

INHERITANCE OF CERTAIN MATERNAL TRAITS  
IN BEEF CATTLE

by

NAT MATHAN KIEFFER

Bachelor of Science  
Southwestern Louisiana Institute  
Lafayette, Louisiana  
1952

Master of Science  
Louisiana State University and  
Agricultural and Mechanical College  
Baton Rouge, Louisiana  
1956

Submitted to the faculty of the Graduate School of the  
Oklahoma State University of Agriculture and  
Applied Science in partial fulfillment  
of the requirements for the degree of  
DOCTOR OF PHILOSOPHY  
August, 1959

SEP 1 1960

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Thesis Approved:

*Dayla Chambers*  
\_\_\_\_\_  
Thesis Adviser

*Jack R. Harlan*  
\_\_\_\_\_

*James A. Whalley Jr.*  
\_\_\_\_\_

*J. L. Pope*  
\_\_\_\_\_

*Stanley D. Murgrave*  
\_\_\_\_\_

*James Menden*  
\_\_\_\_\_  
Dean of the Graduate School

#### ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. Doyle Chambers, Professor of Animal Husbandry, for his guidance and generous counsel during course of this investigation. I am also indebted to Dr. R. D. Morrison, Associate Professor of Mathematics, for his assistance with the statistical analysis of the data.

Further acknowledgments are due Dr. L. S. Pope, Professor of Animal Husbandry, Mr. Jerry Hrdy, Herdsman for the Federal Reformatory, and Mr. Roger Denman, Herdsman for the Chilocco Indian School for making available data used in this study.

# TABLE OF CONTENTS

	Page
INTRODUCTION . . . . .	1
REVIEW OF LITERATURE . . . . .	3
MATERIALS AND METHODS . . . . .	15
PROJECT 670 . . . . .	15
Description of the Data . . . . .	15
Paternal Half-Sib Correlations of Maternal Effects . . . . .	19
Regression of the Daughters' Performance on the Dams' Performance . . . . .	21
Paternal Half-Sib Correlations of Birth Weight and Weaning Traits . . . . .	23
Correction of the Data for Known Variables . . . . .	24
Age of calf . . . . .	24
The influence of sex . . . . .	24
The influence of age of dam . . . . .	26
The influence of year . . . . .	29
The influence of inbreeding . . . . .	29
PROJECT 650 . . . . .	30
Description of the Data . . . . .	30
Paternal Half-Sib Correlations of Maternal Effects . . . . .	31
Regression of the Daughters' Performance on the Dams' Performance . . . . .	32
Paternal Half-Sib Correlations of Birth Weight and Weaning Traits . . . . .	32
Correction of the Data for Known Variables . . . . .	34
Age of calf . . . . .	34
The influence of sex . . . . .	34
The influence of age of dam and year . . . . .	34
Influence of nutritional treatment . . . . .	35
CHILOCCO . . . . .	36
Description of the Data . . . . .	36
Paternal Half-Sib Correlations of Maternal Effects . . . . .	37
Regression of the Daughters' Performance on the Dams' Performance . . . . .	37
Paternal Half-Sib Correlations of Birth Weight and Weaning Traits . . . . .	39
Correction of the Data for Known Variables . . . . .	39
Age of calf . . . . .	39
The influence of sex . . . . .	40
Age of dam and year effects . . . . .	40

# TABLE OF CONTENTS (Continued)

	Page
FEDERAL REFORMATORY . . . . .	41
Description of the Data . . . . .	41
Paternal Half-Sib Correlations of Maternal Effects . . . . .	41
Regression of the Daughters' Performance on the Dams' Performance . . . . .	42
Paternal Half-Sib Correlations of Birth Weight and Weaning Traits . . . . .	42
Correction of the Data for Known Variables . . . . .	42
Age of calf . . . . .	42
The influence of sex . . . . .	42
Influence of age of dam and year . . . . .	43
Statistical Procedures . . . . .	44
Paternal half-sib correlations of maternal effects . . . . .	44
Paternal half-sib correlations of birth weight and weaning traits . . . . .	44
Intra-sire regression of the daughters' performance on the dams' performance . . . . .	47
Heritability Estimates . . . . .	48
Paternal half-sib correlation method . . . . .	48
Intra-sire regression of the daughters' performance on the dams' performance . . . . .	52
Standard errors of the estimates . . . . .	52
RESULTS AND DISCUSSION . . . . .	53
PROJECT 670 . . . . .	54
Heritability Estimates of Maternal Effects Computed from Paternal Half-Sib Correlations . . . . .	54
Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance . . . . .	59
Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations . . . . .	67
PROJECT 650 . . . . .	75
Heritability Estimates of Maternal Effects Computed from Paternal Half-Sib Correlations . . . . .	75
Heritability Estimates of Maternal Effects Computed from the Regression of the Daughters' Performance on the Dams' Performance . . . . .	78
Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations . . . . .	82

# TABLE OF CONTENTS (Continued)

	Page
CHILOCCO . . . . .	87
Heritability Estimates of Maternal Effects Computed from Paternal Half-Sib Correlations . . . . .	87
Heritability Estimates of Maternal Effects Computed from Regressing the Daughters' Performance on the Dams' Performance . . . . .	91
Heritability Estimates of Birth Weight and Weaning Traits Computed from Half-Sib Correlations . . . . .	95
FEDERAL REFORMATORY . . . . .	98
Heritability Estimates of Maternal Effects Obtained from Paternal Half-Sib Correlations . . . . .	98
Heritability Estimates of Maternal Effects Derived from the Regression of the Daughters' Performance on the Dams' Performance . . . . .	100
Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations . .	103
GENERAL DISCUSSION . . . . .	105
Heritability Estimates of Maternal Effects Derived from Paternal Half-Sib Correlations . . . . .	105
Heritability Estimates of Maternal Effects Obtained from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance . . . . .	107
Heritability Estimates of Birth Weight and Weaning Traits Obtained from Paternal Half-Sib Correlations . .	110
SUMMARY AND CONCLUSIONS . . . . .	114
LITERATURE CITED . . . . .	116
APPENDIX . . . . .	120

# LIST OF TABLES

Table	Page
I. Post-Weaning Performance of Replacement Heifers (Proj. 670) . . . . .	18
II. Distribution of Daughters by Lines, Years of Birth, and Sires (Proj. 670) . . . . .	20
III. Distribution of Daughters by Lines, Years of Birth, and Sires (Proj. 670) . . . . .	22
IV. Record Combinations Used to Study the Inheritance of Maternal Effects by Regressing the Daughters' Performance on the Dams' Performance (Proj. 670) . . . . .	23
V. Average Birth and 210-Day Weights of Bulls and Heifers (Proj. 670) . . . . .	25
VI. Average Birth Weights, Weaning Weights, and Condition Scores from Cows of Different Ages (Proj. 670) . . . . .	28
VII. Correction Factors for Age of Dam (Proj. 670) . . . . .	28
VIII. Distribution of Daughters by Years of Birth and Sires (Proj. 650) . . . . .	33
IX. Record Combinations Used to Study the Inheritance of Maternal Effects by Regressing the Daughters' Performance on the Dams' Performance (Proj. 650) . . . . .	33
X. Correction Factors for Level of Wintering (Proj. 650) . . . . .	36
XI. Distribution of Daughters by Years of Birth and Sires (Chilocco) . . . . .	38
XII. Theoretical Analysis of Variance for Computation of Variance Components (Maternal Effects) . . . . .	49
XIII. Theoretical Analysis of Variance for Computation of Variance Components (Birth and Weaning Traits) . . . . .	50
XIV. Lifetime Performance of Half-Sib Daughters by Lines, Years of Birth, and Sires (Proj. 670) . . . . .	55
XV. Analysis of Variance of Maternal Effects for Paternal Half-Sib Daughters Pooled from All Lines (Proj. 670) . . . . .	58

# LIST OF TABLES (Continued)

Table	Page
XVI. Lifetime Performance of Daughter-Dam Groups by Line, Year of Birth, and Sire of the Daughter (Proj. 670) . . . . .	60
XVII. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance by Line and Year of Birth of the Daughter (Proj. 670) . . . . .	62
XVIII. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance Within Year of Birth of the Daughter (Proj. 670) . . . . .	66
XIX. Average Performance of Calves by Years, Lines, and Sires (Proj. 670) . . . . .	68
XX. Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations (Proj. 670) . . . . .	73
XXI. Lifetime Performance of Half-Sib Daughters by Years of Birth and Sires (Proj. 650) . . . . .	76
XXII. Analysis of Variance of Maternal Effects for Paternal Half-Sib Daughters (Proj. 650) . . . . .	77
XXIII. Lifetime Performance of Daughter-Dam Groups by Year of Birth and Sire of the Daughter (Proj. 650) . . . . .	79
XXIV. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance by Year of Birth of the Daughter (Proj. 650) . . . . .	80
XXV. Average Performance of Calves by Years, Replications, and Sires (Proj. 650) . . . . .	83
XXVI. Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations (Proj. 650) . . . . .	85
XXVII. Average Weight Per Day of Age of Calves Produced by Half-Sib Daughters by Year of Birth and Sire of the Daughter, 1957 Records (Chilocco) . . . . .	88



# LIST OF TABLES (Continued)

Table	Page
XXVIII. Average Weight Per Day of Age of Calves Produced by Half-Sib Daughters by Year of Birth and Sire of the Daughter, 1958 Records (Chilocco) . . . . .	88
XXIX. Average Feeder Grade of Calves Produced by Half-Sib Daughters by Year of Birth and Sire of the Daughter, 1958 Records (Chilocco) . . . . .	89
XXX. Analysis of Variance of Maternal Effects for Paternal Half-Sib Daughters (Chilocco) . . . . .	90
XXXI. Average Performance of Daughter-Dam Groups by Sire of the Daughter (Chilocco) . . . . .	92
XXXII. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance (Chilocco) . . . . .	93
XXXIII. Average Performance of Calves by Years and Sires (Chilocco) . . . . .	96
XXXIV. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs (Chilocco) . . . . .	97
XXXV. Lifetime Performance of Half-Sib Daughters by Years of Birth and Sires (Fed. Ref.) . . . . .	99
XXXVI. Analysis of Variance of Maternal Effects for Paternal Half-Sib Daughters (Fed. Ref.) . . . . .	99
XXXVII. Average Performance of Daughter-Dam Groups by Year of Birth and Sire of the Daughter (Fed. Ref.) . . . . .	101
XXXVIII. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance by Year of Birth of the Daughter (Fed. Ref.) . . . . .	102
XXXIX. Average Performance of Calves by Years and Sires (Fed. Ref.) . . . . .	104
XL. Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations (Fed. Ref.) . . . . .	104
XLI. Heritability Estimates of Maternal Effects Computed from Paternal Half-Sib Correlations . . . . .	106

# LIST OF TABLES (Continued)

Table	Page
XLII. Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Average Performance of the Daughter on the Average Performance of the Dam . . . . .	108
XLIII. Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations . . . . .	111
XLIV. Pooled Sums of Squares and Sums of Cross Products from All Lines. (Intra-Sire Regression of the Lifetime Performance of the Daughter (Y) on the Lifetime Performance of the Dam (X) (Proj. 670) . . . . .	121
XLV. Pooled Sums of Squares and Sums of Cross Products from All Lines. (Intra-Sire Regression of the First Record of the Daughter (Y) on the Average of All Records of the Dam (X) Made Up to and Including the Birth Year of the Daughter) (Proj. 670) . . . . .	122
XLVI. Pooled Sums of Squares and Sums of Cross Products from All Lines. (Intra-Sire Regression of the First Record of the Daughter (Y) on the First Record of the Dam (X) (Proj. 670) . . . . .	123
XLVII. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Line 1 (Proj. 670) . . . . .	124
XLVIII. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Line 2 (Proj. 670) . . . . .	125
XLIX. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Line 3 (Proj. 670) . . . . .	126
L. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Line 4 (Proj. 670) . . . . .	127
LI. Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs Within Lines (Proj. 670) . . . . .	128
LII. Sums of Squares and Sums of Cross Products from the Intra-Sire Regression of the Lifetime Performance of the Daughter (Y) on the Lifetime Performance of the Dam (X) Within Year of Birth of the Daughter (Proj. 650) . . . . .	129
LIII. Sums of Squares and Sums of Cross Products from the Intra-Sire Regression of the First Record of the Daughter (Y) on the First Record of the Dam (X) Within Year of Birth of the Daughter (Proj. 650) . . . . .	130

# LIST OF TABLES (Continued)

Table		Page
LIV.	Sums of Squares and Sums of Cross Products from the Intra-Sire Regression of the 1958 Record of the Daughter (Y) on the 1958 Record of the Dam (X) Within Year of Birth of the Daughter (Proj. 650) . . .	131
LV.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Replication 1 (Proj. 650) . .	132
LVI.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Replication 2 (Proj. 650) . .	133
LVII.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Replication 3 (Proj. 650) . .	134
LVIII.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs in Replication 4 (Proj. 650) . .	135
LIX.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs Within Replications (Proj. 650) . . . . .	136
LX.	Sums of Squares and Sums of Cross Products from the Intra-Sire Regression of the Average Performance of the Daughter (Y) on the Average Performance of the Dam (X) Within Year of Birth of the Daughter (Fed. Ref.)	137
LXI.	Analysis of Variance of Birth Weight and Weaning Traits for Paternal Half-Sibs (Fed. Ref.) . . . . .	138

## INTRODUCTION

The weight and grade of the beef calf determines to a large extent its value when marketed at weaning. In Oklahoma alone, more than a million beef cows over 2 years of age are being maintained for the production of beef calves, the majority of which are marketed at weaning as feeder calves.

It has been found that large differences exist among the standardized production records of beef cows even when these cows of similar breeding and age were bred to bulls of comparable merit. Significant differences have also been found to exist among average birth weights and weaning weights and grades of calves by bulls which were bred to cows of similar producing ability.

The brood cow influences traits such as birth weight, gain from birth to weaning, and weaning score both by the genes she transmits and the maternal environment she provides. The sire's effect upon the performance of his offspring is limited to the calf's response to the genes which he transmits.

The influence through maternal environment appears at 2 periods of the calf's life. The first is the prenatal period from conception until birth. The second period is from birth to weaning. The variations in maternal environment among cows for birth weight of their calves are presumably due to such factors as differences in the body size of the cow and differences in the ability to provide nutrients for the developing fetus. The quantity of milk provided the calf is the most important maternal

effect on the pre-weaning growth of the calf. Other items involved in postnatal care such as protection of the calf by its dam may possibly influence the gain from birth to weaning. Maternal environmental factors which influence gain also exert a correlated effect on weaning score. Calves which have an adequate supply of milk during the pre-weaning period usually gain more rapidly and score higher than calves of similar breeding but from poorer milking dams.

In order to produce permanent improvement in a characteristic through selection, it is necessary that the observed differences between individual animals have a heritable basis. A reliable estimate of heritability of a trait is one of the most important considerations in formulating an effective program of improvement through breeding.

The primary objectives of this study were to obtain estimates of heritability for maternal effects on birth weight, weaning weight, and weaning score, and to obtain estimates of heritability for the direct effect of the sire upon his progeny for these same traits.

## REVIEW OF LITERATURE

Prior to the report of Knapp and Nordskog in 1946, no genetic studies on the variations in beef cattle weights and gains had been reported. Several studies had been published on related traits in swine (Lush, 1936; Whatley, 1942; Hazel et al., 1943; Nordskog et al., 1944; Baker et al., 1943), in sheep (Terrill and Hazel, 1943), and in dairy cattle (Lush, 1940). The lack of genetic information on weights and gains in beef cattle was probably due to the limited amount of data available on this class of livestock. As Brown (1956) pointed out, the long generation interval and the expense of maintaining experimental herds have contributed to the slow accumulation of data suitable for genetic studies of economic traits in beef cattle.

Knapp and Nordskog (1946) made a study of the records from 177 steer calves produced by 23 sires at the United States Range Livestock Experiment Station, Miles City, Montana, to estimate the relative importance of heredity on birth weight, weaning weight, weaning score, post-weaning gain, and efficiency of gain. All calves were dropped on the range during approximately an 8 week period in April and May each year. The calves were scored by a committee of 3 men working independently. The average of the 3 scores was used as the score of each animal. Heritability of weaning weight computed by regressing the offspring's weaning weight on the sire's weaning weight was 30 percent.

Heritability of birth weight determined by regressing the offspring's birth weight on the sire's birth weight was 42 percent, whereas the estimate computed by the paternal half-sib correlation method was 23 percent.

Weaning score was estimated to be 53 percent heritable by paternal half-sib analysis and -14 percent by regressing the weaning score of the offspring on the weaning score of the sire.

Dawson et al. (1947) made a study of the birth weights of 227 beef Shorthorn calves born as singles. The calves were born from 1930 to 1944 and were dropped during all seasons of the year. They were sired by 13 bulls and were the progeny of 112 cows. The inheritance of birth weight calculated by the paternal half-sib correlation method using uncorrected birth weights was 29 percent. When the birth weights were corrected for age of dam and sex of calf, heritability of birth weight was found to be 11 percent.

Gregory et al. (1950) reported heritabilities of 45, zero, and 26 percent for birth weight, gain from birth to weaning, and weaning weight respectively for data from the University of Nebraska North Platte Substation. Heritability estimates of 100, 45, and 52 percent were obtained for birth weight, gain from birth to weaning, and weaning weight respectively for data from the University of Nebraska Valentine Substation. The North Platte data were collected over two periods. Thirty-three birth and weaning weights were collected during 1936, and a total of 248 birth weights and 237 weaning weights were collected from 1944 through 1947. The weaning weights were corrected to a constant age of 200 days by regression of weight on age. The differences between the means of the sexes for gain and weaning weight were not significant at either station. Five pounds were added to the birth weight of the female calves.

Data on 74 birth weights and 69 weaning weights were available from the Valentine Substation during the years 1935 and 1936. The calves born

in 1935 were the offspring of 4 sires and the calves born in 1936 were the offspring of 2 sires that had been used the previous year. The weaning weights of calves at this station were corrected to a constant age of 150 days by regression of weight on age. Four pounds were added to the birth weights of the heifer calves. The paternal half-sib correlation technique was the only method used in estimating heritability since no birth or weaning records were available on the sires and dams.

Knapp and Clark (1950) reported a revision of their earlier heritability estimates published in 1946. The revised estimate of heritability of weaning weight was 28 percent with a lower 99 percent confidence interval of 7 percent, while the revised estimate of the heritability of birth weight was 53 percent with a lower 99 percent confidence interval of 26 percent. The estimated heritability of weaning score was 28 percent with a lower 95 percent confidence interval of 4 percent. All analyses were made on an intra-year basis. The animals used in this study were representatives from a maximum of 110 sire groups.

Knapp and Clark (1951) reported the results of a study on 613 steers from 83 Hereford sires in experiments conducted in cooperation between the United States Bureau of Animal Industry and the Montana Agricultural Experiment Station. Heritability of weaning score was estimated to be 31 percent. The scores were obtained by a 3-man-committee scoring independently. The average of the 3 scores was used as the score for each animal. The scores ranged from 52 to 94 which is comparable to grades of common to fancy feeders.

Burris and Blunn (1952) reported heritability of birth weight to be 22 percent. Data for this study consisted of records of 502 calves,



which included 188 Hereford, 184 Angus, and 130 Shorthorn. Heritability was determined by paternal half-sib regressions.

The results of a heritability study from data collected over a 10 year period at the United States Range Livestock Experiment Station, Miles City, Montana, were reported by Shelby et al. (1955). The data in this study consisted of the records of 635 Hereford steers fed in Record of Performance tests from 1942 to 1951 inclusive. The steers were by 88 sires from 9 inbred lines of different pedigree origin. All analyses were made on a sires-within-lines and years basis. Heritability was estimated by the paternal half-sib correlation technique. Heritability of weaning weight was 23 percent with a 95 percent confidence interval from 3 to 41 percent. Birth weight was found to be 72 percent heritable.

Koger and Knox (1952) analyzed the weaning grades of calves from 2 breeds of cattle. Weaning grades were available on 115 Angus calves and their dams. The Angus calves were scored on lowness, thickness, and smoothness. In addition, each calf was given an over-all composite score. All scoring was done by one man. Heritability of total score was estimated to be 50 and 30 percent as computed by the paternal half-sib correlation method and the regression of offspring's weaning score on dam's weaning score respectively.

The Hereford calves were graded by a committee of 3 or more people working independently. The average heritability estimates from half-sib correlations and from intra-sire regression of offspring's score on dam's score were 24 and 23 percent respectively.

Kidwell (1954) made a study of the heritable variations in the weaning weights of 58 steer and 97 heifer calves. These animals were born

and weaned on 4 different ranches, each with 2 to 6 sire groups. The data were analyzed on an intra-year, intra-sex group basis to eliminate the effects of sex and year. Heritability of weaning weight was estimated to be 100 percent in this study. While this estimate was considerably higher than other reported estimates, pre-weaning environment, which tends to affect all calves from the same location alike but which varies among locations, was included in this estimate.

Dawson et al. (1955) published the results of a study which showed birth weight to be 51 percent heritable. This estimate was determined by the paternal half-sib correlation method from data which consisted of the records of 58 Milking Shorthorn steers raised at the Agricultural Research Center, Beltsville, Maryland, from 1943 through 1949. The steers were the progeny of 9 sires and 51 dams.

Koch and Clark (1955a) analyzed data consisting of the records of 4553 birth and weaning weights, 3831 weaning scores, 1694 fall yearling weights, and 1483 fall yearling scores collected at the United States Range Livestock Experiment Station, Miles City, Montana. The birth, weaning, and fall yearling weights were accumulated over the period 1929-1951 from 137 different sires. The weaning and fall yearling scores were obtained over the years 1936-1951 and involved 124 different sires. The data were adjusted for sex to a heifer basis; corrections were made for the influence of age of dam; and the weaning weights were adjusted to a standard age of 182 days. Sire differences were determined on a within-line and year basis. Maternal half-sib correlations and paternal half-sib correlations computed for the various traits studied are shown below.

