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I am submitting herewith a dissertation written by Haley Marshall Jamison entitled "Factors Affecting Intra-cow Variation in Production of Beef Cattle." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

Harold J. Smith
Major Professor

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FACTORS AFFECTING INTRA-COW VARIATION
IN PRODUCTION OF BEEF CATTLE

A Dissertation
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Haley Marshall Jamison
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TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF LITERATURE	3
Effect of Fixed Sources of Variation on Average Daily	
Gain and Type Score at Weaning	3
Sex of calf	3
Year of birth	5
Age of dam	5
Season of birth	8
Weaning age	9
Repeatability Estimates	10
Heritability Estimates	10
III. EXPERIMENTAL PROCEDURE	18
Source of Data	18
Classification of Data and Method of Analysis	20
IV. RESULTS AND DISCUSSION	32
Sex Effects	32
Year Effects	39
Age of Dam	40
Reproductive Status	41
Season of Birth	42
Sex of Previous Calf	43
Weaning Age	43

CHAPTER	PAGE
Calving Interval	44
Average Daily Gain of Previous Calf	44
Dry Days of the Dam	44
Estimation of Repeatability	45
Estimates of Heritability	49
The appropriateness of the analyses	53
V. SUMMARY	55
LITERATURE CITED	59
APPENDIX	66

LIST OF TABLES

TABLE		PAGE
I.	A Summary of Estimated Effects of Age of Dam on Weaning Weight and Average Daily Gain	6
II.	Summary of Repeatability Estimates of Weaning Weight and Type Score as a Character of the Dam	11
III.	Heritability Estimates of Weaning Weight in Beef Cattle . .	13
IV.	Heritability Estimates of Type Score at Weaning in Beef Cattle	17
V.	Reproductive Status and Other Classes of Effects Associated with that Classification	27
VI.	Statistical and Biological Expectation of Mean Squares for Repeatability	30
VII.	Statistical and Biological Expectation of Mean Squares for Half-sibs	31
VIII.	Number of Calves, Least-squares Estimates and Standard Errors for Type Score and Average Daily Gain at Weaning (Analysis I)	33
IX.	Number of Calves, Least-squares Estimates and Standard Errors for Type Score and Average Daily Gain at Weaning (Analysis II)	35
X.	Analysis of Variance of Performance Traits Studied (Analysis I)	37

TABLE

PAGE

XI.	Analysis of Variance of Performance Traits Studied (Analysis II)	38
XII.	Analysis of Variance and Variance Components of Performance Traits Studied for Repeatability Estimates (Analysis I). .	46
XIII.	Analysis of Variance and Variance Components of Performance Traits Studied for Repeatability Estimates (Analysis II)	47
XIV.	Analysis of Variance and Variance Components of Performance Traits Studied for Heritability Estimates (Analysis I) . .	50
XV.	Analysis of Variance and Variance Components of Performance Traits Studied for Heritability Estimates (Analysis II)	51
XVI.	Distribution of Calves by Station, Year and Breed Along with Means and Standard Deviations of Average Daily Gain at Weaning	67
XVII.	Distribution of Calves by Station, Year and Breed Along with Means and Standard Deviations of Type Score at Weaning	69

CHAPTER I

INTRODUCTION

Selection is the most effective tool that a beef cattle breeder has at his disposal for the permanent genetic improvement of his herd. Improving the herd by selection is a slow, continuous process that requires much assiduity on the part of the breeder if satisfactory results are to be attained. The generation interval is much longer in cattle than in most other farm animals and multiple births, which increase the rate of progress from selection, are relatively unusual in cattle. Only a part of the superiority of the selected parents over the unselected herd average for a particular trait is transmitted to the offspring. Differences among animals due to environmental effects are not transmitted from generation to generation. Therefore, only a portion of the selection differential of the parents is realized in the offspring.

It is necessary that accurate and independent estimates of environmental factors of variation be obtained in order to precisely estimate heritability and, thereby, bring about expected genetic progress in improvement of economically important traits. At the time of this study, much of the research reported in the available literature concerned with the effect of various environmental factors on average daily gain from birth to weaning and on the type score at weaning of beef calves involved either uncontrolled or unmeasured factors. One approach to removing more of such variation would be to study repeated observations on the same

cow, since this method removes genetic differences between cows.

The objectives of this study were:

1. To obtain estimates on an intra-cow basis of the influence of sex of calf, year of birth, age of dam, reproductive status of the dam, season of birth, sex of the previous calf, weaning age, calving interval of the dam, average daily gain of the previous calf and the number of dry days of the dam on average daily gain from birth to weaning and on the type score of her calf at weaning.
2. To develop appropriate correction factors to adjust average daily gain and type score for environmental and developmental influences.
3. To calculate the heritability and repeatability estimates for average daily gain and type score.

CHAPTER II

REVIEW OF LITERATURE

A large number of studies have been carried out to estimate the effect of environmental and genetic factors on average daily gain from birth to weaning and on the type score at weaning in beef cattle. These investigations have been conducted under varying environmental and managerial conditions and with various breeds of cattle. Therefore, variations in the magnitude and intensity of these influences on average daily gain and type score are not surprising.

I. EFFECT OF FIXED SOURCES OF VARIATION ON AVERAGE DAILY GAIN AND TYPE SCORE AT WEANING

Sex of calf. Most investigators have found sex to significantly influence average daily gain from birth to weaning. Bull calves usually had a faster growth rate than steers and steers had faster growth rates than heifers. In a study involving nearly 2,000 calves, Lehmann et al. (1961) reported that bull calves had an average daily gain of 0.18 pound and steer calves 0.01 pound per day greater than heifers. Brinks et al. (1961) found that heifer calves gained 5 per cent less than steers and 6 per cent less than bulls from birth to weaning. Taylor et al. (1960) reported that male calves had an average daily gain of 1.77 pounds while the female calves gained 1.53 pounds. According to Barker (1964) the average daily gain of bull calves was 0.13 pound per day greater than

steers and that of steers was 0.12 pound per day greater than heifers. Gregory, Blunn and Baker (1950) found no significant sex differences in gains from birth to weaning, although the mean difference was generally in favor of the males. In a study by Sawyer, Bogart and Olouta (1948), heifer calves were heavier at weaning than steer calves but the differences lacked statistical significance.

Loganathan (1962), in a study involving 471 purebred Hereford calves and 196 grade Hereford calves, found that male purebred calves had an average daily gain of 1.83 pounds and females 1.66 pounds. Corresponding figures for the grade calves produced in the same herd were 1.89 and 1.76 pounds, respectively.

Marlowe and Gaines (1958), in a study involving 6,173 calves, found that heifer calves made an average daily gain of 0.12 pound less than steer calves. In another study, Marlowe (1962) reported that bull calves grew about 14 per cent faster than heifer calves when no creep-feeding was practiced. Steer calves were intermediate between bulls and heifers, growing at a 7 per cent faster rate than heifer calves but 7 per cent slower than bull calves.

A limited number of studies on the influence of sex on type score at weaning are reported in the literature. Koch and Clark (1955a), in a study involving 5,962 Hereford calves, concluded that sex influences on type score at weaning were negligible. Sex differences observed in weaning type score by Marlowe and Gaines (1958), Taylor et al. (1960), Lehmann et al. (1961) and Marlowe (1962) were 0.5, 0.3, 0.9 and 0.5 units, respectively, in favor of heifer calves. Loganathan (1962) reported

that, among purebred calves, males scored 12.0 and females 11.8. The difference, however, was not significant. The corresponding figures for grade calves produced in the same herd were 12.1 and 12.0, respectively.

Year of birth. The year calves were born was found by most workers to have a significant effect on average daily gain to weaning and type score (Gregory, Blunn and Baker, 1950; Koch, 1951; Burgess, Landblom and Stonaker, 1954; Brown, 1961; and Loganathan, 1963). Botkin and Whatley (1953) theorized that much of year influence on weaning traits in beef cattle is caused by variation in nutrient intake which in turn are affected to a considerable extent by the amount of rainfall during the grazing season.

Age of dam. Many estimates for the effects of age of dam on weaning weight and average daily gain from birth to weaning have been made by research workers. These investigations have been carried out with various breeds and under varying environmental conditions. A summary of these estimates is shown in Table I. Most workers have found that age of dam effects have a highly significant influence on weaning weight and average daily gain.

In general, the estimates of these effects indicate that cows wean their heaviest calves when 6 to 8 years of age. Most reports indicate that calves out of 2-, 3- and 4-year-old cows have average daily gains at weaning of about 0.23, 0.14 and 0.08 pound, respectively, less than calves out of 5-year-old dams.

