MONTANA STATE UNIVERSITY

Sire by region interaction for production traits in beef cattle

by Thomas Robert Nunn

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Animal Science
Montana State University
© Copyright by Thomas Robert Nunn (1974)

Abstract:
Data from 38,261 field records obtained from the American Simmental Association were used to evaluate the importance of sire x region interactions in beef cattle for birth weight, weaning weight, yearling weight, gestation length and calving ease. Data were analyzed by least squares procedures by a model containing sire, region and sire x region interaction effects. Trait ratios were used in all analyses. Only progeny born and weaned in the same herd were included. The United States was divided into nine regions with one region deleted due to small numbers. Montana was further divided into three sub-regions to study the interaction within one state for birth weight and weaning weight. Birth weight and weaning weight were analyzed using separate analyses of records from all eight regions, four regions containing 85% of the records, two regions (Texas and Oklahoma vs. Montana) and the three regions of Montana. Records from five regions were analyzed for yearling weight and from three regions for gestation length and calving ease. The number of records for these latter three traits was small.

The progeny of 10-13 sires were used in each analysis. The region effect was not significant for any trait. The sire effect was significant for all analyses except weaning weight within Montana, yearling weight and calving ease. The sire x region interaction effect was significant for all analyses of weaning weight ($P<.01$) except Montana and approached significance ($P=.07$) for birth weight within Montana. Genetic correlations were calculated from the sire and sire x region interaction variance components for each analysis to assess the average change in sire performance among regions. Correlations were not defined for the within Montana weaning weight or calving ease. Correlations of unity were obtained for all analyses of birth weight except Montana and for gestation length indicating no change in the ranking of sires. For birth weight within Montana and yearling weight, correlations of 0.21 and 0.25 were obtained, respectively, suggesting some changes in the ranking of sires. Correlations of 0.47 to 0.54 suggested that changes in the ranking of sires occurred for weaning weight. This was confirmed from the least squares means for the sire x region subclasses. The sine x region variance component was less than 27° of the total variance for any given analysis of weaning weight. Although this was a small percent, it could be important biologically. The least squares means for the sire x region subclasses indicated that in many cases a given sire ranked above average in one region but below average in other regions. This indicated that errors could be made in applying the results of progeny tests in one region to progeny performance and selection in a different region. The need for evaluating sires in all regions and on a within region basis was suggested.

In presenting this thesis in partial fulfillment of the requirements for an advanced degree of Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Thomas R Hunn

Date March 1, 1974.

SIRE BY REGION INTERACTION FOR PRODUCTION TRAITS IN BEEF CATTLE

by

THOMAS ROBERT NUNN

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Animal Science

Approved:

R V Blackwell
Head, Major Department

O D Kress
Chairman, Examining Committee

Henry L Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

March, 1974

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. D. D. Kress for his advice and guidance throughout his graduate program. Also, appreciation is extended to Dr. R. L. Blackwell and Dr. P. J. Burfening for their advice and suggestions in preparing this manuscript and to Mr. R. Friedrick for his assistance with computer programming.

Appreciation is expressed to the American Simmental Association for supplying the data for this study. The author also extends his thanks to the Nova Scotia Department of Agriculture for granting the Leave of Absence necessary for this period of study.

Sincere gratitude is expressed to Mrs. Frankie Larson for typing this manuscript.

TABLE OF CONTENTS

	Page
VITA	ii
ACKNOWLEDGEMENTS	iii
INDEX TO TABLES	v
INDEX TO FIGURES	vi
INDEX TO APPENDIX TABLES	vii
ABSTRACT	ix
INTRODUCTION	1
LITERATURE REVIEW	2
General	2
Classification of Interactions	5
Dairy Cattle	8
Sheep	12
Beef Cattle	16
Gestation Length and Calving Ease	16
Birth Weight	17
Weaning Weight	18
Postweaning Gain and Yearling Weight	21
MATERIALS AND METHODS	26
RESULTS AND DISCUSSION	40
Introduction	40
Birth Weight	41
Weaning Weight	46
Yearling Weight	51
Gestation Length	54
Calving Ease	55
Discussion	56
SUMMARY	62
LITERATURE CITED	65
APPENDIX	72

INDEX TO TABLES

Table		Page
1.	EDITS FOR THE VARIOUS TRAITS	27
2.	NUMBER OF SIRES, NUMBER OF REGIONS, TOTAL NUMBER OF PROGENY AND AVERAGE NUMBER OF PROGENY PER SIRE AND REGION FOR EACH TRAIT	29
3.	CLASSIFICATION OF THE UNITED STATES INTO REGIONS	31
4.	EXPECTATIONS OF THE MEAN SQUARES	36
5.	NUMBER OF PROGENY PER REGION FOR MONTANA	39
6.	LEAST SQUARES ANALYSES OF VARIANCE FOR BIRTH WEIGHT.	42
7.	ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR BIRTH WEIGHT	44
8.	LEAST SQUARES ANALYSES OF VARIANCE FOR WEANING WEIGHT.	47
9.	ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR WEANING WEIGHT.	48
10.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (ALL REGIONS)	50
11.	LEAST SQUARES ANALYSES OF VARIANCE FOR YEARLING WEIGHT, GESTATION LENGTH AND CALVING EASE.	52
12.	ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR YEARLING WEIGHT, GESTATION LENGTH AND CALVING EASE.	53

INDEX TO FIGURES

Figures		Page
1.	Four different types of genetic x environmental interactions	7
2.	Map of continental United States showing division into regions	32
3.	Map of Montana showing division into three regions	34

INDEX TO APPENDIX TABLES

Table		Page
1.	NUMBER OF PROGENY PER SIRE AND REGION FOR BIRTH WEIGHT BEFORE DELETIONS	73
2.	NUMBER OF PROGENY PER SIRE AND REGION FOR WEANING WEIGHT BEFORE DELETIONS	75
3.	NUMBER OF PROGENY PER SIRE AND REGION FOR YEARLING WEIGHT BEFORE DELETIONS	77
4.	NUMBER OF PROGENY PER SIRE AND REGION FOR GESTATION LENGTH AND CALVING EASE BEFORE DELETIONS	78
5.	LEAST SQUARES SIRE AND REGION MEANS AND STANDARD ERRORS FOR THE VARIOUS TRAITS	80
6.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (ALL REGIONS)	81
7.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (ALL REGIONS)	82
8.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (REGIONS 3, 6, 7, 8)	83
9.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (REGIONS 3,6,7,8)	84
10.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS, MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (REGIONS 6 and 7)	85
11.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (MONTANA)	86
12.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (MONTANA)	87
13.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (ALL REGIONS)	88
14.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (REGIONS 3, 6, 7, 8)	89