## Maternal Half-Sib Correlations

Birth wt.	Wn. wt.	Gain b-wn.	Wn. score	Yrlg. wt.	Gain wn-yrhg.	Yrlg. score
.26	.34	.34	.22	.20	.09	.02

## Paternal Half-Sib Correlations

Birth wt.	Wn. wt.	Gain b-wn.	Wn. score	Yrlg. wt.	Gain wn-yrhg.	Yrlg. score
.09	.06	.05	.05	.12	.10	.07

Comparison of the paternal half-sib correlations with the maternal half-sib correlations indicated that maternal environment had considerable influence on birth weight, gain from birth to weaning, and weaning score. Likewise, the correlations for gain from weaning to yearling and the values for yearling score indicated maternal environment had less effect upon these traits. As was pointed out by the writers, the relationships among maternal half-sibs differ from those of paternal half-sibs because of additional influences through the maternal environments provided during the prenatal and postnatal periods. Except for sex linked genes, the genetic relationships are the same in both paternal and maternal half-sibs. The environmental relationships differed because some of the factors considered as environmental for paternal half-sibs were included in the relationships of maternal half-sibs through maternal environment.

Koch and Clark (1955b), utilizing part of the same data reported by Koch and Clark (1955a), reported the heritability estimates shown below. These estimates were computed by regressing the various traits of the offspring on those of the dam.

Birth wt.	Wn. wt.	Gain b-wn.	Wn. score	Yrlg. wt.	Gain wn-yrhg.	Yrlg. score
.44	.11	.07	.16	.43	.18	.14

The data from which the estimates were computed consisted of records on 4234 calves and their 1231 dams for birth and weaning weight, 1762 calves and their 671 dams for weaning score, 1623 calves and their 822 dams for fall yearling weight, and 797 calves and their 443 dams for fall yearling score. The year effect and the age of dam effect were eliminated by grouping pairs of records into subclasses according to the years the cows were born and the years the calves were born. All of these estimates, with the exception of birth weight, were lower than the estimates obtained from the paternal half-sib correlation (Koch and Clark, 1955a) when in fact they were expected to be larger because of the direct effect of maternal environment. According to the authors this situation might have arisen because environmental correlations between the paternal half-sibs were not adequately discounted. This would have caused any genetic-environmental interaction to be confounded with sire differences, thus biasing the paternal half-sib correlations upward. Another explanation advanced was that negative correlations might have existed between the genes directly affecting the growth responses of some of the traits concerned.

Koch and Clark (1955c), using data from the same source as described by Koch and Clark (1955a), compared the theoretical composition of paternal and maternal half-sib correlations and the correlations between offspring and dam and offspring and sire with observed values to estimate

the influence of maternal environment. The correlations used to evaluate maternal environment were derived from a system of path coefficients. These comparisons suggested that maternal environment from conception to birth and from birth to weaning had a large influence on birth weight, gain from birth to weaning, and weaning score, but a small influence on yearling gain and yearling score. The results further suggested a negative correlation between maternal environment from birth to weaning and the traits, weaning gain and score. This was in agreement with findings reported by Koch and Clark (1955a). Heritabilities of birth weight, weaning weight, and weaning score taking maternal environment into account were 42, 19, and 16 percent respectively.

Rollins and Wagnon (1956a) made a study of the weaning weights of 577 calves produced by 2 grade Hereford herds maintained by the University of California at the San Joaquin Experimental Range. One herd was fed supplementary feed during the fall and winter when the range was nutritionally deficient, whereas the other herd was not supplemented except to stop death losses during periods of extremely unfavorable climatic conditions. The data were standardized for the effects of pasture, year, sex, age of calf at weaning, and age of dam. In the unsupplemented herd heritability of weaning weight was estimated to be 54 percent by the paternal half-sib correlation method, and 15 percent by the regression of offspring's weaning weight on dam's weaning weight. Estimates of heritability in the supplemented herd were 9 percent by the paternal half-sib correlation method and 84 percent by the regression of the offspring's weaning weight on the dam's weaning weight. According to the authors, the dam's characteristics which exert a maternal effect on the weaning weight

of her calf, may have been correlated with her weaning weight to such an extent as to bias heritability based on doubling the regression coefficient of offspring on dam. This was in agreement with results presented by Koch and Clark (1955a).

Rollins and Wagnon (1956b) computed heritability of weaning grade from the same data described by Rollins and Wagnon (1956a). All grading was done at weaning each year by the same person. The grading system used was that developed by Guilbert (1951). Heritability was estimated for the paternal half-sibs within each herd and then pooled over both herds. The pooled estimate was 36 percent.

McCormick et al. (1956) estimated heritability of birth weight to be -17 and 68 percent for 180 bull and 194 heifer calves respectively in a purebred herd of Polled Hereford cattle. Heritability of 210-day weight was computed separately for purebred and grade Hereford calves by the paternal half-sib correlation method on a between-sire-within-season basis. In the purebred herd, heritability of 210-day weight was estimated to be 33 and 26 percent for 168 bull and 186 heifer calves respectively, whereas estimates of -6 and 49 percent were obtained for 174 grade bull and 153 grade heifer calves respectively.

Dinkel and Musson (1956) stated that about 36 percent of the individual differences in weaning weight are inherited. The data in this study included weaning weights on 646 calves sired by 62 bulls on 11 ranches. Since the environmental differences were large from year to year and ranch to ranch, the analysis was made by comparing the weights of calves from the different sires in the same year on each ranch.

Results of a study by Brown (1958) indicated heritability of weaning weight to be 26 and 11 percent in purebred Angus and Hereford herds

respectively. The data for this study consisted of the weaning records of 255 Hereford calves and 212 Aberdeen-Angus calves. The calves were born in all months of the year, but most of the calving dates were during the fall, winter, and spring months. Those born in the fall received grain in a creep while running with their dams in years when full grazing was inadequate. All weaning weights were adjusted to a standard age of 240 days, and the data were adjusted to a heifer basis by subtracting 25 and 107 pounds from Hereford steers and bulls respectively, and 23 and 67 pounds from Angus steers and bulls respectively.

Lindholm and Stonaker (1957) analyzed the weaning records of 118 Hereford steers by 19 sires. These steers were raised by the Colorado Agricultural Experiment Station in the 6-year period 1946-1951. Unadjusted weaning weights were used because it was felt by the writers that adjusted weights might possibly bias the true biological relationships. No adjustment was made for age of dam differences since ages of dams were randomly distributed within the sire groups. Heritability of weaning weight computed by the paternal half-sib correlation method was 81 percent. The writers felt that this estimate was probably biased upward since an intra-class correlation of .38 indicated a difference in weaning age of calves in the different sire groups.

The 1949 report of the Chief of the Bureau of Animal Industry stated that the selection of sires may materially affect the weaning weight of the second generation. This report further stated that the heritable effect of the maternal grandsire on the weaning weight of the calf was found to be about the same as the heritable effect of the sire of the calf. No data were given to support these statements.

Dawson et al. (1954) published findings which indicated maternal effects for weaning weight to be 19 percent heritable. In this study paternal half-sib correlations were computed for the daughters of the various sires for which data were available using the 6-month weight of their calves as the criteria. According to the authors the estimated heritability of 19 percent contained the fraction of additively genetic inheritance transmitted to the daughters by their sires which was concerned with their mothering ability, i.e., uterine environment, milk production, and possibly other items involved in postnatal care. This estimate also contained some of the additive genetic inheritance concerned with the growth potential of the daughters' calves themselves.

Chambers et al. (1958) studied the inheritance of mothering ability in a grade herd of Hereford cows by relating the performance of the daughter to the performance of her dam. There were 59 daughters by 7 different sires and from 46 different dams. The dams had a maximum of 8 records, whereas the daughters had a maximum of 2 records. The statistical procedure used to estimate heritability of mothering ability was to obtain an intra-sire, intra-season regression of the daughter's performance as measured by 210-day calf weights on that of her dam. Four different regressions were computed. These regression coefficients along with the estimates of heritability are presented below.

Although the amount of data used in this study was quite limited, the heritabilities estimated were rather consistent and suggested that selection of replacement heifers from the more productive dams would be effective in raising the average weaning weights of beef calves.



<u>Item Studied</u>	<u>No. Pairs</u>	<u>Reg. Coef.</u>	<u>Heritability</u>
1. First record of dau. and dam	59	.15	.30
2. 1957 record of dau. and dam	56	.19	.38
3. Lifetime ave. of dau. and dam	59	.43	.86
4. 1956 and 1957 records of dau. and dam	25	.45	.90

## MATERIALS AND METHODS

The data used in this study were the birth weights and weaning weights of calves produced by cows located in 4 different herds. Two of these herds (Projects 670 and 650) were owned by the Oklahoma Agricultural Experiment Station and were located at the Ft. Reno Livestock Experiment Station, El Reno, Oklahoma. The two remaining herds were owned by the Federal Government and were located at El Reno and Chilocco, Oklahoma, respectively. Because these herds were located in different geographical areas, and since the management practices varied for each herd, correction of the data for known variables and all statistical analyses were made on an intra-herd basis. For this reason the data are described separately for each herd. Since the statistical procedures used were common to all herds, these methods are discussed under the same heading for all herds.

### PROJECT 670

#### Description of the Data

In 1949, 97 females were purchased as foundation stock for 4 unrelated lines of breeding designed to study the inheritance of economically important traits in beef cattle.

The foundation stock for Line 1, an Angus line, consisted of 22 yearling or 2-year old granddaughters of a single sire. They were by 6 different sires from 6 different herds. This line has been maintained as a closed line with mild inbreeding.

Line 2, a Hereford line, consisted of 6 cows and 19 heifers from a single herd. These females were about 25 percent related to a single sire. Mild inbreeding has been practiced in this line also.

The foundation animals for Line 3, a large-type Hereford line, were 25 weanling heifers purchased from 3 different herds. These heifers were sired by 5 different bulls. This line has been developed as an out-bred line.

Twenty-five small-type weanling Hereford heifers were purchased as the foundation animals for Line 4. The heifers were all obtained from 1 herd and were of the Comprest type tracing to Colorado Domino 68. They were sired by 11 different bulls.

There was very little selection of females in the 4 lines during the period covered by this study. This has been due to expansion of the cow numbers in each of the lines.

With the exception of foundation cows in calf at the time of purchase and some cows bred to calve in the fall of 1950 and 1951, all cows have been bred to calve within a restricted period in the spring of the year. The calves were weighed and identified within 24 hours of birth. With the exception of the entire 1953 calf crop and the 1957 calves of Line 4, none of the male calves were castrated prior to weaning. The calves were weighed at approximately 28-day intervals until they were weaned at an average age of 210 days. None of the calves were creep-fed. The calves were given a score for condition by the same man each year. The scoring system used consisted of 9 numerical classifications. The calves given a score of 1 were in a very unthrifty condition and were considered to be culls, while calves scoring 9 were in a high state of condition similar

to that obtainable with nurse cows. The post-weaning treatment of the replacement females has been variable from year to year although the treatment was the same for all females in any one season. Table 1 shows the post-weaning performance and average age at first calving of the replacement heifers within the various lines. In the winter of 1949-1950 a total of 55 foundation heifers in Lines 2, 3, and 4 were wintered in trap to gain approximately .75 pounds per day. Cottonseed cake, oats, and alfalfa hay were fed in limited amounts and varied with the initial body weight of the heifers. The average daily gain was from .76 pounds for the heifers in Line 2 to .95 pounds for the heifers in Line 3. All of these heifers were grazed together during the summer of 1950 without additional feed and were wintered in traps again in 1950 on prairie hay and cottonseed cake to gain .5 pounds per day. The Line 3 and 4 heifers were bred to calve first at 3 years of age.

The 1951 replacement heifers were placed on a 5-month feeding test immediately after weaning. They were individually self-fed the following mixed ration: 300 pounds chopped alfalfa hay, 455 pounds corn and cob meal, 140 pounds whole oats, 70 pounds wheat bran, and 35 pounds cottonseed meal. Average daily gains were 1.69 pounds for the Line 2 heifers and 1.60 pounds for the Line 1 heifers.

The 1952 replacement heifers received the same treatment as those retained for the breeding herd in 1951. Average daily gains ranged from 1.66 pounds for heifers in Lines 3 and 4 to 1.37 pounds for the Line 1 heifers.

Thirty-nine heifers were self-fed by lines in the fall and winter of 1953. The ration fed consisted of 150 pounds chopped alfalfa hay, 200

TABLE I

## POST-WEANING PERFORMANCE OF REPLACEMENT HEIFERS (PROJ. 670)

Year	Line	No. on Feed	Ave. Days on Feed	Ave. Initial Weight (lbs.)	Ave. Final Weight (lbs.)	Ave. Daily Gain (lbs.)	Ave. Age at First Calving (yrs.)
1949	2	6	142	478	586	.76	2.5
1949	3	24	142	420	555	.95	3.0
1949	4	25	142	386	497	.78	3.0
1951	1	3	143	455	678	1.60	3.0
1951	2	12	152	368	624	1.69	2.5
1952	1	4	154	418	628	1.37	2.0
1952	2	3	154	382	625	1.58	2.0
1952	3	8	154	416	671	1.66	2.7
1952	4	7	154	429	684	1.66	2.0
1953	1	11	154	445	691	1.60	3.0
1953	2	10	154	423	644	1.44	3.0
1953	3	11	154	435	691	1.67	3.0
1953	4	7	154	400	609	1.36	3.0
1954	1	13	154	392	735	2.23	2.0
1954	2	11	154	355	662	1.99	2.0
1954	3	5	154	413	751	2.19	2.0
1954	4	3	154	367	760	2.55	2.0
1955	1	9	154	482	778	1.92	2.0
1955	2	10	154	394	650	1.66	2.0
1955	3	13	154	520	828	2.00	2.0
1955	4	11	154	405	640	1.53	2.0
1956	1	14	156	424	521	.62	2.0
1956	2	10	156	385	457	.46	2.0
1956	3	8	156	479	551	.46	2.0
1956	4	5	156	442	527	.54	2.0

pounds chopped oat hay, 450 pounds ground shelled corn, 100 pounds wheat bran, and 100 pounds of cottonseed meal. The heifers were fed for a period of 154 days and gained an average of 1.52 pounds per day. The heifers were bred to calve first at 3 years of age.

The 1954 replacement heifers were self-fed by lines a ration similar to the one fed the 1953 heifers. This group of heifers gained an average of 2.24 pounds per day and calved first as 2-year olds. The post-weaning treatment of the 1955 heifers was the same as for the 1954 heifers. The average daily gain for all heifers was 1.78 pounds. These heifers were bred as yearlings.

In 1956 the replacement females were fed silage and 1 pound of cottonseed cake per head per day on winter range for a period of 156 days. They made an average daily gain of .52 pounds and had an average final weight of 514 pounds at the end of the 156-day feeding period. These heifers were bred to calve first at 2 years of age.

#### Paternal Half-Sib Correlations of Maternal Effects

The paternal half-sib correlations of maternal effects were calculated for the daughters of the various sires for which data were available using the average birth weights, weaning weights, and condition scores of their calves as the criteria. All analyses were made on an intra-line basis. Within each line the data were divided into subclasses according to the year of birth and sire of the daughter. Sires of the individual calves were treated as random environmental effects. The records available for this phase of the study were collected over a 9-year period from 1950-1958. Table II shows the distribution of the daughters by line, year

TABLE II

DISTRIBUTION OF DAUGHTERS BY LINES, YEARS OF BIRTH, AND SIREs (Proj. 670)

Sire	Total No. of Dau.	Fdn. <sup>1</sup>	Birth Year of Daughter			
			1953	1954	1955	1956
Line 1						
PQ4	4	4	-	-	-	-
AQP	4	4	-	-	-	-
PQ3	3	3	-	-	-	-
QP22	3	3	-	-	-	-
EEP	4	4	-	-	-	-
PQ7	4	4	-	-	-	-
MP3	2	2	-	-	-	-
PQ1	2	2	-	-	-	-
QMP	2	2	-	-	-	-
QP50	4	-	4	-	-	-
041	11	-	-	5	3	3
020	2	-	-	2	-	-
092	3	-	-	3	-	-
112	2	-	-	-	2	-
264	4	-	-	-	-	4
Line 2						
H18	11	11	-	-	-	-
29	3	3	-	-	-	-
933	3	3	-	-	-	-
HC2	4	4	-	-	-	-
901	10	7	-	-	-	3
35	12	-	5	7	-	-
311	2	-	-	-	2	-
120	4	-	-	-	-	4
Line 3						
SB	3	3	-	-	-	-
D17	8	8	-	-	-	-
168	6	6	-	-	-	-
24	3	3	-	-	-	-
GM1	2	2	-	-	-	-
182	4	4	-	-	-	-
176	2	-	2	-	-	-
247	14	-	-	2	10	2
D95	3	-	-	-	-	3
Line 4						
DS1	3	3	-	-	-	-
Q13	5	5	-	-	-	-
CC	3	3	-	-	-	-
33	7	4	3	-	-	-
17	4	-	4	-	-	-
BL	6	-	-	-	6	-
434	2	-	-	-	-	2

<sup>1</sup>Fdn. includes foundation females and heifers calved within the herd prior to 1953.

of birth and sire. The daughters born within the herd prior to 1953 were classified as foundation animals for the purpose of this study since their post-weaning treatment and subsequent performance were similar to that of the foundation heifers.

Making the analysis within-line and birth-year-of-the-daughter tended to eliminate the effects of line, environmental treatment peculiar to the daughters born in any one year, age of cow, and year in which the daughters' calves were born since the daughters of the same line-birth-year-group were bred to calve in the same seasons.

In Line 1 the data consisted of the average records of 54 daughters produced by 15 different sires. The 49 daughters in Line 2 were the offspring of 8 different sires while there were 45 daughters by 9 different sires in Line 3. The data for Line 4 consisted of the average records of 30 daughters produced by 7 sires.

#### Regression of the Daughters' Performance on the Dams' Performance

The daughter-dam pairs within each line were divided into subclasses by sire of the daughter and year of birth of the daughter and of the dam. Thus, all daughters and all dams within each sire-birth-year group were contemporaries. The birth year groups were classified the same as were the birth-year-daughter groups in the paternal half-sib analysis and fell into five categories: foundation females, heifers born in 1953, 1954, 1955, and 1956. Table III shows the distribution of the daughters by lines, years of birth, and sires. There were a total of 106 daughter-dam pairs. These 106 daughters were sired by 22 different bulls and were from 79 different dams. The records used in this phase of the study were



TABLE III  
DISTRIBUTION OF DAUGHTERS BY LINES, YEARS OF BIRTH,  
AND SIRE (PROJ. 670)

Sire	Line	No. of Daus.	Birth Year of Daughter				
			1950-52	1953	1954	1955	1956
QP50	1	4	-	4	-	-	-
041	1	13	-	-	7	3	3
QP1	1	3	-	3	-	-	-
QP22	1	3	3	-	-	-	-
264	1	3	-	-	-	-	3
FQ3	1	2	2	-	-	-	-
112	1	2	-	-	-	2	-
QP23	1	3	-	-	3	-	-
933	2	3	3	-	-	-	-
35	2	13	-	6	7	-	-
120	2	4	-	-	-	2	2
311	2	2	-	-	-	2	-
29	2	3	3	-	-	-	-
HC2	2	4	4	-	-	-	-
901	2	10	7	-	-	-	3
247	3	10	-	-	-	2	8
176	3	2	-	2	-	-	-
D95	3	3	-	-	-	-	3
182	3	4	4	-	-	-	-
17	4	4	-	4	-	-	-
33	4	6	3	3	-	-	-
BL	4	5	-	-	-	5	-

collected over a 9-year period from 1950-1958. All regressions were computed within line, sire, and year of birth of the daughter. Table IV shows the record combinations studied for the various traits along with the number of pairs for each trait.

TABLE IV

RECORD COMBINATIONS USED TO STUDY THE INHERITANCE OF MATERNAL EFFECTS  
BY REGRESSING THE DAUGHTER'S PERFORMANCE ON THE DAM'S PERFORMANCE

Record Combination	Traits Studied		
	No. Pairs Birth Wt.	No. Pairs Weaning Wt.	No. Pairs Cond. Score
Lifetime average of the daughter on lifetime average of the dam	105	106	104
First rec. of the daughter on first rec. of the dam	92	106	100
First rec. of the daughter on the ave. of all records of the dam up to and including birth year of the daughter	101	106	103
Average rec. of the daughter on average rec. of the dam disregarding line of breeding	105	106	104

#### Paternal Half-Sib Correlations of Birth Weight and Weaning Traits

The paternal half-sib correlations for birth weight, weaning weight, and condition score were computed on a within-year and line basis. This allows the comparison of sire-progeny groups within the same year and line, thus eliminating year and line effects between different sire groups. The records for the traits studied were collected over a 9-year period from

1950-1958. Records were available on 744 birth weights, 732 weaning weights, and 728 condition scores. There were 64 different sire-progeny groups represented in this phase of the study.

#### Correction of the Data for Known Variables

##### Age of calf

Since the average age at weaning was approximately 210 days, this age was taken as the standard weaning age and all weights were adjusted to it. This was done by prorating gains made by each calf during the 28-day weigh period bracketing the standard age. The weights of calves which were less than 210 days of age at weaning were adjusted to the standard age by adding to their weaning weight the product of their weight per day of age and the deviation of their age from 210 days.

##### The influence of sex

The sex influence on birth weight was evaluated over all years, lines, and ages of dam. The difference between sexes at birth has been reported as 4 to 6 pounds by Knapp et al., 1940; Gregory et al., 1950; Burris and Blunn, 1952; Botkin and Whatley, 1953; Koch and Clark, 1955d; and Koch et al., 1959. The average difference in favor of bull calves in the present study was approximately 5 pounds.

Sex differences for weaning weights of bulls and heifers reported in the literature have shown considerable variation according to the age at which the calves were weaned. Rollins et al. (1954) reported a 68 pound difference between bulls and heifers at an average age of 240 days. Koch (1951) found bulls to be 44 pounds heavier than heifers at 176 days of

age. Brown (1958) reported Hereford bulls to be 107 pounds heavier than heifers at 240 days of age while Angus bulls were found to be only 67 pounds heavier than heifers at 240 days of age.

