



Early growth and carcass traits of cattle containing Simmental, Angus and Hereford breeding
by Thomas Joseph Lawlor

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Animal Science

Montana State University

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Abstract:

Performance of 543 (birth) to 153 (carcass) calves raised on 3-year-old and older Hereford dams was analyzed using least-squares procedures. Analyses of variance generally included year, breed group, sex, age of dam, appropriate two-factor interactions and appropriate covariates. Data were collected during the years 1976 through 1979 at the Northern Agricultural Research Center near Havre. Breed groups studied were 50% Simmental-50% Hereford (ISIH), 25% Simmental-75% Hereford (1S3H), Angus-Hereford (AH) and straightbred Herefords (HH).

The ISIH group had the longest gestation length, heaviest birth weight, most calving difficulty, lowest level of calves weaned, greatest growth rate, least fat, highest yield and lowest degree of marbling. Conversely, the AH group differed in all traits except postweaning ADG, where it was similar. The 1S3H and HH groups were similar and intermediate for most traits differing only by the 1S3H group having a longer gestation length and higher preweaning ADG. Least-squares means for the growth traits (kg) birth weight, preweaning and postweaning ADG were 41.4, .884 and 1.17 for 1S1H; 37.9, .856 and 1.08 for 1S3H; 37.2, .858 and 1.18 for AH; 37.9, .813 and 1.12 for HH.

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Signature Thomas J. Lander Jr.

Date August 13, 1980

In memory of my parents,
Thomas J. and Annette T. Lawlor

EARLY GROWTH AND CARCASS TRAITS OF CATTLE CONTAINING
SIMMENTAL, ANGUS AND HEREFORD BREEDING

by

THOMAS JOSEPH LAWLOR, JR.

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

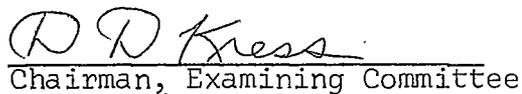
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TABLE OF CONTENTS

	Page
Dedication	i
Vita	iii
Acknowledgements	iv
Table of Contents	v
List of Tables	vii
List of Figures	xi
List of Appendix Tables	xii
Abstract	xiii
Introduction	1
Review of Literature	2
Crossbreeding Theory	2
Gestation Length	9
Birth Weight	14
Calving Difficulty	23
Mortality	32
Preweaning Average Daily Gain	36
Postweaning Average Daily Gain	44
Carcass Traits	49
Materials and Methods	55
Experimental Design	55
Management of Animals and Experimental Design	59
Postweaning Trial at Huntley	63
Statistical Analysis	64
Results and Discussion	69
Birth Traits	69

	Page
Calf Viability	76
Preweaning and Weaning Traits	84
Net Kilograms Weaned	93
Postweaning Average Daily Gain	98
Carcass Traits	101
Traits Associated with the Cow	117
General Discussion.	130
Summary	140
Literature Cited.	142
Appendix Tables	158

LIST OF TABLES

Table		Page
1	Breed Group Means for Birth Traits and Late Mortality	11
2	Design and Number of Animals	58
3	Analyses of Variance for Gestation Length, Birth Weight and Calving difficulty. .	70
4	Breed Group Means and Standard Errors for Gestation Length, Birth Weight and Calving Difficulty	71
5	Calving Difficulty Means and Standard Errors for the Interactions of Breed Group x Sex of Calf and Breed Group x Age of Dam	74
6	Analyses of Variance for Early Survival (0= Dead, 1= Alive).	77
7	Analyses of Variance for Late Survival (0= Dead, 1= Alive).	78
8	Analysis of Variance for Percentage Weaned	78
9	Breed Group Means and Standard Errors for Early and Late Survival and Percentage of Calves Weaned of Those Born	80
10	Characteristics of Calves that Died Between 24 Hours After Birth to Weaning	82
11	Analyses of Variance for Prebreeding Weight, Average Daily Gain and 180-Day Weight	85

Table		Page
12	Breed Group Means and Standard Error for Calf Prebreeding Weight, Average Daily Gain and 180-Day Weight	86
13	Analyses of Variance for Wither Height, Weight/Height and Condition Score . .	89
14	Breed Group Means and Standard Errors for Wither Height, Weight/Height and Condition Score	90
15	Analyses of Variance for Net Kilograms Weaned for Cows Producing a Calf (Actual and 180-Day Weight)	94
16	Breed Group Means and Standard Errors for Net Kilograms Weaned for Cows Producing a Calf (Actual and 180-Day Weight)	95
17	Analyses of Variance for Net Kilograms Weaned for All Cows Bred (Actual Weaning Weight and 180-Day Weight) . .	96
18	Breed Group Means and Standard Errors for Net Kilograms Weaned for All Cows Bred (Actual and 180-Day Weight)	97
19	Analysis of Variance for Postweaning Average Daily Gain (Havre 140-Days) .	99
20	Analysis of Variance for Postweaning Average Daily Gain (Huntley 140-Days) .	100
21	Breed Group Means and Standard Errors for 140-Days Postweaning Gain (Kg/Day) . .	100
22	Analyses of Variance for Carcass Weight, Dressing Percentage and Yield Grade .	103

Table		Page
23	Analyses of Variance for Length, Width and Area of the Rib Eye	104
24	Breed Group Means and Standard Errors for Carcass Weight, Dressing Percentage and Yield Grade	105
25	Breed Group Means and Standard Errors for Length, Width and Area of the Rib Eye .	106
26	Analyses of Variance for Carcass Grade and Marbling Score.	111
27	Breed Group Means and Standard Errors for Carcass Grade and Marbling Score. . . .	111
28	Analyses of Variance for Fat Thickness and Final Age at Slaughter.	112
29	Breed Group Means and Standard Errors for Fat Thickness and Final Age at Slaughter	113
30	Analyses of Variance for Carcass Traits of Huntley Steers.	114
31	Breed Group Means and Standard Errors for Carcass Traits of Huntley Steers. . . .	116
32	Analyses of Variance for Cows' Condition Score at Birth, Weaning and Change in Condition	118
33	Breed Group Means and Standard Errors for Cows' Condition at Birth, Weaning and Change in Condition Scores.	121
34	Analyses of Variance for Cows' Precalving and Weaning Weight, Weight/Height at Weaning and Weight Change from Precalving to Weaning	122