Table		Page
15.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (REGIONS 3, 6, 7, 8)	90
16.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS, MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (REGIONS 6 and 7)	91
17.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (MONTANA)	92
18.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (MONTANA)	93
19.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR YEARLING WEIGHT	94
20.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR YEARLING WEIGHT.	95
21.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR GESTATION LENGTH	96
22.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR GESTATION LENGTH	97
23.	LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR CALVING EASE	98
24.	LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR CALVING EASE	99

ABSTRACT

Data from 38,261 field records obtained from the American Simmental Association were used to evaluate the importance of sire x region interactions in beef cattle for birth weight, weaning weight, yearling weight, gestation length and calving ease. Data were analyzed by least squares procedures by a model containing sire, region and sire x region interaction effects. Trait ratios were used in all analyses. Only progeny born and weaned in the same herd were included. The United States was divided into nine regions with one region deleted due to small numbers. Montana was further divided into three sub-regions to study the interaction within one state for birth weight and weaning weight. Birth weight and weaning weight were analyzed using separate analyses of records from all eight regions, four regions containing 85% of the records, two regions (Texas and Oklahoma vs. Montana) and the three regions of Montana. Records from five regions were analyzed for yearling weight and from three regions for gestation length and calving ease. The number of records for these latter three traits was small. The progeny of 10-13 sires were used in each analysis. The region effect was not significant for any trait. The sire effect was significant for all analyses except weaning weight within Montana, yearling weight and calving ease. The sire x region interaction effect was significant for all analyses of weaning weight ($P<.01$) except Montana and approached significance ($P=.07$) for birth weight within Montana. Genetic correlations were calculated from the sire and sire x region interaction variance components for each analysis to assess the average change in sire performance among regions. Correlations were not defined for the within Montana weaning weight or calving ease. Correlations of unity were obtained for all analyses of birth weight except Montana and for gestation length indicating no change in the ranking of sires. For birth weight within Montana and yearling weight, correlations of 0.21 and 0.25 were obtained, respectively, suggesting some changes in the ranking of sires. Correlations of 0.47 to 0.54 suggested that changes in the ranking of sires occurred for weaning weight. This was confirmed from the least squares means for the sire x region subclasses. The sire x region variance component was less than 2% of the total variance for any given analysis of weaning weight. Although this was a small percent, it could be important biologically. The least squares means for the sire x region subclasses indicated that in many cases a given sire ranked above average in one region but below average in other regions. This indicated that errors could be made in applying the results of progeny tests in one region to progeny performance and selection in a different region. The need for evaluating sires in all regions and on a within region basis was suggested.

INTRODUCTION

A genotype-environment interaction may be defined as the differential response of genotypes over environments. The effect of genotype on phenotype is not the same in two different environments.

Beef cattle are raised over a wide range of climatic conditions and in various types of production programs. There is also a great amount of movement of breeding cattle among environments. The existence of genotype-environment interactions may mean that the best performing genotype in one environment is not the best in a different environment. If these interactions are important sources of variation, the increased use of sires by artificial insemination over a wide range of geographical areas should cause concern in the selection of sires. Studies with beef cattle are not in agreement as to the importance of genotype-environment interactions.

The purpose of the present study was to evaluate the importance of sire x region interactions in beef cattle and to determine if significant interactions were due to changes in the ranking of sires among regions. The traits studied included calving ease, gestation length, birth weight, weaning weight and yearling weight.

LITERATURE REVIEW

General

Hammond (1947) suggested that selection is most effective if carried out under environmental conditions which favor the fullest expression of the trait desired. Once the trait is selected to the desired level, the animals could be used in other environments, if other characters required by the new environment are present in the animals.

Lush (1945) and Falconer (1952) have recommended that selection should occur in the same environment in which the selected animals and their offspring are expected to perform. Falconer and Latyszewski (1952) pointed out that if genotype-environment interactions are important, Hammond's thesis may not be correct. They suggested that a great increase in heritability would be the only reason for favoring selection in an environment other than the one in which the improved animal is expected to live.

Robertson, O'Connor and Edwards (1960) have asked several important questions regarding the importance of genotype-environment interactions: "Does the environmnetal level affect the ability to pick the animals of superior genetic merit in that environment? In technical terms, is the heritability different in the different environments? Is the ranking of animals on the basis of genetic merit the same in all environments? In other words, what is the correlation between breeding value in the different environments, or rather less helpfully, is there an interaction between genotype and environment?"

The idea of expressing genotype-environment interaction as a genetic correlation if only two environments are considered was developed by Falconer (1952). Performance of a trait in the two environments is regarded as two different traits which are genetically correlated. This helps to decide if selection should be made in the environment in which the animals are expected to live or in some other environment in which the desired trait is more fully expressed.

Robertson (1959) expanded on this idea and presented formulae for estimating the genetic correlation of the performance of the same genotype in two or more environments from the mean squares in a two-way factorial analysis of variance. He stated that an interaction may be due to a difference in the between genotype variance or in the true ranking of genotypes. A genetic correlation of unity indicates no interaction. Robertson further stated that estimation of the genetic correlation gives a practical rather than statistical indication of the significance of the results. He suggested that an estimate of genetic correlation equal to about 0.8 would be of biological importance.

A similar method of estimating the genetic correlation from the genotype and genotype by environment interaction components of variance was presented by Dickerson (1962). He suggested that one of the most probable kinds of genotype-environment interaction is a change in emphasis between traits as the environment changes.

Falconer and Latyszewski (1952) selected two strains of mice for

six-week body weight, one under restricted and one under full diet conditions. When environments were exchanged for the two strains, the one selected under restricted feed was superior to the full diet strain when on limited feed. Under full feeding, the full diet strain was superior but the restricted diet strain followed closely and was better than the unselected level for full diet.

Falconer (1960) reported on a similar experiment using mice, in which selection for high and low body weights was carried out on both normal and restricted diets. An exchange of diets was made between the two high lines and the two low lines. The best overall performance for high growth rate was produced by selection on the restricted diet and for reduced growth, on the normal diet. The results indicated that selection should be made in the environment in which the animals are destined to live.

