calves would be more influential in determining variability among calf weaning weights than the maternal ability of their dams. Under these theoretical conditions, expression of permanent cow differences would be highly dependent upon their calves' genotypes for growth. With these circumstances, it is reasonable to assume that limited growth potential of calves to weaning could limit repeatability of calf weaning weights. This theory is valid only if the genetically inherited growth potential of Angus calves is low enough to be a limiting factor in their preweaning growth performance. Gregory et al. (1965), from results of a crossbreeding trial comparing straightbreds and reciprocal crosses, reported that Herefords had excelled in growth potential and that Angus and Shorthorns had excelled in maternal ability.

A second possible explanation for a lower weaning weight repeatability for Angus than for Herefords is a behavioral trait of Angus dams. "It is generally accepted among cattlemen that Angus cows are more tolerant of "bum" or foster calves than are Hereford cows" (Hohenboken and Brinks, 1969). This belief is strongly supported by personal observation of this researcher and that of the research staff and herdsmen at the Oklahoma Agricultural Experiment Station where the data used in the present study were collected. Several cows involved in the present study have been observed nursing more than one calf even though it was known that they only had one. This behavioral trait tends to obscure permanent differences among cows and their maternal ability as measured by the weaning weights of their calves; and thus, the repeatability estimate will be lower than if such a trait were not present as is the general case for the Hereford breed.

As the variation among calves of the same cow increases, there is a tendency for the repeatability of calf weaning weight traits to decrease. Tables XIV and XV show that the variation among Angus calves of the same cow was slightly greater than that for Hereford calves. Sellers et al. (1970) reported just the opposite relationship. This difference for the present study, if it is real, may be partially explained by a breed by geographical location interaction. It seems reasonable to assume that temporary environmental stresses of drought and excessive heat might adversely affect the Angus cow's maternal ability proportionately more than that of the Hereford cow since Angus cows are usually considered heavier milkers than Herefords. Frahm (1972), using a large subset of the same cows as were involved in the present study, indicated that Angus cows on the average give more milk than Herefords. If the Angus cows maternal ability does fluctuate more than that of the Hereford cow with sudden short term changes in the weather, then Angus calves of the same cow would tend to be more variable resulting in a lower repeatability for Angus than Herefords for calf weaning weight traits. Therefore, less consistency of performance of Angus than Hereford cows could be due to their greater sensitivity to environmental fluctuations masking their genetic and permanent environmental effects.

A fourth possible explanation for breed differences in repeatability of calf weaning weight traits is that differences between breeds may exist for some or all of the variance and covariance causal components of the maternal half-sib covariance term, COV(MHS). These components were discussed in detail by Willham (1963) and are presented here in simplified form:

$$COV\ (MHS) = \tfrac{1}{4}V(G_c) + COV\ (G_cG_m) + V\ (G_m) + V\ (D_m) + V\ (E_m)$$

where,

G_c is the direct additive genetic effect.

G_m is the maternal additive genetic effect.

D_m is the maternal dominance genetic effect.

E_m is the maternal environment effect.

If the covariance, COV (G_cG_m), exists between genes for growth and maternal ability in beef cattle, it potentially could be either positive or negative. Estimates of this covariance in the literature have all been computed from either Hereford or Brahman data and have all been negative and average approximately -.55 (Koch and Clark, 1955d; Hill et al., 1966; Deese and Koger, 1967; Hohenboken and Brinks, 1971; Vesely and Robison, 1971). The relative sizes of each of these five components of the COV (MHS) perhaps do vary by breed; and if enough of these components vary in the same direction for one breed, the repeatability of calf weaning weights would probably also vary in the same direction, up or down. This basis or reason for breed differences in the repeatability of calf weaning weights is purely speculative since inadequate research has been published to indicate whether or not there are breed differences for these causal components of the maternal half-sib covariance.

From this discussion of the phenotypic relationship among maternal half-sib weaning weight traits, the following general conclusions seem apparent on the whole at this point based on the results of the present study and those published in the literature:

1. The phenotypic relationship, repeatability, among maternal half-sib weaning weight traits is positive and large enough in both the Angus and Hereford breeds to justify culling of producing beef females after one or at the most two weaning records. However, it must be remembered that temporary environmental effects are not constant from calf to calf of the same cow and appear to account for 50 to 75% of the variation in calf weaning weight traits.

2. There is a distinct tendency for repeatability based on the likeness of adjacent weaning weight records of the same cow to decrease as the adjacency of the records increases or becomes further apart. "It appears that the predictive value of early records for production in later life may not be as great as is often assumed" (Cunningham and Henderson, 1965b).

3. The evidence for a difference in the repeatability of adjusted weaning weights and weaning weight ratios is highly insignificant since estimates for these two traits were very similar or identical in magnitude and sign. Therefore, both traits probably have the same degree of accuracy for predicting future cow productivity and for indicating the effectiveness of selection for increased weaning weights.

4. The literature furnishes inconclusive evidence for a breed difference between Hereford and Angus for the repeatability of calf weaning weight traits; however, the present study supplied highly significant evidence of a breed difference for Oklahoma conditions. The intraclass correlation estimates of the repeatability of calf weaning weights obtained in the present study were 0.27±.02 and 0.50±.04 for Angus and Herefords, respectively. Further studies are needed before breed dif-

ferences can be substantiated for all conditions.

Relationship Between Heifer Growth and Subsequent Cow Productivity

Improvement in beef calf weaning weights is basically dependent upon increased preweaning calf growth potential and improved maternal environment provided by the cow during gestation and nursing. Beef cow maternal effects can be considered as environmental in relation to her calf but are determined by genetic and environmental factors relative to the cow. Selection of beef replacement heifers for increased calf weaning weights is commonly based primarily on their own weaning weight, condition and conformation and maybe secondarily on their corresponding yearling traits. Koch (1972) indicated in a review paper that there is some evidence in the literature that suggests a phenotypic antagonism of genetic and/or environmental origin may exist in beef cattle between preweaning growth rate and maternal ability. A genetic antagonism would decrease effectiveness for weaning weight selection, and an environmental antagonism would cause heifers raised in above average preweaning environments to be below average in producing ability as measured by their calves' weaning weights. The present study evaluated via use of linear correlation and regression coefficients the phenotypic relationship in Angus and Hereford beef cattle between heifer growth, measured by adjusted weaning (CoWW) and yearling (CoYW) weights, and her subsequent cow productivity as measured by the adjusted weaning weights (CaWW) of each of her calves, by the adjusted weaning weight average (CaWW, 2-10) of all her calves and by her "Most Probable Producing Ability" index (MPWW, 2-10) based on all of her calves. Also the ratios of each of these weights were evaluated in like manner.

The estimates obtained in the present study of the linear phenotypic relationship between beef heifer growth traits and her subsequent productivity are given in Tables XXII, XXIII and XXIV. Table XXII contains the correlation estimates pooled across cow birth year-herd sublcasses or contemporary groups. Similarly "pooled" regression estimates for heifer weaning and yearling weight traits on measures of cow productivity are presented in Tables XXIII and XXIV, respectively. These three tables also give the number of pairs of observations involved in the computation of each estimate, the level of significance of each estimate and the level of significance for the difference between the Angus and Hereford correlation estimates of the same relationship. Tables XXIII and XXIV also give the standard error, coefficient of determination and standard error of estimate for each regression estimate. These regression estimates are actually partial regression coefficients obtained from models including "dummy" variables for cow herd and cow birth year; thus, they can be thought of as pooled coefficients with the pooling being across cow herd and cow birth year subclasses or contemporary groups. The regression coefficients for CaWW at each age of cow and CaWW mean on CoWW and CoYW are plotted in Figure 2 by breed. Because graphs of the corresponding ratio values and correlation estimates would have been very similar in shape and magnitude to those shown in Figure 2, plots were not constructed for these estimates.