TABLE I
A SUMMARY OF ESTIMATED EFFECTS OF AGE OF DAM ON WEANING WEIGHT AND AVERAGE DAILY GAIN

Author	Ages of Dams											
	2	3	4	5	6	7	8	9	10	11	12	
	Weaning Weight (lb.)											
Knapp et al. (1942) Botkin and Whatley (1953) Burgess, Landblom and Stonaker (1954)	---	-29.0	-16.0	-5.0	0.0	0.0	-5.0	-10.0	-39.0	-51.0	---	
Rollins and Guilbert (1954) Koch and Clark (1955a) McCormick, Southwell and Warwick (1956)	---	-18.0	-11.0	-5.0	0.0	0.0	-7.0	-13.0	-21.0	-31.0	---	
Clark et al. (1958) Pahnish et al. (1958) Minyard and Dinkel (1960)	---	-44.0	-19.0	-7.0	-1.0	0.0	3.0	-3.0	1.0	---	---	

TABLE I (continued)

Author	Ages of Dams											
	2	3	4	5	6	7	8	9	10	11	12	
Magee et al. (1961)	-50.0	-15.0	-10.0	---	---	---	---	---	---	---	---	
Hamann, Wearden and Smith (1963)	-64.0	-22.0	-1.0	4.0	23.0	27.0	32.0	---	---	---	---	
Average Daily Gain (lb.)												
Marlowe and Gaines (1958) ^a	-.30	-.17	-.11	-.08	-.04	0.00	-.06	-.01	-.07	---	---	
Lehmann et al. (1961) ^a	-.13	0.00	0.10	0.14	0.20	0.13	0.14	0.10	0.10	0.06	-.03	
Loganathan (1962) ^a	-.23	-.14	-.08	0.00	0.01	0.06	0.05	0.03	0.09	0.02	---	
Barker (1964) ^a	-.18	-.09	-.02	0.02	0.03	0.03	0.06	0.03	0.05	0.04	0.03	

^aEstimates based on average daily gain from birth to weaning.

Type score at weaning is a subjective measure; however, it is a trait of economic importance and hence is usually included in a selection index. Loganathan (1962) concluded that calves of 2- and 3-year-old dams graded 1.0 and 0.8 grade point lower, respectively, than those from the older cows. He observed a positive linear association in calf grade as age of dam increased from 2 to 7 years. This work is in general agreement with that reported by Marlowe and Gaines (1958), Lehmann et al. (1961) and Barker (1964).

Season of birth. The season in which a calf is born affects the environmental surroundings of the calf and its dam during the suckling period. The factors that change with season include, among others, feed supply, temperature and parasites.

Marlowe and Gaines (1958) found that season of year had a significant influence on the growth of non-creep-fed calves, but was of no practical importance in the growth of creep-fed calves. This work indicated that non-creep-fed calves born from June through December grew 0.1 pound a day slower than calves born from February through May.

Barker (1964) observed average daily gains of calves born in January, February and March to be significantly higher ($P < .01$) than those born in other months. Loganathan (1962) reported that calves born in April and May made faster gains than those born in January, February and March.

Barker (1964) studied the effect of month of birth on type score at weaning. His data indicated that calves born in August, September,

October and November had a lower type score at weaning than calves born during other months. Marlowe and Gaines (1958) made a study of the effects of season of birth on type score at weaning. The study involved 4,166 non-creep and 2,007 creep-fed calves. In the non-creep group, calves born in July and August graded 0.9 point less than calves born in December through March 15. Calves born from March 16 through December 15 in the creep-fed group graded 0.2 point higher than calves born in December through March. These findings are in general agreement with those reported by Loganathan (1962). Lehmann et al. (1961), in their work at Front Royal, Virginia, on 1,987 purebred and grade calves, concluded that calves born in April, May and June had a lower type score at weaning than those born in January through March.

Weaning age. Variation in weaning age is another of the factors concealing the outward expression of genotype and one that should be taken into account when selection is based on weaning traits.

Work by Koch (1951) at the U. S. Range Livestock Experiment Station, Miles City, Montana, involving the weaning weights of 745 Hereford calves, indicated that weaning weight increased 2.27 pounds with each additional day of age. Burgess, Landblom and Stonaker (1954) reported an estimate of 1.67 pounds increase with each additional day of age. In a study involving 159 calves, Rollins and Guilbert (1954) found the regression of weight on age for the period from birth to 4 months to be 1.90 pounds per day and from 120 to 240 days to be 1.81 pounds per day.

There is little information reported in the literature concerning the influence of age of calf on type score. Marlowe and Gaines (1958), in their work at the Virginia station, found a small but significant effect of age of calf on type score. In their study, age of calf was broken down into 30-day periods from 90 to 300 days and the workers concluded that, although some of the differences were statistically significant, they were of no practical consequence. Koch and Clark (1955a) found a small positive relationship between age at weaning and weaning score.

II. REPEATABILITY ESTIMATES

Numerous studies have been made to determine the degree of association between repeated records of the same individual. Repeatability estimates, a summary of which is shown in Table II, have been made under varying environmental conditions and range from 0.19 to 0.52 for weaning weight and 0.22 to 0.45 for type score at weaning. The extremes in both directions can possibly be attributed to sampling error but may be due to varying degrees of environmental control.

III. HERITABILITY ESTIMATES

Since 1946, when Knapp and Nordskog reported the first estimates of heritability, literature on genetic parameters of beef cattle has been increasing at a rapid rate. Warwick's (1958) paper entitled "Fifty Years of Progress in Breeding Beef Cattle" was the first attempt to summarize heritabilities in beef cattle. Other summaries have been

TABLE II

SUMMARY OF REPEATABILITY ESTIMATES OF WEANING WEIGHT AND TYPE
SCORE AS A CHARACTER OF THE DAM

Author	Weaning Weight			Weaning Type Grade		
	Number		r	Number		r
	Cows	Calves		Cows	Calves	
Koger and Knox (1947, 1952)	436	1698	0.49	436	----	0.25
Koch (1951)	180	745	0.52	----	----	----
Botkin and Whatley (1953)	151	603	0.43	----	----	----
Dinkel (1955)	----	----	----	236	1650	0.33
Koch and Clark (1955a)	1166	4849	0.31	673	1976	0.22
Rollins and Wagnon (1956)	----	577	0.42	----	----	----
Hoover <u>et al.</u> (1956)	301	1151	0.32	----	----	----
McCormick, Southwell and Warwick (1956)	95	461	0.42	----	----	----
Stonaker (1958)	----	----	0.49	----	----	----
Taylor <u>et al.</u> (1960)	103	458	0.30 ^a	103	458	0.27
Minyard and Dinkel (1960)	364	1038	0.42 ^{a, b}	364	1038	0.23 ^b
	----	2351	0.42	----	----	----
Loganathan (1962)	252	471	0.42 ^a	252	471	0.23
Luecker, Brown and Gifford (1963)	80	260	0.19	80	260	0.45
Berg (1961)	----	665	0.31 ^a	----	----	----

^aActual daily gain from birth to weaning.

^bHereford, Angus and Shorthorn pooled.

reported recently (Temple, 1964; Petty, 1964). A summary of heritability estimates for weaning weight from these studies is shown in Table III. A similar summary for type score at weaning is found in Table IV.

A high percentage of these estimates have been made by the paternal half-sib method. Weighted averages of the paternal half-sib estimates for weaning weight indicate that weaning weight is about 30 per cent heritable. The wide range of estimates ($-.16$ to 1.28) possibly can be the result of sampling error.

The heritability estimates for type score at weaning range from 0.21 reported by Meyerhoeffer, Carter and Priode (1963) to 0.79 reported by Christian (1963). This summary indicates an overall average of heritability for type score to be about 32 per cent.

TABLE III

HERITABILITY ESTIMATES OF WEANING WEIGHT IN BEEF CATTLE

Author	Sex ^a	Breed ^b	Number of		Sires	Methods of Estimation				Regression of	
						Paternal Half-sib	Maternal Half-sib	Dam	Sire		
Knapp and Nordskog (1946)	S	H	177	23		0.12	----	----	----	----	----
Gregory et al. (1950)	M	H	270	6		0.26	----	----	----	----	----
Gregory et al. (1950)	M	H	69	4		0.52	----	----	----	----	----
Knapp and Clark (1950)	S	H	613	83		0.28	----	----	----	----	----
Kidwell (1954)	M	H	155	9		1.00	----	----	----	----	----
Dawson et al. (1954)	M	B	74 prs.	---		----	----	0.15	----	----	----
Shelby, Clark and Woodward (1955)	S	H	635	88		0.23	----	----	----	----	----
Koch and Clark (1955b)	M	H	4553	137		0.24	----	----	----	----	----
Koch and Clark (1955c)	M	H	4234	1231		----	----	0.11	----	----	----
Koch and Clark (1955c)	M	H	1105	85		----	----	----	0.25	----	----
Koch and Clark (1955d)	M	H	----	----		----	----	----	----	0.19 ^c	----
Hitchcock et al. (1955)	M	H	----	----		----	----	0.17	----	0.39	----
Rollins and Wagnon (1956)	M	H	321	----		0.09	----	----	----	----	----
Rollins and Wagnon (1956)	M	H	256	----		0.54	----	----	----	----	----
Lasley and Pugh (1956)	M	H	323	8		0.33	----	----	----	----	----
McCormick, Southwell and Warwick (1956)	B	H	167	16		0.25	----	----	----	----	----
McCormick, Southwell and Warwick (1956)	H	H	187	18		0.33	----	----	----	----	----

TABLE III (continued)