In a similar study, Fowler and Ensminger (1960) selected swine for rate of gain on high (H) and low (L) planes of nutrition (full vs. restricted feed). After six generations of selection, half of each line was transferred to the other treatment. This gave four groups, HH, HL, LH and LL. Results of selection showed the LH group to be more efficient in feed conversion and to gain faster than the HH pigs. The HL group gained slower and was less efficient in feed utilization than the LL group. The importance of interaction was shown from the pooled estimate of r_g which was 0.70 for rate of gain between the two treatments. The authors concluded that two types of genotypes were

produced in this study; on the low plane of nutrition, a genotype for efficient feed utilization and on the high plane, a genotype for large appetite and food consumption.

Results from the three previously cited studies supported Lush's (1945) and Falconer's (1952) conclusions that selection should be carried out in the environment in which the animals are to perform.

Classification of Interactions

Haldane (1946) was the first to classify different types of interaction. With two environments and two genotypes, he outlined six different types of interaction. He further showed that with m genotypes and n environments, there would be $\frac{(mn)!}{m!\ n!}$ possible kinds of interaction.

McBride (1958) proposed a classification of genotypes into "inter" and "intra" populations and environments into "macro" and "micro", with four different types of interaction resulting. "Macro-environments" would include different climates or management practices; whereas, "micro-environments" refer to minor environmental differences such as sub-clinical infections. Population differences would be those between breeds, lines or strains. McBride suggested that the interactions likely to be of importance in large animal breeding are those involving, "inter-population genotypes" and "macro-environments" and those between "intra-population genotypes" and "macro-environments".

A similar classification was made by Dunlop (1962) in describing differences in genotypes and environments as "large" or "small".

Small genetic differences are those occurring among individuals of a herd or related herds of a breed or strain; whereas, large differences refer to those between breeds, strains or species. Similarly, he defined small environmental differences as those between individuals in the same general environment and large differences as those between regions or widely different management practices. From this classification, the important interactions in large animal breeding would be small genetic x large environmental differences (i.e., selection in one environment for use in another) and large genetic x large environment differences (i.e., selecting a breed for a certain area).

Pani and Lasley (1972) outlined a slightly different and perhaps more practical classification based on the ranking of genotypes from one environment to another and the statistical significance of the interaction effects. This classification is outlined in figure 1. A significant interaction may be caused by a change in the ranking of genotypes (type 4) or a difference in the magnitude of genotypes (type 3). A change in the ranking of genotypes is important where selection is carried out in one environment for use in another or different environment. Differences in the magnitude of interaction can influence heritability and affect the effectiveness of selection for performance in other environments.

Hull and Gowe (1962) studied the magnitude of genotype-environment interaction using two strains of poultry at three widespread

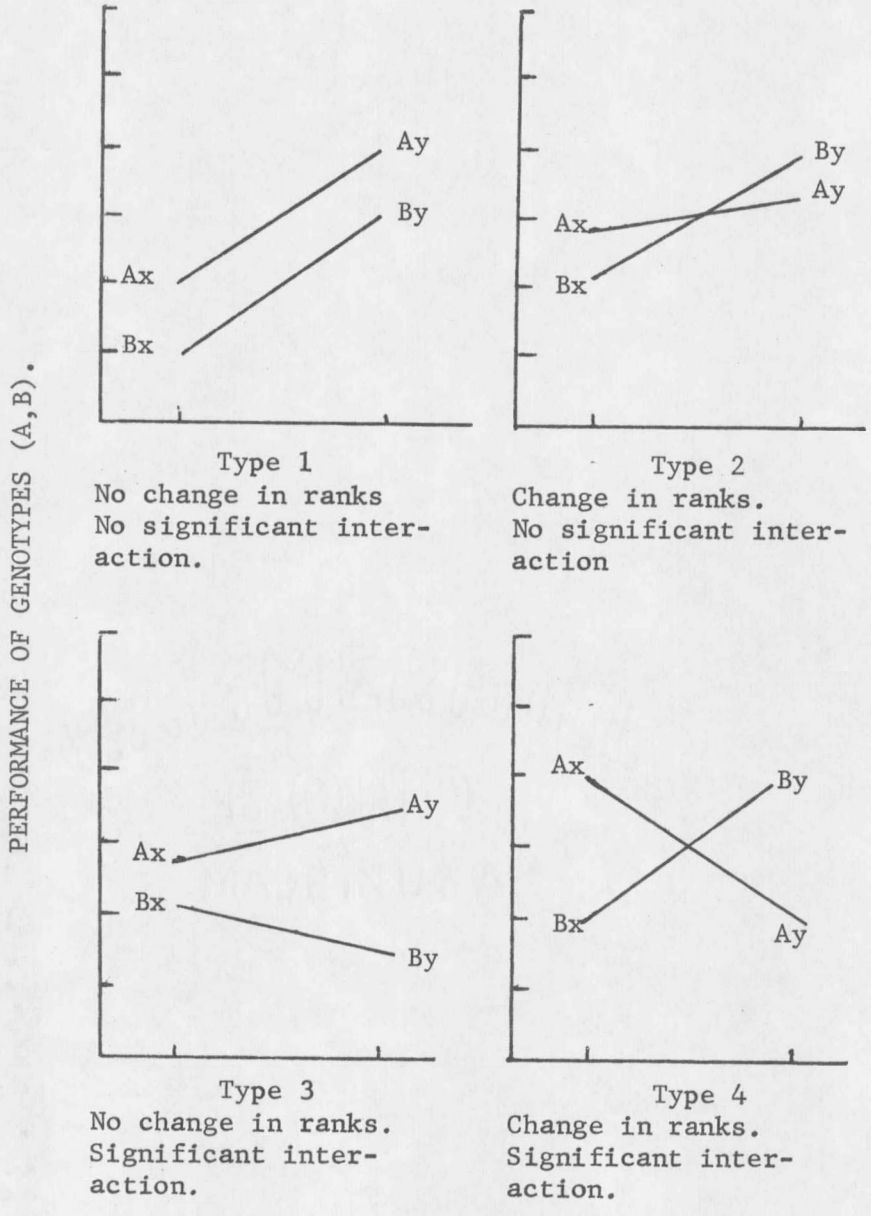


Figure 1. Four different types of genetic x environmental interactions. (From Pani and Lasley, 1972).

locations in three different years and under two rearing programs at each location. From the results, they outlined the conditions under which interaction is likely to be important in a breeding program. Variation due to environmental treatments must be large in comparison to the non-genetic variation within the environments and the genetic variance between the genotypes must be large when compared to the total phenotypic variance within environment. Thus, large and important interactions were found in this study only when the environmental effects were large and the genetic differences were wide. However, it should be noted that this conclusion was based on the performance of only two strains.