Table		Page
35	Breed Group Means and Standard Errors for Cows' Precalving and Weaning Weight, Weight/Height at Weaning and Weight Change from Precalving to Weaning . . .	124
36	Means and Standard Errors for Cows' Weight Change from Precalving to Weaning for the Year x Breed Group Interaction. . .	125
37	Analyses of Variance for Milk Production Trials.	127
38	Breed Group Means and Standard Errors for Milk Production Trials.	128
39	Genetic and Environmental Components of Breed Groups.	132
40	Growth Traits of Breed Groups Expressed as a Percentage of the Straightbred Hereford's Growth	134
41	Growth Traits of Breed Groups Expressed as a Percentage of the Straightbred Hereford's Growth After Adjusting for Differences in Selection Intensities. .	136

LIST OF FIGURES

Figure		Page
1	Relationship between birth weight and calving difficulty score	75

LIST OF APPENDIX TABLES

Appendix Table		Page
1	Means and Standard errors for Age of Dam Classifications	
2	Yearly Means and Standard Errors.	
3	Sex of Calf Means and Standard Errors . .	
4	Incidence and Type of Dystocia Among Breed Groups.	
5	Characteristics of Calves that Died Between 24 Hours After Birth to Weaning	
6	Residual Correlations Among Birth Traits.	
7	Residual Correlations Among Preweaning Traits.	
8	Residual Correlations Among Carcass Traits at Havre	

ABSTRACT

Performance of 543 (birth) to 153 (carcass) calves raised on 3-year-old and older Hereford dams was analyzed using least-squares procedures. Analyses of variance generally included year, breed group, sex, age of dam, appropriate two-factor interactions and appropriate covariates. Data were collected during the years 1976 through 1979 at the Northern Agricultural Research Center near Havre. Breed groups studied were 50% Simmental-50% Hereford (1S1H), 25% Simmental-75% Hereford (1S3H), Angus-Hereford (AH) and straightbred Herefords (HH). The 1S1H group had the longest gestation length, heaviest birth weight, most calving difficulty, lowest level of calves weaned, greatest growth rate, least fat, highest yield and lowest degree of marbling. Conversely, the AH group differed in all traits except postweaning ADG, where it was similar. The 1S3H and HH groups were similar and intermediate for most traits differing only by the 1S3H group having a longer gestation length and higher preweaning ADG. Least-squares means for the growth traits (kg) birth weight, preweaning and postweaning ADG were 41.4, .884 and 1.17 for 1S1H; 37.9, .856 and 1.08 for 1S3H; 37.2, .858 and 1.18 for AH; 37.9, .813 and 1.12 for HH.

INTRODUCTION

In recent years, crossbreeding of beef cattle has been utilized to achieve improvements in beef production. Existing variation among breeds allows considerable flexibility in matching germ plasm to the demands of different climatic, nutritional and management situations to most efficiently produce highly palatable and nutritious beef. The choice of breeds to use in crossbreeding should be based on additive breed effects, heterosis and complementarity. Both heterosis and complementarity will depend specifically on the breed combination.

Recommendation for specific breed combinations can be accurately made only when breed combinations have been characterized for the entire spectrum of production traits. The objective of the present study was to examine early growth and carcass traits of beef cattle containing Simmental, Angus and Hereford breeding.

REVIEW OF LITERATURE

Crossbreeding Theory

The virtues of crossbreeding have been known for a long time. Charles Darwin (1868) believed that natural selection had produced in us an instinct against incest, and that natural selection was effective in developing this instinct because of the greater survival value of the more vigorous offspring of exogamous matings (Zirkle, 1950). It would be inappropriate to discuss the variations of crossbred vs. straightbred populations without giving mention to the underlying cause of the phenomena involved. It is complementarity and heterosis which animal breeders will most want to capitalize on. Complementarity; a trait of the production unit rather than the individual, is the cumulative effect of interactions among the phenotypes of the sire, dam and produce on the phenotypes of the production system (Fitzhugh et al., 1975).

Heterosis depends on dominance (d) for its occurrence. The concept of dominance can be described as an interaction. The definition of heterosis is, in fact, a definition of interaction. Interaction is the failure of an additive scheme to describe the situation. Thus, the use of dominance serves to illustrate what occurs genetically upon crossing populations (Willham, 1970). The amount of heterosis following a cross between two particular populations depends on the square of the

difference of gene frequency (y) between the populations. Therefore heterosis in the F_1 for the single locus situation is $H_{F_1} = dy^2$.

If some loci are dominant in one direction and some in the other direction their effects will tend to cancel out, and no heterosis may be observed. The occurrence of heterosis on crossing is therefore, dependent on directional dominance, and the absence of heterosis is not sufficient ground for concluding that the individual loci show no dominance (Falconer, 1960).

More than two alleles does complicate the mathematics somewhat because more than one dominance deviation per locus is possible. But if one allele of several at a locus is favored then this allele can be used along with the rest lumped together, and the rationale for the two-allele system is preserved (Willham, 1970). Heterosis in the F_1 is thus the sum of the joint effects of all the loci, or $H_{F_1} = dy^2$ unless epistasis is considered to be important.

Genetic divergence can be carried too far. When a deterioration of adaptive epistatic combinations of each breed occurs, then there are problems (Willham, 1970). Falconer (1960) also states the same theory whereby two populations each

adapted to different ways of life are crossed, the crossbred individuals will be adapted to neither, and will consequently be less fit than either of the parent populations. Fortunately for crosses among breeds of domestic animals, epistatic interaction among loci is negligible (Falconer, 1960).