The correlation and regression coefficient estimates or measures of the heifer growth-subsequent cow productivity relationship obtained in the present study will be discussed jointly because of the general similarity of results from these two estimators. Comparison of correspond-

TABLE XXII

CORRELATION COEFFICIENTS (r) FOR CoWW, CoWWR, CoYW AND CoYWR WITH MEASURES OF COW PRODUCTIVITY BY BREED, POOLED ACROSS COW BIRTH YEAR-HERD SUBCLASSES

Measures of Cow Productivity	Angus No. of Pairs	Angus r	Hereford No. of Pairs	Hereford r	Angus No. of Pairs	Angus r	Hereford No. of Pairs	Hereford r
	CoWW				CoYW			
CaWW (2)	461	0.13**	140	0.19*	359	0.15**	129	0.30**
CaWW (3)	410	0.07	118	0.26**	296	0.12*	102	0.33**
CaWW (4)	326	0.07	93	0.13	221	0.12	82	0.12
CaWW (5)	240	0.14*	66	0.19	162	0.22**	57	0.28*
CaWW (6)	190	0.12	48	0.29*	128	0.16	39	0.17
CaWW (7)	146	0.03	39	0.33**	99	0.23*	28	0.35
CaWW (8)	112	0.06	30	0.17	65	0.01	20	0.19
CaWW (9)	80	0.03	10	0.42	46	0.07	7	0.68
CaWW (10)	65	-.02	4	0.21	34	-.01	4	0.10
CaWW (11)	29	0.10			8	0.60		
CaWW (2-11)	573	0.15**	162	0.20**	427	0.19**	144	0.29**
MPWW (2-11)	573	0.14**	162	0.24**	427	0.20**	144	0.29**
	CoWWR				CoYWR			
CaWWR (2)	461	0.14**	140	0.18*	359	0.15**	129	0.29**
CaWWR (3)	410	0.07	118	0.24**	296	0.12*,a	102	0.36**,b
CaWWR (4)	326	0.07	93	0.12	221	0.12	82	0.13
CaWWR (5)	240	0.14*	66	0.21	162	0.21**	57	0.27*
CaWWR (6)	190	0.11	48	0.29*	128	0.18*	39	0.12
CaWWR (7)	146	0.04	39	0.34*	99	0.24*	28	0.28
CaWWR (8)	112	0.06	30	0.19	65	0.01	20	0.08
CaWWR (9)	80	0.05	10	0.38	46	0.06	7	0.66
CaWWR (10)	65	-.03	4	0.20	34	-.01	4	0.08
CaWWR (11)	29	0.09			8	0.61		
CaWWR (2-11)	573	0.15**	162	0.20**	427	0.20**	144	0.29**
MPWWR (2-11)	573	0.14**	162	0.23**	427	0.20**	144	0.30**

**P<.01.

*P<.05.

a,b Coefficients in same line within cow trait bearing different superscript letters are significantly (P<.01) different.

TABLE XXIII

PARTIAL REGRESSION COEFFICIENTS (b) AND STANDARD ERRORS BY BREED FOR MEASURES OF COW PRODUCTIVITY ON CoWW AND CoWWR[a]

Measures of Cow Productivity	Angus No. of Pairs	Angus b	Angus S.E. (lbs.)	Angus C.D.[b]	Angus SEE[c] (lbs.)	Hereford No. of Pairs	Hereford b	Hereford S.E. (lbs.)	Hereford C.D.[b]	Hereford SEE[c] (lbs.)
					CoWW					
CaWW(2)	461	0.15**	0.05	0.121	36.9	140	0.26*	0.12	0.206	44.6
CaWW(3)	410	0.07	0.05	0.092	38.5	118	0.35**	0.13	0.111	47.3
CaWW(4)	326	0.09	0.06	0.100	39.7	93	0.15	0.13	0.132	44.2
CaWW(5)	240	0.16*	0.07	0.066	40.7	66	0.18	0.13	0.219	37.6
CaWW(6)	190	0.13	0.07	0.162	36.2	48	0.24	0.13	0.291	36.0
CaWW(7)	146	0.04	0.08	0.105	37.6	39	0.33	0.17	0.254	41.6
CaWW(8)	112	0.06	0.12	0.026	49.0	30	0.15	0.18	0.145	41.2
CaWW(9)	80	0.03	0.10	0.008	33.1	10	0.31	0.30	0.363	34.4
CaWW(10)	65	-.02	0.12	0.115	35.0	4	0.22	0.72	0.043	44.8
CaWW(11)	29	0.09	0.18	0.020	33.9					
CaWW(2-11)	573	0.12**	0.04	0.139	30.0	162	0.23*	0.09	0.228	40.2
MPWW(2-11)	573	0.05**	0.02	0.155	14.1	162	0.19**	0.06	0.207	27.3
					CoWWR[d]					
CaWWR(2)	461	0.15**	0.05	0.122	8.7	140	0.25*	0.12	0.199	10.4
CaWWR(3)	410	0.08	0.05	0.082	9.1	118	0.31*	0.12	0.102	11.1
CaWWR(4)	326	0.09	0.06	0.080	9.5	93	0.13	0.12	0.133	10.1
CaWWR(5)	240	0.16*	0.07	0.061	9.5	66	0.20	0.12	0.218	8.6
CaWWR(6)	190	0.13	0.07	0.156	8.4	48	0.24	0.12	0.294	8.3
CaWWR(7)	146	0.05	0.08	0.082	8.6	39	0.32*	0.16	0.266	9.5
CaWWR(8)	112	0.06	0.12	0.023	11.2	30	0.15	0.17	0.144	9.2
CaWWR(9)	80	0.04	0.10	0.014	7.9	10	0.26	0.28	0.328	7.8
CaWWR(10)	65	-.03	0.12	0.115	8.0	4	0.21	0.71	0.041	10.9
CaWWR(11)	29	0.08	0.17	0.020	7.7					
CaWWR(2-11)	573	0.12**	0.04	0.123	7.0	162	0.22*	0.09	0.217	9.3
MPWWR(2-11)	573	0.06*	0.02	0.097	3.3	162	0.18**	0.06	0.202	6.3

**P<.01.

*P<.05.

[a]For simplicity, dummy variables for cow birth year and cow herd are not reported for any of these models.

[b]Coefficients of determination which are the proportionate reduction in the sum of squares of the dependent variable attributable to the combined effect of all independent variables including the dummy variables.

[c]Standard error of estimate.

[d]S.E. and SEE for ratio relationships are in ratio index points and not in pounds.

TABLE XXIV

PARTIAL REGRESSION COEFFICIENTS (b) AND STANDARD ERRORS BY BREED FOR MEASURES OF COW PRODUCTIVITY ON CoYW AND CoYWR[a]

Measures of Cow Productivity	Angus No. of Pairs	Angus b	Angus S.E. (lbs.)	Angus C.D.[b]	Angus SEE[c] (lbs.)	Hereford No. of Pairs	Hereford b	Hereford S.E. (lbs.)	Hereford C.D.[b]	Hereford SEE[c] (lbs.)
					CoYW					
CaWW(2)	359	0.13**	0.04	0.137	36.6	129	0.32*	0.10	0.184	43.0
CaWW(3)	296	0.09	0.05	0.132	39.7	102	0.43**	0.13	0.153	47.4
CaWW(4)	221	0.08	0.06	0.111	39.4	82	0.13	0.13	0.120	45.1
CaWW(5)	162	0.20**	0.08	0.087	40.7	57	0.26*	0.13	0.252	38.9
CaWW(6)	128	0.15*	0.07	0.160	34.3	39	0.12	0.13	0.178	37.6
CaWW(7)	99	0.22*	0.09	0.192	36.4	28	0.36	0.20	0.262	41.5
CaWW(8)	65	-.01	0.13	0.009	40.2	20	0.20	0.27	0.171	45.3
CaWW(9)	46	0.05	0.12	0.016	29.1	7	0.48	0.26	0.502	29.5
CaWW(10)	34	-.01	0.16	0.136	35.8	4	0.07	0.47	0.010	45.6
CaWW(11)	8	0.12	0.07	0.392	3.3					
CaWW(2-11)	427	0.14**	0.04	0.172	30.7	144	0.29**	0.08	0.247	39.5
MPWW(2-11)	427	0.07**	0.02	0.200	13.8	144	0.20**	0.06	0.215	27.0
					CoYWR[d]					
CaWWR(2)	359	0.18**	0.06	0.122	8.6	129	0.43**	0.13	0.166	10.0
CaWWR(3)	296	0.14	0.07	0.116	9.4	102	0.68**	0.18	0.171	10.9
CaWWR(4)	221	0.20*	0.09	0.105	9.2	82	0.19	0.18	0.122	10.3
CaWWR(5)	162	0.36**	0.01	0.099	9.4	57	0.34	0.17	0.243	8.9
CaWWR(6)	128	0.25*	0.11	0.164	8.0	39	0.13	0.18	0.168	8.9
CaWWR(7)	99	0.35**	0.13	0.173	8.3	28	0.41	0.30	0.240	9.6
CaWWR(8)	65	-.04	0.20	0.007	9.4	20	0.12	0.39	0.124	10.1
CaWWR(9)	46	0.07	0.20	0.023	6.8	7	0.61	0.35	0.466	6.7
CaWWR(10)	34	-.01	0.25	0.140	8.1	4	0.08	0.68	0.007	11.1
CaWWR(11)	8	0.13	0.09	0.377	0.7					
CaWWR(2-11)	427	0.20**	0.05	0.147	7.1	144	0.40**	0.12	0.237	9.1
MPWWR(2-11)	427	0.09**	0.02	0.127	3.2	144	0.29**	0.08	0.211	6.2

**P<.01.

*P<.05.