Author	Sex ^a	Breed ^b	Number of		Methods of Estimation	Regression of			
			Calves	Sires	Paternal Half-sib	Maternal Half-sib	Dam	Sire	Other
McCormick, Southwell and Warwick (1956)	S	H	173	17	0.26	----	----	----	----
McCormick, Southwell and Warwick (1956)	H	H	152	21	-.06	----	----	----	----
Shelby et al. (1957)	B	H	542	116	0.43	----	----	----	----
Lindholm and Stonaker (1957)	S	H	118	19	0.81	----	----	----	----
Brown (1958)	M	H	----	----	0.26	0.52	----	----	----
Brown (1958)	M	A	----	----	0.11	1.10	----	----	----
Carter and Kincaid (1959)	S	H,A,S	212	24	0.08	----	----	----	----
Carter and Kincaid (1959)	H	H,A,S	212	24	0.69	----	----	----	----
Wagnon and Rollins (1959)	H	H	140	12	0.42	----	----	----	----
Wagnon and Rollins (1959)	H	H	165	12	0.57	----	----	----	----
Kieffer, Chambers and Stephens (1959)	M		295 prs.	----	----	----	0.32	----	----
Kieffer, Chambers and Stephens (1959)	M		495	68	0.39	----	----	----	----
Minyard and Dinkel (1960)	M	H,A	2351	120	0.32	----	----	----	----
Swiger (1961)	M	H	748	23	0.25	----	----	----	----
Lehmann et al. (1961)	M	H,A,S	1987	115	0.21	----	----	----	----
Pahnish et al. (1961)	B	H	329	11	0.28	----	----	----	----
Pahnish et al. (1961)	H	H	329	11	0.57	----	----	----	----
Magee et al. (1961)		H,A	----	----	0.30	----	----	----	----

TABLE III (continued)

Author	Sex ^a	Breed ^b	Number of Calves	Number of Sires	Methods of Estimation				
					Paternal Half-sib	Maternal Half-sib	Regression of Offspring on Dam	Regression of Offspring on Sire	Other
Lasley, Day and Comfort (1961)	M	H	414	8	----	----	----	----	0.11 ^c
Blackwell et al. (1962)	S	H	499	36	0.08	----	----	----	----
Blackwell et al. (1962)	H	H	420	42	0.31	----	----	----	----
Gregory and Stewart (1962)	M	M	425	29	----	----	----	0.54	----
Swiger et al. (1962)	M	H	2092	48	-0.16	----	----	----	----
Swiger et al. (1962)	M	A, S	647	----	-0.02	----	----	----	----
Hamann, Wearden and Smith (1963)	M	M	334	25	0.48	----	----	----	0.49 ^d
Hamann, Wearden and Smith (1963)	M	A	332	----	----	----	----	----	----
Christian (1963)	M	H	828	54	0.19	----	----	----	----
Christian (1963)	M	A	253	18	0.58	----	----	----	----
Gacula and Brown (1963)	B	H, A, S	179	19	----	----	----	0.11	----
Swiger et al. (1963)	M	H, A, S	1671	240	0.28	----	----	----	----
Shelby et al. (1963)	S	H	616	87	0.24	----	----	----	----
Pahnish et al. (1963)	B	H	----	17	0.05	----	----	----	----
Pahnish et al. (1963)	H	H	----	17	0.23	----	----	----	----
Mahmud and Cobb (1963)	M	H	1306	28	0.24	----	----	----	----
Wilson (1963)	S	H	473	56	0.38	----	----	----	----
Sewell et al. (1963)	M	M	942	12	0.18	----	----	----	----
			308 prs.	----	----	----	0.08	----	----
Brinks et al. (1963)	H	H	3548	----	0.43	----	----	----	----

TABLE III (continued)

Author	Sex ^a	Breed ^b	Number of		Methods of Estimation			
					Paternal Half-sib	Maternal Half-sib	Regression of Offspring on	
			Calves	Sires			Dam	Sire Other
Loganathan (1962)	M	H	471	34	0.39	----	----	----
Loganathan (1962)	M	H	196	26	1.28	----	----	----

^aSex code: S = steers, B = bulls, H = heifers and M = mixed.

^bBreed code: H = Hereford, A = Angus, S = Shorthorn and B = Brangus.

^cPath coefficient.

^dFull sib correlations (maternal influence removed).

TABLE IV

HERITABILITY ESTIMATES OF TYPE SCORE AT WEANING IN BEEF CATTLE

Author	Sex ^a	Number of Calves	Number of Sires	Method of Estimation			
				Paternal Half-sib	Maternal Half-sib	Regression of Offspring on	
						Dam	Sire Other
Koger and Knox (1952)	M	715	15	0.30	----	0.50	----
Shelby et al. (1957)	B	542	116	0.60	----	----	----
Carter and Kincaid (1959)	S	190	----	0.41	----	0.07	0.16
Carter and Kincaid (1959)	H	200	----	0.51	----	----	----
Meyerhoeffer, Carter and Priode (1963)	M	1682	----	0.21	----	----	----
Lehmann et al. (1961)	M	1987	----	0.33	----	----	----
Blackwell et al. (1962)	S	499	----	0.38	----	----	----
Blackwell et al. (1962)	H	420	----	0.26	----	----	----
Shelby et al. (1963)	S	616	87	0.23	----	----	----
Brinks et al. (1964)	H	3584	----	0.28	----	----	----
Mahmud and Cobb (1963)	M	1306	----	0.36	----	----	----
Meyerhoeffer, Carter and Priode (1963)	H	908	----	0.20	----	----	----
Meyerhoeffer, Carter and Priode (1963)	B	----	----	0.29	----	----	----
Christian (1963)	M	253	18	0.34	----	----	----
Christian (1963)	M	828	54	0.79	----	----	----

^aSex code: S = steer, B = bulls, H = heifers and M = mixed.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE OF DATA

The data used in this study were collected from the Angus and Hereford herds of the Main Station of the Tennessee Agricultural Experiment Station at Knoxville and six branch stations over a 7-year period (1957-63). Three branch stations (Alcoa, Greeneville and Oak Ridge) are located in East Tennessee, two (Columbia and Springfield) are located in Middle Tennessee and one (Ames Plantation) is located in West Tennessee.

Included were the records of 1,272 Angus and 2,231 Hereford calves which were the progeny of 1,962 purebred and grade Hereford and Angus cows. They were sired by purebred bulls. Only records of cows that had weaned at least one calf were used. The distribution of calves by station, year and breed along with the means and standard deviations of average daily gain from birth to weaning and type score at weaning are shown in Tables XVI and XVII of the Appendix, pages 67 and 69, respectively.

Most of the purebred herds used in this study were established in the early 1950's. Grade herds existed prior to that time. These grade cattle were gradually phased out of the herds during the early fifties and replaced by purebreds by the mid-fifties at several stations. During this period, dwarfism occurred in some herds. To eliminate dwarfism, a

program was started whereby all animals producing dwarfs and their relatives were gradually eliminated and replaced by animals that by pedigree analysis were believed to be free of dwarfism. In most herds this rebuilding program extended into the early 1960's.

Although the number of bulls from an outside source has decreased in recent years, none of the herds was closed to outside breeding. Bulls used in a particular herd were either produced in that herd, produced at a different station, or purchased from an outside source. In cases where a bull was used in the herd in which he was produced, related matings were minimized. Most service bulls received a post-weaning performance test at the Main Station in Knoxville.

The cow herds were managed similarly at all stations. They had access to pasture the year round and were fed hay and protein supplement as required during the winter months. The grazing season in Tennessee was usually from mid-March to mid-December. Early culling of cows was based primarily on factors other than their performance records, including dwarfism, non-pregnancy, sickness, injury and temperament.

For breeding purposes the cows were stratified on the basis of age and past performance record and then randomly assigned to sire groups. All cows were pasture bred in single sire herds. The cow herds at Middle Tennessee Experiment Station, Columbia; Tobacco Experiment Station, Greeneville; UT-AEC Agricultural Research Laboratory, Oak Ridge; and Highland Rim Experiment Station, Springfield, were bred to calve in the spring only. The cows in herds at the Main Station, Knoxville; Alcoa Farms, Alcoa, and Ames Plantation, Grand Junction, calved primarily in

the spring; however, some fall calving was practiced. Those calves born between December 1 and May 31 were considered spring calves, and those born between June 1 and November 30 were classified as fall calves.

The cows at a station were usually re-randomized into larger herds at the end of the breeding season and rotated among the various pastures. None of the cow herds were intentionally subjected to any type of treatment that would produce differences in the performance of their calves to weaning. During the period included in this study, these herds were used primarily to evaluate performance tested bulls.

II. CLASSIFICATION OF DATA AND METHOD OF ANALYSIS

Data recorded at birth included birth date, birth weight, sex, sire and dam of calf. Weaning data included weaning weight, weaning type score and weaning condition score. Weaning data on spring calves were usually recorded in September; however, it was usually October when the calves were actually weaned. This allowed time for an index based on rate of gain and type score to be computed in order that selection of bull calves to be performance tested could be made at weaning.

All calves were graded by two or more staff members of the Animal Husbandry-Veterinary Science Department of The University of Tennessee. Each grader worked independently. Usually the same graders scored calves at all locations. Federal-State standards for grades of feeder cattle were used as a basis of the grading except that each grade was sub-divided into thirds. Each calf was classified as being in the upper, middle or lower third of the grade. The grades were coded by giving a

numerical value of 10 to middle Good and adding or subtracting one (1) for each one-third of a grade above or below.

The coded scores of each grader were averaged to the nearest 0.1 grade point (1/30th of a grade). The numerical codes were: fancy plus (17), fancy (16), fancy minus (15), choice plus (14), choice (13), choice minus (12), good plus (11), good (10), good minus (9), medium plus (8), medium (7) and medium minus (6).