Overdominance is not necessary for heterosis but it is required for the crossbred to exceed both parental types (Mather and Jinks, 1971). Overdominance occurs between two alleles when the heterozygote lies outside the range of the two homozygotes in genotypic value with respect to the trait under discussion. Two types of overdominance can be distinguished, overdominance as a property of a single locus, and overdominance as a property of a segment of a chromosome. Though the evidence of Mendelian genetics suggests that overdominance is not a very common property of genes, many cases are nevertheless known. Overdominance due to pleiotropy is not infrequent. Also what appears to be overdominance with respect to certain characters may be attributed to epistatic interaction (Falconer, 1960).

The genetic consequences of crossbreeding are threefold:

1. The production of heterosis. This depends on the degree of dominance and the square of the gene frequency difference

between the populations crossed and may be positive or negative. 2. The incorporation of desired genes into a population at a faster rate than increasing the frequency of the genes by selection within the population. This depends on the gene frequency difference between populations relative to the gene frequency change possible by selection (Cartwright, 1970 and Willham, 1970). 3. The incorporation of a combination of desirable traits into a population. This depends on the degree of dominance and the gene frequency difference (Willham, 1970).

The F_1 cross exhibits individual heterosis, one half the additive effects of each breed, the maternal effect of the dam breed and any interaction (complementarity) of the new genotype with management or marketing systems. There is no loss of any epistatic superiority of purebreds due to recombination in gametes produced by crossbred parents (Dickerson, 1969, 1973). Differences in heterosis between the sexes of F_1 individuals has been reported by Stonaker (1963), and it was hypothesized that heterosis is influenced by the sex chromosome. Stonaker (1963) called this effect homogametic heterosis. Whatever the reason for this difference in heterosis among sexes, it should be recognized and the sexes analyzed separately.

"Existing breeds of each species are essentially mildly inbred lines. They differ (1) in mean gene frequencies and hence in transmitted effects in breed crosses due to divergence in selection for particular traits and for adaptation to particular environments, as well as to the random drift associated with limited effective population size, (2) in average heterozygosity relative to each other and to the hypothetical population of all possible breed crosses, which also is due largely to varying degrees of inbreeding or of drift toward fixation in gene frequencies and (3) in epistatic combination effects of genes on performance (Dickerson, 1973)."

Heterosis in crossing existing breeds does differ from heterosis in linecrossing within a breed in several very important respects: (1) crossbreeding heterosis represents average improvement in performance over straightbred parents instead of inbred parents, (2) no extra current costs are involved for developing inbred lines and (3) diversity represented among breeds is more likely (than that among inbred lines within a breed) to provide genetic combinations suited to a variety of production - management - marketing situations, including specialized "sire" and "dam" breeds (Moav, 1966; Mason, 1969 and Dickerson, 1973).

Relative efficiency of different methods for utilizing genetic diversity and heterosis depends upon rate of reproduction, magnitude of heterosis, divergence in paternal and maternal performance vs. individual performance and of epistatic deviations from additive-dominant gene effects. Dickerson (1973) recommended methods of crossbreeding for each of these dependencies: 1.) greater heterosis favors specific crossbreeding or synthetics, 2.) lower reproduction rate favors rotational crossbreeding or synthetics rather than specific crossbreeding, 3.) larger breed differences in maternal as compared to individual performance increases advantage of crossing specific "terminal sire" with maternal crossbred dams, 4.) greater recombination loss of parental epistatic superiority in progeny of crossbred parents means less potential role for multibreed synthetics as compared to rotation or specific crossbreeding.

Results indicate that improving additive genotypic value in purebred sires will be approximately as effective in improving crossbred performance as it is in improving purebred performance. Dunn et al. (1970) showed there were no major differences in the pooled sire components of variance for the straightbreds and crossbreds, indicating similar additive

genetic variance in the two groups. Koger et al. (1975) and Dunn et al. (1970) reported high genetic correlations between straightbred and crossbred progeny of purebred sires. Dunn pointed out that there were no significant differences in estimates of heritability between the two groups although higher heritabilities in the crossbreds were noticed. Results in laboratory species also show higher heritabilities for crossbreds (Vinson et al., 1969). Since crosses are less variable, the higher heritability is probably the result of a smaller environmental and a larger genetic contribution to the differences (Stonaker, 1973).

Specific combining ability among sires of the same breed appears to be small and would be difficult to measure effectively (Koger et al., 1975). Low values for sire x breed of dam interaction have been observed by Gregory et al. (1965, 1966 a,b), Dunn et al. (1970) and Koger et al. (1975). Benyshek et al. (1979) did report a significant sire x breed of dam interaction accounting for .3 to 4.0% of the total variation. Therefore it appears heterosis is due to an effect of the breed rather than to sire effects within breeds.

Gestation Length

Significant breed of sire effects have been reported for gestation length of their calves by Sagebiel et al. (1973), Smith et al. (1976), Deutscher and Slyter (1978), Gregory et al. (1978a) and Anderson et al. (1979). Sire breeds that were characterized by longer than average gestation length tended to sire calves with heavier than average birth weight (table 1) (USDA, 1976). In straightbred Herefords, Sagebiel et al. (1967) and Sagebiel et al. (1973) observed a 285- and 286-day gestation length, respectively. Sagebiel et al. (1967) with straightbred Angus observed a 279-day gestation length. Anderson et al. (1979) with Angus sired crossbred calves also observed a gestation length of 279 days. In Simmental-sired crossbred calves, gestation lengths of 286.2, 285.2 and 286 days have been observed by Smith et al. (1976), Burfening et al. (1978a) and Anderson et al. (1979), respectively.

Male calves have longer gestation lengths than female calves. Differences of .83, 1.9, 1.2, 1.7, 1.1 and 1.05 days have been reported by Sagebiel et al. (1967), Bellows et al. (1971), Cundiff et al. (1974), Smith et al. (1976), Burfening et al. (1978a) and Belcher and Frahm (1979), respectively. The actual birth dates between the sexes may vary more than these

results would indicate. Cundiff et al. (1974) reported average conception date of female embryos was 2.8 days earlier than that of male embryos ($P < .05$). Gestation length was 1.2 days shorter for females than for males ($P < .05$). Thus, females were born 4.0 ($P < .01$) days earlier than males.