[a]For simplicity, dummy variables for cow birth year and cow herd are not reported for any of these models.

[b]Coefficients of determination which are the proportionate reduction in the sum of squares of the dependent variable attributable to the combined effect of all independent variables including the dummy variables.

[c]Standard error of estimate.

[d]S.E. and SEE for ratio relationships are in ratio index points and not in pounds.

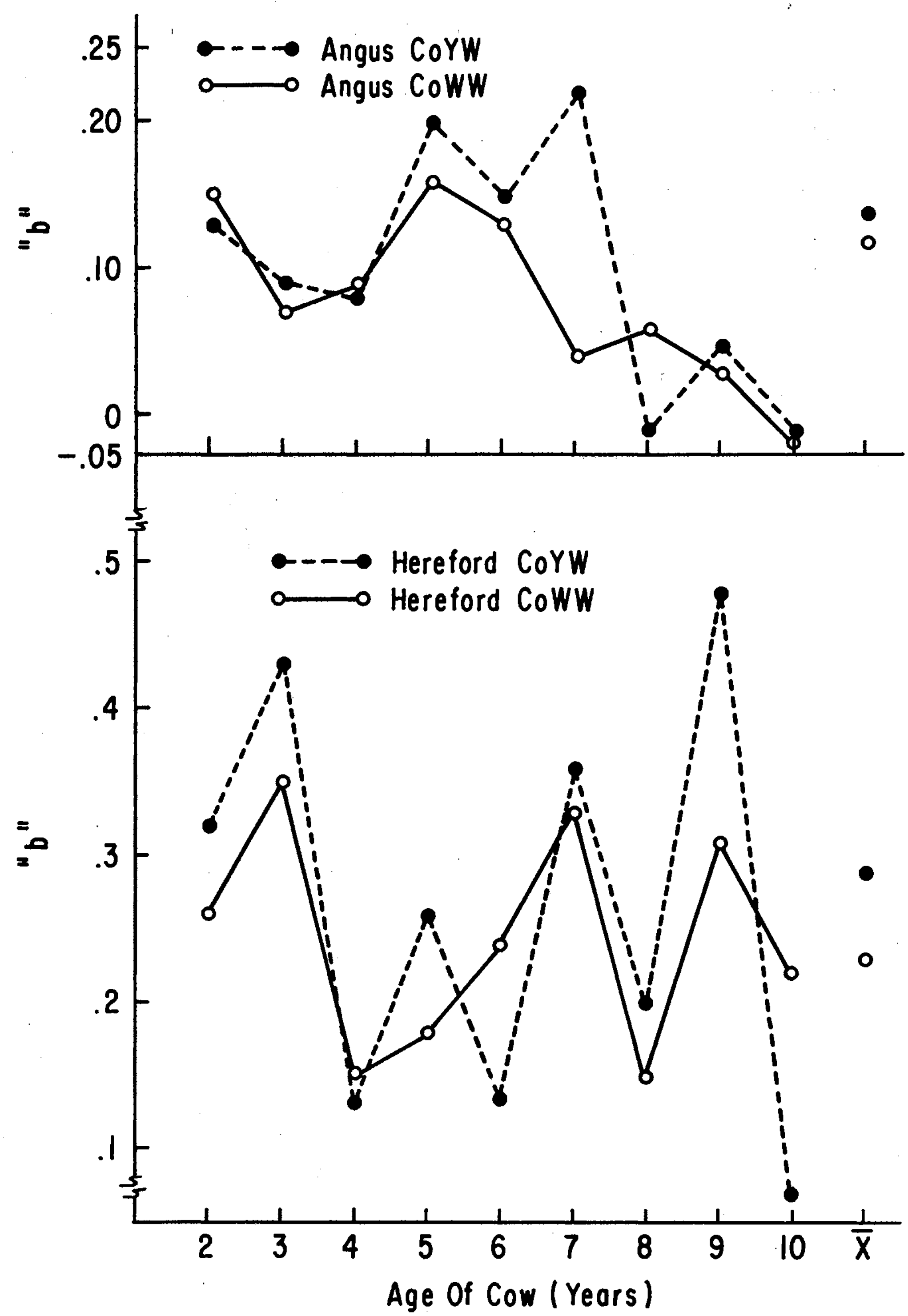

Figure 2. Partial Regression Coefficients (b) for CaWW at Each Age of Cow and CaWW Mean ($\overline{X}$) on CoWW and CoYW by Breed

ing correlation and regression estimates in Tables XXII, XXIII and XXIV indicates that in general they are of similar magnitude and sign; only variation in calculation roundoff errors for estimates near zero could cause the two estimates of the same relationship to be of different sign as was the case for one pair of estimates in these results. The relative sizes of the variances, Appendix Table XXVII, involved in calculating these estimates indicates the source of some of the variation in these two estimators for corresponding values. Since these correlation and regression estimates, Tables XXII, XXIII and XXIV, are in fair agreement on the whole, there apparently is little bias in these correlation estimates from using selected heifers in this study and not the entire heifer crop from which they were selected (Lush, 1940; Kempthorne, 1969).

Referring to Tables XXII, XXIII and XXIV, it is interesting to note that 44 and 50% of the correlation and 44 and 41% of the regression coefficients for Angus and Herefords, respectively, are significantly different from zero at the P<.05 level. For those coefficients involving heifer weaning and yearling weights, respectively, 33 and 54% of the Angus and 48 and 43% of the Hereford estimates are significantly different from zero at the P<.05 level. The nonsignificant estimates tend to be those involving calves from older cows and those involving comparatively low numbers of observation pairs. It is encouraging that most, 94% of the Angus and 100% of the Hereford, of these estimates of the heifer growth-subsequent cow productivity phenotypic relationship are positive and that a large percentage, 44% of the Angus and 45% of the Hereford, are significantly different from zero even though a few are close to zero. This indicates that there is a useful phenotypic relationship between the preyearling growth of a heifer and the growth of her subsequent calves preweaning such that selection based on either of these heifer traits should result in some phenotypic increase in weaning weights over time.

No significant differences were found at the P<.05 level between any of the corresponding actual weight, CoWW and CoYW, and ratio, CoWWR and CoYWR, correlation estimates within breed for the heifer growth-subsequent cow productivity relationship, Table XXII. Likewise, Tables XXIII and XXIV indicate the same comparative relationship between similarly corresponding regression estimates within breed. However, there is a slight tendency for the CoYWR regression estimates to be somewhat larger in magnitude than the corresponding CoYW estimates, Table XXIV, even though CoYWR appears to account for less of the variation in measures of cow productivity than CoYW when corresponding coefficients of determination are compared. The values in Table XXIII also suggest that weight measures of heifer growth on the average account for slightly more of the variation in weight measures of subsequent cow productivity than do corresponding ratio with ratio measures. Nevertheless, the weight and ratio estimates reported in Tables XXII, XXIII and XXIV indicate that both of these methods on the whole measure the heifer growth-subsequent cow productivity relationship with similar degrees of accuracy. This agrees with previously discussed results in this paper for the use of weights and weight ratios when estimating phenotypic relationships. Also as indicated previously, no precendent was found in the literature for comparing these two types of measures.

The differences, especially for Angus, noted in Tables XXIII and XXIV between the magnitudes of the regression coefficients for CaWW(2-11) and MPWW(2-11) on the cow growth traits are probably due to the covariances involving MPWW(2-11) being relatively smaller as the variances in Table XXVII would indicate. The method of calculation of MPWW(2-11) tends to minimize extreme values and thus minimize the respective variances and covariances compared to those of CaWW(2-11).

Due to the methods of analyses, this discussion is handicapped in that statistical tests for significant differences between various comparable partial regression coefficient estimates of the heifer growth-subsequent cow productivity relationship were not calculated. Insufficient information, no covariance term, was obtained on the computer printout to conduct these tests. The tests of significant differences for the corresponding correlation estimates and examination for overlapping confidence intervals (b±S.E.) will be used to indicate differences in comparable regression estimates.

No significant differences within breed within type of measure were found at the $P<.05$ level between the correlation estimates of the heifer growth-subsequent cow productivity relationships involving CoWW or CoWWR and those involving CoYW or CoYWR, Table XXII. However, there is a general trend within both breeds for the correlation estimates involving heifer yearling weight to be larger than those involving heifer weaning weight. This trend appears to be more evident in the Hereford than Angus estimates. Even though the regression estimates were not tested for significance of this difference, examination of these estimates in Tables XXIII and XXIV and in Figure 2 furnishes further evidence of these trends which seem to be most pronounced in the regression estimates.