Dairy Cattle

Generally, dairy cattle management practices could be expected to be somewhat more uniform than those of beef cattle. However, the importance of genotype-environment interactions may be similar for both classes of livestock, in that selection and testing of bulls may be carried out under good management conditions for use over herds of lower management or in other locations. For these reasons, several representative papers are reviewed on dairy cattle, most of which center on sire x herd interactions. Also, several papers on growth traits which may be more directly applicable to beef cattle interactions are reviewed.

Legates, Verlinden and Kendrick (1956) analyzed records of 24,754 daughters of Guernsey and Holstein sires used in artificial

insemination units throughout the United States. Results of this study showed that the interaction component accounted for essentially none of the total variance for milk yield, fat yield and butterfat test on a within-state basis. Specific sire x herd interactions were not of major importance in these data. Other studies by Wadell and McGilliard (1959), Van Vleck, Wadell and Henderson (1961), Burdick and McGilliard (1963) and McDaniel and Corley (1967) determined that the interaction component was a small or negligible percent of total variance.

Van Vleck (1963) calculated genetic correlations between progeny groups in four management levels for milk and fat yield. All correlations were high, ranging from 0.93 to 1.0. Similar experiments by Mason and Robertson (1956), Roberston et al. (1960), McDaniel and Corley (1967) and Burnside and Rennie (1968) resulted in correlations very near unity for sire evaluations at different herdmate levels, indicating that sires will rank essentially the same under different herd levels. However, Brumby (1961) tested identical twins in two herd levels and obtained a genetic correlation of 0.11, indicating that genotype-environment interaction was an appreciable source of variance.

Van Vleck (1963) found that genetic variance was higher for high production level herds and the fraction of total variance due to genetic variance was lower in the low production herds than in the higher herds. An earlier study by Mason and Robertson (1956) produced a similar result with significantly higher heritability estimates in high

producing herds. Heritability estimates were 0.05, 0.12 and 0.22 for low, medium and high level herds.

Studies by Robertson et al. (1960), Legates (1962), McDaniel and Corley (1967), Lytton and Legates (1966) and Burnside and Rennie (1968) concluded that the variance between progeny groups was higher at high levels of production. However, not all have found heritability to be higher at the high levels of production, due to the within-sire variance increasing at the higher levels also. The studies of Robertson et al. (1960), Legates (1962) and Burnside and Rennie (1968) found little or no difference in heritability estimates at different herd levels.

Records of 10,548 artificially sired progeny of 48 Holstein sires used in the northern and southern regions of the United States were examined by Lytton and Legates (1966) to study sire x region interactions for milk yield, fat yield, and fat test. Genetic correlations between the breeding values of the sires in the two regions approached unity, indicating that the sires ranked essentially the same. The sire x region interaction variance was close to zero. The results indicated that the ranking order of sires was not likely to be influenced by regional differences.

Mao and Burnside (1969) used artifically sired progeny to study the interaction of sire with various herd management factors. They found no interaction of sire with milk price, use of artificial

breeding, source of water on pasture, forage feeding methods in winter and summer, exercise in winter, herd size, grain feeding in winter and housing system. However, a significant interaction was found between sire proof and level of grain feeding in summer.

In an earlier study using Michigan DHIA records, Burdick and McGilliard (1963) found no interaction of importance between sires and herd environments classified by production level, days dry, location, calving interval, or type of housing. The ranking of sires was essentially the same in all environments studied. Wiggans and Van Vleck (1970) observed no significant sire by housing system interaction in a study comparing stanchion and free stall housing for Holstein cows.

From the results of these studies, it would appear that interactions involving levels of herd production, type of housing and other differences in herd environments are unimportant for dairy cattle for milk and butterfat production.

Bonnier, Hansson and Skjervold (1948) studied the effect of two levels of nutrition on monzygous twins and reported significant interactions for weight gain from 1 to 27 months of age. However, the twin set x feeding level interaction was not significant for increase in height at the shoulders.

Hansson, Brannang and Claesson (1953) reported no significant interaction for growth from 1 to 25 months of age with identical twins on four planes of nutrition.

Two methods of rearing male calves from two days of age to a market weight of 130 kg were contrasted by Burnside, MacLeod and Grieve (1969). They found no evidence of significant pair x ration interaction for growth in body weight, heart girth and height at shoulder.

Freeman (1969) fed identical and fraternal Holstein twins on high and low grain rations and found pair x ration interactions to be small or negligible for growth to 40 months of age.

Sheep

Pani and Lasley (1972) suggested that due to regional differences in housing, feeding, management, climate and altitude, genotype-environment interactions may be more important in sheep than other farm animals such as dairy cattle or poultry. They also suggested that the environmental conditions to which sheep and beef cattle are exposed may be fairly similar. A number of studies concerning sheep are reviewed for these reasons.

Carter et al. (1971b) compared the performance of two breed crosses of ewes (North Country Cheviot x Leicester and Hampshire x Hampshire-Rambouillet) at two locations, Ontario, Canada and Virginia, U.S.A. Significant ewe breed x location interactions were found for birth weight ($P<.05$) and 120 day weight ($P=.07$) of the lambs produced. However, these interaction effects were small and of no great biological importance. The interaction was not significant for preweaning ADG.

An earlier paper by Carter et al. (1971a) reported on ewe productivity for the same experiment. Important and significant interactions of location x breed cross were found for percentage of ewes lambing, weight of lamb weaned per ewe mated, and average lambing date. The authors concluded that local adaptation of ewe breeds was important for total production.

Morley (1956) measured the weight gain of Australian Merino half sibs on high and low planes of nutrition from 3 to 17 months of age and found no evidence of genotype-environment interaction for weight at 6 months of age. However, significant interactions were observed for weight at 12 and 17 months of age. Heritability estimates for these traits did not vary with plane of nutrition.

Dunlop (1963) studying five strains of Australian Merinos at three different locations, found strain x location interactions to account for only a very small fraction of the total variance for birth weight and weaning weight.