Significant breed of dam effects have been reported by Sagebiel et al. (1973), Smith et al. (1976a) and Gregory et al. (1978a). The dam contributes not only by transmitting a sample half of her genes to the calf but also through her maternal ability. Significant maternal effects were found in all three crosses for gestation length among Angus, Hereford and Shorthorns (Sagebiel et al., 1973). This indicates that the fetus is not completely responsible for variation in the gestation period. Gestation lengths for 2, 3, 4 and 5-year-old age of dam subclasses were $283.5 \pm .2$, $285.0 \pm .3$, $285.4 \pm .3$ and $285.5 \pm .2$ days, respectively (Smith et al., 1976a). Burfening et al. (1978a) showed a small linear increase in gestation length with increasing age of dam. Bellows et al. (1971) reported a significant positive correlation between condition score and gestation length for Hereford dams.

The high estimates of heritability for gestation length (Sagebiel et al., 1968 and Burfening et al., 1978a), would seem

TABLE 1. -- BREED GROUP MEANS FOR BIRTH TRAITS AND LATE MORTALITY

Breed group ¹	No. ²	Gest. length (days)	Birth weight (lb.)	Calving difficulty (%)	Mortality ³	
					Early (%)	Late (%)
HH -----	141	285.5	76.5	18	3.7	4.9
AA -----	166	281.6	68.1	12	4.8	3.8
Heterosis (H by A)		-.6	1.9	-4	-3.0	-2.9
HA + AH ----	375	282.9	74.3	11	1.3	1.5
JH + JA ----	302	281.8	64.6	5	2.6	4.3
SDH + SDA --	232	285.6	78.9	27	6.1	3.4
LH + LA ----	371	288.1	79.8	24	5.1	4.3
CH + CA ----	382	285.9	85.1	34	9.6	5.9
SH + SA ----	399	286.3	83.8	29	6.8	4.3
H dams -----	1106	286.4	79.2	24	5.4	5.0
A dams -----	1262	283.3	74.7	17	4.8	3.0

1

H = Hereford, A = Angus, J = Jersey, SD = South Devon, L = Limousin, C = Charolais, S = Simmental; sire breed is first and dam breed is second.

2

Number of births.

3

Early mortality is within 24 hrs. of birth; late mortality is from 24 hrs. after birth until weaning.

(USDA, 1976)

to indicate that much of the variation is additively genetic and heterosis would, therefore, probably be small. This agrees with the low heterosis values obtained between the Angus and Hereford breeds of .4%, .5%, .15% and -.6% by Sagebiel et al. (1967), Rollins et al. (1969), Sagebiel et al. (1973) and Long and Gregory (1974), respectively. Sagebiel et al. (1967) and Sagebiel et al. (1973) reported more heterosis exhibited in male births. Although heterosis may affect gestation length in a small positive (longer) way the net effect on birth date may be negative (earlier). Gaines et al. (1966) reports calves sired by crossbred bulls were born approximately 1½ weeks earlier than calves sired by purebred bulls. This may be due to hybrid vigor for sexual maturity, libido, semen quality, or to some other cause.

Gestation length accounted for 19% of the variation in birth weight on an overall basis and for 13% of the variation on a within subclass basis (Gregory et al., 1978a). In Simmental-sired calves as gestation length increased, birth weight increased approximately .25 kg/day (Burfeining et al., 1978a). This was similar to the respective values of .30 and .20 for Hereford and Angus dams reported by Bellows et al. (1971) and the .25 overall regression reported by Smith et al.

(1976a). However, the increase was not linear. As gestation length increased, birth weight increased at a decreasing rate. The regression of birth weight on gestation length should not be interpreted as an accurate estimate of growth rate during late gestation (Smith et al., 1976). In Hereford cows, the effect of gestation length on birth weight ranked second in importance to precalving body weight of the dam (Bellows et al., 1971).

Birth Weight

Some of the sources of variation affecting birth weight of calves are year, breed of sire, sex of calf, age of dam, breed of dam and their interactions. Significant year effects were noted by Gregory et al. (1965), Brinks et al. (1967), Sagebiel et al. (1973), Thrift et al. (1978), Gregory et al. (1978b) and Crockett et al. (1979). Sagebiel et al. (1973) reported the year effect could be due to a sire effect since different groups of three sires within each breed were used each year, but a genotype x environment interaction may have been a contributing factor. In Hereford cattle a significant genotype x environment interaction was reported by Burns et al. (1979) showing a 1.2 kg advantage for the local genotypes over the introduced groups.

Burfening et al. (1978c) reported management unit accounted for 24% of the total variation in birth weight, with the sire within management unit accounting for 7.8%. Deutscher and Slyter (1978) reported a significant year by management system (drylot vs. pasture) interaction. Variation in birth weight from year to year may be attributed to environmental factors, genetic factors, changes in management of the herd or their interactions.

Significant breed of sire effect has been reported by Gregory et al. (1965), Pahnish et al. (1969), Turner and McDonald (1969), Reimer and Cobb (1971), Sagebiel et al. (1973), Long and Gregory (1974), Smith et al. (1976a), Anderson et al. (1978), Chapman et al. (1978), Deutscher and Slyter (1978), Gray et al. (1978), Gregory et al. (1978b), Thrift et al. (1978) and Crockett et al. (1979). These differences can be partially summarized as the Simmental and Charolais crosses having the heaviest and Jersey crosses the lightest birth weights. Limousin and South Devon crosses were similar in birth weights and intermediate between Charolais and Simmental crosses and the Hereford-Angus crosses (USDA, 1976).