Age of dam at calving was arbitrarily divided into discrete classes on the one-half year; therefore, the age of dam 3 would be an animal whose age was between 2-1/2 and 3-1/2 years. All animals 10-1/2 years old or over were classified as age of dam 11.

Each record was classified as to the reproductive status of the dam at time of calving. These classes were: (1) calving first at 2 years of age, (2) calving first at 3, (3) calving first at 4, (4) known to have calved previously but no record, (5) calving but not raising calf to weaning, (6) calving and raising calf to weaning and (7) not calving the previous year.

Due to a linear dependency between year and age of dam, a unique estimate of these effects on an intra-cow basis was not possible. This dependency is brought about because the calving pattern for each cow fixes both the year she appeared as a dam and the ages at which she was a dam.

Reports of other workers (Barker, 1964; Blackwell, Knox and Hurst, 1958; Brinks et al., 1961; Brown, 1961; Clark et al., 1958; Koch et al., 1959; Lehman et al., 1961; Loganathan, 1963; McCormick, Southwell and

Warwick, 1956; Marlowe, 1962; Marlowe and Gaines, 1958; and Taylor et al., 1960) have indicated that calves out of 2-, 3- and 4-year-old cows had average daily gains at weaning of about 0.23, 0.14 and 0.08 pound, respectively, less than calves out of 5-year-old dams. Most of the reported work suggested that the effects of age of dam beyond 5-year-old cows were not significant; therefore, the average daily gain of all calves out of 2-, 3- and 4-year-old dams was adjusted using the above factors.

The work reported in the available literature indicates that age of dam has little, if any, effect on type score at weaning; therefore, no adjustment was made for this trait. The analysis, utilizing the data adjusted for age of dam in an attempt to eliminate the confounding of this factor with year, will be referred to throughout this study as Analysis I.

In a second method of eliminating the confounding of year and age of dam, average daily gain and type score of each calf at weaning were expressed as deviations from his respective year, station and breed mean. These deviations were used in a second analysis in lieu of the observed performance values. This analysis will henceforth be referred to as Analysis II.

Sire effects were so distributed that considerations of such effects in these analyses were deemed unnecessary. A study of the unadjusted means indicated there were no significant interactions between the various classes of effects.

The method of least squares for analysis of data with disproportionate subclass numbers (Harvey, 1960) was used to estimate the

effect of these factors on the performance traits.

In Analysis I, constants were fitted for sex of calf, year, reproductive status, season of birth, sex of previous calf and continuous variables for weaning age, calving interval, average daily gain at weaning of the previous calf and the number of days between weaning one calf and the birth of the next. For Analysis II the constants fitted were identical to Analysis I except that age of dam was substituted for year. The assumed model considered appropriate for Analysis I was:

$$Y_{ijklmno} = \alpha + c_i + s_j + y_k + p_l + se_m + sp_n + b_1 W_{ijklmno} + b_2 I_{ijklmno} + b_3 ADG_{ijklmno} + b_4 D_{ijklmno} + e_{ijklmno}.$$

$$i = 1, 2 \dots 3503.$$

$$m = 1, 2.$$

$$j = 1, 2.$$

$$n = 1, 2.$$

$$k = 1, 2 \dots 7.$$

$$o = 1, 2 \dots 3503.$$

$$l = 1, 2 \dots 7.$$

Where:

$Y_{ijklmno}$ = the observed value of the o^{th} calf, in the n^{th} sex of previous calf, born in the m^{th} season, out of a dam in the l^{th} reproductive group, in the k^{th} year of the j^{th} sex of the i^{th} dam.

α = the theoretical population mean with equal subclass frequencies when average daily gain and type score at weaning are equal to the value of zero (absorbed). The population mean with equal frequencies, when average daily gain and type score at weaning both are equal to

the average, is:

$$\mu = \alpha + b_1\bar{W} + b_2\bar{I} + b_3\overline{ADG} + b_4\bar{D}.$$

c_i = effect of the i^{th} dam (absorbed).

s_j = effect of the j^{th} sex.

y_k = effect of the k^{th} year.

p_l = effect of the l^{th} reproductive group.

se_m = effect of the m^{th} season of birth.

sp_n = effect of the n^{th} sex of previous calf.

b_1 = partial regression of Y on weaning age.

$W_{ijklmno}$ = weaning age for a given calf.

b_2 = partial regression of Y on calving interval.

$I_{ijklmno}$ = days from the birth of one calf until the birth of the next calf for a given dam.

b_3 = partial regression of Y on ADG of previous calf.

$ADG_{ijklmno}$ = average daily gain of previous calf.

b_4 = partial regression of Y on dry days.

$D_{ijklmno}$ = number of days between weaning of one calf and the birth of the next.

$e_{ijklmno}$ = random errors.

The mathematical model underlying Analysis II was:

$$Y_{ijklmno} = \alpha + c_i + s_j + d_k + se_m + sp_n + b_1W_{ijklmno} + b_2I_{ijklmno} + b_3ADG_{ijklmno} + b_4D_{ijklmno} + e_{ijklmno}.$$

Where:

$Y_{ijklmno}$ = the observed value of the o^{th} calf, in the n^{th} sex of previous calf, born in the m^{th} season, out of a dam in

the l^{th} reproductive group, in the k^{th} age of dam group of the j^{th} sex and of the i^{th} dam.

α = the theoretical population mean with equal subclass frequencies when average daily gain and type score at weaning are equal to the value of zero (absorbed).

The population mean with equal frequencies when average daily gain and type score at weaning both are equal to the average, is:

$$\mu = \alpha + b_1 \bar{W} + b_2 \bar{I} + b_3 \overline{ADG} + b_4 \bar{D}.$$

c_i = effect of the i^{th} dam (absorbed).

s_j = effect of the j^{th} sex.

d_k = effect of the k^{th} age of dam.

p_l = effect of the l^{th} reproductive group.

se_m = effect of the m^{th} season of birth.

sp_n = effect of the n^{th} sex of previous calf.

b_1 = partial regression of Y on weaning age.

$W_{ijklmno}$ = weaning age for a given calf.

b_2 = partial regression of Y on calving interval.

$I_{ijklmno}$ = days from the birth of one calf until the birth of the next for a given dam.

b_3 = partial regression of Y on ADG of previous calf.

$ADG_{ijklmno}$ = average daily gain of previous calf.

b_4 = partial regression of Y on dry days.

$D_{ijklmno}$ = number of days between weaning of one calf and the birth of the next.

$e_{ijklmno}$ = random errors.

In both analyses the data were analyzed on an intra-cow basis.

This approach removed the breed and station differences.

In Analysis II, expressing average daily gain and type score at weaning as deviations from the breed, station and year mean automatically removed the year effect.

In obtaining least squares estimates in both analyses for the effects of reproductive status and the other variables associated with that trait, all classifications could not make a contribution to the overall analysis since cows not calving the previous year or cows calving but failing to raise their calves would have a varying amount of missing data. The discrete classes of reproductive status and the missing data associated with each are shown in Table V.

In order to obtain unbiased least squares estimates for all the variables described in the mathematical models, three sets of sum of squares and crossproducts were calculated for each analysis.

In computing the first set of sum of squares and crossproducts, all of the observations were used and all of the variables in the model were included. However, the sums of squares and crossproducts for variables with missing data, i.e., those associated with reproductive status 1, 2, 3, 4 and 7, were meaningless. In order to maintain symmetry in the sums of squares and crossproduct matrix, a model containing all variables but using only the observations associated with reproductive status 5 and 6 were computed. The third group of calculations,

TABLE V
REPRODUCTIVE STATUS AND OTHER CLASSES OF EFFECTS
ASSOCIATED WITH THAT CLASSIFICATION

Reproductive Status ^a	Calving Interval ^b	ADG of Previous Calf ^b	Sex of Previous Calf ^a	Dry Days of Dam ^b
1	--- ^c	---	---	---
2	---	---	---	---
3	---	---	---	---
4	---	---	---	---
5	xxx ^d	---	xxx	---
6	xxx	xxx	xxx	xxx
7	---	---	---	---

^aDiscrete variable.

^bContinuous variables.

^cMissing observations.

^dObservations present.

again using all variables, was restricted to those observations associated with reproductive status 6.

All rows and columns in the first group of computations associated with sex of previous calf and calving interval were discarded and replaced with the comparable rows and columns from the second pass since only cows in the second pass had comparable information for these traits. The sums of squares involving average daily gain of the previous calf and the number of dry days of the dam from the third pass replaced their comparable rows and columns in the first matrix, since again, these were the only records contributing complete information of these traits.

The composite matrix of sums of squares and crossproducts was used to obtain least squares estimates of the effects as described by the mathematical models.

These data were adjusted using the estimates obtained from the least squares analyses for the fixed environmental effects. Each record also was corrected to a standard weaning age of 210 days, a 365-day calving interval, an average daily gain of previous calf to 1.75 pounds and the number of dry days of the dam to 155 days.

Intra-class correlations among calves out of the same cow were used to determine repeatability of average gain from birth to weaning and type score at weaning. Repeatability was expressed as: $\frac{V_{BC}}{V_{BC} + V_W}$.