The sex corrections for 210-day weight in the present study were made by the method suggested by Koch et al. (1959). According to these writers, a multiplicative factor is more appropriate than an additive factor when the variance among the weights of bulls is significantly larger than the variance among the weights of heifers, as was the case for these data. Both additive and multiplicative adjustments have the same affect on the overall mean, but since they differ in the adjustments made for animals at extreme weights, the variances within a sex are affected differently. Variances are not changed by adding or subtracting a constant amount to or from each weight, but using a ratio or multiplicative adjustment changes the variance provided the ratio is greater or less than unity.

The ratio of the means of the 210-day weights over all lines and years was 1.112. The 210-day weights of the heifers were made equivalent to those of the bulls by multiplying the 210-day weights of the heifers by 1.112.

TABLE V  
AVERAGE BIRTH AND 210-DAY WEIGHTS OF BULLS AND HEIFERS

Items	No. of Animals	Birth Weight (lbs.)	210-Day Weight (lbs.)
Bulls	360	68.0	460
Heifers	305	63.3	414
Diff. (B-H)		4.7	46
Ratio (B/H)			1.112

### The influence of age of dam

Eckles (1919) reported the maximum weights for dairy calves at birth were those from 5 to 8 year old dams. Fitch et al. (1924) found the size of dairy calves from individual cows decreased with the age of the cow after 8 years of age. Koch and Clark (1955d) applied corrections of 4, 2, and 2 pounds to the birth weights of calves out of 2, 3, and 10 year old cows respectively. Other reports were in agreement with these findings and indicated that birth weights of calves increased with age of dam until 5 to 8 years of age (Knapp et al., 1940; Knapp et al., 1942; Braud and Walker, 1949; and Burris and Blunn, 1952).

Knapp et al. (1942) reported that calf weaning weights increased with age of dam up to 6 years and then declined as the cows became older. Knox and Koger (1945) presented results which showed that peak production was attained by 7-year old cows. Koch and Clark (1955d) found that the addition of 41, 18, and 6 pounds were necessary to correct the weaning weight of calves from 3, 4, and 5 year-old cows to the equivalent of the calves produced by 6-year old cows. Three, 6, 12, and 24 pounds were added to the weaning weights of calves produced by 7, 8, 9, and 10-year old cows respectively. Marlowe and Gaines (1958) reported results which showed that maximum production was obtained from cows 6 to 10 years of age. The largest difference was between the calves of 2 and 3-year old cows. The magnitude of the differences decreased with each successive age group until maximum production was reached.

Koch and Clark (1955d) found that the correction factors for differences in age of dam for weaning score was closely associated with the pattern set by weaning weight with the largest difference having been

between the calves of 3 and 4-year old cows. There were no 2-year old cows in this study. Corrections of .6, .3, and .2 of a grade were added to the scores of calves from 3, 4, and 5-year old cows respectively. Corrections of .1, .2, and .4 of a grade were added to the weaning scores of calves from 8, 9, and 10-year old cows respectively. Marlowe and Gaines (1958) found that non-creep-fed calves out of 2-year old cows required a correction of .9 of a grade to make their grades comparable to calves out of 6 and 7-year old cows. Calves out of cows older than 8.5 years had type scores on the average .3 of a grade unit lower than 7 and 8-year old cows.

The method used in this study to correct birth weight, weaning weight, and condition score for the effects of age of dam was to compare averages of records made at each age of dam over all lines. Lush and Shrode (1950) have shown where corrections computed by this method may be biased from the true age effect. These writers pointed out that culling low producing cows at each age will result in each succeeding age group containing a larger share of high producing cows and a smaller share of low producing cows than at the younger ages. As a result, an age of dam correction factor computed by comparing the average production from cows at older ages with the average production from all cows at younger ages would be biased upward from the true age effect. A bias of this nature in these data would be relatively small since the majority of the cows leaving the herd have been culled because of reproductive failures rather than on level of production. Average birth weights, weaning weights, and condition scores for each age of dam are shown in Table VI. Table VII shows the correction factors computed from these averages for each age of dam group.

TABLE VI  
AVERAGE BIRTH WEIGHTS, WEANING WEIGHTS, AND CONDITION  
SCORES FROM COWS OF DIFFERENT AGES

Age of Dam	No. Calves <sup>1</sup>	Birth Weight (lbs.)	No. Calves	Weaning Weight (lbs.)	No. Calves	Cond. Score
2	53	65.4	80	410	80	6.0
3	83	68.5	122	436	122	6.1
4	88	72.0	113	466	113	6.5
5	65	73.9	86	487	86	6.6
6	56	74.3	75	496	75	6.6
7	52	75.6	72	498	72	6.6
8	40	73.2	57	492	57	7.0
9	25	74.2	35	496	35	7.1
10	7	73.0	17	520	17	7.0

<sup>1</sup>Line 1 calves not included in birth weight averages.

TABLE VII  
CORRECTION FACTORS FOR AGE OF DAM

Age of Dam	Birth Weight (lbs.)	Weaning Weight (lbs.)	Cond. Score (units)
2	9	88	1.0
3	6	62	.9
4	2	32	.5
5	0	11	.4
6	0	2	.4
7	0	0	.4
8	0	6	0
9	0	2	0
10	0	0	0

### The influence of year

As it was pointed out earlier, the method of analysis of the paternal half-sib data for birth weight and weaning traits makes adjustment of the data for year effects unnecessary since comparisons of sire-progeny groups are made on a within-year basis. Similarly, the method used in grouping the daughters and dams into birth-year subclasses tended to minimize year effects. However, the failure of all daughters within a birth year group to calve in all years could have possibly introduced year effects into the data where average records were used. A bias of this nature would be relatively small in these data since the yearly calf crop percentage was relatively high.

The weaning weights and condition scores of the calves were corrected for the average effects of year by bringing the average of calf records made in 1954 and 1957 to the average of all years. Twenty-six pounds were added to the 210-day weights of calves weaned in 1954, and 35 pounds were added to the 210-day weights of calves weaned in 1957. Four-tenths of a grade was added to the condition scores of the 1957 calves.

### The influence of inbreeding

Inbreeding of a mild nature was practiced in Lines 1 and 2. This inbreeding was associated with time trends and with the age of the animals in the herd, the younger animals having been more highly inbred. Since no great depression in performance due to the influence of inbreeding has been noted, no correction of the data was made for this variable.



## PROJECT 650

## Description of the Data

In 1948, 120 weanling Hereford heifers were placed on test to study the effects of low, medium, and high levels of supplementary winter feed on beef cows grazing native grass pasture throughout the year. Since 1954, 3 additional replications of the original experiment have been added using the 1954, 1955, and 1956 daughters of the foundation cows for the new replications.

A detailed description of the experimental treatment of this herd has been reported by Zimmerman et al. (1959). The foundation cows were dropped during the winter of 1947-1948. They were divided into 8 lots of 15 animals each. These 8 lots were then assigned at random to receive 3 different levels of supplementary winter feed. Half of these cows calved first at 2 years of age in the spring of 1950, whereas the remainder calved first at 3 years of age in the spring of 1951. From 1950-1953 the cows were mated as a single group to multiple sires. Thus, it was not possible to identify the sires of the individual calves during this period. From 1954-1958 the cows were divided into breeding groups on the basis of their previous productivity. Each breeding group contained cows with like records of past productivity.

The heifers constituting each additional replication were divided into 3 lots of 14 or 15 animals each. The lots were then assigned at random to receive low, medium, or high levels of winter supplemental feed. The heifers which received the different levels of supplemental feed were fed the first winter as weanlings to make the following gains: Low level --

no gain during the winter period. Medium level -- .5 pound gain per day. High level -- 1.0 pound gain per day. All of these heifers were bred to calve first at 2 years of age. They were divided into breeding groups of equal numbers with each group having been balanced according to the sire of the heifers, production of the heifer's dam, and the heifer's own level of supplementary feeding.

The management followed in regard to the calves was essentially the same for all replications. The calves were weighed and identified within 24 hours of birth. Bull calves were castrated at 6 to 8 weeks of age and all calves were weaned in early October. At weaning the calves were scored for condition by 2 men each year. The average of the 2 scores constituted the score for each calf. The system of scoring was the same as for the calves in Project 670. None of the calves were creep-fed.

#### Paternal Half-Sib Correlations of Maternal Effects

The paternal half-sib correlations for maternal effects were calculated for the daughters of the various sires for which data were available using the average birth weights, weaning weights, and condition scores of their calves as the criteria. The analysis was made separately for each replication, and then pooled over all replications to obtain the estimates of heritability. Making the analysis on a within-replication basis made unnecessary correction of the data for age of dam and year effects since the heifers in any one replication were of the same age and were bred to calve in the same seasons.

The data for Replication 2 (heifers born in 1954) consisted of the average records of 34 daughters produced by 4 different sires. The 30

daughters in Replication 3 (heifers born in 1955) were offspring of 5 different sires, 2 of which had daughters in Replication 2. The data for Replication 4 (heifers born in 1956) consisted of the single records of 31 daughters produced by 6 different sires, 1 of which had daughters in Replication 3. The records available for this phase of the study were collected over a 3-year period from 1956-1958.

#### Regression of the Daughters' Performance on the Dams' Performance

The daughter-dam pairs were grouped by the sire and year of birth of the daughter. All daughters in each sire-birth-year group were contemporaries as were their dams. Table VIII shows the distribution of the daughters by sires and year of birth or replication. There was a total of 93 daughter-dam pairs. These 93 daughters were by 12 different sires and were from 68 different dams. The records used in this phase of the study were collected over a 9-year period from 1950-1958. Table IX shows the record combinations in the study of the inheritance of maternal effects with the number of pairs for each trait.

#### Paternal Half-Sib Correlations of Birth Weight and Weaning Traits

The paternal half-sib correlations for birth weight, weaning weight, and condition score were computed on a within-year, replication, and plane of winter nutrition basis. The records for the birth and weaning weights were collected over a 5-year period from 1954-1958, while the condition scores were collected over a 3-year period from 1956-1958. Records were available on 579 birth weights, 577 weaning weights, and 375 condition scores. There were 30 different sire-progeny groups represented in this phase of the study.

TABLE VIII

DISTRIBUTION OF DAUGHTERS BY YEARS OF BIRTH AND SIRE (PROJ. 650)

Sire	No. of Daughters	Year of Birth		
		1954	1955	1956
113	11	11	-	-
247	9	9	-	-
901	22	11	11	-
182	6	3	3	-
120	5	-	5	-
242	5	-	5	-
219	11	-	5	6
309	5	-	-	5
450	5	-	-	5
425	3	-	-	3
D95	5	-	-	5
311	6	-	-	6

TABLE IX

RECORD COMBINATIONS USED TO STUDY THE INHERITANCE OF MATERNAL  
EFFECTS BY REGRESSING THE DAUGHTER'S PERFORMANCE ON THE  
DAM'S PERFORMANCE

Record Combination	No. Pairs Birth wt.	Traits Studied	
		No. Pairs Weaning wt.	No. Pairs Cond. Score
Lifetime average of the daughter on life- time average of the dam	93	93	87
First rec. of the daughter on first rec. of the dam	84	84	
1958 rec. of the daughter on 1958 rec. of the dam	50	50	48

## Correction of the Data for Known Variables

### Age of calf

Since weights were available on the calves in this project at weaning time only, adjustments of weaning weights to a standard age could not be made by the method of linear interpolation. The weaning weights of the calves in this study were corrected to a standard age of 210 days with correction factors computed by Botkin and Whatley (1953) from a series of formulas outlined by Whatley and Quaife (1937). This method of adjustment assumes that the growth rate of calves is essentially linear during that portion of the growth curve to which the corrections are applied.

### The influence of sex

The birth and weaning weights of the heifer calves were adjusted to that of steer calves by adding 5 pounds to the birth and 25 pounds to the weaning weights of the heifers. Botkin and Whatley (1953) found that steers were on the average 24.6 pounds heavier than heifers at 210 days of age. Knapp et al. (1942) reported steers to be an average of 22 pounds heavier than heifers at 180 days of age, while Koger and Knox (1945) found a 32 pound sex difference in favor of steers at 205 days of age.

### The influence of age of dam and year

All of the cows within the separate replications were the same age and were bred to calve in the same seasons with the exception that only one-half of the cows in Replication 1 calved first at 2 years of age in the spring of 1950. The records of 2-year old cows in Replication 1 were

made equivalent to those of 3-year old cows by adding 3 and 46 pounds to the birth and weaning weights of their first calves respectively.

No adjustments were made for year effects since the analysis was made on a within-replication basis. With the exception of those cows in Replication 1 which calved first as 2-year olds, all cows within the same replication were bred to calve at the same age within the same season.

#### Influence of nutritional treatment

Initially, each replication contained equal numbers of heifers for each of the three levels of wintering. However, death losses and removal of heifers from the herd because of reproductive failures resulted in a disproportionate number of heifers receiving the different levels of winter treatment in each of the replications. Zimmerman et al. (1959) reported a significant difference in the performance of the heifers receiving the different levels of winter treatment in Replications 2, 3, and 4. No significant difference for treatment was found in Replication 1.

The birth weights, weaning weights, and condition scores of calves produced by heifers receiving the low and high levels of winter feeding in Replications 2, 3, and 4, which were used to evaluate maternal effects, were adjusted to the average of the calves produced by heifers on the medium level of wintering. All adjustment factors were computed on an intra-replication basis. No adjustment of the data for lot effects (level of wintering) was made for the paternal half-sib analysis of birth weight and weaning traits since this analysis was made on an intra-lot basis.

TABLE X  
CORRECTION FACTORS FOR LEVEL OF WINTERING

Trait	Level of Supplemental Winter Feeding		
	Low	Medium	High
Birth weight (lbs.)	+ 7.0	0.0	0.0
Weaning weight (lbs.)	+32.0	0.0	-9.0
Condition score (units)	+ 0.2	0.0	-0.4

### CHILOCCO

#### Description of the Data

The herd of cattle owned by the Chilocco Indian School consisted of approximately 275 registered Hereford cows 3 years of age or older.

Weaning records were available on 164 calves produced in 1957. Birth weights and weaning scores were not available for the 1957 calf crop.

Records available on calves in 1958 consisted of 150 birth weights and 146 weaning weights and scores.

All cows have been bred to calve first at 3 years of age. All cows of the same age were bred to the same bull. The majority of the calves were dropped over the 3-month period of January-March, with a few having been calved in April and May. The policy on castration of the bull calves has varied from year to year. In 1957 all bull calves, except 27 which were retained as possible herd bull prospects, were castrated near the end of the calving season in late March and early April. The bull calves in 1958 were not castrated prior to weaning. None of the calves were creep-fed. The calves were given a feeder grade at weaning by 1

man. The scoring system and corresponding grades were: 15-13, fancy; 12-10, choice; 9-7, good; 6-4, medium; and 3-1, common. Since 1953 the replacement females have been placed in dry lot immediately after weaning and full fed a ration consisting of 3 parts oats and 1 part wheat bran. In addition silage and hay (alfalfa or prairie) were fed free choice. The heifers were fed for approximately 180 days or until adequate new green forage was available. The second winter the heifers were fed on the range approximately 2 pounds of cottonseed cake per head per day with a liberal amount of alfalfa or prairie hay.

#### Paternal Half-Sib Correlations of Maternal Effects

The paternal half-sib correlations for maternal effects were calculated for the daughters of the various sires for which data were available using the average weight per day of age and weaning scores of their calves as the criteria. The daughters of each sire were divided into subclasses according to their year of birth. Table XI shows the distribution of the daughters by sires and years of birth. Separate analyses were made for the weaning records made in 1957 and 1958 and then pooled over both years to obtain the estimates of heritability. Weaning weights were available on the calves of 136 daughters in 1957, while both weaning weights and scores were available for the calves of 136 daughters in 1958. The daughters were the progeny of 14 different sires.

#### Regression of the Daughters' Performance on the Dams' Performance

The daughter-dam pairs within each season were divided into subclasses by sire of the daughter. Further division into birth-year-of-the



TABLE XI  
DISTRIBUTION OF DAUGHTERS BY YEARS  
OF BIRTH AND SIRE (CHILOCCO)

Sire	Total No. of Daughters	Birth Year of Daughter								
		1947	1948	1949	1950	1951	1952	1953	1954	1955
569	25	-	2	4	4	3	2	3	4	3
756	34	-	-	-	5	7	7	7	6	2
519	14	-	-	-	-	5	2	7	-	-
576	12	5	5	1	1	-	-	-	-	-
5	5	3	2	-	-	-	-	-	-	-
157	5	1	2	2	-	-	-	-	-	-
118	3	3	-	-	-	-	-	-	-	-
1048	19	-	-	-	-	-	-	-	11	8
173	21	-	-	-	-	-	-	5	10	6
937	15	-	-	-	-	-	1	6	3	5
058	24	-	-	-	-	-	6	8	7	3
318	5	-	-	1	4	-	-	-	-	-
623	5	-	-	1	4	-	-	-	-	-
400	3	-	-	-	-	3	-	-	-	-

daughter subclasses was not made because of the small number of daughters which would have been represented in some sire-birth-year groups. The majority of the daughters in any one sire group were born in either 1953 and 1954, or 1954 and 1955.

The record combinations used to study the inheritance of maternal effects were the single records of the daughters and dams that were made in 1957-1958 and the average of the records made in the 2 years. There were a total of 69 daughter-dam pairs with the daughters having been sired by 8 different sires and from 59 different dams.

#### Paternal Half-Sib Correlations of Birth Weight and Weaning Traits

The paternal half-sib correlations for birth weight, weaning weight, and feeder grade were computed on a within-year basis. Records were available on 150 birth weights, 146 weaning scores, and 310 weaning weights. There were 15 different sires represented in this phase of the study.

#### Correction of the Data for Known Variables

##### Age of calf

In these data weight per day of age was used rather than an age-standardized weaning weight because the ages of the calves at weaning varied from an average of 232 days in 1957 to an average of 210 days in 1958. Weight per day of age was used rather than average daily gain because birth weights were not available for the 1957 calf crop. The range in age for the 1957 calves at weaning was from 141 to 285 days with a standard deviation of 34 days. The range in age of the 1958 calves was from 126 to 270 days with a standard deviation of 33 days.

### The influence of sex

Adjustment of sex differences was made by adding 5 pounds to the birth weights and .06 pound to the weight per day of age of the heifer calves respectively. These adjustment factors were computed on a within year basis by taking the average difference between the 2 sexes. The male calves retained as bulls in the 1957 calf crop were excluded from the computations because the decision to retain the calves intact was based on weight gains. Separate correction factors for bulls and steers were not calculated because it was not possible to separate the physiological effects of castration from the effect that selection for size may have had in deciding which bulls to castrate.

### Age of dam and year effects

Since age of dam and sire of calf were confounded in these data, adjustments of birth and weaning weights for age of dam were made by using the correction factors computed by Botkin and Whatley (1953). Four and 2 pounds were added to the birth weights, while 45 and 15 pounds were added to the weaning weights of calves from 3 and 4 year old cows respectively. Cows over 5 years of age were considered as mature.

The age of dam and sex corrected weight per day of age for the calves in 1957 and 1958 was 1.92 and 1.91 pounds respectively. Since the difference between these gains was not significant, no correction of the data was made for year.

## FEDERAL REFORMATORY

### Description of the Data

This herd of cattle consisted of approximately 250 registered and grade Angus cows. Records were available over the 3 year period from 1956-1958 for birth weights, weaning weights, and feeder grades.

The majority of the calves were dropped over the 3-month period of February-April, with a few calves having been calved in May and June. The cows were bred to calve first at 2 years of age. Birth weights were taken within 24 hours of birth and the bull calves were castrated toward the end of the calving season in April. The calves in all years were creep-fed from approximately 100 days of age until weaned during October. The calves were given a feeder grade at weaning by 2 men; however, the same men did not grade the calves each year. The average of the 2 grades was taken as the grade for each calf. The grading system was the same as was used for the Chilocco calves.

### Paternal Half-Sib Correlations of Maternal Effects

The paternal half-sib correlations of maternal effects were calculated for the daughters of the various sires for which data were available using the average birth weights, weaning weights, and feeder grades of their calves as the criteria. The data were divided into subclasses according to the year of birth and sire of the daughter. Twenty-five of the daughters were born in 1954, and 10 were born in 1955. The daughters were sired by the same 3 bulls in both years. The data were analyzed separately for each sire-birth-year group and pooled over both years to obtain the estimates of heritability.

### Regression of the Daughters' Performance on the Dams' Performance

The average performance of the daughters within-sire-birth-year groups was regressed on the average performance of the dam. There was a total of 27 daughter-dam pairs with the daughters having been sired by 3 different bulls and from 24 different dams.

### Paternal Half-Sib Correlations of Birth Weight and Weaning Traits

The paternal half-sib analysis was computed on a within year basis. The data for this phase of the study were collected over the 2-year period of 1957-1958. Data were available on 260 birth weights, 261 weaning weights, and 253 feeder grades. Eleven different sire groups were represented in this analysis.

### Correction of the Data for Known Variables

#### Age of calf

In these data average daily gains were used instead of an age-standardized weaning weight since the ages at weaning varied from an average of 190 days in 1957 to 230 days in 1956. The range in age for the 1956 calves at weaning was from 117-264 days with a standard deviation of 27 days. The age range at weaning for the 1957 and 1958 calves was from 115-245 and 131-242 days respectively. The standard deviations of age at weaning were 33 and 27 days for the 1957 and 1958 calves respectively.

#### The influence of sex

Computation of sex correction factors for birth and weaning weights was made according to the methods described for Project 670. Six pounds

were added to the birth weights of the heifers while the weight per day of age of the heifers was made equivalent to steers by multiplying the weight per day of age of the heifers by 1.082.

#### Influence of age of dam and year

The method used to correct birth weight, weaning weight, and feeder grade for age of dam was to compare averages of records made at each age of dam. Birth weight adjustments of 8, 4, and 2 pounds were made for calves from 2, 3, and 4-year old cows respectively, while average daily gain corrections of .36, .22, .13, and .08 pounds were made for calves out of 2, 3, 4, and 5-year old cows respectively. Feeder grade adjustments of .7, .7, .4, and .3 of a grade were made for calves out of 2, 3, 4, and 5-year old cows respectively. Cows over 5 years of age were considered mature for all traits.