Differences among Hereford and Angus sires show Hereford-sired calves heavier by .3 kg to 3.8 kg as reported by Gregory et al. (1965), Gaines et al. (1966), Pahnish et al. (1969), Sagebiel et al. (1969), Turner and McDonald (1969), Reimer and Cobb (1971), Laster et al. (1973), Sagebiel et al. (1973), Long and Gregory (1974), Gray et al. (1978), Thrift et al. (1978). Calves by Simmental sires have been shown to be heavier than Hereford and Angus sires (Laster et al., 1973; Smith et al., 1976; Thrift et al., 1978 and Thompson et al., 1979). Birth weights from eight experiments of 50% Simmental calves

had an unweighted average of 37.6 kg ranging from 32.7 to 40.3 kg (Laster et al., 1973; Smith et al., 1976a; Anderson et al., 1978; Burfening et al., 1978b; Burfening et al., 1978c; Chapman et al., 1978; Crockett et al., 1979 and Thrift et al., 1978).

Reports using crossbred bulls are limited, but theoretically a 50% reduction in heterosis is obtained in a backcross. Thrift et al. (1978) reported calves sired by Maine-Anjou x Angus bulls were 1.8 kg heavier ($P < .01$) than the average of calves sired by straightbred bulls. Gaines et al. (1966) reported no difference in birth weight of calves sired by crossbred or purebred bulls.

Within the Hereford breed, line-of-sire can be a significant source of variation when inbred lines are crossed as reported by Flower et al. (1963) and Brinks et al. (1967). Kress et al. (1979) did not find a significant line-of-sire effect. Different results may be due to varying levels of inbreeding or difference in the gene frequencies due to different traits of selection.

A significant sire breed x sex interaction was reported by Smith et al. (1976a). This interaction, although significant, explained less than 1% of the total variation. The effect of

sex of calf on birth weight has numerously been reported. An unweighted average of 10 studies involving crossbred calves show male calves 2.6 kg heavier (Sagebiel et al., 1969; Laster et al., 1973; Long and Gregory, 1974; Smith et al., 1976; Burfening et al., 1978a,b; Chapman et al., 1978; Gray et al., 1978 and Gregory et al., 1978a,b). This value agrees well with a 7-8% advantage for male vs. female calves in Herefords (Koch et al., 1973).

The magnitude of the differences between the sexes for birth weight varies with the age of the dam. In Simmental sired calves, the difference in birth weight between bull and heifer calves was 2.8, 3.2, 3.4 and 3.7 kg respectively, for calves from 2, 3, 4 and 5 to 8-year-old dams (Burfening et al., 1978d). In a crossbreeding experiment by Turner and McDonald (1979) a significant age of dam effect was observed only in the steers.

Thompson et al. (1979) observed that the mean birth weight increased with dam age up to 6 years and tended to decline slowly but erratically after 7 years. Thrift et al. (1978) reported the same trend, with an increase in birth weight from 2 through 5 years of age, remaining constant for the next four (6, 7, 8, 9+) age of dam classifications. Smith et al. (1976a)

reported that the effect of dam age on birth weight was not consistent among breed groups.

This inconsistency may be due to differences in maternal ability among breeds or to the transmitted effects of the breed, which could affect how much variability will be expressed. A maternal effect is a phenotypic value of a dam measurable only as a component part of her offspring's phenotypic value. Not only are the genes of the dam responsible for the maternal effect expressing themselves in the phenotypic value of the offspring, but the dam also contributes a sample half of her genes to the offspring (Willham, 1972). Koch (1972) reported that maternal effects observed from the differences in reciprocal crosses is a real source of variation affecting birth weight. Cundiff et al. (1974) found that progeny of Angus-Hereford cows were 1.3 kg heavier at birth than progeny of the reciprocal cross. Gregory et al. (1965) observed small differences from reciprocal crosses between Hereford, Angus and Shorthorns. Sagebiel et al. (1973) reported no significant maternal effect on birth weight in the Angus, Hereford and Shorthorn breeds.

Breed of dam thus contributes in two ways to the phenotypic value of her offspring (maternal and transmitted effects)

while the sire does so only through his contribution of a sample half of his genes. This contribution by the dam is dependent upon the genetic correlation between direct and maternal effects. If a negative genetic correlation exists between the direct and the maternal effect, the dam either gives her offspring a plus set of genes for the direct effect and a poor maternal effect or vice versa (Koch, 1972 and Willham, 1972). A negative genetic correlation for birth weight has been observed in Herefords by Brinks et al. (1967) and Kress et al. (1979).

Breed of dam has been reported as a significant source of variation in birth weight among crossbred calves (Sagebiel et al., 1973; Smith et al., 1976 and Gregory et al., 1978b). A nonsignificant effect of breed of dam in crossbred calves was reported by Chapman et al. (1978). Within the Hereford breed line-of-dam was reported significant by Brinks et al. (1967), but nonsignificant by Kress et al. (1979).

Heterosis, as indicated by a significant breed of sire x breed of dam interaction, was reported by Gregory et al. (1965), Reimer and Cobb (1971), Long and Gregory (1974), Deutscher and Slyter (1978), Gregory et al. (1978b) and Thrift et al. (1978). Pahnish et al. (1969) found a significant breed of sire x breed

of dam effect only in males. Nonsignificant effects were observed by Sagebiel et al. (1973), Gray et al. (1978) and Chapman et al. (1978).

The range in heterosis for birth weight with the Angus and Hereford breeds is -3% (Crockett et al., 1978) to 3.5% (Gregory et al., 1965 and Reimer and Cobb, 1971). The percentage of heterosis among lines within the Hereford breed has been reported as .1, 3.4, -.7, 2.6 and 3.0 by Flower et al. (1963), Brinks et al. (1967), Burfening and Kress (1973), Humes et al. (1973) and Kress et al. (1979), respectively.

Rollins et al. (1969) pointed out that the larger cross-bred calves at birth may indicate hybrid vigor in embryonic growth and development. Burfening and Kress (1973) suggested that the biggest part of heterosis may be exhibited by the cow for maternal ability rather than by the calf. Thrift et al. (1978) pointed out that the amount of variation accounted for by the breed of sire x breed of dam interaction is relatively small in relation to the amount of variation accounted for by the main effects of breed of sire and breed of dam. This agrees with Gregory et al. (1965) who pointed out the importance of additive genetic variation on birth weight and the relatively high heritability of .42 given by Petty and

Cartwright (1966).