King and Young (1955) wintered Cheviot, Blackface and Wiltshire lambs under two widely different levels of temperature and two planes of nutrition. They reported no significant breed x environment interaction for change in body weight but did find significant interaction for measurement of cannon, tibia and pelvis.

King, Watson and Young (1959) compared Blackfaces and their crosses (x Lincoln, Wiltshire and Leicester rams) and Welsh and their

crosses (x Suffolk and Wiltshire rams) wintered as lambs on four planes of nutrition. There was a similar response of all the different genotypes to the four nutritional environments for growth and carcass traits, with no evidence of breed cross x plane of nutrition interaction.

Osman and Bradford (1965) used whiteface Targhee type sheep at two locations in California to study genotype-environment interaction and the effects of environment on phenotypic and genetic variation. The two locations (Davis and Hopland) provided mainly a contrast in plane of nutrition. The results indicated that phenotypic variance was higher in the good environment (Davis) and heritability estimates were higher for 120 day weight and yearling weight. There was no evidence of large or important genotype-environment interactions for birth weight, weaning weight or yearling weight.

The importance of sire x plane of nutrition interaction for postweaning gain, body measurements, wool and carcass traits was evaluated by Osman and Bradford (1967) using 40 ram lambs and 78 wether lambs of grade Targhee, Corriedale and Targhee x Corriedale breeding. Significant sire x plane of nutrition interactions were reported for only five of the 38 comparisons made, indicating that the interactions were not a major source of variation.

Brown, Baugus and Sabin (1961) compared two inbred lines of Hampshire and crossbred lambs (Hampshire x range ewes) to determine the effects of sex x line interaction on birth weight, 30 day weight,

120 day weight and number of days to reach 27 kg. The interaction effect was significant only for the number of days required by the inbred lambs to reach 27 kg.

Significant interaction for gain to 6 months of age in ram lambs and for gain to 12 months of age in ewe lambs was reported by Radomska (1965) when comparing half sib progeny of Merino rams in two different environments (flocks vs. test stations). No interaction for birth weight or weaning weight was noted.

Vesely and Robison (1969), utilizing Rambouillet and Romnelet lambs from 75 sires, investigated the importance of genotype x sex interactions in sheep. Differences in heritability estimates between the two sexes for the growth and fleece traits studied were small. All genotype x sex interactions were nonsignificant in the Romnelet. In the Rambouillet, only one sub-group showed significant sire x sex interaction for some traits. The authors concluded that genotype x sex interactions were not of enough magnitude or incident to be of importance.

Results of the studies reviewed on genotype-environment interactions in sheep are somewhat inconclusive. The study of Carter et al. (1971a, 1971b) would suggest that these interactions, particularly for fertility traits, may be more important when large differences in genotypes and environments are involved.

Beef Cattle

Gestation length and calving ease. Relatively little information is available on the importance of genotype-environment interaction on gestation length and calving ease.

Edwards et al. (1966) found significant sire x region interactions for gestation length in a British study of 8,750 calves sired by Charolais and Hereford bulls out of Friesian, Ayrshire, Shorthorn, Jersey and Guernsey dams and some purebred dairy calves. They also observed significant sire x region interactions for difficult calvings during one of the calving seasons.

Significant ($P<.05$) cow breed x year interactions for dystocia score in female calves were reported by Sagebiel et al. (1969) in a study of 529 calves of the Hereford, Angus and Charolais breeds and all reciprocal crosses among them. However, none of the interactions of bull breed x year in both sexes or cow breed x year in male calves were significant for this trait.

Laster et al. (1973) studied various factors affecting dystocia in Hereford and Angus cows bred to Hereford, Angus, Jersey, South Devon, Limousin, Simmental and Charolais bulls. Significant ($P<.05$) breed of sire x sex of calf and breed of sire x breed of dam x sex of calf interactions were reported for calving difficulty.

An analysis of field records of Simmental sired calves by Burfening et al. (1973) showed a significant ($P<.01$) effect for the interaction of percent Simmental x sex of the calf on calving ease.

However, this same interaction was not significant for gestation length.

Birth weight. Butts et al. (1971) studied two herds of Hereford cows, one originating at the U. S. Range Livestock Experiment Station, Miles City, Montana and the other at the Brooksville Beef Cattle Research Station, Brooksville, Florida. The two herds were sub-divided with half of each being transferred to the other location. Records analyzed during 1962-1968 indicated significant location x origin interactions ($P<.01$) for birth weight. Male and female calves of Montana origin were 2.9 and 3.6 kg heavier, respectively, at birth, than calves of Florida origin at the Montana location. Birth weights did not differ at the Florida location.

A significant sire x region interaction for birth weight was noted by Edwards et al. (1966) in a study on the use of Charolais and Hereford bulls on cows of various dairy breeds in England and Wales.

Ellis, Cartwright and Kruse (1965) observed a significant breed or cross x year interaction ($P<.01$) for Hereford, Brahman and crossbred calves of these two breeds. A later study by Turner and MacDonald (1969) found a significant breed of sire x year interaction for calves of various beef crosses. In comparing progeny of 11 Hereford sires at two locations in Montana (Bozeman and Miles City), Woodward and Clark (1950) found no significant sire x location interaction for birth weight.

A study of five lines of Herefords by Brinks et al. (1967) revealed no significant line of sire or line of dam x year interaction for birth weight.

A review of literature reveals various studies involving the sex of the calf. In general, these interactions appear to be more important than the other kinds reviewed.

A differential sex response to inbreeding of dam and calf was reported by Brinks, Clark and Kieffer (1963). In this study, male calves were influenced more by inbreeding of the dam, while female calves were influenced more by inbreeding of the calf. Pahnish et al. (1964) found heritability estimates of birth weight to be 0.32 and 0.14 in male and female calves, respectively.

Ellis et al. (1965) observed a significant ($P<.01$) breed or cross x sex interaction with Hereford, Brahman and crossbred calves. A significant breed of sire x sex interaction ($P<.005$) was found by Laster et al. (1973) for calves from Hereford and Angus dams by seven different bull breeds.

Bradley et al. (1966), using records of Hereford and Hereford x Red Poll calves, found no significant sire x sex or breed of dam x sex interactions for birth weight. A study by Kress and Webb (1972) also reported no significant sire x sex interaction in analyzing records from one Hereford and one Angus herd. From a study of field records, Burfening et al. (1973) found no significant percent Simmental x sex of calf interaction.