Where V_{BC} was the variance between cows within stations and V_W was the within cow variance. The method of Hazel and Terrill (1945) was used to obtain the approximate standard errors of the repeatability estimates. Tests of significance among individual least squares

estimates were made with Kramer's (1957) modification of Duncan's range test. Descriptions of symbols and analyses of variance procedure are shown in Table VI.

Estimates of heritability were calculated for average daily gain from birth of weaning and type score at weaning from paternal half-sib comparisons according to the method of Hazel and Terrill (1945). This method assumes the dams to be unrelated and the sires to be a random sample from an unselected population. The limits are based on the assumption that the ratio of two mean squares is distributed as F. Description of symbols and the analyses of variance procedure are shown in Table VII.

TABLE VI
STATISTICAL AND BIOLOGICAL EXPECTATION OF MEAN SQUARES
FOR REPEATABILITY

Source	d. f. ^a	Expectation of Mean Square
A (Herd-Breed)	$h(b-1)$	$V_{WC} + k_2 V_{BC/A} + k_3 V_{HB}$
B (Between Cows/A)	$hb(d-1)$	$V_{WC} + k_1 V_{BC/A}$
C (Within Cows/A)	$hbd(c-1)$	$V_{WC/B}$

Biological Components of Variance ^b
(Random mating)

$$V_{WC/B} = V_{TE}$$

$$V_{BC/A} = V_G + V_{PE}$$

$$V_G = V_A + V_D + V_I$$

$$V_T = V_G + V_{PE}$$

$$^a h = K_1; b = K_2; d = K_3.$$

^b V_D = Variation due to dominance deviations.

V_G = Total genetic variance.

V_I = Variation due to epistatic deviation.

V_T = Total variance.

V_{BC} = Between cow variance.

V_{PE} = Permanent environmental variance between cows.

V_{TE} = Temporary environmental variance.

V_{WC} = Within cow variance.

TABLE VII
STATISTICAL AND BIOLOGICAL EXPECTATION OF MEAN SQUARES
FOR HALF-SIBS

Source	d. f.	Expectation of Mean Square
A (Herd-Breed)	$h(b-1)$	$V_{BC} + k_3 V_{BD/B} + k_5 V_{BS/A} + k_6 V_{HB}$
B (Between Sires/A)	$hb(s-1)$	$V_{BC} + k_2 V_{BD/B} + k_4 V_{BS/A}$
C (Between Dam/B)	$hbs(d-1)$	$V_{BC} + k_1 V_{BD/B}$
D (Between Calves/C)	$hbsd(c-1)$	$V_{BC/C}$

Biological Components of Variance^a

$$V_{BC/C} = 0.5V_A + V_E$$

$$V_{BD/B} = 0.25V_A + V_{MG} + V_{ME} + 0.25V_D + 0.1875^b V_I$$

$$V_{BS/A} = 0.25V_A + 0.0625^b V_I$$

$$V_G = V_A + V_D + V_I$$

$$V_M = V_{MG} + V_{ME}$$

$$V_T = V_G + V_E + V_M$$

^a V_A = Additive genetic variance.

V_E = Environmental variance within full sibs.

V_{MG} = Variance due to genetic variation in direct maternal effects.

V_{ME} = Permanent environmental difference between groups of full sibs.

V_D = Variation due to dominance deviation effects.

V_G = Total genetic variance.

V_I = Variation due to epistatic deviation.

V_T = Total variance.

^b These constants are only approximations.

CHAPTER IV

RESULTS AND DISCUSSION

The least squares estimates of the environmental effects for average daily gain from birth to weaning and type score at weaning, for Analyses I and II are presented in Tables VIII and IX, respectively. The analyses of variance for average daily gain from birth to weaning and type score at weaning for Analyses I and II are presented in Tables X and XI, respectively.

I. SEX EFFECTS

Sex of calf in both analyses had a significant effect ($P < .01$) on average daily gain from birth to weaning but had little influence on type score.

In both analyses, male calves had an average daily gain from birth to weaning of 0.16 pound greater than females. These estimates are well within the range of the findings of other workers: 0.12 pound by Marlowe and Gaines (1958), 0.11 pound by Koch et al. (1959), 0.24 pound by Taylor et al. (1960), 0.12 pound by Marlowe (1962) and 0.17 pound by Loganathan (1962). Other estimates of sex of calf effects reported are either larger and smaller than those calculated from these data. These discrepancies between estimates of the sex effects may be attributable to the range in weaning age (180-240 days) in various studies.

TABLE VIII
 NUMBER OF CALVES, LEAST-SQUARES ESTIMATES AND STANDARD ERRORS
 FOR TYPE SCORE AND AVERAGE DAILY GAIN AT WEANING
 (ANALYSIS I)

Variable	Number of Calves	Average Daily Gain	Type
Sex			
Males	1714	0.08±.00 ^a	0.04±.03 ^a
Females	1789	-.08±.00 ^b	-.04±.03 ^a
Year			
1957	370	0.09±.02 ^d	0.03±.01 ^{b,c,d}
1958	458	0.08±.01 ^d	0.05±.02 ^{c,d}
1959	419	-.02±.01 ^{b,c}	-.22±.02 ^a
1960	475	-.06±.01 ^a	-.12±.06 ^{a,b}
1961	555	0.00±.01 ^c	0.19±.05 ^d
1962	636	-.04±.01 ^b	-.08±.06 ^{a,b,c}
1963	590	-.04±.01 ^{a,b}	0.16±.04 ^d
Reproductive status ^f			
1	460	-.02±.01 ^b	-.51±.08 ^a
2	392	-.01±.01 ^{b,c}	-.17±.09 ^b
3	164	-.01±.00 ^{b,c,d}	0.26±.07 ^{d,e}
4	435	-.06±.02 ^a	0.40±.10 ^e
5	204	0.05±.02 ^e	0.06±.01 ^{c,d}
6	1687	0.01±.10 ^e	0.10±.05 ^d
7	161	0.03±.01 ^e	-.14±.09 ^{b,c}

TABLE VIII (continued)

Variable	Number of Calves	Average Daily Gain	Type
Season of birth			
Spring	3241	$-.05 \pm .02^a$	$-.14 \pm .12^a$
Fall	262	$0.05 \pm .01^b$	$0.14 \pm .07^a$
Sex of previous calf			
Male	942	$0.02 \pm .01^a$	$0.09 \pm .04^a$
Female	949	$-.02 \pm .01^b$	$-.09 \pm .04^b$
Regression of Y on:			
Weaning age		$-.0005 \pm .0000^{**}$	$0.0061 \pm .0010^{**}$
Calving interval		$0.0001 \pm .0000$	$-.0011 \pm .0010$
ADG of previous calf		$-.2267 \pm .0014^{**}$	$-.7138 \pm .2050^{**}$
Number of dry days		$0.0006 \pm .0000^{**}$	$-.0012 \pm .0000$

a,b,c,d,e Those estimates followed by the same letter within a column within subclass do not differ significantly at the 0.05 level of probability.

- ^f1 - Calving first at 2 years of age. 5 - Calving but not raising it to weaning.
 2 - Calving first at 3 years of age. 6 - Calving and raising it to weaning.
 3 - Calving first at 4 years of age. 7 - Not calving the previous year.
 4 - Known to have calves previously but no record.

^{**}P<.01.

TABLE IX
NUMBER OF CALVES, LEAST-SQUARES ESTIMATES AND STANDARD ERRORS
FOR TYPE SCORE AND AVERAGE DAILY GAIN AT WEANING
(ANALYSIS II)

Variable	Number of Calves	Average Daily Gain	Type
Sex			
Males	1714	0.08±.00 ^a	0.04±.02 ^a
Females	1789	-.08±.00 ^b	-.04±.02 ^a
Age of dam			
2	502	-.08±.02 ^a	-.13±.14 ^{b,c}
3	642	-.03±.01 ^b	0.15±.09 ^{e,f}
4	564	-.01±.00 ^c	0.23±.08 ^f
5	437	0.01±.01 ^{c,d}	0.23±.07 ^f
6	361	0.02±.01 ^{c,d}	0.18±.07 ^f
7	320	0.04±.01 ^d	0.12±.07 ^{e,f}
8	299	0.03±.01 ^d	0.04±.08 ^{c,e}
9	153	0.01±.01 ^{c,d}	-.23±.10 ^b
10	111	0.02±.01 ^{c,d}	-.14±.12 ^b
11	185	-.01±.00 ^{b,c}	-.46±.08 ^a
Reproductive status ^g			
1	460	-.02±.01 ^a	-.04±.02 ^a
2	392	-.03±.01 ^a	-.17±.08 ^a
3	164	-.02±.00 ^a	0.13±.14 ^a
4	435	0.01±.01 ^{b,c}	0.19±.10 ^a
5	204	0.04±.02 ^c	0.04±.10 ^a
6	1687	0.02±.01 ^{b,c}	0.05±.05 ^a
7	161	-.00±.00 ^{a,b}	-.22±.08 ^a

TABLE IX (continued)

Variable	Number of Calves	Average Daily Gain	Type
Season of birth			
Spring	3241	$-.02 \pm .00^a$	$-.06 \pm .11^a$
Fall	262	$0.02 \pm .01^a$	$0.06 \pm .02^a$
Sex of previous calf			
Male	942	$0.02 \pm .00^a$	$0.03 \pm .01^a$
Female	949	$-.02 \pm .01^b$	$-.03 \pm .01^b$
Regression of Y on:			
Weaning age		$-.0003 \pm .0000$	$0.0064 \pm .0000^{**}$
Calving interval		$0.0002 \pm .0000$	$-.0008 \pm .0000$
ADG of previous calf		$-.2080 \pm .0312^{**}$	$-.5963 \pm .2085^{**}$
Number of dry days		$-.0000 \pm .0000$	$-.0012 \pm .0000$

a,b,c,d,e,f Those estimates followed by the same letter within a column within subclass do not differ significantly at the 0.05 level of probability.