The influence of year was investigated by comparing the performance of equal numbers of cows of the same ages in each of the 3 years. Since the average daily gains and weaning scores were very similar for all years, no adjustment of the data was made for year effects. The average daily gain was 1.90, 1.88, and 1.92 pounds for 1956, 1957, and 1958 respectively. Average feeder grades were 11.2, 11.1, and 11.3 for 1956, 1957, and 1958 respectively.

## Statistical Procedures

### Paternal half-sib correlations of maternal effects

The method of analysis of variance with a single classification and unequal subclass numbers as described by Snedecor (1946) was followed for the estimation of variance components associated with sires and error. The following linear model was considered to be adequate for this phase of the study:

$$Y_{ij} = M + D_i + E_{ij}, \text{ where}$$

$Y_{ij}$  is the observed phenotypic value for the  $j^{\text{th}}$  daughter sired by the  $i^{\text{th}}$  sire.

$M$  is the effect common to all daughters. It is the population mean if all other effects are zero.

$D_i$  is the effect common to all daughters sired by the  $i^{\text{th}}$  sire.

$E_{ij}$  is the effect common to the  $j^{\text{th}}$  daughter and sired by the  $i^{\text{th}}$  sire.

### Paternal half-sib correlations of birth weight and weaning traits

The method of least squares for estimation in a hierarchical classification with disproportionate subclass numbers has been described by Anderson and Bancroft (1952). This method was programmed to facilitate processing the data through a high speed electronic computer. This program, designed by Pulley (1959), computed the analysis of variance for the hierarchical classification and the coefficients of the variance components for each mean square.

Since several modifications (according to the number of stages) of the hierarchical classification were used to analyze different sections

of the data, the mathematical model for each modification is given below:

(1) 3-stage classification

Source of variation

Total

Years

Sires within years

Calves within sires

The following linear model was considered adequate for this situation:

$$Y_{ilt} = M + A_i + D_{il} + E_{ilt}, \text{ where}$$

$Y_{ilt}$  is the observed phenotypic value for the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, and weaned in the  $i^{\text{th}}$  year.

$M$  is the effect common to all calves. It is the population mean if all other effects are zero.

$A_i$  is the effect common to all calves weaned in the  $i^{\text{th}}$  year.

$D_{il}$  is the effect common to all calves sired by the  $l^{\text{th}}$  sire, and weaned in the  $i^{\text{th}}$  year.

$E_{ilt}$  is the effect common to the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, and weaned in the  $i^{\text{th}}$  year.

(2) 4-stage classification

Source of variation

Total

Years

Lines of breeding and/or lots (nutr. levels) within years

Sires within lines or lots

Calves within sires



The following model was used:

$$Y_{iklt} = M + A_i + C_{ik} + D_{ikl} + E_{iklt}, \text{ where}$$

$Y_{iklt}$  is the observed phenotypic value for the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  lot or line, and weaned in the  $i^{\text{th}}$  year.

$M$  is the effect common to all calves. It is the population mean if all other effects are zero.

$A_i$  is the effect common to all calves weaned in the  $i^{\text{th}}$  year.

$C_{ik}$  is the effect common to all calves in the  $k^{\text{th}}$  line or lot, and weaned in the  $i^{\text{th}}$  year.

$D_{ikl}$  is the effect common to all calves sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  line or lot, and weaned in the  $i^{\text{th}}$  year.

$E_{iklt}$  is the effect common to the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  line or lot, and weaned in the  $i^{\text{th}}$  year.

### (3) 5-stage classification

Source of variation

Total

Years

Replications within years

Lots within replications

Sires within lots

Calves within sires

The following model was used as representative of this situation:

$$Y_{ijklt} = M + A_i + B_{ij} + C_{ijk} + D_{ijkl} + E_{ijklt}, \text{ where}$$

$Y_{ijklt}$  is the observed phenotypic value for the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  lot, in the  $j^{\text{th}}$  replication, and weaned in the  $i^{\text{th}}$  year.

M is the effect common to all calves. It is the population mean if all other effects are zero.

$A_i$  is the effect common to all calves weaned in the  $i^{\text{th}}$  year.

$B_{ij}$  is the effect common to all calves in the  $j^{\text{th}}$  replication, and weaned in the  $i^{\text{th}}$  year.

$C_{ijk}$  is the effect common to all calves in the  $k^{\text{th}}$  lot, in the  $j^{\text{th}}$  replication, and weaned in the  $i^{\text{th}}$  year.

$D_{ijkl}$  is the effect common to all calves sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  lot, in the  $j^{\text{th}}$  replication, and weaned in the  $i^{\text{th}}$  year.

$E_{ijklt}$  is the effect common to the  $t^{\text{th}}$  calf, sired by the  $l^{\text{th}}$  sire, in the  $k^{\text{th}}$  lot, or in the  $j^{\text{th}}$  replication, and weaned in the  $i^{\text{th}}$  year.

Intra-sire regression of the daughters' performance on the dams' performance

The model considered to fit the biological situation for the daughter-dam regressions was as follows:

$$Y = M + BX + E$$

Y is the phenotypic observation on the daughter, X is the phenotypic observation on the dam, M and B are population parameters, and E represents the true errors which are assumed to be independently distributed with a mean of zero and variance of  $\sigma^2$ . This model assumes that the X's are measured without error (selected), and the corresponding Y's (unselected) are then measured. Snedecor (1946) has presented the requisite formulas for the computation of the regression coefficients used in this study. In terms of X and Y the regression coefficient b is an estimate of B and is computed by the following formula:

$$b_{yx} = \frac{\sum_{xy}}{\sum x^2}$$

where

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

Here X is the observation on the dam, Y is the observation on the daughter, and N is the number of daughter-dam pairs.

### Heritability Estimates

#### Paternal half-sib correlation method

All methods of estimating heritability rest on the degree to which animals with similar genotypes resemble each other more than less closely related animals (Lush, 1940).

In order to obtain an estimate of heritability by the paternal half-sib correlation method, it is necessary to compute the components of variance due to sires and error, the error term being the variance between half-sibs by the same sire and always having a coefficient of 1. The variance components for sires and error were obtained by equating the expected mean squares to the calculated mean squares and substituting in the estimated coefficients of the expected mean squares. The theoretical analysis of variance for heritability estimates of maternal effects is given in Table XII, and the theoretical analysis of variance for heritability estimates of birth weight and weaning traits is given in Table XIII.

Lush (1948) has presented a thorough discussion on the estimation of heritability by the paternal half-sib correlation method. The sire component of variance is important because it is needed to estimate the additively genetic portion of the variance. Under the conditions of random

TABLE XII  
THEORETICAL ANALYSIS OF VARIANCE FOR COMPUTATION  
OF VARIANCE COMPONENTS (MATERNAL EFFECTS)

Source	D/F	SS	MS	Coefficients of Variance Components E(MS) <sup>1,2</sup>
Total	N-1	TSS		$\sigma_E^2 + \sigma_D^2$
D	d-1	SSD	$\frac{SSD}{d-1}$	$1 + d_1$
E in D	$\sum_i e_i - d$	SSE	$\frac{SSE}{N - \sum d_i}$	1

D = Sires

E = Daughters

$d_1$  = Coefficient of sire E(MS)

<sup>1</sup>Methodology according to Pulley (1959).

<sup>2</sup>Coefficients of expected mean squares computed according to Snedecor (1946).

TABLE XIII

THEORETICAL ANALYSIS OF VARIANCE FOR COMPUTATION OF VARIANCE  
COMPONENTS (BIRTH WEIGHT AND WEANING TRAITS)

Source	D/F	SS	MS	Coefficients of Variance Components E(MS) <sup>1,2</sup>
Total	N-1	TSS		$\sigma_E^2 + \sigma_D^2 + \sigma_C^2 + \sigma_B^2 + \sigma_A^2$
A	a-1	SSA	$\frac{SSA}{a-1}$	$1 + d_4 + c_3 + b_2 + a_1$
B in A	$\sum_i b_i - a$	SSB	$\frac{SSB}{\sum_i b_i - a}$	$1 + d_3 + c_2 + b_1$
C in B	$\sum_{ij} c_{ij} - \sum_i b_i$	SSC	$\frac{SSC}{\sum_{ij} c_{ij} - \sum_i b_i}$	$1 + d_2 + c_1$
D in C	$\sum_{ijk} d_{ijk} - \sum_{ij} c_{ij}$	SSD	$\frac{SSD}{\sum_{ijk} d_{ijk} - \sum_{ij} c_{ij}}$	$1 + d_1$
E in D	$N - \sum_{ijk} d_{ijk}$	SSE	$\frac{SSE}{N - \sum_{ijk} d_{ijk}}$	1

A = Years

B = Replications

C = Lines and/or lots

D = Sires

E = Calves

 $a_1$  = Coefficient of year E(MS) $b_1, b_2$  = Coefficient of replication E(MS) $c_1, c_2, c_3$  = Coefficient of line and/or lot E(MS) $d_1, d_2, d_3, d_4$  = Coefficient of sire E(MS).

In each stage a new estimate of the coefficient of the expected mean square is computed for each component.

<sup>1</sup> Methodology according to Pulley (1959).

<sup>2</sup> Coefficients of expected mean squares computed according to Anderson and Bancroft (1952).

mating, genic values of half-sibs are correlated by 25 percent, dominance deviations are uncorrelated, and epistatic deviations are correlated by an undetermined but small amount. The probability of joint transmission of combinations of non-allelic genes leads to the expectations that an epistatic effect requiring  $n$  non-allelic genes will be correlated  $(1/4)^n$  between half-sibs. If epistasis is negligible and the environmental correlations among half-sibs have been adequately discounted, the expected value of the sire component of variance is  $1/4\sigma_G^2$  under random mating. The expected value of the mean square within sires is  $3/4\sigma_G^2 + \sigma_E^2$ . An estimate of heritability is  $\frac{4\sigma_S^2}{\sigma_S^2 + \sigma_E^2}$ .

If the breeding system has deviated from random mating because of inbreeding, the genic values of the half-sibs will not be correlated by one-fourth, but will be somewhat greater because of the extra relationship through inbreeding. In this case the fraction of the total variance due to sires would not be multiplied by 4, but by a lesser amount in order to discount the additional relationship of the half-sibs brought about through inbreeding. In Lines 1 and 2 in Project 670 mating was not random but deviated because of inbreeding. Since the magnitude of the deviations from random mating was not known for all animals in these 2 lines, the components of variance were not adjusted for the effects of inbreeding. In all probability the heritabilities computed for these 2 lines are slightly biased upward, but taking into consideration the relatively long generation interval with the short period of time these lines have been in existence, inbreeding was not thought to have been a major source of error in these data.

Intra-sire regression of the daughters' performance on the dams' performance

Lush (1940) has presented an excellent discussion on this method of estimating heritability. Heritability is obtained by doubling the intra-sire regression coefficient computed by the method discussed earlier. The intra-sire regression of daughter on dam is essentially a parent-offspring resemblance but computing it on an intra-sire basis tends to automatically discount environmental contributions and any peculiarities of the mating system. This results because the analysis is restricted to such variance as is found within groups of females which get mated to the same sire. Differences between such groups of females remain un-analyzed as to the extent to which they are hereditary or environmental in origin. In the present study the calves of the daughters and of the dams were sired by different bulls within the same sire-of-the-daughter-group. However, this source of variation was thought to have been random with respect to the various daughter-dam pairs, and as such should not have introduced any systematic biases into the data.

#### Standard errors of the estimates

The standard errors for the half-sib correlations and intra-sire regression coefficients were computed by the method described by Hazel and Terrill (1945). In computing the standard errors of the heritability estimates only the actual number of sires used was considered.

## RESULTS AND DISCUSSION

The estimates of heritability obtained for maternal effects on birth weight, weaning weight, and weaning score and the direct effect of the sire upon the birth weight, weaning weight, and weaning score of his offspring are discussed separately for each herd.

Heritability estimates for maternal effects computed from intraclass correlations of calves of paternal half-sisters and from the regression of the daughters' performance on the dams' performance contain the fraction of additively genetic inheritance transmitted by a sire or dam to its daughters which is concerned with the daughters' mothering ability, that is, uterine environment, milk production, and other items involved in postnatal care. These estimates also contain some of the additively genetic inheritance transmitted by a sire or dam to its daughters which is concerned with the growth potential of the daughters calves.

Heritability estimates of birth weight and weaning traits computed from intraclass correlations of paternal half-sib calves contain the fraction of additively genetic inheritance transmitted by a sire directly to his offspring which is concerned with the offspring's prenatal growth and gains made from birth to weaning. The extent to which the heritability estimates for maternal effects and for the direct effect of the sire upon his progeny may also contain non-additive inheritance has been discussed in the section on materials and methods.



## PROJECT 670

The cattle in Project 670 consisted of 4 unrelated lines of registered stock owned by the Oklahoma Agricultural Experiment Station at Ft. Reno. Line 1 (Angus) and Line 2 (Hereford) were maintained as closed lines with mild inbreeding, whereas Lines 3 and 4 were Hereford lines developed as outbred lines. There has been very little selection of the females in the 4 lines because of expansion of the herd.

Heritability Estimates of Maternal Effects Computed From  
Paternal Half-Sib Correlations

The data for this part of the study consisted of the average birth weights, weaning weights, and condition scores of calves produced by 178 paternal half-sisters. The paternal half-sisters were sired by 39 different bulls. The records were collected over a 9-year period from 1950-1958, and all analyses were made within lines and birth years of the daughters. The estimates of heritability were computed from the pooled analysis of the different lines.

The average lifetime performance of the daughters of the various sires by lines and years of birth for the different traits is presented in Table XIV. The average weaning weights of calves produced by heifers born in 1953, 1954, and 1955 were appreciably less than the average weaning weights of calves produced by foundation heifers and heifers born in 1956. Since all birth weights, weaning weights, and condition scores were standardized for the effects of sex, age of dam, age of calf, and year in which the calf was weaned, it would appear that the post-weaning treatment of these daughters had a detrimental effect on the daughters<sup>o</sup>

TABLE XIV

LIFETIME PERFORMANCE OF HALF-SIB DAUGHTERS BY LINES,  
YEARS OF BIRTH, AND SIRE (PROJ. 670)

Sire	No. of Dau.	Year of Birth	Ave. No. Rec.	Adj. Ave. Birth Wt.	Adj. Ave. Wn. Wt.	Adj. Ave. Cond. Score
Line 1						
PQ4	4	Fdn. <sup>1</sup>	5.8	64.0	514	7.5
AQP	4	Fdn.	5.0	63.2	488	7.0
PQ3	3	Fdn.	3.3	59.0	489	7.2
Q22	3	Fdn.	2.7	60.2	488	7.0
EEP	4	Fdn.	5.5	63.5	519	7.4
PQ7	4	Fdn.	5.0	66.0	554	7.5
MP3	2	Fdn.	5.5	66.5	519	7.4
PQ1	2	Fdn.	5.0	69.0	490	6.6
QMP	2	Fdn.	6.0	65.0	519	7.4
Q50	4	1953	1.0	69.8	434	5.4
041	5	1954	1.8	61.6	425	5.3
020	2	1954	2.0	66.5	527	6.7
092	3	1954	3.3	64.3	498	7.0
041	3	1955	1.7	61.0	427	7.7
112	2	1955	1.5	61.5	434	6.2
041	3	1956	1.0	62.0	538	7.7
264	4	1956	1.0	67.5	580	7.0
Line 2						
H18	11	Fdn.	4.9	73.2	454	6.6
29	3	Fdn.	4.0	82.3	467	6.6
933	3	Fdn.	3.3	84.0	519	5.9
HC2	4	Fdn.	3.8	75.2	450	5.9
901	7	Fdn.	3.0	74.4	436	5.6
35	5	1953	1.8	81.4	451	6.7
35	7	1954	1.4	75.3	446	6.2
311	2	1955	1.5	75.2	418	4.7
120	4	1956	1.0	63.5	475	7.2
901	3	1956	1.0	68.7	500	6.7

<sup>1</sup>Fdn. includes foundation females and heifers calved within the herd prior to 1953.

TABLE XIV (Continued)

Sire	No. of Dau.	Year of Birth	Ave. No. Rec.	Adj. Ave. Birth Wt.	Adj. Ave. Wn. Wt.	Adj. Ave. Cond. Score
Line 3						
SB	3	Fdn. <sup>1</sup>	3.0	72.3	500	6.1
D17	8	Fdn.	5.2	82.2	531	7.1
168	6	Fdn.	6.3	82.0	546	7.6
24	3	Fdn.	4.0	75.3	506	6.7
GM1	2	Fdn.	4.5	80.0	542	7.2
182	4	Fdn.	4.0	90.2	572	7.2
176	2	1953	1.0	80.0	449	6.2
247	2	1954	2.0	84.0	468	6.6
247	10	1955	1.3	78.2	448	5.8
247	2	1956	1.0	79.0	526	9.0
D95	3	1956	1.0	77.3	529	7.7
Line 4						
DS1	3	Fdn.	3.0	62.3	423	7.6
Q13	5	Fdn.	4.6	72.0	460	7.0
CC	3	Fdn.	6.0	74.0	500	7.7
33	4	Fdn.	2.5	81.0	535	6.6
33	3	1953	2.0	77.3	452	7.2
17	4	1953	2.8	75.0	442	6.7
BL	6	1955	2.0	74.7	394	5.6
434	2	1956	1.0	82.0	518	8.0

<sup>1</sup>Fdn. includes foundation females and heifers calved within the herd prior to 1953.

subsequent production.

Table XV shows the estimates of heritability for the various traits. Heritabilities of birth weight, weaning weight, and condition score were .92, .64, and .17 respectively. The estimate of .92 for birth weight appears to be exceptionally high. However, it would seem that the maternal effect on birth weight would be a maximum in relation to other traits since the calf is in an intra-uterine environment provided by the cow from conception until birth. The estimate of .17 for condition score is lower than was expected in view of the large estimate for weaning weight. It would seem that maternal effects which increase weaning weight would also affect condition score favorably since the condition score of a calf is related to the milking ability of its dam. However, the large standard error associated with the estimate for condition score suggests that considerable error was associated with the evaluation of scores in this study. Larger errors are expected to be associated with scores than with weights because of the subjective nature of the scoring system.

All of the estimates in this phase of the study may have been biased upward to some extent by common environment and assortive mating. As was outlined in the section on materials and methods, the foundation animals within both Lines 1 and 3 were purchased from different herds. To the extent that environment common to the daughters of a sire within the same line-birth-year group caused their subsequent performance to be correlated, then heritability based on paternal half-sib correlations from such data would be biased upward because of common environment. If the average genetic merit of the mates of the various sires from which the daughters were produced was different, the effects of assortive mating would be

TABLE XV  
ANALYSIS OF VARIANCE OF MATERNAL EFFECTS FOR PATERNAL HALF-SIB  
DAUGHTERS POOLED FROM ALL LINES (PROJ. 670)

Item and Source of Variation	D/F	Mean Square	Herit.	St. Error
Birth weight			.92	.40
Total	159	76.22		
Between sires	27	76.22		
Daughters within sires	132	34.41		
Weaning weight			.64	.32
Total	159			
Between sires	27	3,331.43		
Daughters within sires	132	1,893.66		
Condition score			.17	.28
Total	159			
Between sires	27	1.2802		
Daughters within sires	132	1.0897		

included in the estimate of heritability. This would tend to increase sire differences, thus biasing heritability upward. The extent to which the effects of assortive mating and common environment influenced the production records of the foundation females is not known.

Heritability Estimates of Maternal Effects Computed from the Intra-Sire Regression of the Daughters' Performance on the Dams' Performance

Records were available on a total of 106 daughter-dam pairs for this phase of the study. The 106 daughters were by 22 different bulls and from 79 different dams. The records were collected over a 9-year period from 1950-1958. All regressions were computed within line, year of birth, and sire of the daughter.