Weaning weight. In the study of Butts et al. (1971) involving a reciprocal transfer of Hereford cattle between Montana and Florida,

significant ($P<.01$) location x origin interactions were noted for weaning weight over a seven year period. Male and female calves of Montana origin were 8.2 and 17.2 kg heavier, respectively, than calves of Florida origin at the Montana location. At the Florida location, males and females of Florida origin were 20.4 and 12.2 kg heavier, respectively, than calves of Montana origin.

An analysis of data on 5,000 calves of several beef and dairy crosses by Edwards et al. (1966) found significant sire x year, sire x rearing method and sire x sex interactions for live weight at 90, 180 and 270 days of age. Brinks et al. (1967) observed significant sire x year but not line of dam x year interactions for weaning weight of female calves from crosses involving five Hereford lines. Similarly, Urick et al. (1968) noted significant ($P<.01$) line of sire x year interaction for female but not male calves in an analysis of data involving the same Hereford lines. Line of dam x year interaction was not significant for either sex.

Significant breed of sire x year interaction was found by Turner and MacDonald (1969) in a study of several beef crosses.

The progeny of Hereford sires were tested at two locations by Woodward and Clark (1950). No significant sire x location interaction was noted for preweaning ADG. Rollins and Wagnon (1956) found no significant difference in heritability estimates from two Hereford herds on two nutritional levels. Harwin, Brinks and Stonaker (1966) studied data on 1,627 inbred and linecross calves and found no

significant mating system (inbred or linecross) x year interaction. However, the mating system x sex interaction was significant ($P<.01$).

Wilson et al. (1969) evaluated growth traits for 80 steers and 94 heifers involving 13 year-sire subclasses. They found a significant year-sire x sex interaction for 205 day weight with real differences in the ranking of sires based on their steer and heifer progeny. Similar results were reported by Kress and Webb (1972) in a study of records from one Hereford and one Angus herd. In this study, significant sire x sex interactions were found for preweaning ADG and weaning weight ($P<.05$) for the Hereford calves and for preweaning ADG of the Angus calves ($P<.01$). Rank correlations for the ranking of sires on their heifer progeny performance and bull progeny performance were not significantly different from zero, indicating that changes in the ranking of sires occurred.

A differential sex response to inbreeding of calf and dam was observed by Brinks et al. (1963). Female calves were affected more by inbreeding of the calf; whereas, male calves were affected more by inbreeding of the dam.

Several studies have indicated that sire x sex interactions may not be important sources of variation for weaning weight. Knapp and Phillips (1942) and Koger and Knox (1945) reported no significant sire x sex interaction for weaning weight in range calves. These results were confirmed by Pahnish et al. (1961) who found no evidence of a

sire x sex interaction for weaning weight within ranches and years in a study of 661 calves from 11 Hereford sires.

From a study using Hereford and Red Poll calves, Bradley et al. (1966) reported no significant sire x sex or breed of dam x sex interactions.

Tanner, Frahm and Whiteman (1969) analyzed records on 487 bull, steer and heifer Angus calves from 24 sires over a 3 year period and found no significant sire x sex interaction. They concluded that progeny tests could be conducted in which sires are represented by different sexes if accurate sex adjustment factors are available. Thrift et al. (1970) also found no significant sire x sex interaction in evaluating the progeny records of 8 Hereford bulls.

Postweaning gain and yearling weight. Pani and Lasley (1972) suggested that interactions should be more important for postweaning traits in beef cattle due to their exposure to larger and more variable environmental effects following weaning.

From the study involving the reciprocal transfer of two Hereford herds between Montana and Florida, Butts et al. (1971) reported significant ($P<.01$) location x origin interaction for yearling weight in both males and females. The cattle in this study represented two distinct genotypes (origins) of the same breed.

Pani, Krause and Lasley (1973) analyzed data on 876 calves from 17 Hereford sires during 1961-1967 to evaluate the importance of sire x year interaction effects. In bull calves, the sire x year

interaction was significant for ADG on feed and yearling weight with interaction accounting for 13.0 and 12.5 percent, respectively, of the total variance for these two traits. However, this interaction was not significant for both traits in the heifer calves, accounting for only a small part of the total variance.

Warwick, Davis and Hiner (1964) fed 25 pairs of monozygotic twins of beef breeding on low and high levels of concentrate and found a significant ration x pair interaction for growth to slaughter weight.

Significant sire x sex, sire x year and sire x rearing method interactions were reported by Edwards et al. (1966) from a study of data on 5,000 calves of several beef and dairy crosses.

Urick et al. (1968) analyzed data on 229 bull and 226 heifer calves from straightline and crossline combinations of five Hereford lines. They found significant ($P<.01$) line of sire x year interactions for 12 and 18 month weight of heifers but not for final test weight of bulls. In the same study, line of dam x year interactions were significant ($P<.01$) for the 196 day test gain of the males but were nonsignificant for 12 month weight of the heifers.

It was shown by Wiltbank, Kasson and Ingalls (1969) that genotype-environment interaction could be important for age and weight at puberty. They reported significant ($P<.01$) interactions of breed or cross x nutrition level for age and weight at puberty and gain from

weaning to puberty for Hereford, Angus and crossbred heifers of the two breeds on two nutritional levels from weaning to puberty. However, no significant interactions were found for 12 month weight or 6 to 12 month gain.

The performance of two lowland breeds and two mountain breeds at both locations under very different pasture conditions was tested by Skjervold and Gravir (1961). They found no significant breed x location interaction for gain following 6 months of age.

Brown and Gacula (1962) compared heifers on pasture with bulls from the same sires on a performance test. Management and sex were confounded, providing the two environments. There was no significant sire x environment interaction for postweaning gain. The 42 sires represented were ranked similarly on bull progeny and heifer progeny performance.

The progeny of 5 Hereford sires were evaluated at three widely separated locations in North Carolina by Dillard et al. (1964). Sire x location and sire x ration interactions were found to be unimportant for age and weight at slaughter. A later study was reported by Ahlschwede et al. (1969) on 355 steers from 18 Hereford sires fed at the same three locations on two rations (corn-soybean in drylot vs. pasture). They also found sire x location and sire x ration interactions to be nonsignificant for postweaning gain. The authors concluded that such interactions would contribute little to error in the ranking of sires based on progeny tests.