- | | |
|--|---|
| 1 - Calving first at 2 years of age. | 5 - Calving but not raising to weaning. |
| 2 - Calving first at 3 years of age. | 6 - Calving and raising it to weaning. |
| 3 - Calving first at 4 years of age. | 7 - Not calving the previous year. |
| 4 - Known to have calved previously but no record. | |

$^{**}P < .01$.

TABLE X
ANALYSIS OF VARIANCE OF PERFORMANCE TRAITS STUDIED
(ANALYSIS I)

Source	Degrees of Freedom	Mean Squares	
		Avg. Daily Gain	Type Score
Sex	1	10.647**	2.621
Year	6	0.481**	7.292**
Reproductive performance	6	0.110**	13.741**
Season of birth	1	0.210**	1.763
Sex of previous calf	1	0.258**	6.847*
Regression of Y on:			
Weaning age	1	0.212**	37.873**
Calving interval	1	0.002	1.147
ADG of previous calf	1	1.407**	13.943**
Number of dry days	1	0.241**	1.035
Error	1942	0.029	1.154

*P<.05.

**P<.01.

TABLE XI
ANALYSIS OF VARIANCE OF PERFORMANCE TRAITS STUDIED
(ANALYSIS II)

Source	Degrees of Freedom	Mean Squares	
		Avg. Daily Gain	Type Score
Sex	1	12.157**	2.650
Age of dam	9	0.072**	3.481**
Reproductive status	6	0.056*	1.429
Season of birth	1	0.040	0.326
Sex of previous calf	1	1.296**	4.529*
Regression of Y on:			
Weaning age	1	0.071	43.755**
Calving interval	1	0.038	0.660
ADG of previous calf	1	1.079**	8.870**
Number of dry days	1	0.000	1.087
Error	1939	0.025	1.088

* $P < .05$.

** $P < .01$.

Separate estimates for bulls and steers were not calculated because it was not possible to separate the physiological effects of castration from the effects of selection. In most of the work reported in the literature, workers did not separate data from steers and bulls in calculating the effect of sex on the performance traits studied. However, Brinks et al. (1961) reported that heifer calves gained 5 per cent less than steers and 6 per cent less than bulls from birth to weaning.

The value of 0.04 for the sex of calf effect on type score at weaning in both analyses was non-significant. A limited number of studies on the effect of sex of calf on type score at weaning indicate that this effect is negligible. Barker (1964) reported that bull calves typed slightly higher than steers, and steers higher than heifers. Marlowe and Gaines (1958), at the Virginia Station, reported that bull calves graded 0.6 unit higher than heifers and steers 0.5 unit higher than heifers.

The fact that male calves graded higher than females may possibly reflect the earlier sexual development of bulls or a preference of the grader for male calves.

II. YEAR EFFECTS

The year effects estimated in Analysis I for both average daily gain and type score were highly significant. However, no definite trend could be observed from the estimate. Calves born in 1957 and 1958 had higher average daily gains from birth to weaning than did calves born in other years.

The fixed environmental effects of years per se have little if any meaning. They are perhaps a measure of the variation in grazing conditions which in turn are affected to a considerable extent by the amount of rainfall during the grazing season.

III. AGE OF DAM

Age of dam constants were obtained only from Analysis II of this study. Age of dam was considered a discrete variable in Analysis II since it was thought (Swiger, 1961) that neither a straight line nor a quadratic curve would describe biologically the aging process.

The effects of age of dam on growth rate from birth to weaning were highly significant. These data show that a cow's individual performance was lowest at 2, 3, 4 and 11 years of age. These estimates were in general agreement with those of Marlowe and Gaines (1958), Rollins and Guilbert (1954), Blackwell, Knox and Hurt (1958) and Koger and Knox (1954), who found that cows within a 6-10 year age range weaned calves with higher average daily gains. In addition, their estimates compare favorably with the adjustments of 0.23, 0.14 and 0.08 used to adjust for age of dam in Analysis I.

The estimates of age of dam effects on type score indicate that the maximum type score of a cow's calves were obtained when she was within the age range of 3-7 years, and decreased as she became older. The largest improvement in a cow's performance as measured by type score of her calves occurred between the ages of 2 and 3 years. The findings are in agreement with the work reported by Marlowe and Gaines (1958),

Lehmann et al. (1961) and Barker (1964) when age of dam differences were determined on a between-cow basis. Loganathan (1962) concluded that calves of 2- and 3-year-old dams graded 1.0 and 0.8 grade point lower, respectively, than those from older cows. He observed a linear association between calf grade and age of dam as age of dam increased from 2 to 7 years.

Lush and Shrode (1950) pointed out that a comparison of averages of all records made at each age of dam would tend to bias the estimates upward from the true age effects because some cows were culled at each age; thus, each succeeding age would contain a larger share of the high-producing cows than the preceding age. Estimates based on an intra-cow analysis would eliminate this bias entirely if the production pattern of high-producing and low-producing cows were similar.

IV. REPRODUCTIVE STATUS

Reproductive status in these analyses was considered a discrete variable. An attempt was made to describe the sample with reference to all possible reproductive conditions (page 21).

In Analyses I and II, significant effects of reproductive status of the dam on growth rate of her calf from birth to weaning were found. Cows that calved the previous season, but did not raise their calves, weaned calves with the highest average daily gain. In Analysis I, there were no significant differences among reproductive classes 5, 6 and 7. From a knowledge of the biology involved, it would appear reasonable to postulate that a cow not calving the previous year would have more

reserve body stores and thereby provide the present calf with a larger supply of milk. This would have an effect on growth rate from birth to weaning.

Cows calving first as either a 2-, 3- or 4-year-old, weaned calves that had higher type scores than calves out of cows in any other reproductive group. Calves out of cows that did not calve the previous season or did calve, but did not wean their previous calves, had no apparent advantage in type score over calves of cows that weaned a calf the previous season.

V. SEASON OF BIRTH

Season of birth had no significant effect on type score in either analysis or on growth rate to weaning in Analysis II. In Analysis I fall-born calves had significantly ($P < .05$) higher average daily gains than did spring-born calves.

These findings are not in agreement with those of Barker (1964) and Marlowe and Gaines (1958), who reported that calves born in January, February and March had a significantly higher average daily gain from birth to weaning than calves born in other months.

In this study, estimates of the effects of season of birth were obtained with all other sources of variation included in the mathematical model held constant. Also, the number of fall calves represented only about 7 per cent of the total number of calves in the analyses.

VI. SEX OF PREVIOUS CALF

In both analyses, the sex of the previous calf significantly affected type score ($P < .05$) and growth rate to weaning ($P < .01$) of the present calf. Cows that had female calves the previous season weaned calves that had lower type scores and lower average daily gains than cows that had male calves the previous year. The biological implications involved in these results are not clear.

VII. WEANING AGE

Differences in weaning ages are perhaps one of the many factors concealing the outward expression of genotype and one that should be taken into account when selection is based on performance at weaning. Previous work has indicated that growth from birth to about 150 days of age is essentially linear after which average daily gain tends to decrease.

The effect of weaning age on type score at weaning was highly significant in Analyses I and II; whereas, the effect of weaning age on average daily gain from birth to weaning was significant ($P < .01$) only in Analysis I. These data indicated that older calves graded higher and gained less. However, the differences were so small as to be of no practical importance within the range of weaning age represented in these data. Barker (1964) pointed out that calves 120 through 179 days of age at weaning had a higher average daily gain and a lower type score than those from 180 to 300 days of age at weaning.

VIII. CALVING INTERVAL

In both analyses a non-significant positive relationship existed when growth rate of the calf was regressed on calving interval of the dam and a negative relationship existed for type score. From these data one could conclude, within the range of calving interval represented in this study, that the time interval between the birth of the previous calf and the birth of the present calf was a relatively unimportant source of variation for the production traits studied.

IX. AVERAGE DAILY GAIN OF PREVIOUS CALF

The effect of average daily gain from birth to weaning of the previous calf was highly significant in both analyses. Rapid growth of the previous calf within the range represented in these data, depressed both type score at weaning and growth rate from birth to weaning of the present calf. If growth rate of the calf is influenced by the amount of milk given by the dam, and her reserve is low as a result of rapid growth of the previous calf, one could conclude that these findings possibly are biologically feasible.

X. DRY DAYS OF THE DAM

A non-significant relationship existed when type score was regressed on the number of dry days of the dam in both analyses. However, in Analysis I when average daily gain was regressed on the number of dry days of the dam, within the limits of these data, a significant

($P < .01$) relationship existed. These data indicated that, on the average, as the number of dry days increased growth rate from birth to weaning would increase 0.0006 units per day. These findings are in agreement with the work of Swanson (1965) at the University of Tennessee which indicated that dairy animals not having a 60-day dry period would not produce as much milk the following lactation.