Few comparisons of the relationship of CoWW and CoYW with measures of cow productivity, as shown in Tables XXII, XXIII and XXIV, were found in the literature. Koch and Clark (1955c) reported correlations of 0.06 and 0.12 for Hereford CoWW and CoYW, respectively, with their calves' weaning weights. Hereford correlations reported by Brinks et al. (1964) between MPWW and CoWW and CoYW, respectively, were phenotypic 0.09 and 0.15; genetic 0.00 and 0.14; environmental 0.13 and 0.15. Brinks et al. (1964) also reported for the same relationships standardized partial regressions of -.08 and 0.01, phenotypic; -.58 and -.04, genetic; and 0.01 and -.02, environmental. Correlations of 0.06 and 0.14 between a Hereford cow's breeding value based on her own weaning and yearling weights, respectively, with that for the weaning weight of her first calf were reported by Inbau (1972). Phenotypic correlations for Herefords of CoWW and CoYW with MPWW were reported by Kress and Burfening (1972) as 0.15 (P<.01) and 0.12 (P<.01), respectively. No reports for the comparison of the relationships of concern here were found in the literature involving Angus cattle. The few available studies from the literature reported here support on the whole the general but statistically insignificant trend in the present study, Tables XXII, XXIII and XXIV and Figure 2, for CoYW to be somewhat more highly related phenotypically than CoWW with measures of cow productivity. Since no reports found in the literature compared Angus and Hereford data for these relationships, the present study alone seems to indicate that the trend for heifer yearling weight to be more highly related to her subsequent cow productivity than does her weaning weight appears to be more pronounced in Hereford than Angus cattle.

The results of this comparison of CoWW and CoYW and those in the literature imply that selection of heifers for superior calf weaning weights might best be accomplished by using their yearling weights. A partial explanation of this might be that yearling weight is more highly heritable than weaning weight and that these two traits are highly correlated (Inbau, 1972). Phenotypic correlations for CoWW with CoYW and for CoWWR with CoYWR calculated from the data used in the present study were 0.73 ($P<.01$) and 0.71 ($P<.01$) for Angus and 0.65 ($P<.01$) and 0.63 ($P<.01$) for Herefords, respectively. Selection for weaning weight using yearling weight as the selection criteria is indirect selection; and according to Pirchner (1969) if selection intensity is equal for both methods, indirect is better than direct selection if the genetic correlation of these two traits times the correlation between yearling weight phenotype and genotype is larger than the correlation between weaning weight phenotype and genotype. Using values from Petty and Cartwright (1966), the ratio of change due to indirect to that due to direct selection for weaning weight (Pirchner, 1969) is approximately 0.80. This indicates that something other than the heritabilities of and genetic relationship of weaning and yearling weights influence the relative sizes of the heifer weaning and yearling weight phenotypic relationships to subsequent cow productivity. A negative environmental and/or genetic correlation between maternal environment and direct genetic effects for weaning weight might adversely influence the phenotypic relationship between a heifer's weaning weight and that of her calves such that this relationship would be smaller in magnitude than that between a heifer's yearling weight and the weaning weights of her calves. This hypothesis will be discussed further later in this paper.

No reports similar to the present one were found in the literature that compared Angus and Herefords for the degree of relationship between a heifer's growth traits and her subsequent cow performance as measured by the weaning weights of her calves. However, Vogt and Marlowe (1966) reported heritabilities of preweaning average daily gain estimated as twice the intrasire regression of offspring on dam for Angus and Herefords as 0.06±.06 and 0.20±.07, respectively. For the present study, only one difference between Angus and Hereford correlations for the same traits, Table XXII, was significant at the $P<.05$ level. However, there appears to be a general tendency for the Hereford correlations to be larger in magnitude than the comparable Angus values. The corresponding regression coefficients reported in Tables XXIII and XXIV and plotted in Figure 2 lend further evidence to the hypothesis of breed differences for these relationships. For almost every breed comparison in Tables XXIII and XXIV, the coefficients of determination for the Angus estimates are smaller than those of the Herefords. The differences in amount of variation in Angus and Hereford samples used in this study, Appendix Table XXVII, explains part of the breed differences in standard errors of estimate. Based on the present study and the one available report from the literature, there appears to be a trend for but inconclusive evidence for a greater relationship between heifer growth traits and the subsequent weaning weights of her calves for Herefords than for Angus.

Very few estimates were found in the literature for any of the Angus heifer growth-subsequent cow productivity phenotypic relationships evaluated in the present study, Tables XXII, XXIII and XXIV. Using weaning weights of Brahman-Angus cows and calves, Dawson et al. (1954) reported regressions of 0.02 and 0.08 for calf weaning weight on that of cow within sire of calf and within sire of cow, respectively. Vogt and Marlowe (1966) reported heritabilities of average daily gain birth to weaning estimated as twice the intrasire regression of offspring on dam for Angus as 0.06±.06. A correlation of 18-month adjusted weight and MPWW of 0.24 (P<.05) was reported by Frey et al. (1972). These few Angus estimates from the literature tend to be slightly lower than those found in the present study involving heifer weaning weight, Tables XXII, XXIII and XXIV; however, the estimate reported by Frey et al. (1972) involving 18-month heifer weight is slightly larger than the comparable estimate for 14-month weight of the present study, Table XXII.

Compared to those for Angus, many more estimates were found in the literature that were comparable to the Hereford heifer growth-subsequent cow productivity phenotypic relationships evaluated in the present study, Tables XXII, XXIII and XXIV. For the heifer and offspring weaning weight phenotypic relationship, these were 0.06 correlation (Koch and Clark, 1955c); 0.42 and -.06 regression coefficients for two nutritional environments (Rollins and Wagnon, 1956); 0.002 and 0.28 (P<.05) regression coefficients for heifer on each calf and on calf average, respectively, (Brown, 1958); 0.04 regression and 0.005 gross correlation coefficients (Sewell et al., 1963); 0.09 correlation and -.08 standardized partial regression of MPWW on heifer weaning weight (Brinks et al., 1964); 0.07 correlation and 0.12 standardized partial regression (Christian et al., 1965); -.16 correlation of heifer weaning weight and MPWW (Ellicott et al., 1970); 0.03 partial regression and 0.14 correlation of MPWW on heifer weaning weight (Mangus and Brinks, 1971); regressions of 0.05 for linecrosses and 0.12 for inbreds (Hohenboken and Brinks, 1971a); correlations of 0.06 first calf and 0.13 progeny average with heifer weaning weight (Inbau, 1972); 0.15 (P <.01) correlation of heifer weaning weight and MPWW (Kress and Burfening, 1972). On the whole, these reports from the literature are lower than comparable Hereford estimates from the present study in Tables XXII and XXIII for the phenotypic relationship between heifer and offspring weaning weights.

Estimates found in the literature for the phenotypic relationship between the yearling weight of a Hereford heifer and the weaning weights of her subsequent calves were: 0.12 correlation (Koch and Clark, 1955c); -.01 correlation of heifer 18-month weight and her calves' weaning weights (Lindholm and Stonaker, 1957); 0.24 ($P<.01$) correlation and 0.18 ($P<.01$) regression of first calf weaning weight on heifer 18-month weight (Marchello et al., 1960); 0.15 and 0.20 correlations and 0.01 and 0.31 standardized partial regressions of MPWW on 12 and 18-month weights, respectively, (Brinks et al., 1964); 0.14 correlation (Inbau, 1972); 0.12 ($P<.01$) correlation of heifer yearling weight and MPWW (Kress and Burfening, 1972). As was the case for the relationships involving Hereford heifer weaning weights, these reports from the literature on the whole are lower than comparable Hereford estimates reported in the present study in Tables XXII and XXIV for the phenotypic relationship between heifer yearling weight and offspring weaning weights.

No discussions of explanations for or reasons why breed differences might exist between Angus and Herefords for the phenotypic relationship between a heifer's preyearling growth rate and the weaning weights of her calves were found in the literature. Also, very few authors discussed possible theories for explaining the differences in magnitude of the relationship between a heifer's weaning and yearling weights and the weaning weights of her calves, respectively. And at the present, the evidence for both these differences, especially that for breed differences, is somewhat limited and inconclusive.

However, there is one type of evidence pertinent to these differences which has been discussed to some length in the literature and mentioned previously in this paper. That is the theory that a negative genetic and/or environmental relationship exists in beef cattle between the preweaning performance of heifers and the weaning weights of their subsequent calves. The possibility of negative environmental and genetic relationships between direct and maternal effects for beef cattle weaning weights was discussed extensively by Koch (1972). Willham (1963) explained the causal components of the dam-offspring covariance, COV(DO), which are presented here in simplified form:

$$\mathrm{COV}\ (\mathrm{DO}) = \tfrac{1}{2}\mathrm{V}\ (G_c) + 5/4\ \mathrm{COV}\ (G_cG_m) + \mathrm{COV}\ (D_cD_m) + \tfrac{1}{2}\mathrm{V}\ (G_m) + \mathrm{COV}\ (E_cE_m)$$

where,

G_c is the direct additive genetic effect.