No significant sires x station interaction for postweaning gain was found by Averdunk, Orel and Schmitter (1968) in testing 97 progeny of 9 sires, with one-half of each progeny group fed at each of two test stations.

Klosterman, Cahill and Parker (1968) compared Hereford, Charolais and their crosses under two management systems and found breed x management system interaction was not important for ADG on feed.

It was concluded by Kress, Hauser and Chapman (1971) that genotype x diet interaction was not an important source of variation for growth from 7 to 24 months of age for identical and fraternal twins on high and low energy rations.

Knapp and Phillips (1942) reported significant sire x sex interaction for 140-day postweaning gain of Hereford calves, indicating that data from both sexes is needed to evaluate a sire for gaining ability. Carter and Kincaid (1959) reported heritability estimates of half sib steers and heifers to be 0.38 and 0.54, respectively, for postweaning gain.

Many of the studies reviewed indicated no importance for sire x sex interactions for postweaning gain or yearling weight. Bradley et al. (1966) reported no significant sire x sex interactions for postweaning gain or final test weight in Hereford and Hereford x Red Poll calves. Similarly, Wilson et al. (1969) reported no significant sire x sex interactions for the same traits from a progeny test using 80 steers and 94 heifers.

Records on 487 bull, heifer and steer Angus calves from 24 sires were evaluated over a three-year period by Tanner et al. (1969). They found no significant sire x sex interactions for 168-day feedlot gain. The authors concluded that sires could be evaluated on progeny tests using different sexes if accurate sex adjustment factors are used. Thrift et al. (1970) reported no significant sire x sex interactions for postweaning ADG or adjusted final weight for steer and heifer progeny of 8 Hereford bulls.

In general, interactions involving sex do not appear to be important for postweaning gain or yearling weight. Pani and Lasley (1972) suggested that other environmental factors become more important than sexual differences after weaning.

MATERIALS AND METHODS

The data for the study were from 38,261 field records obtained from the American Simmental Association. These records were the progeny records of Simmental sires used throughout the United States. Progeny were from 24 breeds of dams including some 50% Simmental dams. The progeny were either 50% or 75% Simmental.

Several disadvantages were recognized in the use of field records for this study. The records were not collected specifically for the purpose of this study. Field records collected without supervision would be subject to greater error in the identification of the progeny and the accuracy of measurements reported than records collected under experimental conditions. The data used in this study were collected under a wide variety of conditions and procedures and varied as to completeness for some traits. Opportunity for error occurred from the time of collection until records were used in the present study. Records with errors were minimized by the use of edits as discussed later.

The traits analyzed were birth weight, 205-day weaning weight (adjusted for age of dam), yearling weight (365-day weight), gestation length and calving ease. Calving ease was scored as follows: 1 = unassisted, 2 = easy pull, 3 = hard pull, 4 = cesarian and 5 = abnormal presentation. The number of abnormal presentations was small (7 records) and they were omitted from all analyses.

Some records were excluded from the study according to the edits outlined in table 1. Records were excluded if they were outside of

TABLE 1. EDITS FOR THE VARIOUS TRAITS

Trait	Edits - reasons for exclusion of data
All traits	Non-matching breeder and member number records
Birth weight	Average, standard, induced calving, <18.2 kg, >77.3 kg
Weaning weight	<160 days, >250 days, <90.9 kg, >681.8 kg
Yearling weight	<330 days, >440 days, <159.1 kg, >909.1 kg <160 day test
Gestation length	Average, standard, induced calving, <267 days, >303 days
Calving ease	Induced calving, dead on arrival, abnormal presentation

certain ranges or if standard values were reported. For some herds, average values were reported for traits based on the performance of only a sample of the progeny. These records were also excluded. In addition, preliminary inspection of the birth weight and weaning weight files indicated that approximately one-third of the records for each of these two traits did not match for breeder and member number. This indicated that one-third of the calves had changed ownership during the dam's pregnancy or in the period from birth to weaning. For this reason, all records with non-matching breeder and member numbers were edited for all traits. Hence, all calves in the study were born and weaned in the same herd. Since the main purpose of this study was to evaluate the importance of sire x region interactions, it was considered necessary to eliminate those records involving the transfer of an animal from one region to another. In this way, the possibility of a record being made in one region and reported in another region was eliminated. A total of 21,711 records were available for analysis following editing. The average number of edited progeny records per sire and region is shown in table 2.

Trait ratios rather than absolute values were used in the analysis of each trait. These ratios were calculated on a within mangement unit basis in order to eliminate several sources of variation. The use of ratios would reduce the error variance and result in more homogeneous variances between herds. Progeny were assigned into

TABLE 2. NUMBER OF SIRES, NUMBER OF REGIONS, TOTAL NUMBER OF PROGENY AND AVERAGE NUMBER OF PROGENY PER SIRE AND REGION FOR EACH TRAIT

	No. regions	No. sires	Total progeny	Average per region	Average per sire
Birth weight	8	13	6,272	784	482
Weaning weight	8	12	12,933	1,617	1,078
Yearling weight	5	10	805	161	80
Gestation length	3	13	847	282	65
Calving ease	3	13	854	285	66

management units on the basis of the following criteria: 1) member number, 2) weaning weigh date of the calf, 3) sex of the calf, 4) percent Simmental of the calf, 5) preweaning management code (1 = dam, 2 = dam plus creep feed, 3 = foster dam) and 6) postweaning feeding group (used only for yearling weight). Data were available from three different years. The weaning weigh date of the calf was included to put the ratio on a within-year basis. Most of the records were from heifers but some bulls and steers were included. The majority of calves were raised on their dams with or without creep feed.

Ratios were calculated only for those animals actually used in the study after editing, in order that the average of each management unit would be 100. A ratio greater than 100 would indicate a heavier weight for birth weight, weaning weight or yearling weight and a longer gestation period and more calving difficulty.

For the purpose of this study, the United States was divided into nine regions on a code system similar to that used by the Beef Improvement Federation (1972). This classification is outlined in table 3. The first digit of each code indicates the region and the second digit the particular state or district within a region. The nine northeastern states (region 1) contained only 4 herds with 24 progeny and were deleted from all the analyses. A geographic division of the states into regions is shown in figure 2. The majority of records were from the midwestern states, Texas-Oklahoma and Montana (regions 3, 6 and 7, respectively).