The number of daughters by each sire and the average birth weights, weaning weights, and condition scores of their calves and of their dams' calves are presented in Table XVI. Table XVII shows the estimates of heritability for the various traits computed from these data for each record combination in each line. The heritability of birth weight computed by regressing the average of all records of the daughter on the average of all records of the dam ranged from .07 for Line 2 to .58 for Lines 1 and 3. When the sums of squares and sums of cross products were pooled over all lines, the estimate was .28 with a standard error of .16. Two additional estimates of the heritability of birth weight were computed by regressing the first record of the daughter on the average of all records of the dam up to and including the birth weight of the daughter and regressing the first record of the daughter on the first record of the dam. The sums of squares and sums of cross products pooled

TABLE XVI

LIFETIME PERFORMANCE OF DAUGHTER-DAM GROUPS BY LINE, YEAR  
OF BIRTH, AND SIRE OF THE DAUGHTER (PROJ. 670)

Sire	Birth Year of Dau.	Line	Birth Weight				Weaning Weight				Condition Score			
			No.	Prs.	Dau.	Dam	No.	Prs.	Dau.	Dam	No.	Prs.	Dau.	Dam
Q50	1953	1	4		69.8	68.0	4		434	523	4		5.4	7.3
041	1954	1	7		62.8	62.7	7		457	507	7		5.9	7.1
041	1955	1	3		61.0	65.3	3		427	515	3		7.7	7.6
041	1956	1	3		62.0	63.3	3		538	491	3		7.7	6.8
QP1	1953	1	2		60.5	63.5	3		482	503	2		4.4	7.4
Q22	1951	1	3		60.3	67.3	3		488	516	3		7.0	7.4
264	1956	1	3		67.7	61.7	3		575	505	3		6.7	6.7
MP3	1950	1	2		66.5	59.0	2		519	450	2		7.4	6.4
112	1955	1	2		61.5	65.0	2		434	528	2		6.2	7.2
092	1954	1	3		64.3	60.3	3		498	488	3		7.0	7.4
933	1951	2	3		84.0	78.3	3		519	467	3		6.6	6.7
35	1953	2	6		79.8	75.5	6		457	450	6		6.8	6.2
35	1954	2	7		75.3	77.3	7		446	465	7		6.2	6.6
120	1955	2	2		77.5	75.5	2		402	524	2		7.4	4.0
120	1956	2	2		68.5	71.0	2		475	470	2		6.5	7.0
311	1955	2	2		75.2	75.0	2		418	474	2		4.7	7.2
29	1950	2	3		82.2	73.3	3		467	414	3		6.6	6.0
HC2	1951	2	3		74.7	75.7	3		445	442	3		6.2	6.2
HC2	1952	2	1		77.0	71.0	1		465	450	1		6.6	6.5
901	1951	2	3		74.0	78.0	3		450	478	3		6.5	7.1
901	1952	2	4		74.8	76.0	4		425	454	4		4.9	6.6
901	1956	2	3		68.7	76.0	3		500	479	3		6.7	6.9

TABLE XVI (Continued)

Sire	Birth Year of Dau.	Line	Birth Weight			Weaning Weight			Condition Score		
			No. Prs.	Dau.	Dam	No. Prs.	Dau.	Dam	No. Prs.	Dau.	Dam
247	1954	3	2	84.0	80.5	2	468	582	2	6.6	8.2
247	1955	3	8	78.5	80.8	8	428	533	8	5.6	7.1
176	1953	3	2	80.0	77.0	2	449	509	2	6.2	5.8
D95	1956	3	3	77.3	78.6	3	529	530	3	7.7	7.2
182	1952	3	4	90.0	80.8	4	572	550	4	7.2	7.4
17	1953	4	4	75.0	72.5	4	442	452	3	6.7	7.4
33	1952	4	3	80.0	75.3	3	527	487	3	6.9	6.7
33	1953	4	3	77.3	67.7	3	452	455	3	7.2	6.7
BL	1955	4	5	74.6	73.4	5	383	471	5	5.5	7.0



TABLE XVII

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION OF THE DAUGHTERS' PERFORMANCE ON THE DAMS' PERFORMANCE BY LINE AND YEAR OF BIRTH OF THE DAUGHTER (PROJ. 670)

Record Combination	Line	Birth Weight			Weaning Weight			Cond. Score		
		No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error
Lifetime ave. of the dau. on the lifetime ave. of the dam	1 2 3 4	32 39 19 15	.58 .07 .58 .12	.72 .46 .58 .40	33 39 19 15	-.80 .30 .46 .30	.34 .36 .62 .40	32 39 19 14	-.20 .42 -.32 -.68	1.40 .36 .54 .58
All lines pooled <sup>1</sup>		105	.28	.16	106	.12	.24	104	-.14	.26
First rec. of the dau. on the ave. of all rec. of the dam up to and including the birth year of the dau.	1 2 3 4	32 35 19 15	.06 1.68 .28 .90	.60 .88 .54 .40	33 39 19 15	-.82 .44 .52 .88	.46 .38 .38 .58	33 39 18 13	-1.52 .30 .00 -.46	.75 .52 .56 .62
All lines pooled <sup>1</sup>		101	.60	.34	106	.13	.24	103	-.36	.26
First rec. of the dau. on the first rec. of the dam	1 2 3 4	32 26 19 15	.24 1.24 .32 -.04	.38 .78 .30 .58	33 39 19 15	-.50 .36 .36 .85	.36 .38 .38 .54	30 39 18 13	-.82 .28 .54 -.54	.64 .44 .50 .38
All lines pooled <sup>1</sup>		92	.31	.24	106	.06	.20	100	-.12	.26

<sup>1</sup>The pooled sums of squares and sums of cross products for the above record combinations are shown in Appendix Tables XLIV-XLVI.

over all lines yielded an estimate of .60 by the first method and .31 by the latter method.

Of the 3 estimates computed from pooled sums of squares and sums of cross products, heritabilities estimated from the average of all records are thought to be more reliable. Heritability estimated from first records of daughters and dams gives the earliest indication of the dam's genetic worth for the various maternal traits as measured by the mothering ability of her daughter. However, heritability estimates based on first records have the disadvantage of being influenced to a large extent by fluctuations in environment and by chance combinations of non-additive genes. Heritability estimated by regressing the first record of the daughter on the average of all records of the dam up to and including the phenotype of the daughter should be more reliable than heritability estimated from single records because the dams have more than one record.

By taking into consideration the small number of daughter-dam pairs available within each line, the heritability estimates for weaning weight were very similar for Lines 2, 3, and 4. Heritability of weaning weight obtained by regressing average records was .30, .46, and .30 for Lines 2, 3, and 4 respectively. Estimates computed by regressing the first record of the daughter on the average of all records of the dam up to and including the daughter's own weaning weight were .44, .52, and .88 for Lines 2, 3, and 4 respectively. Similar estimates were obtained by regressing the first record of the daughter on the first record of the dam. Large negative heritability estimates of weaning weight were obtained for Line 1 from all record combinations used. The estimate computed from the regression of average records was  $-.80$ , while heritability computed from the

regression of the first record of the daughter on the average of all records of the dam up to and including the weaning weight of the daughter was  $-.82$ . The regression of first records yielded an estimate of  $-.50$ . Estimates of heritability computed from the sums of squares and sums of cross products pooled over all lines ranged from  $.13$  for the regression of the first record of the daughter on the average of all records of the dam up to and including the daughter's own weaning weight to  $.06$  for the regression of the first record of the daughter on the first record of her dam. The standard errors exceeded the estimates of heritability for all pooled estimates.

Estimates of heritability of condition score computed from the sums of squares and sums of cross products pooled over all lines were negative for all record combinations studied. Estimates for Line 1 were large and negative for all record combinations and corresponded closely in both size and direction with the estimates obtained for weaning weight in this line. Heritability of condition score was negative in Line 4 for all record combinations, while positive estimates were obtained for Line 2. The standard errors associated with all heritability estimates of condition score were large and in many cases exceeded the size of the corresponding heritability estimate.

Heritabilities for all traits computed from the pooled sums of squares and sums of cross products were smaller than those obtained by the half-sib correlation method. The reason for this discrepancy is not known. As was pointed out in the discussion on the paternal half-sib correlations of maternal effects, the existence of common environment among the foundation females purchased from different herds could have biased heritability upward.

In the regression analysis the dams of contemporary daughters were produced in different herds. If the previous environmental treatment of dams produced in different herds had masked the genetic potential of dams from some herds but not of dams from other herds, the association of the daughter's production with the dam's production would have been lower than if the dam's phenotype were an accurate indication of her breeding value. In this case the effect of common environment would have been to bias heritability downward.

Sampling errors may also account for a part of the discrepancy in degree of heritability estimated by the regression analysis and by the half-sib correlation method. Due to the larger number of daughters used in the half-sib analysis, the influence of errors of random sampling would be expected to be less than in the regression analysis. It is interesting to note that if Line 1 is omitted, the average of the heritability estimates for weaning weight computed from the intra-sire regression of the daughter's production on the dam's production for all record combinations agrees very well with the estimates computed by the paternal half-sib method.

Table XVIII presents heritability estimates computed from the intra-sire regression of the daughter's performance on the dam's performance within year of birth of the daughter. Line of breeding was ignored in this analysis. All estimates were computed from the regression of average records. The estimates obtained for weaning weight for the different birth-year groups are of particular interest because of the different environmental treatment of the heifers born in the different years. The environmental treatment of the different birth-year groups was discussed

TABLE XVIII

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION OF THE DAUGHTERS' PERFORMANCE ON THE DAMS' PERFORMANCE BY YEAR OF BIRTH OF THE DAUGHTER (PROJ. 670)

Record Combination	Birth Year of Dau.	Birth Weight			Weaning Weight			Cond. Score		
		No. Pairs	Herit.	St. Error	No. Pairs	Herit.	St. Error	No. Pairs	Herit.	St. Error
Lifetime ave. of the dau. on lifetime ave. of the dam	Prior to 1953	29	-.30	.32	29	.50	.54	29	-.20	.74
	1953	21	.52	.46	22	-.19	.54	20	-.80	.66
	1954	19	.88	1.02	19	.24	.50	19	.13	1.02
	1955	22	.00	.42	22	-.32	.60	22	.40	1.20
	1956	14	2.76	1.24	14	.18	2.00	14	1.54	.96

earlier. Heritability of weaning weight for both groups of heifers fed to make limited post-weaning gains was positive while 2 of the 3 estimates for the heifers full fed as weanlings were negative. These estimates would seem to indicate a closer association between the production of heifers which made relatively small post-weaning gains and the production of their dams rather than the association between the production of the full fed heifers and the production of their dams. It would appear that full feeding of the heifers prior to their first lactation masked the genetic potential of the heifers for milk production to the extent that there was essentially no correlation between the heifer's performance and her dam's performance.

Heritability Estimates of Birth Weight and Weaning Traits  
Computed from Paternal Half-Sib Correlations

The data analyzed in this section of the study consisted of 744 birth weights, 732 weaning weights, and 728 condition scores. All records were obtained over a 9-year period from 1950-1958 and involved 64 different sires. All analyses were made on a within-year and line basis. The analysis of variance from which each estimate of heritability was obtained is shown in Appendix Tables XLVII-LI.

Table XIX presents the average performance of calves by years, lines, and sires. The number of calves by each sire in each year for the different traits is also shown. The average birth and weaning weights of all calves in Line 1 were 64 and 505 pounds respectively, while the average condition score was 6.9. The calves in Line 2 had an average condition score of 6.5, while the average birth and weaning weights of

TABLE XIX  
AVERAGE PERFORMANCE OF CALVES BY YEARS, LINES, AND SIRES  
(PROJ. 670)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Line 1							
QPS	1950	2	65.5	2	526	2	6.4
PEV	1950	-	--	1	502	1	5.5
PE1	1950	1	71.0	1	469	1	7.9
PQ9	1950	1	66.0	1	512	1	6.9
QMP	1950	1	81.0	1	570	1	6.9
FE1	1951	1	66.0	1	467	2	7.4
MP3	1951	2	65.0	2	457	2	5.0
QMP	1951	1	79.0	1	512	1	7.9
Q22	1951	9	60.1	8	567	9	7.2
GO	1951	1	66.0	1	401	-	-
Q22	1952	8	59.5	6	494	7	7.2
48	1952	10	65.7	10	522	10	7.8
Q50	1953	8	66.4	8	505	7	7.8
QP1	1953	6	58.2	6	484	6	6.8
041	1953	4	71.0	4	552	4	7.4
QP1	1954	11	61.6	11	510	11	7.3
041	1954	9	64.4	9	504	9	6.9
092	1954	3	63.0	3	505	3	6.6
041	1955	15	63.3	15	531	15	7.1
112	1955	7	64.8	7	492	6	7.3
Q22	1956	1	54.0	1	535	1	6.0
041	1956	20	65.2	19	501	20	6.9
104	1956	3	60.3	3	471	3	6.4
264	1956	13	65.5	12	478	13	5.2
620	1956	1	69.0	1	410	1	8.0
041	1957	17	63.6	16	512	16	6.8
205	1957	11	62.0	11	450	11	4.9
041	1958	16	65.1	16	506	16	8.1
046	1958	6	67.0	6	507	6	6.7
196	1958	12	64.4	12	525	12	7.4
620	1958	1	72.0	1	414	1	6.5

TABLE XIX (Continued)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Line 2							
H18	1950	-	-	1	498	1	8.4
29	1950	-	-	3	449	3	6.1
L41	1950	-	-	1	488	1	7.0
H18	1951	2	79.0	2	460	2	6.4
CR4	1951	3	76.0	3	444	3	6.6
HC2	1951	6	72.0	6	510	6	6.8
HC2	1952	1	71.0	1	454	1	7.4
901	1952	19	72.8	19	459	19	7.0
933	1952	5	69.8	5	472	5	7.3
35	1953	27	74.4	27	486	24	7.3
35	1954	20	77.6	20	464	20	6.3
901	1954	1	100.0	1	463	1	5.4
242	1954	3	84.3	3	424	3	5.7
LD5	1955	1	67.0	1	480	-	-
120	1955	3	80.0	3	559	3	8.2
242	1955	1	86.0	1	511	1	6.4
309	1955	5	75.0	5	456	5	6.8
311	1955	13	72.4	13	451	13	5.8
343	1955	8	79.5	8	464	8	6.0
901	1956	20	74.6	20	421	19	5.6
120	1956	16	69.6	16	429	16	6.4
A2	1957	26	78.1	26	445	26	6.2
RS	1958	1	77.0	1	368	1	5.0
GA	1958	2	74.0	2	476	2	7.2
S61	1958	25	80.4	16	466	24	6.6
664	1958	8	65.9	8	496	8	7.0



TABLE XIX (Continued)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Line 3							
176	1952	7	74.3	7	486	7	6.8
182	1952	10	89.5	9	546	8	7.8
176	1953	11	80.8	11	538	11	6.8
182	1953	10	79.0	10	532	10	7.0
247	1954	6	81.7	6	563	6	7.2
D84	1954	3	78.0	3	454	3	6.1
D95	1954	11	77.0	11	522	11	7.0
247	1955	25	81.7	24	584	24	7.4
247	1956	13	84.2	13	547	13	7.5
D95	1956	11	79.3	11	543	11	7.2
450	1956	3	81.0	3	432	3	4.7
247	1957	21	84.4	21	526	21	6.5
450	1957	9	75.1	9	462	9	5.9
247	1958	18	82.4	18	503	17	7.6
450	1958	5	79.0	5	529	5	8.2
516	1958	4	85.2	4	436	4	5.9
533	1958	2	75.5	2	412	2	5.4

TABLE XIX (Continued)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Line 4							
17	1952	3	63.7	3	477	3	6.9
22	1952	2	60.5	2	436	2	5.9
33	1952	5	66.6	5	489	5	5.7
182	1952	2	73.0	2	468	2	5.9
17	1953	11	72.2	11	465	9	7.5
33	1953	6	72.2	6	511	6	7.8
HC2	1954	5	79.0	5	539	5	7.6
D77	1954	8	73.5	8	495	7	6.8
48	1954	6	68.7	6	448	6	6.9
BL	1955	21	71.8	21	479	20	6.8
D95	1955	1	65.0	0	-	-	-
424	1956	10	64.4	10	405	8	6.8
430	1956	3	72.3	3	483	3	7.6
434	1956	14	75.8	14	498	14	6.7
Z20	1957	7	66.6	7	427	7	6.5
Z50	1957	13	75.0	13	434	12	6.6
Z69	1957	11	73.6	11	483	11	7.1
Z50	1958	7	80.6	7	437	7	6.9
Z69	1958	6	82.0	6	448	6	6.9
901	1958	5	74.0	5	417	5	7.2
450	1958	7	73.4	7	427	7	7.2
620	1958	5	72.8	5	393	5	6.5

the calves were 75 and 460 pounds respectively. The calves in Line 3 had an average birth weight of 81 pounds, and they averaged 526 pounds at weaning. These calves had an average condition score of 7.0. The average birth and weaning weights of the Line 4 calves were 73 and 461 pounds respectively, and they had an average condition score of 6.9. The average birth weight, weaning weight, and condition score of calves from all lines were 73 pounds, 487 pounds, and 6.8 respectively.

Table XX shows the heritability estimates for the various traits for each line. The estimates for birth weight ranged from 1.00 for Line 2 to .22 for Line 1. The estimate computed within lines was .64 with a standard error of .19. Heritability of weaning weight computed for the different lines ranged from .36 for Line 2 to 1.32 for Line 3. The estimate computed within lines was .66 with a standard error of .20. Heritability of condition score ranged from 1.18 for Line 3 to -.36 for Line 4. As was expected, Lines 1 and 3 which had the highest heritability estimates for weaning weight also had the highest estimates of heritability for condition score. The estimate of heritability for condition score computed from within lines was .52 with a standard error of .19. The negative heritability estimate of condition score obtained for Line 4 may have been due to increased within sire variance because the calves of some sires were of both the comprest and non-comprest types. Comprest calves tend to possess a higher state of condition than non-comprest calves.

With the exception of condition score, line differences were significantly different for all traits studied. The estimates of heritability for the various traits for the different lines were highly variable and

TABLE XX

HERITABILITY ESTIMATES OF BIRTH WEIGHT AND WEANING TRAITS COMPUTED  
FROM PATERNAL HALF-SIB CORRELATIONS (PROJ. 670)

Line	Birth Weight		Weaning Weight		Cond. Score	
	Herit.	St. Error	Herit.	St. Error	Herit.	St. Error
1	.22	.30	.51	.36	1.07	.44
2	1.00	.40	.36	.44	.21	.33
3	.71	.52	1.32	.60	1.18	.60
4	.68	.38	.42	.32	-.36	.36
All lines	.64	.19	.66	.20	.52	.19

in some cases exceeded 100 percent. Obviously, heritability estimates in excess of 1.00 or less than zero have no biological meaning. At least a part of the large sire differences in Lines 1 and 3 was due to 1 sire in each of the two lines. From Table XIX it can be seen that sire 041 in Line 1 produced offspring in 6 consecutive years, whereas sire 247 in Line 3 produced offspring in 5 consecutive years. Comparison of the average performance of these two sires within their respective lines with that of other sires which produced calves in the same years shows that in most years sire variances were influenced considerably by the same sire. Also, the heritability estimates in the present study may be a bit too high because in some years the older bulls were mated to the older cows and the younger bulls were mated to the younger cows. If the age of dam corrections used in these data did not adequately compensate for age of dam differences, or if the genetic merit of the 2 age of dam groups were different, the observed sire differences would include both the effects of assortive mating and age of dam, thus possibly biasing heritability upward.

## PROJECT 650

The cattle in Project 650 were high grade Herefords owned by the Oklahoma Agricultural Experiment Station at Ft. Reno. All of these cows were on experimental tests designed to study the effects of low, medium, and high levels of supplementary winter feed on beef cows grazing native grass pasture throughout the year.

Heritability Estimates of Maternal Effects Computed  
from Paternal Half-Sib Correlations

The data for this part of the study were the records of 95 daughters produced by 12 different sires. The records were collected over the 3-year period from 1956-1958. The data were analyzed within year of birth of the daughters, and the estimates of heritability were computed from the pooled analysis of the different daughter-birth-year groups.

The number of daughters by each sire within year of birth of the daughter and the average birth weights, weaning weights, and condition scores of their calves are presented in Table XXI. From this table it can be seen that the performance of paternal half-sisters differed considerably for all traits. The daughters born in 1954 had a potential of 3 calves, whereas the daughters born in 1955 and 1956 had a potential of 2 calves and 1 calf respectively.

Table XXII shows the heritability estimates of maternal effects for the various traits considered. Heritabilities for birth and weaning weights were estimated to be .80 and .58 respectively, whereas condition score was estimated to be .08 heritable. These estimates were thought to be relatively free from any systematic biases in regard to the mating

TABLE XXI

LIFETIME PERFORMANCE OF HALF-SIB DAUGHTERS BY YEARS OF BIRTH  
AND SIRES (PROJ. 650)

Sire	No. of Dau.	Birth Year	Ave. Birth Wt.	Ave. Weaning Wt.	Ave. Cond. Score
113	11	1954	78.1	424	6.4
247	9	1954	82.2	449	6.4
901	11	1954	77.5	412	6.2
182	3	1954	83.0	461	7.0
901	11	1955	75.8	402	7.1
120	5	1955	74.8	387	5.4
242	5	1955	75.6	376	5.2
219	6	1955	70.3	403	6.2
182	3	1955	88.3	389	5.7
309	6	1956	71.6	391	6.2
311	6	1956	66.2	355	5.6
219	6	1956	67.5	356	5.7
450	5	1956	73.6	359	5.7
425	3	1956	71.0	421	6.2
D95	5	1956	65.8	335	5.0

TABLE XXII  
ANALYSIS OF VARIANCE OF MATERNAL EFFECTS FOR PATERNAL  
HALF-SIB DAUGHTERS (PROJ. 650)

Trait and Source of Variation	D/F	Mean Square	Herit.	St. Error
Birth Weight			.80	.47
Total	90			
Between sires	12	101.55		
Daughters within sires	78	39.22		
Weaning Weight			.58	.43
Total	92			
Between sires	12	2,741.34		
Daughters within sires	80	1,335.57		
Condition Score			.08	.32
Total	91			
Between sires	12	1.0676		
Daughters within sires	79	.9478		



system and environment common to the daughters of any one sire. The method of assigning the dams to the different sires for breeding was discussed in the section on materials and methods as was the nutritional treatment of the daughters.

Heritability Estimates of Maternal Effects Computed from the  
Regression of the Daughters' Performance on the Dams'  
Performance

A total of 93 daughter-dam pairs were available for this phase of the study. The 93 daughters were by 12 different sires and were from 68 different dams. All regressions were computed within year of birth and sire of the daughter.

Table XXIII presents the average performance of all calves of the daughters and of their dams for birth weight, weaning weight, and condition score. Table XXIV shows the estimates of heritability computed from these data for birth weight, weaning weight, and condition score. Heritability of birth weight computed by regressing the lifetime average of the daughter on the lifetime average of the dam was .41 which is approximately one-half as large as the estimates computed for birth weight by the paternal half-sib correlation method. When the first record of the daughter was regressed on the first record of the dam, heritability of birth weight was estimated to be .35. Regression of the 1958 record of the daughter on the 1958 record of the dam yielded a heritability estimate for birth weight of 1.10.

Heritability of weaning weight obtained from regressing the lifetime average of the daughter on the lifetime average of the dam was .66 as compared with .58 computed by the paternal half-sib correlation method.