XI. ESTIMATION OF REPEATABILITY

The repeatability estimates for average daily gain were $0.45 \pm .02$ and $0.39 \pm .02$ for Analyses I and II, respectively. The analysis of variance and variance components of the performance traits studies are shown in Tables XII and XIII for Analyses I and II, respectively.

Some of the other estimates reported for average daily gain from birth to weaning are: Taylor et al. (1960), 0.26 to 0.55; Gregory et al. (1950), 0.50; Koch and Clark (1960), 0.34; and Botkin and Whatley (1955), 0.38. Several other investigators reported estimates of weaning weight which are adjusted to a standard age, usually 210 days (Koch and Clark, 1955, 0.34; Botkin and Whatley, 1953, 0.43; Koger and Knox, 1947, 0.49 to 0.59; McCormick et al., 1956, 0.38 to 0.68; and Hoover et al., 1956, 0.32).

Repeatability estimates for type score at weaning were $0.26 \pm .02$ and $0.25 \pm .02$ for Analyses I and II, respectively. These estimates are in general agreement with 0.23 reported by Loganathan (1963) and 0.23 to 0.27 by Taylor et al. (1960). Koger and Knox (1954) and Koch and Clark (1955b) reported estimates of 0.24 and 0.22, respectively.

TABLE XII

ANALYSIS OF VARIANCE AND VARIANCE COMPONENTS OF PERFORMANCE
 TRAITS STUDIED FOR REPEATABILITY ESTIMATES
 (ANALYSIS I)

Source	Degrees of Freedom	Avg. Daily Gain		Type	
		M. S.	Components	M. S.	Components
A (Herd-Breed)	9	1.11688	0.00323	37.76399	0.01125
B (Between Cows/A)	1532	0.084919	0.024387	2.11711	0.04176
C (Within Cows/A)	1960	0.029634	0.029634	1.17051	1.17051

TABLE XIII

ANALYSIS OF VARIANCE AND VARIANCE COMPONENTS OF PERFORMANCE
 TRAITS STUDIED FOR REPEATABILITY ESTIMATES
 (ANALYSIS II)

Source	Degrees of Freedom	Avg. Daily Gain		Type	
		M. S.	Components	M. S.	Components
A (Herd-Breed)	9	0.22048	0.00042	1.27151	0.00000
B (Between Cows/A)	1532	0.07218	0.01901	1.96042	0.37272
C (Within Cows/A)	1960	0.02913	0.02913	1.11620	1.11620

In theory, repeatability represents the upper limits of heritability because its numerator contains all types of genetic as well as permanent environmental influences which contribute to differences among animals. This is true when the traits under study can be measured on the animal and not on the animal's progeny. The fraction of the genetic variance involved would approach one-half as the number of repeat matings increased. The expectation of the numerator for repeatability of cow performance would include both genetic and environmental maternal effects of the dam and permanent environmental effects, but only one-fourth to one-half of the additive genetic differences. Therefore, repeatability estimates from these data could hardly be considered the upper limits of heritability.

The phenotype of a record may be partitioned into a genetic component which includes additive, dominance and epistatic effects; a component due to environmental effects, which are permanent in the sense that they are common to all records on the same cow; and a component due to temporary environmental effects.

In the case of average daily gain from birth to weaning and type score at weaning, the phenotype in question is a function of the cow, expressed through her calf. It is, in fact, a measure of the cow's milking ability without regard to the calf's genotype. The genetic component includes the genetic maternal ability of the cow and the effects common to calves of the same cow; these genetic effects common to calves of the same cow include a sample one-half of the dam's own

additive genotype for average daily gain from birth to weaning and type score at weaning.

The phenotype is: $P = G + PE + TE$.

Where: $G + PE$ are the dam effects and TE includes variation of sires and random errors. If these three components are not correlated, the variance is: $V_P = V_G + V_{PE} + V_{TE}$. Therefore, repeatability of the traits is:

$$r = \frac{V_G + V_{PE}}{V_P}.$$

XII. ESTIMATES OF HERITABILITY

Estimates of heritability for average daily gain from birth to weaning and type score at weaning were obtained by paternal half-sib correlations according to the following formula:

$$h^2 = \frac{4 V_{BS}}{V_{BS} + V_{WC}}.$$

Where: V_{BS} = between sire variance component.

V_{WC} = within cow variance component.

Description of the analysis of variance procedures and symbols are shown in Table VII on page 31.

Estimates of heritability for average daily gain were $0.60 \pm .15$ and $0.39 \pm .12$ for Analyses I and II, respectively. The analysis of variance and variance components of the performance traits studied are shown in Tables XIV and XV for Analyses I and II, respectively. Heritability estimates based on paternal half-sib correlations ranging from

TABLE XIV

ANALYSIS OF VARIANCE AND VARIANCE COMPONENTS OF PERFORMANCE
 TRAITS STUDIED FOR HERITABILITY ESTIMATES
 (ANALYSIS I)

Source	Degrees of Freedom	Avg. Daily Gain		Type	
		M. S.	Components	M. S.	Components
A (Herd-Breed)	9	1.0975	0.0026	37.5007	0.1014
B (Between Sires/A)	196	0.1804	0.0082	4.0861	0.1629
C (Between Dams/B)	2991	0.0478	0.0171	1.4657	0.3718
D (Between Calves/C)	266	0.0293	0.0293	1.0624	1.0624
$k_1 = 1.085$				$k_4 = 16.162$	
$k_2 = 1.051$				$k_5 = 28.091$	
$k_3 = 1.175$				$k_6 = 209.792$	

TABLE XV

ANALYSIS OF VARIANCE AND VARIANCE COMPONENTS OF PERFORMANCE
 TRAITS STUDIED FOR HERITABILITY ESTIMATES
 (ANALYSIS II)

Source	Degrees of Freedom	Avg. Daily Gain		Type	
		M. S.	Components	M. S.	Components
A (Herd-Breed)	9	0.2314	0.0002	1.3101	0.0000
B (Between Sires/A)	196	0.1191	0.0046	3.4120	0.1253
C (Between Dams/B)	2991	0.0443	0.0095	1.3988	0.3065
D (Between Calves/C)	266	0.0341	0.0341	1.0662	1.0662
$k_1 = 1.085$		$k_4 = 16.162$			
$k_2 = 1.051$		$k_5 = 28.091$			
$k_3 = 1.175$		$k_6 = 309.792$			

0.11 to 1.00 and averaging about 0.31 have been reported by various workers (Kidwell, 1954; McCormick, Southwell and Warwick, 1956; Lindholm and Stonaker, 1957; Carter and Kincaid, 1959a; Parrish et al., 1961; and Loganathan, 1962).

Type score at weaning had heritability estimates of $0.41 \pm .13$ and $0.34 \pm .09$ for Analyses I and II, respectively. These estimates are in general agreement with those obtained by the paternal half-sib correlation methods reported by Koger and Knox (1952), Carter and Kincaid (1959), Meyerhoeffer et al. (1961), Christian (1963) and Mahmud and Cobb (1963).

Assuming that the genetic and environmental effects are linear and not correlated, the total phenotypic or observed variation can be written:

$$V_T = V_G + V_I + V_D + V_E.$$

Where: V_T = total variance.

V_G = additive genetic variance.

V_I = variance due to epistatic deviations.

V_D = variance due to dominance deviations.

V_E = environmental variance.

The V_E consists of all environmental effect, including both permanent V_{PE} and temporary V_{TE} environmental effects. Although V_D and V_I are genetic in the sense that they are variations caused by combinations of genes, such variations are not transmissible from one generation to the next, except for a small portion of V_I .

In order for the sire component of variance to contain one-fourth of the additive genetic variance, it is necessary that the sires within

a herd be unrelated and mated to a random sample of unrelated dams in that herd. On the other hand, if the sires are related within a herd, the sire component will contain less than one-fourth of the additive genetic variance; but if the dams to which each sire is mated are related, the sire component will contain more than one-fourth of the genetic variance.

The appropriateness of the analyses. If the adjustments for age of dam from an outside source completely accounted for the effect, this method of eliminating the confounding of age of dam and year would be appropriate. On the other hand, expressing each record on the basis of deviations from the mean on a within breed, station and year basis would eliminate the confounding and the estimates obtained for the other associated variable would be without bias. This would be particularly true with a large sample.

After data in both analyses were adjusted, using least square estimates, and estimates of heritability were obtained, some differences were noted. In Analysis I, the sire component of variance was larger than the comparable component in Analysis II for average daily gain. This indicated that the adjustment used from an outside source increased the between sire, within station and breed variance. One possible explanation is that the outside adjustments for age of dam were not completely appropriate. Thus, some variation due to the effects of age of dam remained in the estimates for year effects. It appears that year and sire are not completely independent. Therefore, when year effects

were removed, a portion of the sire effects was also removed.

From these data, one could predict that the true heritability estimates for average daily gain and type score lie somewhere between the estimates of the two analyses.