G_m is the maternal additive genetic effect.

D_c is the direct dominance genetic effect.

D_m is the maternal dominance genetic effect.

E_c is the direct environmental effect.

E_m is the maternal environmental effect.

Several researchers have reported directly or implied negative estimates of the phenotypic relationship between the preweaning environmental factors relating to increased nutritive level and growth performance of heifers and their subsequent producing ability as measured by milk production or calf weaning weights (Swanson and Spann, 1954; Hansson, 1956; Rollins and Wagnon, 1956; Swanson, 1960 and 1967; Brinks *et al.*, 1964; Christian *et al.*, 1965; Koch, 1969; Ellicott *et al.*, 1970; Martin *et al.*, 1970; Mangus and Brinks, 1971; Kress and Burfening, 1972; Holloway and Totusek, 1972. These reports are in partial conflict with the estimates, Tables XXII, XXIII and XXIV, obtained in the present study which on the whole were positive; however, these reports from the literature do indicate that distinct differences in the size of the COV (DO) term might exist between breeds in the cattle population and that some of the three covariance terms in the COV (DO) may be negative depending on the breeds and locations involved. If any of these covariances are negative, the offspring-dam relationship could be lower than anticipated from the direct genetic or maternal effects. Therefore, the same logic as presented previously in this paper for this type of evidence for breed differences in the repeatability of weaning weight may also be applicable here.

Evidence of differences in maternal ability between cows and between breeds was reviewed extensively by Koch (1972) using milk production and reciprocal crossbreeding studies. He concluded that there is evidence of differences of both types for milk production and maternal effects on calf weaning weight. Koch (1972) also suggested, based on a comparison of Hereford paternal and maternal half-sib correlations from the literature, that the genetic and permanent environmental effects of maternal environment and the covariance of individual and maternal effects represents 35 to 45% of the phenotypic variation in calf gain from birth to weaning. Deese and Koger (1967), Hill et al. (1966) and Hohenboken and Brinks (1971b) have reported estimates of the heritability of maternal environment in Herefords for weaning weight which average about 37%. Estimates, using only Hereford cattle, of the genetic correlation between maternal environment and individual genetic effects on weaning weight by Koch and Clark (1955d), Hill _et al._ (1966), Deese and Koger (1964), Hohenboken and Brinks (1971a) and Koch (1972) ranged from -.70 and -.10 and averaged about -.50. If this average estimate is "real", then it tends to decrease the effectiveness of selection for weaning weight using weaning weight as the selection criteria. Perhaps heifer yearling weights are more highly related than are their weaning weights to their offspring weaning weights because the COV $(G_c G_m)$ term might be more positive for the heifer yearling-calf weaning weight relationship due to less maternal influence on yearling than weaning weight.

According to a review by Koch (1972), results of both dairy calf rearing and beef studies strongly suggest that the maternal environment, basically milk production, provided by beef cows for their heifer calves from birth to weaning has a direct inverse influence on subsequent heifer maternal ability; and if this conclusion is valid, most likely the environmental covariance term in the offspring-dam covariance and the direct influence of maternal environment of ancestral dams are both negative. Koch (1972) also implied that this hypothesis along with possibly a negative genetic correlation between individual growth and maternal environment might explain most of the low offspring-dam correlations observed for weaning weights by various researchers.

Koch (1972) did not speculate as to the possibility of breed differences for these correlations; but this possibility does seem plausible based on the results of the present study. As previously discussed, there is evidence that Herefords give less milk than Angus on the average; therefore, it seems reasonable that daughters of Hereford cows are on the whole subjected to a poorer preweaning maternal environment than are daughters of Angus cows. Thus the more liberal preweaning nutritional environment received by the Angus heifers could possibly have hindered their subsequent maternal performance to a greater extent than the relatively poorer preweaning environment of the Herefords hindered their subsequent maternal performance. Under these conditions, the weaning weight covariance of Hereford calves and cows would be expected to be greater than that of Angus calves and cows. Kieffer (1959) reported that a high early plane of nutrition has a greater detrimental effect on earlier maturing Angus than on later maturing Hereford females; however, Holloway and Totusek (1972) found this breed by treatment interaction to be insignificant.

The previously discussed hypothesis that there is less variation in Angus than Hereford calves, Appendix Table XXVII, due to cross nursing of calves on Angus cows would tend to also decrease the relative size of the weaning weight covariance of Angus calves and cows. Before differences between the Angus and Hereford breeds can be established for the cow-calf early growth relationship, further studies of this nature need to be conducted comparing these two breeds and especially to characterize the Angus breed since such is lacking in the literature.

To gain further understanding of the phenotypic relationship of early heifer growth and productivity with the subsequent calf weaning weights, linear "prediction" equations were developed for each breed as reported in Tables XXV and XXVI. For these equations or models, the reported linear partial regression coefficients of the continuous independent variables were obtained from models which included "dummy" variables for cow herd and cow birth year. Thus, the linear partial regression coefficients in Tables XXV and XXVI can be thought of as linear pooled regression coefficients with the pooling being across cow herd

TABLE XXV

PARTIAL REGRESSION COEFFICIENTS (b) AND STANDARD ERRORS BY BREED FOR MODELS INVOLVING MEASURES OF HEIFER GROWTH ON CaWW (2-11) AND MPWW (2-11)

Regression Coefficient	Angus					Hereford				
	No.	b	S.E.[c]	S.D.[d]	SEE[c]	No.	b	S.E.[c]	S.D.[d]	SEE[c]
			CaWW (2-11) Predicted From CoWW (b_1), CoYW (b_2) or Both (b_1,b_2)							
b_1	573	0.12***	0.04	31.9	30.1	162	0.23*	0.09	44.0	40.2
b_1	427	0.14***	0.04	33.0	30.7	144	0.29**	0.08	43.9	39.5
b_1	427	-.02	0.07	33.0	30.7	144	0.01	0.14	43.9	39.7
b_2	427	0.15***	0.05			144	0.29*	0.11		
			MPWW (2-11) Predicted From CoWW (b_1), CoYW (b_2) or Both (b_1,b_2)							
b_1	573	0.06**	0.02	15.2	14.2	162	0.19**	0.06	29.5	27.3
b_1	427	0.07**	0.02	15.1	13.8	144	0.20***	0.06	29.4	27.1
b_1	427	-.03	0.03	15.1	13.8	144	0.03	0.09	29.4	27.1
b_2	427	0.08***	0.02			144	0.19*	0.08		

***$P<.001$.

**$P<.01$.

*$P<.05$.

[a]For simplicity, dummy variables for cow birth year and cow herd are not reported.

[b]The variables are deviations from their respective herd-birth year subclass mean.

[c]Standard error of estimate (SEE) and standard error (S.E.) in pounds.

[d]Standard deviation of the dependent variable.

TABLE XXVI

PARTIAL REGRESSION COEFFICIENTS (b) AND STANDARD ERRORS BY BREED FOR MODELS INVOLVING MEASURES OF HEIFER GROWTH AND PRODUCTIVITY ON SUBSEQUENT CALF WEANING WEIGHT AVERAGE[a,b]

Regression Coefficient	Angus					Hereford				
	No.	b	S.E.[c]	S.D.[d]	SEE[c]	No.	b	S.E.[c]	S.D.[d]	SEE[c]
				CaWW (3-11) = b_1 (CaWW,2)						
b_1	419	0.30***	0.06	33.2	31.2	129	0.54***	0.07	42.9	35.2
				CaWW (3-11) = b_1 (CoWW) + b_2 (CoYW) + b_3 (CaWW,2)						
b_1	250	-.14	0.10	35.9	33.1	99	0.15	0.16	45.3	36.4
b_2	250	0.10	0.08			99	0.07	0.14		
b_3	250	0.28***	0.06			99	0.57***	0.09		
				CaWW (4-11) = b_1 (CaWW, 2-3)						
b_1	402	0.40***	0.07	32.8	29.9	97	0.75***	0.08	41.5	30.2
				CaWW (4-11) = b_1 (CoWW) + b_2 (CoYW) + b_3 (CaWW, 2) + b_4 (CaWW, 3)						
b_1	163	-.08	0.11	33.8	30.1	66	-.11	0.18	44.2	33.0
b_2	163	0.01	0.09			66	0.01	0.15		
b_3	163	0.20**	0.07			66	0.42**	0.14		
b_4	163	0.25**	0.07			66	0.33**	0.12		
				CaWW (5-11) = b_1 (CaWW, 2-4)						
b_1	303	0.53***	0.08	31.6	27.8	73	0.76***	0.12	38.5	31.2
				CaWW (5-11) = b_1 (CoWW) + b_2 (CoYW) + b_3 (CaWW, 2) + b_4 (CaWW, 3) + b_5 (CaWW, 4)						
b_1	105	-.03	0.12	30.6	27.0	38	-.22	0.23	38.9	31.6
b_2	105	-.12	0.11			38	0.20	0.22		
b_3	105	0.27**	0.08			38	0.34	0.20		
b_4	105	0.29**	0.09			38	-.07	0.19		
b_5	105	0.04	0.08			38	0.35	0.17		

***P<.001.

**P<.01.

[a]For simplicity, dummy variables for cow birth year and cow herd are not reported for any of these models.