TABLE XXIII

LIFETIME PERFORMANCE OF DAUGHTER-DAM GROUPS BY YEAR OF BIRTH  
AND SIRE OF THE DAUGHTER (PROJ. 650)

Sire	Birth Year of Dau.	Birth Weight			Weaning Weight			Cond. Score		
		No.	Prs.	Dau.	Dam	No.	Prs.	Dau.	Dam	
113	1954	11		78.1	78.1	11		424	495	11 6.4 6.9
247	1954	9		82.2	81.7	9		449	505	7 6.4 7.1
901	1954	11		77.5	75.8	11		412	481	9 6.2 7.2
182	1954	3		83.0	75.0	3		461	497	3 7.0 7.1
901	1955	11		75.8	77.0	11		402	498	11 6.4 7.1
120	1955	5		74.8	81.2	5		387	499	5 5.4 6.7
242	1955	5		75.6	75.8	5		376	487	4 5.2 6.9
219	1955	5		72.2	74.6	5		418	470	4 6.5 7.1
182	1955	3		88.3	79.7	3		389	482	3 5.7 7.0
309	1956	5		74.0	78.2	5		397	420	5 6.6 6.5
311	1956	6		66.2	80.5	6		355	483	6 5.6 6.9
219	1956	6		67.5	83.2	6		356	502	6 5.7 7.4
450	1956	5		73.6	76.8	5		359	481	5 5.7 7.2
425	1956	3		71.0	80.3	3		421	514	3 6.2 7.3
D95	1956	5		65.8	76.0	5		335	477	5 5.0 6.7

TABLE XXIV

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION OF THE DAUGHTERS'  
PERFORMANCE ON THE DAMS' PERFORMANCE BY YEAR OF BIRTH OF THE DAUGHTER<sup>1</sup> (PROJ. 650)

Record Combination	Birth Weight			Weaning Weight			Cond. Score		
	No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error
Lifetime ave. of the dau. on the lifetime ave. of the dam	93	.41	.32	93	.66	.32	87	.00	.40
First rec. of the dau. on the first rec. of the dam	84	.35	.29	84	-.24	.33	--	--	--
1958 rec. of the dau. on the 1958 rec. of the dam	50	1.10	.36	50	.36	.36	48	.22	.50

<sup>1</sup>The sums of squares and sums of cross products for the above record combinations are shown in Appendix Tables LII-LIV.

Other estimates of the heritability of weaning weight were  $-.24$  obtained from the regression of the first record of the daughter on the first record of the dam and  $.36$  estimated from the regression of the 1958 record of the daughter on the 1958 record of the dam.

The heritability estimate of condition score obtained from the regression of the lifetime average of the daughter on the lifetime average of the dam was zero, as compared with an estimate of  $.08$  obtained by the paternal half-sib correlation method. An additional heritability estimate of condition score of  $.22$  was obtained by regressing the 1958 record of the daughter on the 1958 record of the dam. Since condition scores were not available on the first calves of the dams, heritability estimates could not be obtained for condition scores based on first records.

Heritability estimated from the regression of the 1958 record of the daughter on the 1958 record of the dam was higher for all traits than was the regression of the first record of the daughter on the first record of the dam. The reason for the relatively large heritability estimates obtained from the regression of the 1958 records of daughters and dams in comparison with the estimates obtained from the regression of first records of daughters and dams is not altogether clear since both estimates are based on single records. The calves produced in 1958 were either the eighth or ninth for the dams, whereas the daughters born in 1954, 1955, and 1956 produced in 1958 their third, second, and first calves respectively. The first records of the dams were not contemporary since one-half of the dams calved first as 2-year-olds in 1950, whereas the remainder calved first as 3-year-olds in 1951. The records of 2-year-old cows were adjusted to the equivalent of 3-year-old cows. No

adjustment was made for year effects. First records of the daughters born in 1954, 1955, and 1956 were made when they were 2-year-olds in 1956, 1957, and 1958 respectively. Since the first records of dams of daughters in the same sire-birth-year group were made at different ages and in different years, the regression of the daughter's production on the dam's production might have been too low if the dam's record did not accurately reflect her breeding value due to the possibility of year effects or inadequate adjustment of the records for age of dam.

#### Heritability Estimates of Birth Weight and Weaning Traits Computed from Paternal Half-Sib Correlations

The paternal half-sib correlations for birth weight, weaning weight, and condition score were computed on a within-year, replication, and plane of winter nutrition basis. The analysis of variance from which each estimate of heritability was obtained is shown in Appendix Tables LV-LIX. The records for the birth and weaning weights were collected over a 5-year period from 1954-1958, while the condition scores were collected over a 3-year period from 1956-1958. Records were available on 579 birth weights, 577 weaning weights, and 375 condition scores. There were 30 different sire-progeny groups represented in this phase of the study.

The average birth weight, weaning weight, and condition score for the calves of each sire by years is shown in Table XXV. From 1955-1958 the majority of sires in this study were produced in Project 670. Many of the bulls were half-brothers, and all of them had made gains above average for their group on 154-day record of performance tests.

Heritability estimates for the various traits in each replication are shown in Table XXVI. Considering only the individual replications,

TABLE XXV  
AVERAGE PERFORMANCE OF CALVES BY YEARS, REPLICATIONS, AND  
SIRE (PROJ. 650)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Replication I (Foundation Cows)							
1130	1954	25	77.3	25	495		
4247	1954	22	87.0	22	524		
4901	1954	28	80.0	28	492		
5182	1954	24	86.8	24	516		
4901	1955	25	77.1	25	481		
5120	1955	23	77.1	23	487		
5182	1955	7	86.1	7	523		
5219	1955	18	78.0	18	489		
5242	1955	24	78.1	24	495		
5295	1956	20	80.4	20	515	20	6.7
5219	1956	19	79.8	19	504	19	7.1
5242	1956	4	82.2	4	516	4	6.9
5311	1956	15	77.5	15	499	15	6.9
5343	1956	3	73.7	3	485	3	6.2
5408	1956	6	80.8	6	529	6	6.2
5416	1956	2	72.0	2	532	2	7.8
5425	1956	9	82.7	9	523	9	7.3
5450	1956	15	83.2	15	522	15	7.3
4901	1957	1	85.0	1	552	1	7.0
5120	1957	1	75.0	1	508	1	7.0
5284	1957	17	85.2	17	492	17	6.6
5295	1957	11	84.4	11	499	11	6.7
5434	1957	9	81.7	9	479	9	6.4
5450	1957	11	81.1	11	488	11	7.2
5468	1957	15	84.7	15	485	15	7.0
5502	1958	11	79.5	11	496	11	7.4
5516	1958	13	87.8	13	508	13	7.1
5520	1958	11	81.2	11	506	11	7.5
5523	1958	12	83.5	12	484	12	7.9
5526	1958	10	81.1	10	479	8	7.2
5533	1958	10	81.8	9	498	9	7.2
5585	1958	11	81.5	11	487	11	7.3

TABLE XXV (Continued)

Sire	Year	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Cond. Score
Replication II (Daughters born in 1954)							
5309	1956	15	74.8	15	418	15	6.4
5311	1956	11	71.6	11	424	11	6.5
4472	1957	4	83.2	4	432	4	6.5
4785	1957	16	80.2	16	420	15	6.5
5502	1958	3	65.7	3	439	3	7.0
5516	1958	2	85.5	2	486	2	7.5
5520	1958	5	74.4	5	433	5	6.4
5523	1958	3	74.3	3	439	3	7.0
5526	1958	4	79.8	4	448	4	7.0
5533	1958	2	80.5	2	476	2	8.0
5585	1958	2	78.0	2	396	2	7.0
Replication III (Daughters born in 1955)							
5416	1957	10	73.6	10	374	10	5.7
5420	1957	11	74.1	11	351	11	5.5
5502	1958	4	68.5	4	424	4	6.8
5516	1958	4	72.0	4	425	3	6.7
5520	1958	6	74.2	6	406	6	6.5
5523	1958	4	72.5	4	418	4	6.8
5526	1958	4	72.0	4	414	3	6.3
5533	1958	2	73.5	2	391	2	6.5
5585	1958	3	76.0	3	441	3	7.0
Replication IV (Daughters born in 1956)							
0450	1958	17	65.9	16	347	17	5.8
0469	1958	15	68.9	15	376	15	5.9

TABLE XXVI

HERITABILITY ESTIMATES OF BIRTH WEIGHT AND WEANING TRAITS  
 COMPUTED FROM PATERNAL HALF-SIB CORRELATIONS  
 (PROJ. 650)

Replication No.	Birth Weight		Weaning Weight		Cond. Score	
	Herit.	St. Error	Herit.	St. Error	Herit.	St. Error
1	.35	.60	-.02	.80	.88	1.00
2	-.64	1.20	-.50	.84	-.70	.80
3	-.06	1.76	-1.39	1.88	-1.98	2.16
4	-.58	.36	.06	.92	-.76	.32
All Replications	.30	.72	-.10	.72	.00	1.00



positive estimates of heritability were obtained only for birth weight and condition score in Replication 1 and for weaning weight in Replication 4. When the data were analyzed on a within-replication basis, heritability was estimated to be .30, -.10, and zero for birth weight, weaning weight, and condition score respectively.

The within-sire variance was a maximum in these data because each breeding group in each year was balanced with low and high producing cows. This would account for the negative and low positive estimates of heritability in spite of the existence of sizeable sire differences in each year.

## CHILOCCO

The herd of cattle owned by the Chilocco Indian School consisted of approximately 275 registered Hereford cows 3 years of age or older. This herd was maintained to supplement the instructional program for Vocational Agricultural classes and 4-H Club groups.

Heritability Estimates of Maternal Effects Computed  
from Paternal Half-Sib Correlations

Weaning weights were available on the calves of 136 daughters in 1957 and 1958, whereas weaning scores were available on the calves of only 133 of these daughters in 1958. The daughters were the progeny of 14 different sires. The analysis was made within year of birth of the daughter. A separate analysis was made for the weaning records of the daughters in 1957 and 1958 and then pooled over both years to obtain the estimates of heritability.

The number of daughters within each sire-birth-year group and the performance of their calves produced in 1957 and 1958 is shown in Tables XXVII-XXIX. Although all sires had daughters which produced calves in both 1957 and 1958, each daughter did not necessarily produce a calf in each of the two years. Daughters of the same age were bred to the same sire in each year. Thus, since the analysis was made within year of birth of the daughter, it was also within sire of the daughter's calves. As shown in Table XXX, the variance due to birth years of the daughters is considerably larger than the variance due to sires and error. This relatively large variance reflects mainly age of dam differences.

Heritability of weight per day of age computed from the 1957 data was .08 as compared with .19 computed from the 1958 data. The heritability

TABLE XXVII

AVERAGE WEIGHT PER DAY OF AGE OF CALVES PRODUCED BY HALF-SIB DAUGHTERS  
BY YEAR OF BIRTH AND SIRE OF THE DAUGHTER, 1957 RECORDS (CHILOCCO)

Sire No.	Total No. of Dau.	Birth Year of Daughter							
		1947	1948	1949	1950	1951	1952	1953	1954
569	18	--	2.38	2.26	1.97	2.04	2.08	1.92	2.22
756	25	--	--	--	2.10	2.16	1.98	1.83	1.65
519	8	--	--	--	--	2.00	1.92	2.04	--
576	9	1.88	1.84	2.03	2.33	--	--	--	--
5	5	1.98	1.86	--	--	--	--	--	--
157	5	1.95	2.18	2.22	--	--	--	--	--
118	3	2.04	--	--	--	--	--	--	--
1048	10	--	--	--	--	--	--	--	1.78
173	14	--	--	--	--	--	--	2.03	1.69
937	9	--	--	--	--	--	1.96	1.96	1.82
058	20	--	--	--	--	--	1.97	1.92	2.00
318	4	--	--	2.15	2.08	--	--	--	--
623	4	--	--	1.75	2.14	--	--	--	--
400	2	--	--	--	--	2.07	--	--	--

TABLE XXVIII

AVERAGE WEIGHT PER DAY OF AGE OF CALVES PRODUCED BY HALF-SIB DAUGHTERS  
BY YEAR OF BIRTH AND SIRE OF THE DAUGHTER, 1958 RECORDS (CHILOCCO)

Sire No.	Total No. of Dau.	Birth Year of Daughter								
		1947	1948	1949	1950	1951	1952	1953	1954	1955
569	18	--	1.98	2.27	1.81	2.39	2.36	2.12	1.87	1.75
756	21	--	--	--	1.97	1.94	2.16	2.07	1.65	1.62
519	9	--	--	--	--	1.88	2.00	2.15	--	--
576	10	1.81	2.06	--	1.90	--	--	--	--	--
5	5	1.88	1.94	--	--	--	--	--	--	--
157	2	--	1.89	2.24	--	--	--	--	--	--
118	2	1.85	--	--	--	--	--	--	--	--
1048	17	--	--	--	--	--	--	--	1.81	1.68
173	17	--	--	--	--	--	--	2.11	2.01	1.70
937	11	--	--	--	--	--	--	1.97	1.65	1.61
058	14	--	--	--	--	--	2.40	1.51	1.94	1.70
318	3	--	--	--	1.88	--	--	--	--	--
623	4	--	--	--	2.00	--	--	--	--	--
400	3	--	--	--	--	2.23	--	--	--	--

TABLE XXIX

AVERAGE FEEDER GRADE OF CALVES PRODUCED BY HALF-SIB DAUGHTERS BY YEAR OF  
BIRTH AND SIRE OF THE DAUGHTER, 1958 RECORDS (CHILOCCO)

Sire No.	Total No. of Dau.	Birth Year of Daughter								
		1947	1948	1949	1950	1951	1952	1953	1954	1955
569	17	--	9.5	11.5	8.7	11.0	7.5	12.0	9.3	9.0
756	21	--	--	--	10.8	11.5	8.0	10.3	10.2	8.5
519	9	--	--	--	--	10.5	9.0	8.0	--	--
576	9	9.8	9.0	--	10.0	--	--	--	--	--
5	5	9.3	10.0	--	--	--	--	--	--	--
157	2	--	8.0	10.0	--	--	--	--	--	--
118	2	8.5	--	--	--	--	--	--	--	--
1048	17	--	--	--	--	--	--	--	9.5	9.5
173	16	--	--	--	--	--	--	9.3	11.0	9.8
937	11	--	--	--	--	--	--	10.0	10.6	8.8
058	14	--	--	--	--	--	9.0	8.0	11.5	11.0
318	3	--	--	--	9.8	--	--	--	--	--
623	4	--	--	--	11.0	--	--	--	--	--
400	3	--	--	--	--	9.0	--	--	--	--

TABLE XXX

## ANALYSIS OF VARIANCE OF MATERNAL EFFECTS FOR PATERNAL HALF-SIB DAUGHTERS (CHILOCCO)

Trait and Source of Variation	D/F	Mean Square	Herit.	St. Error
Wt. per day of age of 1957 calves			.08	.56
Total	135			
Birth years of daughters	7	.2940		
Sires within years	31	.0581		
Daughters within sires	97	.0545		
Wt. per day of age of 1958 calves			.19	.56
Total	135			
Birth years of daughters	8	.4202		
Sires within years	31	.0863		
Daughters within sires	96	.0740		
Wt. per day of age of 1957 and 1958 calves(pooled)			.14	.56
Total	270			
Birth years of daughters	15	.3613		
Sires within years	62	.0722		
Daughters within sires	193	.0642		
Feeder grade of 1958 calves			-.12	.58
Total	132			
Birth years of daughters	8	7.43		
Sires within years	31	2.55		
Daughters within sires	93	2.63		

estimate of weight per day of age computed from the pooled analysis of the 1957 and 1958 data was .14. Heritability of feeder grade was negative, indicating the additively genetic portion of the phenotypic variance was zero in these data.

#### Heritability Estimates of Maternal Effects Computed from Regressing the Daughters' Performance on the Dams' Performance

The record combinations used in this phase of the study were the single records of the daughters and dams that were made in 1957-1958 and the average of the records made in the 2 years. There was a total of 69 daughter-dam pairs with the daughters having been sired by 8 different bulls and from 59 different dams. All regressions were computed within sire of the daughter.

Table XXXI shows the performance of the daughter-dam pairs within sire of the daughter and year in which the daughters and dams produced their calves. Single records were available on 30 daughter-dam pairs in 1957 and 36 daughter-dam pairs in 1958. Thirteen daughters and their dams calved in both 1957 and 1958, whereas records were available on 69 daughter-dam pairs when one member of each pair had calved in either 1957, 1958, or in both years.

Estimates of heritability for the various traits are shown in Table XXXII. Whereas the regression of weight per day of age of the daughters' calves on weight per day of age of the dams' calves was negative for the 1957 data, the regression coefficient was positive for the 1958 data and heritability of weight per day of age was estimated to be .15. This estimate is in close agreement with the heritability estimate of .19 for weight per day of age computed from the 1958 data by the paternal half-sib

TABLE XXXI  
 AVERAGE PERFORMANCE OF DAUGHTER-DAM GROUPS  
 BY SIRE OF THE DAUGHTER (CHILOCCO)

Sire of Daughter	No. Dau.- Dam Pairs	<u>Birth Weight</u>		<u>Wt. Per Day Age</u>		<u>Feeder Grade</u>	
		Dau.	Dam	Dau.	Dam	Dau.	Dam
1957 calves							
058	4	--	--	1.82	1.81	--	--
623	2	--	--	2.16	2.02	--	--
1048	8	--	--	1.91	2.15	--	--
173	8	--	--	1.82	2.07	--	--
937	6	--	--	1.92	2.03	--	--
519	2	--	--	1.76	1.87	--	--
1958 calves							
058	6	62.3	77.3	1.83	1.94	10.0	8.7
623	3	69.7	72.7	2.04	1.76	11.3	10.3
756	2	74.0	67.0	1.94	1.93	7.5	10.0
1048	8	65.6	75.8	1.74	2.04	9.4	10.1
937	5	70.4	68.8	1.77	1.94	9.4	8.8
569	3	75.3	74.3	1.89	1.61	9.0	8.3
173	9	73.7	77.2	2.08	2.06	10.3	10.8
Average of 1957 and 1958 calves <sup>1</sup>							
623	2	--	--	2.12	1.95	--	--
1048	5	--	--	1.80	2.12	--	--
937	2	--	--	1.83	2.00	--	--
173	4	--	--	1.94	2.26	--	--
Average of 1957 and/or 1958 calves <sup>2</sup>							
058	14	--	--	2.06	1.96	--	--
623	3	--	--	2.09	1.81	--	--
569	5	--	--	2.11	1.79	--	--
937	10	--	--	1.88	2.02	--	--
173	16	--	--	1.96	2.02	--	--
519	3	--	--	1.76	1.97	--	--
1048	10	--	--	1.85	2.12	--	--
756	8	--	--	1.90	1.97	--	--

<sup>1</sup> Average performance where both daughter and dam had a calf in 1957 and 1958.

<sup>2</sup> Average performance where the daughter and dam had a calf in 1957 or 1958.

TABLE XXXII

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION ON THE DAUGHTERS' PERFORMANCE ON THE DAMS' PERFORMANCE (CHILCOCCO)

Trait	No. Dau.-Dam Pairs	Year of Record	Herit.	St. Error
Wt. per day age	30	1957	-.16	.30
Birth wt.	36	1958	103.20	.52
Wt. per day age	36	1958	.15	.34
Wt. per day age	13	1957 and 1958	.02	.54
Wt. per day age	69	1957 and 1958	.20	.22
Feeder grade	36	1958	-.16	.42



correlation method. The regression of the average weight per day of age of the calves produced in 1957 or 1958 by the 69 daughters and their dams yielded a heritability estimate of .20 which agrees favorably with the estimate of .14 computed from the pooled analysis of the 1957 and 1958 data by the paternal half-sib correlation method. Heritability of weight per day of age estimated from the regression of the average of the 1957 and 1958 records of the daughters on the average of the 1957 and 1958 records of the dams (13 pairs) was .02.

The regression of the feeder grades of the daughters' calves on the feeder grades of the dams' calves was negative. Doubling the regression coefficient yielded an estimate of heritability very similar to the negative estimate computed for feeder grade by the paternal half-sib correlation method. The regression of the birth weights of the daughters' calves on the birth weights of the dams' calves was large, and when doubled it yielded an estimate of heritability in excess of 100 percent.

The post-weaning treatment of all the daughters used in the regression analysis was the same; however, the type of management under which their dams were developed was not known. The nutritional treatment of the daughters prior to their first lactation was described in the section on materials and methods. If it can be assumed that the post-weaning treatment of the daughters partially masked genetic differences in the expression of the various traits, both the regression coefficients and intraclass correlations in this study are too low. The regression coefficients would be too low because the association between the daughter's production and the dam's would be reduced. The intraclass correlations would be too small because maximum expression of sire differences would be inhibited.

### Heritability Estimates of Birth Weight and Weaning Traits Computed from Half-Sib Correlations

The paternal half-sib correlations for birth weight, weaning weight, and feeder grade were computed on a within-year basis. Records were available on 150 birth weights, 146 weaning scores, and 310 weaning weights. There were 15 different sires represented in this phase of the study.

The average birth weights, weights per day of age, and feeder grades of calves by sires and years is shown in Table XXXIII. Birth weights and feeder grades were not available for the 1957 calves. Heritabilities computed from these data for the various traits are shown in Table XXXIV. Heritability of weight per day of age was estimated to be .19 from the 1957 data, whereas the estimate computed from the 1958 data was .60. When the analysis was made on a sire-within-years basis, heritability of weight per day of age was estimated to be .42. Heritability of birth weight was found to be .92 while feeder grade was estimated to be .58 heritable.

All of the estimates of heritability in this study may be biased upward because age of dam and sire of calf were confounded in these data. Failure to correct adequately for age of dam differences could magnify sire differences. The older age groups might also have a larger percentage of the higher producing cows than the younger age groups because of earlier selection.