Lactation status of the dam the previous year could affect birth weight of the calf. Pahnish et al. (1969) reported dams that were wet the previous fall produced male calves that were 1.9 kg heavier ($P < .05$) at birth than did dams that were dry the previous fall. Conversely, dams that were dry the previous fall produced heifer calves with a nonsignificant advantage of 1.2 kg in birth weight over cows that were previously lactating. Brinks et al. (1967) reported the effect of lactation status (wet or dry the previous fall) was nonsignificant.

Bellows et al. (1971) found that body weight of the dam exerted a highly significant positive effect on birth weight for both Angus and Hereford cows. This effect ranked first in importance of factors attributed to either the dam or calf and was the most important of variables studied (gestation length was second most important). This would indicate that larger heifers had larger calves through some component of maternal environment. The negative effect of body condition score of the dam on calf birth weight approached significance for Hereford dams. In addition, the positive correlations between weight gains during the first half of gestation and birth weight

were highly significant for Herefords. How these might be related to the influence of maternal environment on birth weight is open to speculation but they could be interpreted to suggest that the partition of nutrients between the dam and fetus is not the same in large and small dams and this results in different fetal growth rates.

Winter supplementation of the dam affected birth weights of Herefords in a drylot (Wyatt et al., 1977). Laster et al. (1974) reported increased levels of energy (4.9, 6.2 or 7.7 kg/head/day) for a 90-day period before the calving season increased ($P < .01$) calf birth weights in straightbred Herefords. Precalving energy level had no effect on the five calf shape measurements taken in this study. The increased calf birth weights were apparently due to an increase in soft tissue rather than an increase in skeletal size.

The regression of day of birth within the calving season on birth weight was a significant source of variation (Turner and McDonald, 1969; Gregory et al., 1978b). This was probably reflecting a season-of-birth effect.

Calving Difficulty

Interest in birth weight is centered around its association with calving difficulty and later growth performance. Birth weight of the calf has been identified as the most important factor associated with calving difficulty (Bellows et al., 1971; Laster et al., 1973 and Burfening et al., 1978b). Calving difficulty increases of 2.3, 1.6, 2.6 and 1.0% per kilogram increase in birth weight have been observed by Laster et al. (1973), Smith et al. (1976), Burfening et al. (1978a) and Gregory et al. (1978a) respectively. Burfening et al. (1978c) reported a positive genetic correlation of .42 between calving difficulty and birth weight.

The regression of incidence of dystocia on birth weight is curvilinear. Predicted increases in incidence of dystocia at lighter weights have been reported by Gregory et al. (1978a) and Notter et al. (1978a). Gregory et al. (1978a) interpreted the increase in calving difficulty to be the failure of a quadratic regression to describe the effects of lighter birth weight on calving difficulty rather than an increase in calving difficulty being caused by birth weights below a given level. Notter et al. (1978a) interpreted their results as not being of biological significance but as a quadratic approximation of

an asymptotic relationship. Burfening et al. (1978b) describe a threshold effect, where no increase in calving difficulty occurs until a certain birth weight is obtained.

Other factors of the calf which can affect calving difficulty are gestation length and shape of the calf. Bellows et al. (1971) and Burfening et al. (1978a) detected correlations of .06 and .25 respectively, for gestation length and calving difficulty. Calves with longer gestation lengths experienced more calving difficulty (Bellows et al., 1971; Laster et al., 1973; Smith et al., 1976a; and Burfening et al., 1978a). The effect of gestation length on calving difficulty is through its association with birth weight rather than a direct effect of gestation length on calving difficulty (Bellows et al., 1971; Smith et al., 1976a; and Burfening et al., 1978a).

Shape of the calf has been postulated as a possible factor affecting calving difficulty (Brinks et al., 1973; Laster et al., 1973; Smith et al., 1976a; and Burfening et al., 1978c). Laster (1974) found that none of the five calf shape measurements he recorded were significantly related to calving difficulty independent of birth weight. It is apparent then, that increase in birth weight is the primary factor attributing

to calving difficulty, although other factors cannot be neglected.

Breed of sire has been reported as a significant source of variation for calving difficulty by Laster et al. (1973), Laster (1974). Long and Gregory (1974), Deutscher and Slyter (1978), Gregory et al. (1978a,b), Notter et al. (1978a) and Bailey and Moore (1979). Sagebiel et al. (1969) reported that the breed of sire effect was significant only for the males when the sexes were analyzed separately. At least a portion of the difference for incidence of dystocia observed between breed of sire subclasses may be attributed to higher birth weights. Breeds with high mean birth weights also have high mean levels of dystocia (see table 1).

When birth weight was included as a covariate, breed of sire was still significant (Smith et al., 1976; Gregory et al., 1978a; and Notter et al., 1978a). This indicated that factors other than birth weight influenced dystocia. The within breed regressions of dystocia on birth weight can underestimate the between-breed relationship (Notter et al., 1978a). Apparently variation in birth weight within breeds is less closely associated with components of size and structure responsible for dystocia than is variation in birth weight among breeds

(Notter et al., 1978a). Laster (1974) pointed out that genetic or environmental factors that affect skeletal dimensions in calves may have more impact on calving difficulty than factors which produce relatively small differences in weight of soft tissues. It appears then that structural differences of calves between breeds may be an additional factor contributing to dystocia from crossbreeding (Laster et al., 1973; and Smith et al., 1976), although there is no experimental data to support this hypothesis.

Significant breed of dam effects have been observed by Sagebiel et al. (1969), Laster et al. (1973), Laster (1974), Long and Gregory (1974), Smith et al. (1976), Gregory et al. (1978a,b), Notter et al. (1978a) and Bailey and Moore (1979). These results could be due to the transmitted effects of the cow to the calf's genotype responsible for dystocia. It may also be due to cows of different breeds being more susceptible to experiencing calving difficulty. Sagebiel et al. (1969) stated that the correlation between dystocia score and a ratio of birth weight to cow weight indicated that larger calves in relation to the cow have more dystocia. Therefore, cows of smaller breeds when mated to larger sire breeds may be more prone to having calving difficulty.