[b]The variables are deviations from their respective herd-birth year subclass mean.

[c]Standard error of estimate (SEE) and standard error (S.E.) in pounds.

[d]Standard deviation of the dependent variable.

and birth year subclasses or contemporary groups. Because of this manner of obtaining these coefficients, no mean is reported for any of the models; and the regression coefficients in Tables XXV and XXVI then become useful in predicting a mean deviation rather than an actual value as depicted in the following example model were i, j, and k have no specific values or limits:

$$(Y_{ijk} - \bar{Y}_{ij.}) = b_p (X_{ijk} - \bar{X}_{ij.})$$

where,

X_{ijk} is the value of the independent trait of concern for the kth cow in the jth herd born in the ith year.

$\bar{X}_{ij.}$ is the mean value of the independent trait of concern of all cows in the jth herd born in the ith year.

b_p is the pooled regression coefficient for the independent trait of concern.

Y_{ijk} is the value of the dependent trait of concern for the kth cow in the jth herd born in the ith year.

$\bar{Y}_{ij.}$ is the mean value of the dependent trait of concern of all cows in the jth herd born in the ith year.

The independent variables of CoWW, CoYW, CaWW(2), CaWW(3) and CaWW(4) were used in the models shown in Tables XXV and XXVI to "predict" mean deviations for dependent variables which were either the average of the subsequent adjusted calf weaning weights of a cow or her "Most Probable Producing Ability" index (MPWW). Tables XXV and XXVI also give the numbers of observations used, the standard deviations of the dependent variable, standard errors for the partial regression coefficients and standard errors of estimate. Table XXVIII in the Appendix gives the means and variances by breed for each variable for each model given in Tables XXV and XXVI.

The values in Table XXV lend support to the previously discussed trend in these data for the relationship between heifer growth and her subsequent cow productivity as measured by the weaning weights of her calves to be somewhat higher in Herefords than in Angus. No comparable analysis to that reported here in Table XXV was found in the literature. However, comparison of the size of the regression coefficients and the standard errors of estimate for the two breeds given in Table XXV seems to indicate that cow productivity is more accurately predicted by heifer growth in Herefords than in Angus. When comparing the standard errors of estimate one should keep in mind the differences between the breeds for the variances of the variables involved, Appendix Table XXVIII.

The two dependent variables of CaWW(2-11) and MPWW(2-11) in Table XXV are highly correlated in the data used in the present study, 0.94 ($P<.01$) for Angus and 0.98 ($P<.01$) for Herefords. Frey (1971) reported a similar correlation of 0.94 ($P<.01$) for Angus.

The models in Table XXV allow the comparison of the use of CoWW and CoYW alone or in combination for estimating future cow productivity. Little evidence for a difference in the predictive value of these two variables for cow productivity for either breed is actually supplied by the values in Table XXV. However, it does seem apparent that CoYW is slightly more accurate individually than is CoWW; and once CoYW is known, CoWW adds little if anything to the predictive ability of a model for cow productivity. This indicates that selection of beef heifers for future weaning weight producing ability can be done based on their weaning weights with nearly the same accuracy as can be done based on their yearling weights; but if yearling weights are known, weaning weights could probably be ignored in the selection process with little or no loss of information and selection accuracy. The yearling weights referred to here are long or 14-month yearling weights taken in late spring just prior to turning the heifers into the breeding pastures.

The idea, previously discussed in this paper, that the maternal environment, milk production, provided a heifer calf by a cow can be excessive to the point of damaging the future productivity of the heifer does not seem to be highly supported by the results reported in Table XXV, or these harmful effects are largely carried over through the time when the yearling weight was taken. If the adverse effects on a heifer preweaning are maternal in origin and assuming they exist, these effects logically could partially dissipate after the heifer left her dam and during the seven months between weaning and yearling weights; and then the heifer's yearling weight would be assumed to be a more accurate predictor of her future productivity than her weaning weight. However, the advantage of yearling over weaning weight in predicting cow performance is small in this study. This tends to indicate that most adverse effects preweaning on a heifer's future cow productivity from an abundantly milking dam might be permanent at least through her first 14 months, assuming they exist. Some researchers have suggested that excessive preweaning nutrition permanently damages a females udder by infiltrating it with fat (Swanson and Spann, 1954; Sorenson et al., 1959; Cox et al., 1959; Reid et al., 1964).

Koch and Clark (1955d) developed theory for and discussed in detail the consequences of selecting beef heifers based on their weaning or yearly weights. These authors indicated that selection of calves based on their weaning weights results in selection for better genetic values for growth response and some genetic improvement in milking ability; however, since these two traits are negatively correlated genetically, part of the observed gain in each trait is offset by that for the other trait. All of the observed gain in milk production is offset by loss in growth response due to the favorable genes for milking ability being unfavorable for growth response. "However, as long as differences in milking ability are of any importance in increasing weaning gain there will be some selection for better milking ability if selection is based on weaning gain" (Koch and Clark, 1955d). These authors went on to imply that selection of cows which produce heavy calves would place greater emphasis on milking ability than on growth response so far as the genotypes of the cows are concerned. Selecting replacement beef heifers on the basis of yearling gain increases genetic value for growth response from weaning to yearling age and results in a decline in genotypic value for milking ability (Koch and Clark, 1955b). Milking ability apparently has a large negative direct influence but is positively correlated genetically with yearling growth response. These authors summarized by suggesting that (a) cows should be selected on the basis of the weaning weights of their calves if selection for milking ability is to keep pace with that for growth response and (b) extreme emphasis should not be placed on calf gains alone, especially yearling gain, or a loss in genetic value for milking ability may result.

In a similar report, Koger (1963) stated: "Selection for maternal ability from an animal's own record is only one-half an effective as for a non-maternal trait with comparable heritability and standard deviation." He went on to indicate that efficiency of selection for maternal ability is increased 50% by use of first progeny records and 60 to 80% by use of lifetime averages over that of the females own record. "Breeding most of the heifers born for at least one record and culling on production will approximately double selection pressure for maternal ability achieved by current practices" (Koger, 1963).

The idea that cows should be selected on the basis of the weaning weights of their calves is evaluated by the six regression models in Table XXVI which predict future performance of a cow based on all of her own growth and productive information available at a given point in her productive life or on only the weaning weight information of the calves she has had to that point. The first model in each pair uses the average weaning weight of all previous calves of a cow as the independent variable to predict the average weaning weight of all future calves of that cow, and the second model of each pair uses CoWW, CoYW and the CaWWs of each available calf of a cow as independent variables to predict the average weaning weight of all future calves of that cow.

The advantage in increased selection accuracy of having information on progeny before selecting cows appears to be higher for Herefords than Angus based on examination of the standard deviation of the dependent variables and standard errors of estimate for the models in Tables XXV and XXVI. This is probably due to the comparative sizes of dam-offspring and maternal half-sib relationships discussed previously in this paper. And as more calves per cow were involved as "predictors", the value of the cows own early growth information became less useful in both breeds. In a practical sense, these data suggest on the whole that when selecting beef females of either breed after they have had at least one calf one should place major emphasis on the performance of their calves and only secondary emphasis on their own early growth performance.

The equations in Table XXVI reflect both the weaning weight phenotypic relationships of maternal half-sibs and of dam-offspring obtained and discussed earlier in this paper. For both breeds and Herefords especially, the repeatability of calf weaning weight was estimated to be somewhat larger in magnitude on the whole than was the relationship between early heifer growth and the subsequent weaning weights of her calves. This suggests as do the prediction equations that after a cow has had one or at the most two calves her own early growth information adds little to that of her calves in predicting her future performance. The previously discussed Angus behavioral trait of more than one calf simultaneously nursing a cow partially explains the low phenotypic relationship in Angus between early heifer growth and subsequent productivity since because of this trait an Angus heifer's early growth is probably not very reflective of her inherited maternal ability nor is the weaning weights of her calves very reflective of her actual maternal ability.