TABLE XXXIII

AVERAGE PERFORMANCE OF CALVES BY YEARS AND SIRES  
(CHILOCCO)

Sire of Calf	No. Calves	Birth Weight	No. Calves	Wt. Per Day of Age	No. Calves	Feeder Grade
1957 calves						
411	--	--	13	1.81	--	--
1048	--	--	17	2.01	--	--
401	--	--	20	1.95	--	--
105	--	--	10	2.08	--	--
402	--	--	13	1.99	--	--
220	--	--	17	2.13	--	--
177	--	--	15	1.97	--	--
271	--	--	6	1.84	--	--
173	--	--	19	1.90	--	--
756	--	--	23	2.02	--	--
569	--	--	11	1.92	--	--
1958 calves						
411	18	71.0	18	1.87	18	10.4
1048	5	67.0	7	1.94	7	9.0
402	15	79.9	16	2.07	16	10.6
220	11	79.9	10	2.03	10	11.5
177	10	68.4	10	1.95	10	9.6
173	9	74.0	8	2.23	8	8.4
756	21	71.2	20	1.92	20	9.4
554	18	75.4	17	1.71	17	10.1
502	14	68.9	14	1.77	14	9.4
527	10	72.9	8	1.67	8	9.4
137	19	77.9	18	1.92	18	9.2

TABLE XXXIV

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING  
TRAITS AMONG PATERNAL HALF-SIBS (CHILOCCO)

Trait and Source of Variation	D/F	Mean Square	Herit.	St. Error
Wt. per day of age of 1957 calves			.19	.19
Total	163			
Between sires	10	.1133		
Calves within sires	153	.0650		
Wt. per day of age of 1958 calves			.60	.34
Total	145			
Between sires	10	.2932		
Calves within sires	135	.0863		
Birth weight of 1958 calves			.96	.40
Total	149			
Between sires	10	270.81		
Calves within sires	139	53.12		
Wt. per day of age of 1957 and 1958 calves			.42	.26
Total	309			
Years	1	.4969		
Sires within years	20	.2033		
Calves within sires	288	.0750		
Feeder grade of 1958 calves			.58	.33
Total	145			
Between sires	10	8.19		
Calves within sires	135	2.55		

## FEDERAL REFORMATORY

The herd of cattle owned by The Federal Reformatory at El Reno, Oklahoma, consisted of approximately 250 registered and grade Angus cows. The cows were bred to calve first at 2 years of age, and all calves were creep-fed.

Heritability Estimates of Maternal Effects Obtained  
from Paternal Half-Sib Correlations

The data for this section of the study consisted of the calf records of 35 paternal half-sisters. The records were collected over the 3-year period from 1956-1958. Twenty-five of the heifers were born in 1954, and 10 were born in 1955. The heifers were sired by the same 3 bulls in both years. The data were analyzed separately for each birth year group and pooled over both years to obtain the estimates of heritability.

The average performance of calves of paternal half-sib daughters is shown in Table XXXV. The daughters were born in 1954 and 1955 and were sired by the same bulls in each year. The average daily gains and feeder grades of the calves of the daughters born in 1955 were lower than average daily gains and feeder grades of the calves of their half-sisters born in 1954. All calves were creep-fed. The majority of the calves produced in 1957 by the 1955 daughters were dropped late in the calving season and were all sired by a bull whose calves in previous years had averaged lower for feeder grades and daily gains than had the calves sired by other bulls in the same herd.

Estimates of heritability for the various traits were computed from the pooled analysis of the 2 daughter-birth-year groups. These estimates

TABLE XXXV

LIFETIME PERFORMANCE OF HALF-SIB DAUGHTERS BY  
YEARS OF BIRTH AND SIRE (FED. REF.)

Sire	No. of Dau.	Year of Birth	Birth Weight	Ave. Daily Gain	Cond. Score
2	7	1954	72.3	1.91	10.6
1	5	1954	69.6	1.90	10.5
7	13	1954	75.2	2.05	11.0
2	4	1955	72.2	1.82	9.1
1	3	1955	72.7	1.84	9.7
7	3	1955	75.7	1.93	9.6

TABLE XXXVI

ANALYSIS OF VARIANCE OF MATERNAL EFFECTS FOR PATERNAL  
HALF-SIB DAUGHTERS <sup>1</sup> (FED. REF.)

Trait and Source of Variation	D/F	Mean Squares	Herit.	St. Error
Birth weight			-.11	.60
Total	33			
Between sires	4	35.62		
Daughters within sires	29	41.60		
Average daily gain			.31	.80
Total	33			
Between sires	4	.0383		
Daughters within sires	29	.0264		
Feeder grade			-.68	.20
Total	33			
Between sires	4	.4574		
Daughters within sires	29	2.2533		

<sup>1</sup> Pooled from 1954 and 1955 daughter groups.

are shown in Table XXXVI. Heritability of average daily gain was estimated to be .31, whereas the intraclass correlation coefficients for birth weight and feeder grade were negative. These negative intraclass correlation coefficients indicated that the additively genetic portion of the phenotypic variance for birth weight and feeder grade was zero since no systematic biases were known which would have either tended to increase the within sire variance or reduced the between sire variance. However, the small number of animals used in this analysis would have allowed sampling errors to influence the heritability estimates obtained.

Heritability Estimates of Maternal Effects Derived from the  
Regression of the Daughters' Performance on the  
Dams' Performance

A total of 27 daughter-dam pairs were available for this phase of the study. The records were collected over the 3-year period from 1956-1958. The daughters were sired by 3 different bulls and they were from 24 different dams. The analysis was made within year of birth and sire of the daughter.

The average performance of calves of the daughters and dams within year of birth and sire of the daughter is shown in Table XXXVII. The estimates of heritability for birth weight, average daily gain, and feeder grade are shown in Table XXXVIII. These estimates were -.30, .20, and .06 for birth weight, weaning weight, and feeder grade respectively. Considering the small number of daughters used in both this analysis and the paternal half-sib analysis, the estimates of heritability computed for the various traits by the 2 methods were fairly similar. With the exception that creep-feeding of the daughters prior to weaning may have possibly

TABLE XXXVII

AVERAGE PERFORMANCE OF DAUGHTER-DAM GROUPS BY YEAR OF BIRTH  
AND SIRE OF THE DAUGHTER (FED. REF.)

Sire	Birth Year of Dau.	Birth Weight			Ave. Daily Gain			Feeder Grade		
		No. Prs.	Dau.	Dam	No. Prs.	Dau.	Dam	No. Prs.	Dau.	Dam
2	1954	6	70.5	66.3	6	1.96	1.92	6	10.6	11.2
1	1954	3	72.7	74.3	3	1.90	2.09	3	10.2	11.8
7	1954	8	77.9	68.5	8	2.04	2.02	8	11.1	11.5
2	1955	4	72.2	72.5	4	1.82	2.08	4	9.1	10.8
1	1955	3	72.7	68.7	3	1.84	1.99	3	9.7	12.4
7	1955	3	75.7	73.0	3	1.93	2.03	3	9.6	10.7



TABLE XXXVIII

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION OF THE DAUGHTERS' PERFORMANCE ON THE DAMS' PERFORMANCE BY YEAR OF BIRTH OF THE DAUGHTER<sup>1</sup> (FED. REF.)

Record Combination	No. Pairs	Birth Weight		Ave. Daily Gain		Feeder Grade	
		Herit.	St. Error	Herit.	St. Error	Herit.	St. Error
Ave. of 1956-1958 rec. of the dau. on the ave. of the 1956-1958 rec. of the dam	27	-.30	.52	.20	.46	.06	.48

<sup>1</sup>The sums of squares and sums of cross products for the above record combination are shown in Appendix Table LX.

reduced the association between their production and their dams' production, no systematic biases were thought to have existed in these data. In addition to the daughter-dam pairs shown in Table XXXVII, information was available on 35 daughters and their dams in which the sire of the daughter was unknown. Twenty-one of these daughters were born in 1952 and 14 were born in 1953. The daughters' production was regressed on the dams' production within birth year of the daughter. The sums of squares and sums of cross products pooled from each birth year group yielded regression coefficients of  $-.09$ ,  $.18$ , and  $-.04$  for birth weight, average daily gain, and feeder grade respectively.

Heritability Estimates of Birth Weight and Weaning Traits  
Computed from Paternal Half-Sib Correlations

Data were available on a total of 261 calves sired by 11 different bulls. The records were collected over the 2-year period of 1957-1958. The analysis was made on a within-year basis.

The average performance of calves by sires and years is shown in Table XXXIX. All calves were creep-fed and the data were analyzed within years for all traits. The analysis of variance from which the heritabilities were derived is shown in Appendix Table LXI. Years were not significantly different for any of the traits in these data. Heritabilities of birth weight, average daily gain, and feeder grade were  $.44$ ,  $.30$ , and  $.76$  respectively.

TABLE XXXIX  
AVERAGE PERFORMANCE OF CALVES BY YEARS AND SIRES  
(FED. REF.)

Sire	No. Calves	Birth Weight	No. Calves	Weaning Weight	No. Calves	Feeder Grade
1957						
7	20	71.8	20	1.91	19	10.6
2	23	72.5	23	1.89	23	10.6
5	21	64.0	21	1.89	21	9.1
17	18	71.2	19	1.93	17	11.2
15	18	66.8	18	1.83	17	10.7
114	23	69.4	23	1.96	23	11.3
264	20	70.8	20	2.09	20	10.2
1958						
7	19	69.7	19	1.99	18	11.3
5	18	66.8	18	1.99	17	9.8
115	22	70.1	22	2.09	22	11.3
155	21	61.2	21	2.01	21	10.8
175	20	66.6	20	1.91	18	11.3
185	17	66.0	17	1.94	17	11.4

TABLE XL  
HERITABILITY ESTIMATES OF BIRTH WEIGHT AND WEANING TRAITS  
COMPUTED FROM PATERNAL HALF-SIB CORRELATIONS (FED. REF.)

Birth Weight			Weaning Weight			Feeder Grade		
No. Calves	Herit.	St. Error	No. Calves	Herit.	St. Error	No. Calves	Herit.	St. Error
260	.44	.24	261	.30	.20	253	.76	.32

## GENERAL DISCUSSION

Because the management practices were different for each herd, heritability estimates of maternal effects and of the direct effect of the sire upon his offspring for the various traits were computed separately for each herd. The heritability estimates considered to be the most reliable for each trait from each herd are presented in the following discussion along with estimates which were computed from the pooled analysis in which the data from all herds were utilized.

Heritability Estimates of Maternal Effects Derived  
from Paternal Half-Sib Correlations

The heritability estimates of maternal effects computed by the paternal half-sib correlation method is shown for each herd in Table XLI. Heritability of weaning weight in Project 670 is thought to be too high because of the effects common environment and assortive mating may have had on the production of daughters of different sires. Heritability estimates computed from the pooled sums of squares of all herds were .60, .39, and .04 for birth weight, weaning weight, and weaning score respectively. With the exception of the estimate for birth weight, these estimates are in close agreement with the estimates obtained from pooled analysis by the intra-sire regression of average records of daughters and dams. In the literature, the only estimate of heritability of maternal effects computed directly was reported for weaning weight by Dawson et al. (1954). This estimate was .19 and was obtained from the intraclass correlation of the weaning weights of calves of paternal half-sisters. Koch and Clark (1955c) reported estimates of total genic value which took into account

TABLE XLI

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM PATERNAL HALF-SIB  
CORRELATIONS

Herd	Actual No. Sires	Birth Weight			Weaning Weight			Weaning Score		
		No. Dau.	Herit.	St. Error	No. Dau.	Herit.	St. Error	No. Dau.	Herit.	St. Error
Proj. 670	39	178	.92	.40	178	.64	.32	178	.17	.28
Proj. 650	12	95	.80	.47	95	.58	.43	95	.08	.32
Chilocco	14	--	--	--	190	.14	.56	133	-.12	.58
Fed. Ref.	3	35	-.11	.60	35	.31	.80	35	-.68	.20
All Herds (pooled)	68	308	.60	.24	498	.39	.22	441	.04	.18

the genic value for direct response in the calf and the genic value for maternal environment. Heritability estimates of total genic value were .42, .19, and .16 for birth weight, weaning weight, and weaning score respectively. These estimates were obtained indirectly from parent-offspring correlations.

Heritability Estimates of Maternal Effects Obtained from the  
Intra-Sire Regression of the Daughters' Performance  
on the Dams' Performance

Table XLIII shows the heritability estimates of maternal effects computed from the intra-sire regression of the average performance of the daughter on the average performance of the dam in each herd. Heritabilities of birth weight, weaning weight, and weaning score computed from the pooled sums of squares and sums of cross products are also shown in this table. Of the estimates obtained from the different record combinations, estimates obtained by the regression of average records of daughters and dams are considered to be the most reliable. This is because more of the plus and minus effects of environment and non-additive inheritance are excluded from average records. Also, the number of daughter-dam pairs is a maximum.

Legitimate comparisons cannot be made for heritability estimates computed for the different herds because management, which was different for each herd, is reflected in the individual estimates. The heritability estimates computed from the regression analysis in Project 670 are thought to be too low because common environment may have affected the production of dams of contemporary daughters. Also, the high plane of post-weaning nutrition to which the heifers born in 1953-1955 were exposed is thought

TABLE XLII

HERITABILITY ESTIMATES OF MATERNAL EFFECTS COMPUTED FROM THE INTRA-SIRE REGRESSION OF THE  
AVERAGE PERFORMANCE OF THE DAUGHTER ON THE AVERAGE PERFORMANCE OF THE DAM

Herd	Actual No. Sires	Birth Weight			Weaning Weight			Cond. Score		
		No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error	No. Prs.	Herit.	St. Error
Proj. 670	22	105	.28	.16	106	.12	.24	104	-.14	.26
Proj. 650	12	93	.41	.32	93	.66	.32	87	.00	.40
Chilocco	8	36	103.20	.52	69	.20	.22	36	-.16	.42
Fed. Ref.	3	27	-.30	.52	27	.20	.46	27	.06	.48
All Herds (pooled)	45	261	.40	.17	295	.32	.16	254	-.09	.20

to have partially masked their genetic potential for milk production. This observation is in agreement with results reported by Swanson and Spann (1954). These writers found that identical twin Jersey heifers which were fed differently from 3-months of age to first parturition had noticeably different lactation records. One group was fed concentrates ad lib, and the other group was fed a normal ration with no grain after 1 year. In the first lactation (106 days) the full fed heifers averaged 728 pounds of milk, whereas the other heifers averaged 1345 pounds of milk over the same period of time. In the second lactation the full fed heifers averaged 768 pounds over a 68-day period as compared with 1437 pounds of milk for the other heifers over the same period of time. Udders taken from the full fed heifers at the end of their second lactation revealed incomplete development of the lobule-alveolar system. The results indicate that excess fattening during growth is detrimental to lactating ability. Genetic differences among females in their ability to lactate may, therefore, be masked by improper development during the period prior to first lactation.

The heritability estimates computed from the data in Project 650 are thought to be relatively free from any systematic biases. The reliability of the estimates computed from the Federal Reformatory and Chilocco data are questionable because of the smaller number of daughter-dam pairs involved. The post-weaning treatment of the heifers at Chilocco was similar to that imposed on the 1953-1955 heifers in Project 670. The estimates of heritability for birth weight, weaning weight, and weaning score computed from the pooled sums of squares and sums of cross products were .40, .32, and -.09.



Because of reasons discussed earlier, the heritability estimates computed by the paternal half-sib correlation method from the pooled analysis may be a bit too high, whereas the estimates computed by the regression method from the pooled analysis may be too low. The best estimate for each trait is probably between the estimates computed by the 2 different methods.

The heritability estimates obtained from the pooled analysis for birth and weaning weight are high enough to suggest that the selection of replacement heifers from the more productive dams and from sires whose female relatives have proven their ability to produce heavy calves at birth and at weaning should be effective in increasing the birth and weaning weights of beef calves. Although maternal traits are expressed only by the female, the greatest opportunity for improving this trait in a herd is probably by the selection of sires because of the high replacement rate required for females and the low reproductive rate of the cows. The initial selection of a sire for improvement of maternal traits in the cow herd would have to be based on the performance of his dam and sisters, although final selection would be based on the performance of his female offspring.

#### Heritability Estimates of Birth Weight and Weaning Traits Obtained from Paternal Half-Sib Correlations

Estimates of heritability of the various traits in each herd and estimates derived from the sums of squares pooled over all herds are shown in Table XLIII. The estimates for Project 670 are thought to be too high because in some years the older bulls of known merit were mated to the older cows of known producing ability, and the younger bulls were mated

TABLE XLIII

HERITABILITY ESTIMATES OF BIRTH WEIGHT AND WEANING TRAITS COMPUTED FROM PATERNAL  
HALF-SIB CORRELATIONS

Herd	Actual No. Sires	Birth Weight			Weaning Weight			Weaning Score		
		No. Calves	Herit.	St. Error	No. Calves	Herit.	St. Error	No. Calves	Herit.	St. Error
Proj. 670	64	744	.64	.19	732	.66	.20	728	.52	.19
Proj. 650	30	579	.30	.72	577	-.10	.72	375	.00	1.00
Chiloeco	15	150	.96	.40	310	.42	.26	146	.58	.33
Fed. Ref.	11	260	.44	.24	261	.30	.20	253	.76	.32
All Herds (pooled)	120	1733	.33	.11	1880	.24	.08	1502	.14	.06

to the younger cows. The estimates obtained for Project 650 were influenced markedly by the method of assigning cows to breeding groups. Each breeding group was balanced with low and high producing cows, thus the within sire variance was a maximum for this herd. The large within sire variance overshadowed sire differences for weaning weight and condition score as depicted by the estimates of heritability for these 2 traits. This situation points out the fact that in herds where large differences exist in cow productivity, sire-of-the-calf differences are likely to be small. At Chilocco, all cows of the same age were mated to the same bull. If age-of-dam differences were not adequately adjusted for, or if the producing ability of the cows in the various age groups was different because of selection, the estimates obtained from this herd may be too high. The calves from the Federal Reformatory utilized in this phase of the study were all creep-fed and were sired by bulls whose mates were of comparable ages. No systematic biases are known for these data.

The heritability estimates derived from sums of squares pooled over all herds were .33, .24, and .14 for birth weight, weaning weight, and weaning score respectively. Heritability estimates for birth weight reported in the literature have ranged from .11 (Dawson et al., 1947) to 1.00 (Gregory et al., 1950). However, the majority of the estimates were included in the range of .26 to .72. Heritability estimates of weaning weight reported in the literature were .26 and .52 by Gregory et al. (1950), .24 by Koch and Clark (1955a), .54 by Rollins and Wagnon (1956), and .36 by Dinkel and Musson (1956). Heritability estimates of weaning score reported in the literature were .53 and -.14 by Knapp and Nordskog (1946), .31 by Knapp and Clark (1951), .50 and .30 by Koger and Knox (1952), .18 by Koch and Clark (1955a), and .36 by Rollins and Wagnon (1956b).

The heritability estimates obtained from the pooled analysis in this study may be too low because of the relatively large influence the within sire variances from Project 650 had on the overall analysis.

## SUMMARY AND CONCLUSIONS

The data for this study consisted of birth weights, weaning weights, and weaning scores collected from 4 different herds. All analyses were made on an intra-herd basis. Where necessary, the data were standardized for age of calf, sex of calf, age of dam, year effects, and level of winter nutrition. With the exception of age of dam corrections for the Chilocco data, the various correction factors were computed from the herds to which they were applied.

The inheritance of maternal effects for birth weight, weaning weight, and weaning score was studied by regressing the performance of the daughters' calves on the performance of the dams' calves, and from the intra-class correlations of the average performance of calves produced by paternal half-sisters.

A total of 295 daughter-dam pairs were available for the intra-sire regression of the daughters' performance on the dams' performance. The daughters were the offspring of 45 different sires. Of the different record combinations used to estimate heritabilities of maternal effects for birth weight, weaning weight, and weaning score, estimates obtained from the regression of the average record of the daughter on the average record of the dam were considered to be the most reliable. Estimates of heritability computed from the sums of squares and sums of cross products of average records pooled over all herds were .40, .32, and -.09 for birth weight, weaning weight, and weaning score respectively.

The average records of calves produced by a total of 498 paternal half-sisters were utilized for the heritability estimates of maternal effects obtained by the paternal half-sib correlation method. The 498 paternal half-sisters were sired by 68 different bulls. Estimates of heritability obtained from the sums of squares pooled over all herds were .60, .39, and .04 for birth weight, weaning weight, and weaning score respectively.

The inheritance of the direct effect of the sire upon his offspring for birth weight, weaning weight, and weaning score was studied from the intraclass correlations of paternal half-sib calves. A total of 1880 calves sired by 120 different bulls was available for this part of the study. Estimates of heritability obtained from the sums of squares pooled over all herds were .33, .24, and .14 for birth weight, weaning weight, and weaning score respectively.