Bellows et al. (1971a) reported that the pelvic area of the dam exerted a significant negative effect on calving difficulty score in both Hereford and Angus dams. Laster (1974) found that in yearling heifers, pelvic area was influenced by breed of sire ($P < .01$) and breed of dam ($P < .05$). Although Laster (1974) showed pelvic area to be a heritable trait, these two factors accounted for only 18% (R^2) of the variation. Gregory et al. (1978b) postulated that certain breeds may be more susceptible to adverse environmental factors contributing to calving difficulty.

The incidence of dystocia is also dependent upon the age of the dam, with younger cows experiencing more dystocia (Brinks et al., 1973; Smith et al., 1976; Burfening et al., 1978b; and Belcher and Frahm, 1979). The primary age difference in regression of incidence of dystocia on birth weight appears to be a leveling off of dystocia at low birth weights in older cows (Burfening et al., 1978a; and Notter et al., 1978a). Laster (1974) found in 2-year-old cows that calf birth weight increases with cow weight at a faster rate than does pelvic area of the cow. Notter et al. (1978a) also observed the same trend in crossbred 2 and 3-year-old cows. the crossbred cows that produced calves with heavier birth

weights tended to have more dystocia, even though the cows were also larger and heavier at the time of calving.

Brinks et al. (1973) calculated the heritability of calving difficulty as a trait of the calf. They obtained values of $.126 \pm .109$ from 2-year-old cows and $.069 \pm .022$ from the older cows. Although both estimates are near zero, it appears that the genotype of the calf is somewhat more important in contributing to calving difficulty among 2-year-old cows than in older cows.

The low heritability estimate by Brinks et al. (1973) along with the estimates of 0-10% by Cundiff et al. (1976) and Tong et al. (1976) show the importance of environmental or non-additive genetic effects. Burfening et al. (1978c) reported a heritability value of .32 for calving difficulty. Burfening et al. (1978c) pointed out that in binomially distributed traits, the estimates of heritability are dependent on the frequency. The incidence of calving difficulty was greater in the study by Burfening et al. (1978c) than in the studies cited previously.

Incidence of dystocia is similar between ages of mature cows (Brinks et al., 1973; Laster et al., 1973; and Burfening et al., 1978b). This trend may be explained by the cows attainment of mature skeletal size. Bellows et al. (1971a,b)

and Neville et al. (1978) observed measurable increases in pelvic area from 2 to 3 years of age with a plateau between 36 and 39 months of age. Smith et al. (1976) described a plateauing of dystocia level in 4-year-old cows for all sire breeds except for Charolais and Simmental. Therefore, only in crosses with large sire breeds is increased cow size after 4 years of any advantage. Along with age of dam, parity can have an effect on calving difficulty. Laster et al. (1973) and Notter et al. (1978a) observed more calving difficulty in primiparous 3-year-old cows compared to 3-year-olds calving for the second time.

Evidence presented in the literature pointed to a higher incidence of dystocia with male calves. The range of significant difference between sexes has been reported between 4.9 and 40.2% (Bellows et al., 1971a; Brinks et al., 1973; Laster et al., 1973; Laster, 1974; Long and Gregory, 1974; Smith et al., 1976; Burfening et al., 1978a,b; Gregory et al., 1978a,b; Notter et al., 1978a; and Belcher and Frahm, 1979). Generally, the higher the average level of calving difficulty observed, the greater the difference observed between the sexes (Laster et al., 1973; Smith et al., 1976; Gregory et al., 1978a,b; and Notter et al., 1978a). These differences could be

due to variation in size or shape between the sexes, but sex differences in other factors related to the fetus, such as hormonal differences, can not be ignored (Bellows et al., 1971a).

A significant interaction between sire breed and dam breed would indicate that crossbreeding increases dystocia. Sagebiel et al. (1969), analyzing the sexes individually, reported a significant interaction for heifers. Laster et al. (1973) found a reverse effect, with straightbred female calves having $6.93 \pm 3.57\%$ higher ($P < .10$) incidence of dystocia than crossbred females. Long and Gregory (1974) found no difference between straightbred and crossbred females. Crossbred male calves do not have significantly larger dystocia scores or more calving difficulties than straightbred male calves (Sagebiel et al., 1969; Laster et al., 1973; and Long and Gregory, 1974).

Several interactions have been reported significant by different observers such as: breed of sire x sex (Laster et al., 1973; and Notter et al., 1978a), breed of sire x age of dam (Laster et al., 1973), breed of dam x age of dam (Laster et al., 1973), breed of dam x sex (Laster et al., 1973 and Burfening et al., 1978b) and age of dam x sex (Laster et al., 1973 and Burfening et al., 1978b). Laster et al. (1973) pointed out

that the breed of sire x sex of calf and breed of sire x age of dam interactions were greater for calves sired by breeds with higher birth weights (Charolais, Simmental, Limousin and South Devon) than for those sired by breeds with lower birth weights (Hereford, Angus and Jersey). This indicates that a factor which affects dystocia is expressed more dramatically when the level of dystocia is high.

Concern over calving difficulty is generated by the losses inflicted upon the cattle industry, due to increases in labor costs, decreased subsequent reproductive performance in cows and a higher incidence of mortality. Laster et al. (1973) reported dystocia significantly decreased incidence of estrus and conception rate. A nonsignificant increase in interval from calving to conception was also observed. Brinks et al. (1973) noted heifers having calving difficulty as 2-year-olds weaned 11% fewer calves of those born the first year and 14% fewer calves per cow exposed the second year. Calves born the second year were an average of 13 days younger and 21 kg lighter at weaning.