From this discussion of the phenotypic relationship between the early growth traits of a beef heifer, weaning and yearling weights, and her subsequent cow productivity as measured by the weaning weights of her calves, the following general conclusions seem apparent on the whole at this point based on the results of the present study and those published in the literature:

1. The phenotypic relationship between early beef heifer growth and subsequent cow productivity is on the whole positive and large enough in both the Angus and Hereford breeds to justify some culling of beef females after their own weaning and/or yearling weights are known. However comparing heifer weaning and yearling weights, a slightly lower

relationship in general appears to exist between a beef heifer's weaning weight than her yearling weight and her subsequent cow productivity as measured by the weaning weights of her calves. And when both traits are known, yearling weight alone is apparently as accurate in predicting future cow productivity as is the use of both traits simultaneously. Thus when possible, beef producers should only make preliminary and obvious cullings based on heifer weaning weights and delay final selection of their replacement heifers at least until yearling weights are known so as to increase their selection accuracy. Because the phenotypic relationship of a heifer's weaning and/or yearling weight with her subsequent cow productivity is lower than is desirable and is usually lower than that relationship among maternal half-sibs, a producer who desires maximum possible accuracy and has the opportunity should delay final selection of his replacement heifers until they have had one or two calves.

2. The estimates involving adjusted weights and weight ratios of the phenotypic relationship between the two heifer growth traits and the measures of her subsequent cow productivity were found to be nearly identical in magnitude and sign; and no significant evidence was found for a difference in the ability of these two types of measures to quantify this relationship. Therefore, both types of traits appear to have the same degree of accuracy and usefullness in indicating cow productivity and effectiveness of selection.

3. The literature furnishes evidence, especially for Herefords, of negative environmental and/or genetic relationships in beef cattle between preweaning growth rate and maternal or milking ability resulting in a phenotypic antagonism between these two traits. This indicates that maternal environment for gain to weaning is negatively affected by

the direct effects of the maternal environment for the previous generation. The present study does not provide direct evidence for or against the suggested size and existence of these relationships; but since the phenotypic relationships estimated in the present study contain or are the additive products of these genetic and environmental relationships, some evidence as to the size of these relationships can be postulated. Assuming they are negative as the literature suggests, the phenotypic estimates obtained in the present study and others from the literature indicate that they are not negative enough to cause the phenotypic relationship on the whole to be negative. This indicates that some phenotypic progress can be made when selecting heifers on the basis of their weaning weights for increased weaning weights of their calves but probably not as much progress as would be possible if all of these relationships were positive. Since little can be done to change genetic correlations between traits and since producers can alter the nutritional environments of their preweaning heifer calves, the phenotypic relationship of heifer weaning weight with her subsequent cow productivity might be improved if female calves were raised at some apparently unknown optimum growth rate which would likely vary for different breeds, crossbreds and management systems (Ellicot et al., 1970; Kress and Burfening, 1972; Koch, 1972). Feeding potential replacement heifers for maximum growth rate preweaning may be detrimental to their future cow producing ability.

4. No evidence was found in the literature that there is a difference between the Angus and Hereford breeds for the phenotypic relationship between early heifer growth and subsequent cow productivity; however, the present study supplied some but inconclusive evidence of a

trend for this relationship to be larger in Herefords than in Angus. If this trend is real, then selection of replacement heifers based on their weaning and/or yearling weight would tend to be more successful in Herefords than Angus for increasing the weaning weights of their calves. This breed difference is similar to that discussed earlier in this paper where the Angus maternal half-sibs tended to be less closely related phenotypically than did the Hereford maternal half-sibs; therefore, there seems to be a pattern based on the present study for genetically related animals in the Angus breed to be less closely related phenotypically than similarly related animals in the Hereford breed. Further studies are needed before breed differences for these relationships can be fully substantiated.

Even though the animals used in the present study were assumed to be random samples from the breeds involved, care must be taken in application of these results to situations different from which these came since many of these results have not been fully substantiated by other researchers. The phenotypic relationship estimates obtained in the present study are just descriptions of a given sample of these two breed populations handled under certain environmental conditions; and these estimates are not biological constants.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate and characterize (a) the phenotypic relationship or repeatability of the weaning weights of maternal half-sib beef calves, (b) the phenotypic relationship of a beef heifer's early growth, measured by her weaning and yearling weights, and her subsequent cow productivity as measured by the weaning weights of her calves, (c) the differences between adjusted weights and adjusted weight ratios to the herd-year average for measuring these two phenotypic relationships and (d) the differences between the Angus and Hereford breeds for these two phenotypic relationships.

From the 14 calf crops for the years of 1958 through 1971, weaning weights of 2,664 and 634 calves from 680 and 183 Angus and Hereford cows, respectively, were studied. For these cows, their own weaning and yearling weights were available on 573 and 427 Angus and 162 and 144 Herefords, respectively; these cow weight records were collected as parts of the data from the 1958 through 1969 calf crops. The data used in this study were collected as parts of two beef cattle selection experiments conducted under range conditions in Oklahoma.

The 205-day calf weaning weights were corrected for the effects of age of dam (within breed) and sex by additive and multiplicative factors, respectively, previously determined for these herds and for the effects of years by additive correction factors obtained from least squares analyses for each herd within each breed. The 205-day calf weaning weights were corrected for age of dam and sex and then divided by the respective breed-herd-year mean to determine the calf weaning weight ratios. Sire was assumed to be a random source of variation in all traits studied. The cow 205-day weaning weights were likewise adjusted for age of dam but not for sex or year of birth. The cow 425-day yearling weights were obtained by multiplying each cow's average daily gain from weaning to 14 months by 220 days and then adding in her adjusted weaning weight. Ratios of cow weaning and yearling weights were calculated by use of the appropriate breed-herd-year mean. Cow productivity was measured by the weaning weights and weaning weight ratios of each of her calves, the weaning weight and weaning weight ratio averages of all her calves and her "Most Probable Producing Ability" index (Lush, 1945) for weaning weight and weaning weight ratio.

Repeatability of calf weaning weight was estimated within calf weaning trait within breed by the intraclass correlation coefficient calculated from variance component estimates obtained from nested analyses of variance with herds, cows and calves as the sources of variation and by the simple linear correlation and regression of later on earlier calf performances of the same cow. The simple correlation and regression estimates were obtained by pooling across herds and were computed separately for each pair-wise combination of calf records classified by age of cow which resulted in estimates at each degree of adjacency, years apart, of calf records. Intraclass correlation estimates of repeatability based on data subsets composed of the calf records of all cows and of only those calf records of cows which had two or more calves differed very little in magnitude and were not significantly different within calf trait within breed. No significant differences were found by any of the three types of repeatability estimators between estimates for weaning weight and weaning weight ratio within breed; and these differences were very small. The simple correlation and regression estimates of repeatability showed that as calf weaning weight records become further apart in years or less adjacent the repeatability estimate generally decreases from approximately 0.29 to 0.14 for Angus and 0.53 to 0.12 for Herefords for 1 to 8 degrees of adjacency, respectively. Significant repeatability estimates were obtained generally at the first 6 and 5 degrees of adjacency for Angus and Herefords, respectively; and about 90% of the individual pairwise estimates were positive for each breed. Highly significant differences were obtained between the two breeds for all three types of repeatability estimates of calf weaning weight. The intraclass correlation estimates of repeatability of calf weaning weight of $0.27 \pm .02$ and $0.50 \pm .04$ were typical for the Angus and Hereford breeds, respectively; and the simple correlation and regression estimates for the first 4 to 5 degrees of adjacency agreed fairly closely with these intraclass correlation estimates within breed.

The heifer growth-subsequent cow productivity phenotypic relationship was estimated within breed by linear simple correlation and regression coefficients pooled across cow herd-birth year subclasses or contemporary groups. These two types of estimators gave estimates very similar in magnitude and sign for all heifer growth-subsequent cow productivity relationships measured. No significant differences were found between any of the corresponding weight or weight ratio estimates of this relationship within breed; and usually these differences were very small or nonexistent. Approximately 94 and 100% of the Angus and Hereford estimates, respectively, of the heifer growth-subsequent cow productivity relationship were positive; and 44 and 45% of these Angus and Hereford estimates, respectively, were significant even though a few estimates were close to zero. For those estimates involving heifer weaning and yearling weights, respectively, 33 and 45% of the Angus and 48 and 43% of the Hereford estimates were significant. No significant differences within breed were obtained for corresponding estimates involving heifer weaning and yearling weights; but there was a general trend, especially for Herefords, for those estimates involving heifer yearling weight to be larger than those involving heifer weaning weight. Breed differences for the measures of the heifer growth-subsequent cow productivity relationship were nonsignificant; however, there was a general trend for the Hereford estimates to be larger than the corresponding Angus values. The regression estimates obtained in the present study for the relationship between heifer weaning weight and those of her calf as a 2-year-old, 10-year-old and the average of all her calves were 0.15 ($P<.05$), -.02 and 0.12 ($P<.05$) for Angus and 0.26 ($P<.05$), 0.22 and 0.23 ($P<.05$) for Herefords, respectively; and those obtained between heifer yearling weight and the same measures of cow productivity were 0.13 ($P<.01$), -.01 and 0.14 ($P<.01$) for Angus and 0.32 ($P<.05$), 0.07 amd 0.29 ($P<.01$) for Herefords, respectively. There was a general trend in these data for the size of the Angus estimates of these relationships to decrease as the age of cow when the calf was born increased; however, the Hereford data did not display such a trend.