CHAPTER V

SUMMARY

The performance records of 1,272 Angus and 2,231 Hereford calves which were progeny of 1,962 purebred and grade Angus and Hereford cows were utilized in this study. These data were collected from the herds of the Main Station of the Tennessee Agricultural Experiment Station and six branch stations over a 7-year period (1957-63). Two important economic traits including average growth rate from birth to weaning and type score at weaning were used in the analyses of the data. The objectives of this study were:

1. To obtain estimates on an intra-cow basis of the influence of sex of calf, year of birth, age of dam, reproductive status of the dam, season of birth, sex of the previous calf, weaning age, calving interval of the dam, average daily gain of the previous calf and the number of dry days of the dam on the average daily gain from birth to weaning and on the type score at weaning of her calf.
2. To develop appropriate correction factors to adjust average daily gain and type score for environmental and developmental influences.
3. To calculate heritability and repeatability estimates for average daily gain and type score.

Due to a linear dependency between year and age of dam, a unique estimate of these effects on an intra-cow basis was not possible. Two different analyses were used in an attempt to remove the linear

dependency existing between age of dam and year.

In Analysis I, daily gain from birth to weaning of all calves out of 2-, 3- and 4-year-old cows was adjusted by adding 0.23, 0.14 and 0.08 pound, respectively. Type scores of calves were not adjusted since the work reported in the literature indicated that age of dam had little, if any, effect on type score at weaning.

In Analysis II, average daily gain and type score of each calf at weaning were expressed as deviations from his respective year, station and breed mean. These deviations were used in the analysis in lieu of the observed performance.

In both analyses, sex of calf had a highly significant effect on average daily gain from birth to weaning but had little influence on type score. Male calves had an average daily gain from birth to weaning of 0.16 pound greater than females.

Estimates of year effects for average daily gain and type score were significant ($P < .01$). However, no definite trend could be observed from these estimates.

The effects of age of dam on growth rate from birth to weaning were highly significant. A cow's individual performance was lowest at 2, 3, 4 and 11 years of age. The largest improvement in a cow's performance, as measured by type score of her calves, occurred between the ages of 2 and 3 years.

These data show that cows that calved the previous season, but did not raise their calves, weaned calves with the highest average daily gain. Cows that calved the previous season, but did not wean their

calves, produced calves which had no apparent advantage in type score over calves of cows that weaned a calf the previous season.

Season of birth had no significant effect on type score. The effect of season of birth on growth rate from birth to weaning was not significant in Analysis II. However, in Analysis I where outside adjustments were used for age of dam, this effect was significant. These results were calculated on the basis that all other sources of variation included in the mathematical model were held constant or removed.

When growth rate and type score were regressed on weaning age, regression coefficients indicated that as the calves became older they had a higher type score. However, growth rate decreased with age.

No significant relationships were found when type score and growth rate were regressed on calving interval. In Analysis I, the regression of average daily gain on the number of dry days of the dam was significant.

These data indicate that, on the average, if the previous calf had a fast growth rate to weaning, average daily gain and type score of the succeeding calf would be lower.

The repeatability estimates for average daily gain were 0.45 and 0.39 for Analyses I and II, respectively. These estimates are of sufficient magnitude that a cow raising a first calf with a low average daily gain could be culled with relatively little chance of culling a cow that might be a high producer in later years.

Repeatability estimates for type score at weaning were 0.26 and 0.25 for Analyses I and II, respectively. These estimates for type score

indicate that this trait is less repeatable than average daily gain and a cow cannot be culled on the basis of the type score of her first calf with as much reliability as the daily gain.

Heritability estimates for average daily gain were 0.60 and 0.39 for Analyses I and II, respectively. The estimates for type score were 0.41 and 0.34 for Analyses I and II, respectively. These estimates suggest that selection based on individuality will be highly effective since there apparently is a high linear association between genotype and phenotype.

The results of this study indicate that, in order to maximize expected genetic progress in the improvement of growth rate and type score at weaning, individual records of calves should be adjusted for age of dam, sex and average daily gain of previous calf.

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APPENDIX

TABLE XVI

DISTRIBUTION OF CALVES BY STATION, YEAR AND BREED ALONG WITH MEANS AND
STANDARD DEVIATIONS OF AVERAGE DAILY GAIN AT WEANING

	1957	1958	1959	1960	1961	1962	1963
Blount Hereford							
Number	18	16	9	11	24	10	24
Average daily gain, lb.	1.54	1.65	1.58	1.31	1.63	1.62	1.45
Standard deviation, lb.	0.37	0.20	0.23	0.16	0.24	0.19	0.27
Blount Angus							
Number	30	25	27	18	28	24	31
Average daily gain, lb.	1.62	1.64	1.67	1.63	1.93	1.72	1.69
Standard deviation, lb.	0.19	0.25	0.21	0.22	0.26	0.20	0.20
Alcoa Hereford							
Number	147	170	125	167	137	165	98
Average daily gain, lb.	1.68	1.81	1.70	1.72	1.67	1.59	1.56
Standard deviation, lb.	0.24	0.25	0.23	0.16	0.22	0.20	0.25
Alcoa Angus							
Number	--	--	--	5	17	25	25
Average daily gain, lb.	--	--	--	1.66	1.66	1.64	1.73
Standard deviation, lb.	--	--	--	0.09	0.23	0.23	0.17
Oak Ridge Hereford							
Number	6	7	10	--	--	100	133
Average daily gain, lb.	1.81	1.73	1.76	--	--	1.55	1.54
Standard deviation, lb.	0.27	0.29	0.24	--	--	0.25	0.22

TABLE XVI (continued)

	1957	1958	1959	1960	1961	1962	1963
Greeneville Hereford							
Number	33	49	36	29	53	48	49
Average daily gain, lb.	1.73	1.63	1.77	1.41	1.75	1.76	1.75
Standard deviation, lb.	0.30	0.27	0.24	0.19	0.20	0.23	0.25
Springfield Hereford							
Number	27	23	29	32	39	38	39
Average daily gain, lb.	1.75	1.81	1.68	1.67	1.59	1.56	1.80
Standard deviation, lb.	0.25	0.25	0.21	0.20	0.26	0.27	0.30
Columbia Hereford							
Number	37	43	46	46	53	53	46
Average daily gain, lb.	1.49	1.74	1.52	1.50	1.55	1.57	1.84
Standard deviation, lb.	0.15	0.23	0.22	0.24	0.20	0.30	0.20
Ames Hereford							
Number	2	1	1	2	--	--	--
Average daily gain, lb.	1.50	1.46	1.37	1.55	--	--	--
Standard deviation, lb.	0.06	0.00	0.00	0.08	--	--	--
Ames Angus							
Number	70	124	136	165	204	173	145
Average daily gain, lb.	1.62	1.59	1.48	1.55	1.70	1.69	1.57
Standard deviation, lb.	0.22	0.25	0.21	0.26	0.24	0.23	0.22

TABLE XVII

DISTRIBUTION OF CALVES BY STATION, YEAR AND BREED ALONG WITH MEANS
AND STANDARD DEVIATIONS OF TYPE SCORE^a AT WEANING

	1957	1958	1959	1960	1961	1962	1963
Blount Hereford							
Number	18	16	9	11	24	10	24
Type score, units	12.4	12.4	12.1	11.4	11.8	11.7	11.2
Standard deviation, units	1.6	1.5	1.6	0.7	1.2	1.2	1.2
Blount Angus							
Number	30	25	27	18	28	24	31
Type score, units	12.6	12.7	12.3	12.8	13.0	12.3	12.9
Standard deviation, units	1.4	1.2	1.6	0.8	1.5	0.8	1.0
Alcoa Hereford							
Number	147	170	125	167	137	165	98
Type score, units	12.0	12.1	12.0	12.1	12.5	11.8	12.2
Standard deviation, units	1.6	1.3	1.2	1.0	1.4	1.2	1.1
Alcoa Angus							
Number	--	--	--	5	17	25	25
Type score, units	--	--	--	13.4	13.0	12.4	12.4
Standard deviation, units	--	--	--	1.4	1.3	1.3	1.2
Oak Ridge Hereford							
Number	6	7	10	--	--	100	133
Type score, units	10.9	11.0	11.6	--	--	11.8	11.9
Standard deviation, units	1.2	1.5	1.0	--	--	1.0	0.9

TABLE XVII (continued)

	1957	1958	1959	1960	1961	1962	1963
Greeneville Hereford							
Number	33	49	36	29	53	48	49
Type score, units	10.9	10.9	11.3	11.0	11.3	11.9	12.0
Standard deviation, units	1.7	1.5	0.9	1.0	1.0	1.0	1.2
Springfield Hereford							
Number	27	23	29	32	39	38	39
Type score, units	12.0	10.7	11.8	11.7	12.0	12.3	12.5
Standard deviation, units	0.8	1.2	1.2	1.2	1.4	1.3	1.4
Columbia Hereford							
Number	37	43	46	46	53	53	46
Type score, units	11.2	11.0	10.9	11.2	11.4	11.6	12.0
Standard deviation, units	1.0	1.1	1.1	1.2	1.1	1.4	1.1
Ames Hereford							
Number	2	1	1	2	--	--	--
Type score, units	11.1	11.0	9.5	11.5	--	--	--
Standard deviation, units	0.1	0.0	0.0	0.7	--	--	--
Ames Angus							
Number	70	124	136	165	204	173	145
Type score, units	12.1	12.0	11.5	11.9	12.4	12.2	12.3
Standard deviation, units	1.4	1.6	1.3	1.3	1.1	1.3	1.4

^aMiddle Good = 10; middle Choice = 13.