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## A P P E N D I X

TABLE XLIV

POOLED SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM ALL LINES. (INTRA-SIRE REGRESSION  
OF THE LIFETIME PERFORMANCE OF THE DAUGHTER (Y) ON THE LIFETIME PERFORMANCE  
OF THE DAM (X).) (PROJ. 670)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	101	2,547.62	387.69	1,376.71
Between sires	25	499.03	94.76	300.46
Within sires	76	2,048.59	292.93	1,076.25
Weaning weight				
Total	102	139,171.65	-7,026.75	320,507.88
Between sires	25	35,787.55	-12,822.38	187,170.99
Within sires	77	103,384.10	5,795.63	133,336.89
Condition score				
Total	100	54.0368	-13.4833	186.3640
Between sires	25	15.5358	-10.9015	59.2835
Within sires	75	38.5010	-2.5818	127.0805

TABLE XLV

POOLED SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM ALL LINES. (INTRA-SIRE REGRESSION OF THE FIRST RECORD OF THE DAUGHTER (Y) ON THE AVERAGE OF ALL RECORDS OF THE DAM (X) MADE UP TO AND INCLUDING THE BIRTH YEAR OF THE DAUGHTER.) (PROJ. 670)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	97	3,115.29	778.69	5,706.47
Between sires	24	1,128.45	181.55	1,476.87
Within sires	73	1,986.84	597.14	4,229.60
Weaning weight				
Total	102	232,893.45	8,745.47	477,330.72
Between sires	25	56,165.58	-2,353.04	289,429.81
Within sires	77	176,727.87	11,098.51	187,900.91
Condition score				
Total	99	105.5000	-29.5802	268.0348
Between sires	25	36.6441	-17.3362	128.4246
Within sires	74	68.8559	-12.2440	139.6102

TABLE XLVI

POOLED SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM ALL LINES. (INTRA-SIRE REGRESSION  
OF THE FIRST RECORD OF THE DAUGHTER (Y) ON THE FIRST RECORD OF THE DAM (X).)  
(PROJ. 670)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	88	5,631.20	986.77	4,991.20
Between sires	24	1,184.69	298.40	996.46
Within sires	64	4,446.51	688.37	3,994.74
Weaning weight				
Total	102	295,181.78	6,132.54	477,329.93
Between sires	25	64,574.99	106.11	287,642.83
Within sires	77	230,606.79	6,026.43	189,687.10
Condition score				
Total	96	161.096	-39.5793	231.0824
Between sires	25	46.1924	-32.4616	93.0492
Within sires	71	114.9037	- 7.1177	138.0332

TABLE XLVII

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS IN LINE 1.  
(PROJ. 670)

Trait and Source of Variation	D/F	Sum of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	200	11,111.37		
Years	8	354.64	44.33	$\sigma^2 + 9.48 \sigma S^2 + 21.80 \sigma Y^2$
Sires within years	21	1,489.12	70.91	$\sigma^2 + 5.42 \sigma S^2$
Calves within sires	171	9,267.61	54.20	$\sigma^2$
Weaning weight				
Total	195	645,477.73		
Years	8	35,924.05	4,490.51	$\sigma^2 + 9.14 \sigma S^2 + 21.08 \sigma Y^2$
Sires within years	22	115,206.98	5,236.68	$\sigma^2 + 5.09 \sigma S^2$
Calves within sires	165	494,346.70	2,996.04	$\sigma^2$
Condition score				
Total	197	350.2683		
Years	8	64.3838	8.0480	$\sigma^2 + 9.32 \sigma S^2 + 21.08 \sigma Y^2$
Sires within years	21	77.2434	3.6783	$\sigma^2 + 5.34 \sigma S^2$
Calves within sires	168	208.6411	1.2419	$\sigma^2$

TABLE XLVIII

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS IN LINE 2.  
(PROJ. 670)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	215	15,882.11		
Years	7	1,243.47	177.64	$\sigma^2 + 16.53 \sigma S^2 + 26.00 \sigma Y^2$
Sires within years	16	2,718.89	169.93	$\sigma^2 + 5.18 \sigma S^2$
Calves within sires	192	11,919.75	62.08	$\sigma^2$
Weaning weight				
Total	211	638,819.07		
Years	8	79,846.32	9,980.79	$\sigma^2 + 14.01 \sigma S^2 + 23.02 \sigma Y^2$
Sires within years	18	69,595.34	3,866.41	$\sigma^2 + 4.66 \sigma S^2$
Calves within sires	185	489,377.42	2,645.28	$\sigma^2$
Condition score				
Total	214	366.4383		
Years	8	42.2341	5.2793	$\sigma^2 + 14.34 \sigma S^2 + 23.01 \sigma Y^2$
Sires within years	17	33.4099	1.9653	$\sigma^2 + 4.93 \sigma S^2$
Calves within sires	189	290.7844	1.5386	$\sigma^2$



TABLE XLIX

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS IN LINE 3.  
(PROJ. 670)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	168	13,233.02		
Years	6	271.55	45.26	$\sigma^2 + 13.31\sigma S^2 + 24.00\sigma Y^2$
Sires within years	10	1,913.89	191.39	$\sigma^2 + 7.52\sigma S^2$
Calves within sires	152	11,047.59	72.68	$\sigma^2$
Weaning weight				
Total	166	690,205.43		
Years	6	130,052.61	21,675.43	$\sigma^2 + 13.08\sigma S^2 + 23.10\sigma Y^2$
Sires within years	10	132,699.43	13,269.94	$\sigma^2 + 7.49\sigma S^2$
Calves within sires	150	427,453.39	2,849.69	$\sigma^2$
Condition score				
Total	164	252.4295		
Year	6	21.5403	3.5901	$\sigma^2 + 12.87\sigma S^2 + 23.00\sigma Y^2$
Sires within years	10	50.3087	5.0309	$\sigma^2 + 7.42\sigma S^2$
Calves within sires	148	180.5804	1.2201	$\sigma^2$

TABLE L

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS IN LINE 4.  
(PROJ. 670)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
<b>Birth weight</b>				
Total	157	11,697.19		
Years	6	1,163.49	193.91	$\sigma^2 + 9.61 \sigma S^2 + 22.05 \sigma Y^2$
Sires within years	15	2,073.81	138.25	$\sigma^2 + 6.02 \sigma S^2$
Calves within sires	136	8,459.90	62.21	$\sigma^2$
<b>Weaning weight</b>				
Total	156	802,043.43		
Years	6	71,306.64	11,884.44	$\sigma^2 + 9.76 \sigma S^2 + 22.01 \sigma Y^2$
Sires within years	14	111,687.76	7,977.70	$\sigma^2 + 6.31 \sigma S^2$
Calves within sires	136	619,049.83	4,551.83	$\sigma^2$
<b>Condition score</b>				
Total	149	294.1107		
Years	6	17.8907	2.9818	$\sigma^2 + 9.20 \sigma S^2 + 21.09 \sigma Y^2$
Sires within years	14	10.9427	.7816	$\sigma^2 + 6.09 \sigma S^2$
Calves within sires	129	265.2774	2.0564	$\sigma^2$

TABLE LI

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS WITHIN LINES.  
(PROJ. 670)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	743	80,508.08		
Years	8	1,543.92	192.99	$\sigma^2 + 11.05 \sigma S^2 + 21.06 \sigma L^2 + 80.11 \sigma Y^2$
Lines within years	22	30,073.62	1,366.98	$\sigma^2 + 12.74 \sigma S^2 + 24.04 \sigma L^2$
Sires within lines	62	8,195.71	132.19	$\sigma^2 + 5.83 \sigma S^2$
Calves within sires	651	40,694.84	62.51	$\sigma^2$
Weaning weight				
Total	731	3,357,579.45		
Years	8	148,015.76	18,501.97	$\sigma^2 + 10.73 \sigma S^2 + 21.05 \sigma L^2 + 79.05 \sigma Y^2$
Lines within years	23	750,147.66	32,615.12	$\sigma^2 + 11.93 \sigma S^2 + 23.02 \sigma L^2$
Sires within lines	64	429,189.50	6,706.09	$\sigma^2 + 5.61 \sigma S^2$
Calves within sires	636	2,030,226.53	3,192.18	$\sigma^2$
Condition score				
Total	727	1,292.5343		
Years	8	71.4312	8.9289	$\sigma^2 + 10.77 \sigma S^2 + 21.05 \sigma L^2 + 78.56 \sigma Y^2$
Lines within years	23	103.9051	4.5176	$\sigma^2 + 11.89 \sigma S^2 + 23.04 \sigma L^2$
Sires within lines	62	171.9047	2.7727	$\sigma^2 + 5.73 \sigma S^2$
Calves within sires	634	945.2932	1.4910	$\sigma^2$

TABLE LII

SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM THE INTRA-SIRE REGRESSION  
OF THE LIFETIME PERFORMANCE OF THE DAUGHTER (Y) ON THE  
LIFETIME PERFORMANCE OF THE DAM (X) WITHIN YEAR  
OF BIRTH OF THE DAUGHTER (PROJ. 650)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	92	2,486.80	460.74	6,232.52
Between sires	14	583.51	70.76	3,173.72
Within sires	78	1,903.29	389.98	3,058.80
Weaning weight				
Total	92	99,661.40	29,550.00	207,076.60
Between sires	14	34,788.46	7,941.61	101,233.67
Within sires	78	64,872.94	21,608.39	105,842.93
Condition score				
Total	86	34.6688	4.5755	92.6653
Between sires	14	4.0093	4.5335	26.8797
Within sires	72	30.6595	.0420	65.7856

TABLE LIII

SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM THE INTRA-SIRE REGRESSION OF THE FIRST RECORD  
OF THE DAUGHTER (Y) ON THE FIRST RECORD OF THE DAM (X) WITHIN YEAR OF  
BIRTH OF THE DAUGHTER (PROJ. 650)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	83	6,852.04	- 405.14	5,039.24
Between sires	14	879.13	-1,459.73	2,178.15
Within sires	69	5,972.91	1,054.59	2,861.09
Weaning weight				
Total	83	106,381.00	2,442.20	216,819.00
Between sires	14	27,321.67	12,190.82	105,302.61
Within sires	69	79,059.33	-9,748.60	111,516.39

TABLE LIV

SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM THE INTRA-SIRE REGRESSION OF THE 1958 RECORD  
OF THE DAUGHTER (Y) ON THE 1958 RECORD OF THE DAM (X) WITHIN YEAR OF BIRTH  
OF THE DAUGHTER (PROJ. 650)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	49	2,432.48	192.68	3,281.38
Between sires	13	454.03	- 955.52	1,149.74
Within sires	36	1,978.45	1,148.20	2,131.64
Weaning weight				
Total	49	132,799.22	3,311.74	139,498.58
Between sires	13	60,235.93	-9,785.26	76,217.64
Within sires	36	72,563.29	13,097.00	63,280.94
Condition score				
Total	47	31.9167	2.5958	58.0128
Between sires	13	16.0083	.8668	31.9020
Within sires	34	15.9084	1.7290	26.1108

TABLE IV

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL  
HALF-SIBS IN REPLICATION 1<sup>1</sup> (PROJ. 650)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	431	35,872.08		
Years	4	1,579.95	394.99	$\sigma_2^2 + 2.53 \sigma S^2 + 11.16 \sigma L^2 + 85.88 \sigma Y^2$
Lots within years <sup>2</sup>	35	2,290.94	65.46	$\sigma_2^2 + 2.47 \sigma S^2 + 10.74 \sigma L^2$
Sires within lots	166	14,948.60	90.05	$\sigma_2^2 + 2.00 \sigma S^2$
Calves within sires	226	17,053.03	75.46	$\sigma_2^2$
Weaning weight				
Total	430	900,147.45		
Years	4	41,920.00	10,480.00	$\sigma_2^2 + 2.53 \sigma S^2 + 11.12 \sigma L^2 + 85.67 \sigma Y^2$
Lots within years	35	59,764.64	1,707.56	$\sigma_2^2 + 2.47 \sigma S^2 + 10.72 \sigma L^2$
Sires within lots	166	336,969.64	2,029.94	$\sigma_2^2 + 2.00 \sigma S^2$
Calves within sires	225	461,493.18	2,051.08	$\sigma_2^2$
Condition score				
Total	231	153.3696		
Years	2	16.2206	8.1103	$\sigma_2^2 + 2.17 \sigma S^2 + 10.06 \sigma L^2 + 76.33 \sigma Y^2$
Lots within years	21	8.5077	.4051	$\sigma_2^2 + 2.11 \sigma S^2 + 9.59 \sigma L^2$
Sires within lots	108	79.1413	.7328	$\sigma_2^2 + 1.67 \sigma S^2$
Calves within sires	100	49.5000	.4950	$\sigma_2^2$

<sup>1</sup>Replication 1 contains calves produced by foundation females born in 1948.

<sup>2</sup>Lots refers to different levels of nutritional winter treatment.

TABLE LVI

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL HALF-SIBS  
IN REPLICATION 2 (PROJ. 650)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	66	4,484.48		
Years	2	648.41	324.21	$\sigma_2^2 + 3.19 \sigma S^2 + 7.50 \sigma L^2 + 21.53 \sigma Y^2$
Lots within years <sup>2</sup>	6	1,705.51	284.25	$\sigma_2^2 + 3.14 \sigma S^2 + 7.17 \sigma L^2$
Sires within lots	19	519.34	27.33	$\sigma_2^2 + 1.97 \sigma S^2$
Calves within sires	39	1,611.22	41.31	$\sigma_2^2$
Weaning weight				
Total	66	110,811.91		
Years	2	7,485.45	3,742.73	$\sigma_2^2 + 3.29 \sigma S^2 + 7.57 \sigma L^2 + 21.94 \sigma Y^2$
Lots within years	6	31,182.52	5,197.09	$\sigma_2^2 + 3.25 \sigma S^2 + 7.31 \sigma L^2$
Sires within lots	19	19,924.59	1,048.66	$\sigma_2^2 + 1.97 \sigma S^2$
Calves within sires	39	52,219.35	1,338.96	$\sigma_2^2$
Condition score				
Total	65	39.7727		
Years	2	4.0731	2.0366	$\sigma_2^2 + 3.19 \sigma S^2 + 7.50 \sigma L^2 + 21.53 \sigma Y^2$
Lots within years	6	2.2557	.3760	$\sigma_2^2 + 3.14 \sigma S^2 + 7.17 \sigma L^2$
Sires within lots	19	8.7564	.4609	$\sigma_2^2 + 1.97 \sigma S^2$
Calves within sires	38	24.6875	.6497	$\sigma_2^2$

<sup>1</sup>Replication 2 contains calves produced by heifers born in 1954.

<sup>2</sup>Lots refer to different levels of winter nutritional treatment.



TABLE LVII

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL  
HALF-SIBS IN REPLICATION 3<sup>1</sup> (PROJ. 650)

Trait and Source of Variation	D/F	Sum of Squares	Mean Squares	Expected Mean Square
Birth weight				
Total	47	3343.98		
Years	1	10.13	10.13	$\sigma^2 + 2.51 \sigma S^2 + 7.82 \sigma L^2 + 22.83 \sigma Y^2$
Lots within years <sup>2</sup>	4	666.58	151.65	$\sigma^2 + 2.42 \sigma S^2 + 7.56 \sigma L^2$
Sires within lots	20	1282.11	64.11	$\sigma^2 + 1.66 \sigma S^2$
Calves within sires	22	1445.17	65.69	$\sigma^2$
Weaning weight				
Total	47	136,922.98		
Years	1	34,722.56	34,722.56	$\sigma^2 + 2.60 \sigma S^2 + 8.16 \sigma L^2 + 23.63 \sigma Y^2$
Lots within years	4	18,255.88	4,563.97	$\sigma^2 + 2.47 \sigma S^2 + 7.85 \sigma L^2$
Sires within lots	20	28,734.21	1,436.71	$\sigma^2 + 1.66 \sigma S^2$
Calves within sires	22	55,210.33	2,509.56	$\sigma^2$
Condition score				
Total	45	71.2391		
Years	1	12.8468	12.8468	$\sigma^2 + 2.51 \sigma S^2 + 7.82 \sigma L^2 + 22.83 \sigma Y^2$
Lots within years	4	6.6713	1.6678	$\sigma^2 + 2.42 \sigma S^2 + 7.56 \sigma L^2$
Sires within lots	20	16.8044	.8402	$\sigma^2 + 1.57 \sigma S^2$
Calves within sires	20	34.9167	1.7458	$\sigma^2$

<sup>1</sup>Replication 3 contains calves produced by heifers born in 1955.<sup>2</sup>Lots refer to different levels of winter nutritional treatments.

TABLE LVIII

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL  
HALF-SIBS IN REPLICATION 4<sup>1</sup> (PROJ. 650)

Trait and Source of Variation	D/F	Sums of Squares	Mean Square	Expected Mean Square
Birth weight				
Total	31	2,305.22	57.022	$\sigma^2 + 5.34 \sigma S^2 + 10.50 \sigma L^2$
Lots <sup>2</sup>	2	742.64	371.22	$\sigma^2 + 5.34 \sigma S^2 + 10.50 \sigma L^2$
Sires within lots	3	57.95	19.32	$\sigma^2 + 5.25 \sigma S^2$
Calves within sires	26	1,504.64	57.87	$\sigma^2$
Weaning weight				
Total	30	76,537.87	12,020.95	$\sigma^2 + 5.20 \sigma S^2 + 10.19 \sigma L^2$
Lots	2	24,041.90	2,010.50	$\sigma^2 + 5.06 \sigma S^2$
Sires within lots	3	6,031.51	2,010.50	$\sigma^2 + 5.06 \sigma S^2$
Calves within sires	25	46,464.47	1,858.58	$\sigma^2$
Condition score				
Total	30	37.4839	5.5450	$\sigma^2 + 5.20 \sigma S^2 + 10.19 \sigma L^2$
Lots	2	11.0899	5.5450	$\sigma^2 + 5.20 \sigma S^2 + 10.19 \sigma L^2$
Sires within lots	3	.5606	.1869	$\sigma^2 + 5.07 \sigma S^2$
Calves within sires	25	25.8334	1.0333	$\sigma^2$

<sup>1</sup> Replication 4 contains calves produced by heifers born in 1956.

<sup>2</sup> Lots refer to different levels of nutritional winter treatment.

TABLE LIX

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS FOR PATERNAL  
HALF-SIBS WITHIN REPLICATIONS (PROJ. 650)

Trait and Source of Variation	D/F	Sums of Squares	Mean Squares	Expected Mean Square
<b>Birth weight</b>				
Total	578	54,603.10		
Years	4	2,458.30	614.57	$\sigma^2 + 2.89\sigma S^2 + 10.06\sigma L^2 + 75.47\sigma R^2 + 114.65\sigma Y^2$
Replications within years	6	8,377.55	1,396.26	$\sigma^2 + 3.14\sigma S^2 + 8.71\sigma L^2 + 34.11\sigma R^2$
Lots within repli- cations	47	5,345.67	113.74	$\sigma_2^2 + 2.70\sigma S^2 + 10.05\sigma L^2$
Sires within lots	208	16,807.55	80.81	$\sigma_2^2 + 2.01\sigma S^2$
Calves within sires	313	21,614.05	69.05	$\sigma^2$
<b>Weaning weight</b>				
Total	576	2,336,466.77		
Years	4	303,932.25	75,983.06	$\sigma^2 + 2.88\sigma S^2 + 10.03\sigma L^2 + 75.32\sigma R^2 + 114.32\sigma Y^2$
Replications within years	6	892,242.31	148,707.05	$\sigma^2 + 3.12\sigma S^2 + 8.70\sigma L^2 + 33.90\sigma R^2$
Lots within repli- cations	47	133,244.94	2,835.00	$\sigma_2^2 + 2.69\sigma S^2 + 10.02\sigma L^2$
Sires within lots	208	391,659.94	1,882.98	$\sigma_2^2 + 2.01\sigma S^2$
Calves within sires	311	615,387.33	1,978.74	$\sigma^2$
<b>Condition score</b>				
Total	374	368.2333		
Years	2	9.6055	4.8027	$\sigma^2 + 2.73\sigma S^2 + 9.50\sigma L^2 + 58.66\sigma R^2 + 123.38\sigma Y^2$
Replications within years	6	89.9030	14.9838	$\sigma^2 + 3.06\sigma S^2 + 8.51\sigma L^2 + 33.19\sigma R^2$
Lots within repli- cations	33	28.5247	.8644	$\sigma_2^2 + 2.52\sigma S^2 + 8.90\sigma L^2$
Sires within lots	150	105.2627	.7018	$\sigma_2^2 + 1.77\sigma S^2$
Calves within sires	183	134.9376	.7374	$\sigma^2$

TABLE LX

SUMS OF SQUARES AND SUMS OF CROSS PRODUCTS FROM THE INTRA-SIRE REGRESSION OF  
THE AVERAGE PERFORMANCE OF THE DAUGHTER (Y) ON THE AVERAGE PERFORMANCE  
OF THE DAM (X) WITHIN YEAR OF BIRTH OF THE DAUGHTER  
(FED. REF.)

Trait and Source of Variation	D/F	$\Sigma x^2$	$\Sigma xy$	$\Sigma y^2$
Birth weight				
Total	26	1,058.67	-144.00	870.00
Between sires	5	211.00	16.00	224.78
Within sires	21	847.67	-128.00	645.22
Average daily gain				
Total	26	.5675	.0037	.8261
Between sires	5	.0933	-.0432	.1862
Within sires	21	.4742	.0469	.6399
Feeder grade				
Total	26	37.1363	.0648	60.4807
Between sires	5	9.6346	-.7677	17.5611
Within sires	21	27.5017	.8325	42.9196

TABLE LXI

ANALYSIS OF VARIANCE OF BIRTH WEIGHT AND WEANING TRAITS  
FOR PATERNAL HALF-SIBS (FED. REF.)

Trait and Source of Variation	D/F	Sums of Squares	Mean Square	Expected Mean Square
<b>Birth weight</b>				
Total	259	16,917.61		
Years	1	508.83	508.83	$\sigma_n^2 + 20.08\sigma_s^2 + 128.70\sigma_y^2$
Sires within years	11	2,211.40	201.04	$\sigma_n^2 + 19.98\sigma_s^2$
Calves within sires	247	14,197.39	57.48	
<b>Average daily gain</b>				
Total	260	1,185.8776		
Years	1	25.6093	25.6092	$\sigma_n^2 + 20.13\sigma_s^2 + 129.10\sigma_y^2$
Sires within years	11	121.5734	11.0521	$\sigma_n^2 + 20.06\sigma_s^2$
Calves within sires	248	1,038.6949	4.1883	
<b>Feeder grade</b>				
Total	252	449.81		
Years	1	13.07	13.07	$\sigma_n^2 + 19.43\sigma_s^2 + 125.06\sigma_y^2$
Sires within years	11	89.37	8.12	$\sigma_n^2 + 19.43\sigma_s^2$
Calves within sires	240	347.37	1.45	

## VITA

Nat Mathan Kieffer

Candidate for the Degree of Doctor of Philosophy

Thesis: INHERITANCE OF CERTAIN MATERNAL TRAITS IN BEEF CATTLE

Major Field: Animal Breeding

Biographical:

Personal Data: Born at Montgomery, Louisiana, July 13, 1930, the son of Loyd and Jessie Kieffer. Married Grace Kloor, Alexandria, Louisiana, January 23, 1951. Father of three daughters, Diana, Margaret, and Leslie Kieffer.

Education: Received the Bachelor of Science degree with a major in General Agriculture from Southwestern Louisiana Institute in May, 1952; received the Master of Science degree with a major in Animal Breeding from Louisiana State University and Agricultural and Mechanical College in August, 1956.

Experiences: Served in the U. S. Marine Corps from June, 1952, to April, 1954. Graduate Assistant at Louisiana State University and Agricultural and Mechanical College, from June, 1955, to August, 1956. Research Assistant at Oklahoma State University of Agriculture and Applied Sciences from September, 1956, to August, 1959.

Professional Organizations: Member of American Society of Animal Production and The Society of The Sigma Xi.