Mortality

Calf losses at or near the time of birth were between 3.7 to 7 times greater ($P < .01$) in calves experiencing dystocia than in those not experiencing dystocia (Laster and Gregory, 1973; Smith et al., 1976; and Notter et al., 1978a). The range in percent mortality between the two groups from the same studies was 8.4 to 15.4. Anderson and Bellows (1967) found that the most common cause of calf mortality at or near the time of birth was injury incurred during difficult or delayed parturition. Laster and Gregory (1973) substantiated Anderson and Bellows (1967) finding. Approximately 90% of the calves dead at birth were attributed to the delay in receiving assistance or the amount of difficulty required to remove the calf. Cundiff et al. (1974) reported calving difficulty had a significant negative influence on postnatal survival to 2 weeks. A nonsignificant 2.2% higher late mortality in calves experiencing dystocia was reported by Notter et al. (1978a). Contrary to these reports, Long and Gregory (1974) found the higher incidence of dystocia in Hereford-sired calves was not associated with lower survival rate.

Sire group influenced ($P < .01$) calf mortality in parturitions involving dystocia, but did not significantly influence

calf mortality in unassisted births (Laster and Gregory, 1973). Breed of sire effects were significant for perinatal mortality when either calving difficulty was included as a fixed effect (Smith et al., 1976a) or with birth weight as a covariate (Gregory et al., 1978a). Notter et al. (1978a) and Gregory et al. (1978a) found significant results for postnatal mortality and calf crop weaned, respectively. Nonsignificant results for breed of sire effects on postnatal mortality and calf crop weaned have been reported by Smith et al. (1976a), Gregory et al. (1978b) and Ellis et al. (1979).

Results for breed of sire effects can vary according to the breeds involved and the ages of the cow. Generally, breed of sire groups that experience the higher levels of calving difficulty also tended to experience higher levels of perinatal mortality and lower levels of calf crop weaned (Gregory et al., 1978a). However, higher incidence of dystocia in Hereford-sired calves (Long and Gregory, 1974) and Brown Swiss-sired calves (Gregory et al., 1978a) was not associated with lower survival rate. Notter et al. (1978a) noted significant breed of sire effects for early mortality (before 72 hours) in 2-year-old cows but not in 3-year-olds.

Age of dam significantly influenced calf losses in studies

by Anderson and Bellows (1967), Koger et al. (1967), Laster and Gregory (1973), Cundiff et al. (1974), Long and Gregory (1974), Brinks and Knapp (1975), Bailey et al. (1977) and Kress et al. (1979). In parturitions involving dystocia, age of dam had no significant influence on calf mortality (Laster and Gregory, 1973). Smith et al. (1976a) reported a nonsignificant age of dam effect for early mortality when calving difficulty was included as a fixed effect, but age of dam was significant for late mortality. Losses from late mortality in calves decreased with increasing age (Smith et al., 1976a). Age of dam effects for late mortality could be due to mothering ability of the cow. Notter et al. (1978a) noted rankings for total and late mortality were similar in 2 and 3-year-olds, and followed rankings for estimated milk production. These results imply that the cow effect on late mortality is associated with the nutrition she provides.

Male calves have lower survival rates at birth, at 72 hours after birth and to weaning than female calves (Anderson and Bellows, 1967; Cundiff et al., 1974; Long and Gregory, 1974 and Gregory et al., 1978a). This difference can be accentuated by the presence of dystocia. Laster and Gregory (1973)

observed higher ($P < .05$) mortality in male calves only with difficult parturitions. The higher level of dystocia associated with male calves does not necessarily mean a higher level of mortality (Gregory et al., 1978b; and Notter et al., 1978a). A contrary report by Bailey et al. (1977) showed males with a higher ($P < .05$) preweaning survival rate.

Notter et al. (1978a) observed that optimum early, late and total survival rates occurred at about one standard deviation above the mean for birth weight. This suggests that initially increasing birth weight is associated with increased calf vigor which can more than compensate for the increased dystocia.

Preweaning Average Daily Gain

Average daily gain from birth to weaning (ADG) is a function of weaning weight (WW), days of age (DA) and birth weight (BW). If growth is linear with age of calf, then ADG may be expressed as $\frac{WW - BW}{DA}$. In this case WW standardized for age of calf may be considered the same trait as ADG, differing from it only because of a scaling factor (Cunningham and Henderson, 1965) or due to differences in birth weight (Sagebiel et al., 1974). The range of .95 to .99 for the genetic correlation of ADG and WW obtained by Petty and Cartwright (1966), Koch et al. (1973), Burfening et al. (1978) and Nelsen and Kress (1979) indicates that a high proportion of the genes affecting ADG also affect WW.

Phenotypic correlation is made up of inheritance, environment or both (Johansson and Rendel, 1968). The high phenotypic correlations of .97 to .98 (Petty and Cartwright, 1966; Koch et al., 1973; Nelsen and Kress, 1979) show that environmental factors influence both ADG and WW in the same direction or not at all. The biology of the situation would indicate that the environmental influence is in the same direction.

Breed of sire significantly affected ADG, adjusted and

actual weaning weights (Gregory et al., 1965; Pahnish et al., 1969; Reimer and Cobb, 1971; Turner and McDonald, 1969; Long and Gregory, 1974; Sagebiel et al., 1974; Smith et al., 1976; Anderson et al., 1978; Deutscher and Slyter, 1978; Gregory et al., 1978a; Gregory et al., 1978b; Peacock et al., 1978; Thrift et al., 1978; and Crockett et al., 1979). Generally, the breed of sire crosses with the lower birth weight tended to have lower ADG and lower adjusted weaning weights (Gregory et al., 1978a). Birth weight can affect weaning weight from two aspects. First from its part-whole relationship and second through its genetic correlation with weaning weight ($r_g = .33$ to $.58$) (Petty and Cartwright, 1966; Koch et al., 1973; Burfening et al., 1978c and Nelson and Kress, 1979). Birth weight is also genetically associated with ADG but apparently to a lesser extent ($r_g = .10$ to $.42$).

Although ADG and adjusted weaning weights can be discussed together, differences among breed of sire groups for birth weight can cause a significant source of variation for adjusted weaning weight but not for preweaning ADG (Sagebiel et al., 1974). This is due to a carry over from the breed of sire effect on birth weight.

Actual weaning weights include differences due to age of