Various linear multiple regression models for each breed were developed with cow herds and birth years as "dummy" variables, heifer weaning and yearling weights and the weights of her calves as a 2, 3 and 4-

year-old as independent variables and the average weaning weight and "Most Probable Producing Ability" index for her subsequent calves as dependent variables. The values obtained for the partial regression coefficients in these models supported in general the previously summarized results obtained in this study.

The conclusions drawn from the results obtained in this study can be summarized as follows:

1. The phenotypic relationships of maternal half-sib weaning weights and of heifer weaning and yearling weights with the weaning weights of her calves are on the whole positive and large enough in both the Angus and Hereford breeds to justify culling or selection of females based on any combination of these relationships. In general for both breeds, a heifer's yearling weight tends to be more highly related to her subsequent cow productivity than does her weaning weight, and the phenotypic relationship among maternal half-sibs is larger than either heifer weight-calf weaning weight relationship. Therefore, a producer of beef calves sold at weaning who desires maximum selection accuracy and has the opportunity should only make preliminary and obvious selections of replacement heifers based on their weaning weights and should delay final selection at least until yearling weights are known and hopefully until after the heifers have had at least one or perhaps two calves.

2. There is a distinct tendency for the maternal half-sib phenotypic relationship, repeatability, based on the likeness of adjacent calf weaning weight records of the same cow to decrease as the adjacency of the records becomes further apart resulting in little predictive value for calf records over 5 years apart. Also, the predictive value of a

heifer's weaning and yearling weights for the weaning weights of each of her calves decreases for Angus but remains generally consistent for Herefords as the age of the cow when the calf is born increases.

3. There is no difference in the utility of weights and weight ratios to the respective herd-year mean for measuring the relationships among maternal half-sibs or between heifer growth and subsequent cow productivity.

4. The generally positive relationships obtained in the present study indicate that any negative effects of excessive maternal environment that a beef heifer might receive preweaning are not generally large enough to cause the phenotypic relationships of the heifer's weaning weight and the weaning weights of her calves to be negative such that phenotypic progress would not be made when heifers were selected on the basis of their weaning weights for increased weaning weights of their calves.

5. There is a difference between Angus and Herefords for the repeatability of calf weaning weights with representative values from the present study being 0.27 for Angus and 0.47 for Herefords.

6. There is an inconclusive trend for the phenotypic relationships between heifer growth and subsequent cow productivity to be larger in Herefords than in Angus; however, these relationships are not large in either breed with values from the present study for average cow productivity being approximately 0.15 for Angus and 0.25 for Herefords.

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APPENDIXES

TABLE XXVII

MEANS AND VARIANCES BY BREED OF ALL OBSERVATIONS INVOLVED FOR EACH TRAIT OF CONCERN IN THE HEIFER GROWTH-SUBSEQUENT COW PRODUCTIVITY RELATIONSHIP STUDY

Trait	Angus			Hereford		
	No.	Mean (lbs.)	Variance $(lbs.)^2$	No.	Mean (lbs.)	Variance $(lbs.)^2$
CoWW	573	434	1565.13	162	450	1360.67
CoYW	427	602	3653.96	144	622	4057.99
CaWW (2)	461	429	1391.68	140	447	2047.52
CaWW (3)	410	426	1484.23	118	432	2368.87
CaWW (4)	326	423	1588.75	93	423	1960.49
CaWW (5)	240	423	1674.86	66	430	1441.01
CaWW (6)	190	430	1320.23	48	444	1376.03
CaWW (7)	146	432	1405.12	39	443	1880.84
CaWW (8)	112	434	2392.30	30	442	1678.92
CaWW (9)	80	443	1078.69	10	464	1202.97
CaWW (10)	65	435	1202.66	4	474	1398.25
CaWW (11)	29	431	1113.13			
CaWW (2-11)	573	426	1020.77	162	436	1935.55
MPWW (2-11)	573	427	230.36	162	436	867.96
CoWWR	573	102	70.08	162	106	69.48
CoYWR	427	101	50.13	144	104	46.11
CaWWR (2)	461	100	76.94	140	102	110.68
CaWWR (3)	410	99	83.24	118	99	128.46
CaWWR (4)	326	99	90.03	93	97	102.32
CaWWR (5)	240	99	91.31	66	98	75.35
CaWWR (6)	190	100	70.45	48	102	74.11
CaWWR (7)	146	100	73.38	39	101	99.32
CaWWR (8)	112	101	125.93	30	101	83.59
CaWWR (9)	80	103	61.51	10	106	59.28
CaWWR (10)	65	101	62.60	4	109	82.92
CaWWR (11)	29	100	57.18			
CaWWR (2-11)	573	99	11.20	162	100	88.74
MPWWR (2-11)	573	100	50.74	162	100	41.59

TABLE XXVIII

MEANS AND VARIANCES BY BREED OF ALL OBSERVATIONS INVOLVED FOR EACH VARIABLE IN EACH MULTIPLE REGRESSION MODEL FOR THE HEIFER GROWTH-SUBSEQUENT COW PRODUCTIVITY RELATIONSHIP STUDY

Variable	Angus			Hereford		
	No.	Mean (lbs.)	Variance $(lbs.)^2$	No.	Mean (lbs.)	Variance $(lbs.)^2$
		CaWW (2-11), MPWW (2-11) = CoWW				
CoWW	573	434	1565.13	162	450	1360.67
CaWW (2-11)	573	426	1020.77	162	436	1935.55
MPWW (2-11)	573	427	230.36	162	436	867.96
		CaWW (2-11), MPWW (2-11) = CoYW				
CoYW	427	602	3653.96	144	622	4057.99
CaWW (2-11)	427	427	1086.62	144	439	1927.61
MPWW (2-11)	427	427	227.78	144	438	864.70
		CaWW (2-11), MPWW (2-11) = CoWW + CoYW				
CoWW	427	433	1400.97	144	450	1236.91
CoYW	427	602	3653.96	144	622	4057.99
CaWW (2-11)	427	427	1086.62	144	439	1927.61
MPWW (2-11)	427	427	227.78	144	438	864.70
		CaWW (3-11) = CaWW (2)				
CaWW (2)	419	427	1445.06	129	445	2076.04
CaWW (3-11)	419	424	1101.98	129	429	1836.98
		CaWW (3-11) = CoWW + CoYW + CaWW (2)				
CoWW	250	435	1373.72	99	453	1287.08
CoYW	250	608	3709.98	99	631	4366.37
CaWW (2)	250	432	1457.35	99	448	1893.78
CaWW (3-11)	250	424	1289.30	99	431	2053.36
		CaWW (4-11) = CaWW (2-3)				
CaWW (2-3)	402	429	1077.62	97	437	1434.84
CaWW (4-11)	402	423	1073.11	97	428	1720.04
		CaWW (4-11) = CoWW + CoYW + CaWW (2) + CaWW (3)				
CoWW	163	435	1202.05	66	448	1232.93
CoYW	163	613	3361.51	66	631	4774.54
CaWW (2)	163	435	1537.59	66	446	1600.46
CaWW (3)	163	429	1241.08	66	435	2271.27
CaWW (4-11)	163	422	1139.95	66	428	1955.28
		CaWW (5-11) = CaWW (2-4)				
CaWW (2-4)	303	431	756.92	73	440	898.72
CaWW (5-11)	303	426	998.40	73	434	1482.16
		CaWW (5-11) = CoWW + CoYW + CaWW (2) + CaWW (3) + CaWW (4)				
CoWW	105	431	1354.80	38	445	1369.01
CoYW	105	614	3569.88	38	622	5897.28
CaWW (2)	105	439	1309.18	38	449	1433.07
CaWW (3)	105	435	1354.84	38	445	1563.16
CaWW (4)	105	425	1484.87	38	427	1601.01
CaWW (5-11)	105	424	939.35	38	440	1517.04

VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: PHENOTYPIC RELATIONSHIPS AMONG MATERNAL HALF-SIB WEANING WEIGHTS AND BETWEEN GROWTH AND SUBSEQUENT COW PRODUCTIVITY IN BEEF CATTLE

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