TABLE 3. CLASSIFICATION OF THE UNITED STATES INTO REGIONS

11[a]	Maine	41	Delaware	81	Idaho
12	New Hampshire	42	Maryland	82	Wyoming
13	Vermont	43	Virginia	83	Colorado
14	Massachusetts	44	West Virginia	84	New Mexico
15	Rhode Island	45	North Carolina	85	Arizona
16	Connecticut	46	South Carolina	86	Utah
17	New York	47	Georgia	87	Nevada
18	New Jersey	48	Florida		
19	Pensylvania				
		51	Kentucky	91	Washington
21	Ohio	52	Tennessee	92	Oregon
22	Indiana	53	Alabama	93	California
23	Illinois	54	Mississippi		
24	Michigan	55	Arkansas		
25	Wisconsin	56	Louisiana		
31	Minnesota	61	Oklahoma		
32	Iowa	62	Texas		
33	Missouri				
34	North Dakota	71	Western Montana		
35	South Dakota	72	Central Montana		
36	Nebraska	73	Eastern Montana		
37	Kansas				

a First digit of code number indicates the region, second digit of code number indicates the state or district.

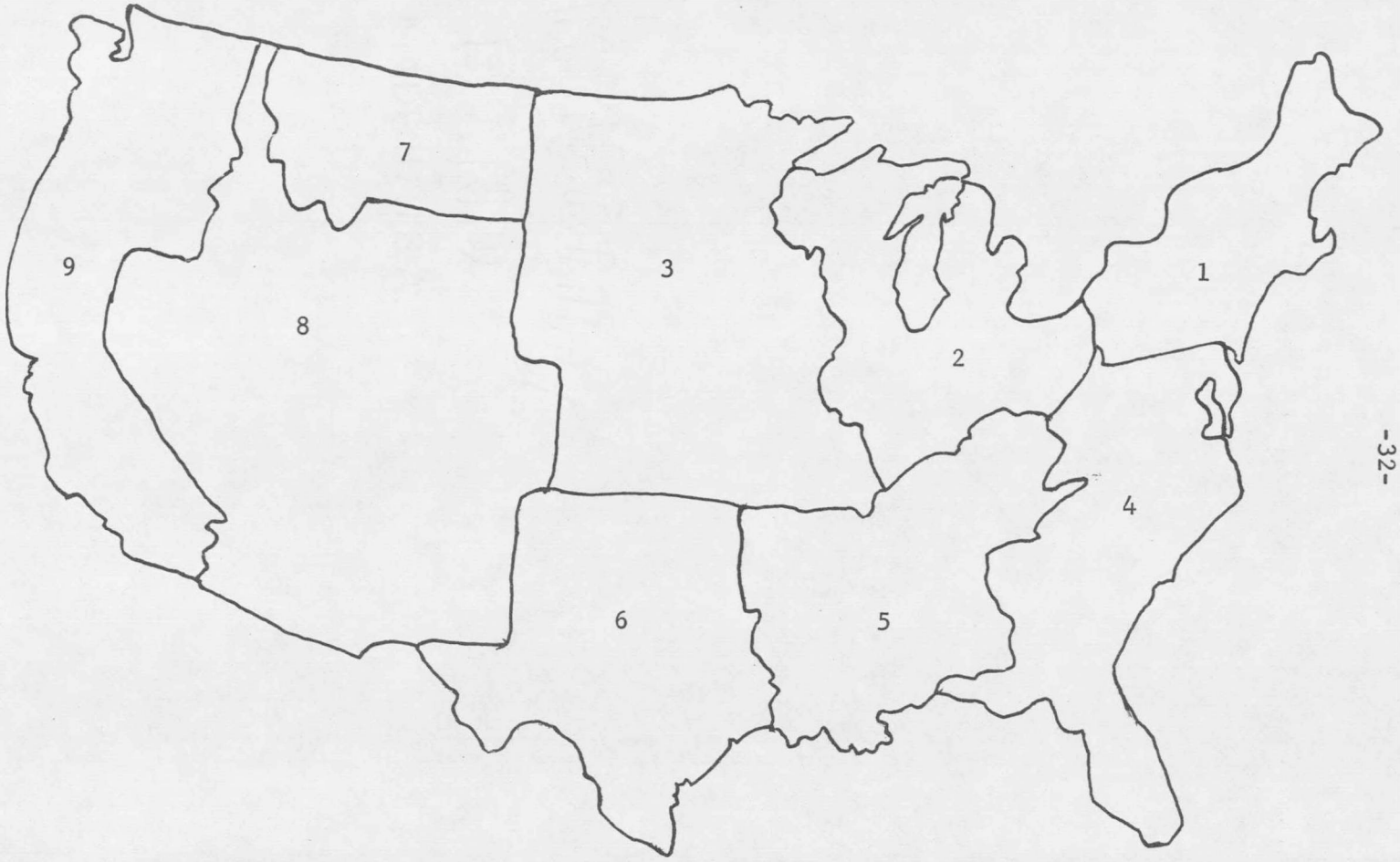


Figure 2. Map of continental United States showing division into regions.

Montana was further divided into three regions (western, central and eastern) to study in greater detail the importance of sire x region interaction within one state. This division was made as outlined by Davis (1968) considering topography, rainfall, temperature, growing season and general beef cattle management practices. The division of Montana into three regions is illustrated in figure 3.

The data were analyzed for all traits by the least-squares method as discussed by Harvey (1960). Each variable was described by the following linear statistical model;

$$Y_{ijk} = u + s_i + r_j + (sr)_{ij} + e_{ijk}$$

where Y_{ijk} = observation on the k^{th} individual in the j^{th} region by the i^{th} sire

u = the fixed underlying population mean

s_i = the effect of the i^{th} sire

r_j = the effect of the j^{th} region

$(sr)_{ij}$ = the interaction of the i^{th} sire with the j^{th} region

e_{ijk} = random errors

The following assumptions were made regarding the distribution of the effects: $s_i = N(0, \sigma_S^2)$ (random); $r_j = 0$ (fixed); $(sr)_{ij} = N(0, \sigma_{SR}^2)$ (random); $e_{ijk} = N(0, \sigma_E^2)$ (uncontrolled, uncorrelated random effect that varied among individuals within sire-region subclasses); s_i, r_j, $(sr)_{ij}$ and e_{ijk} were assumed to be independent and uncorrelated.

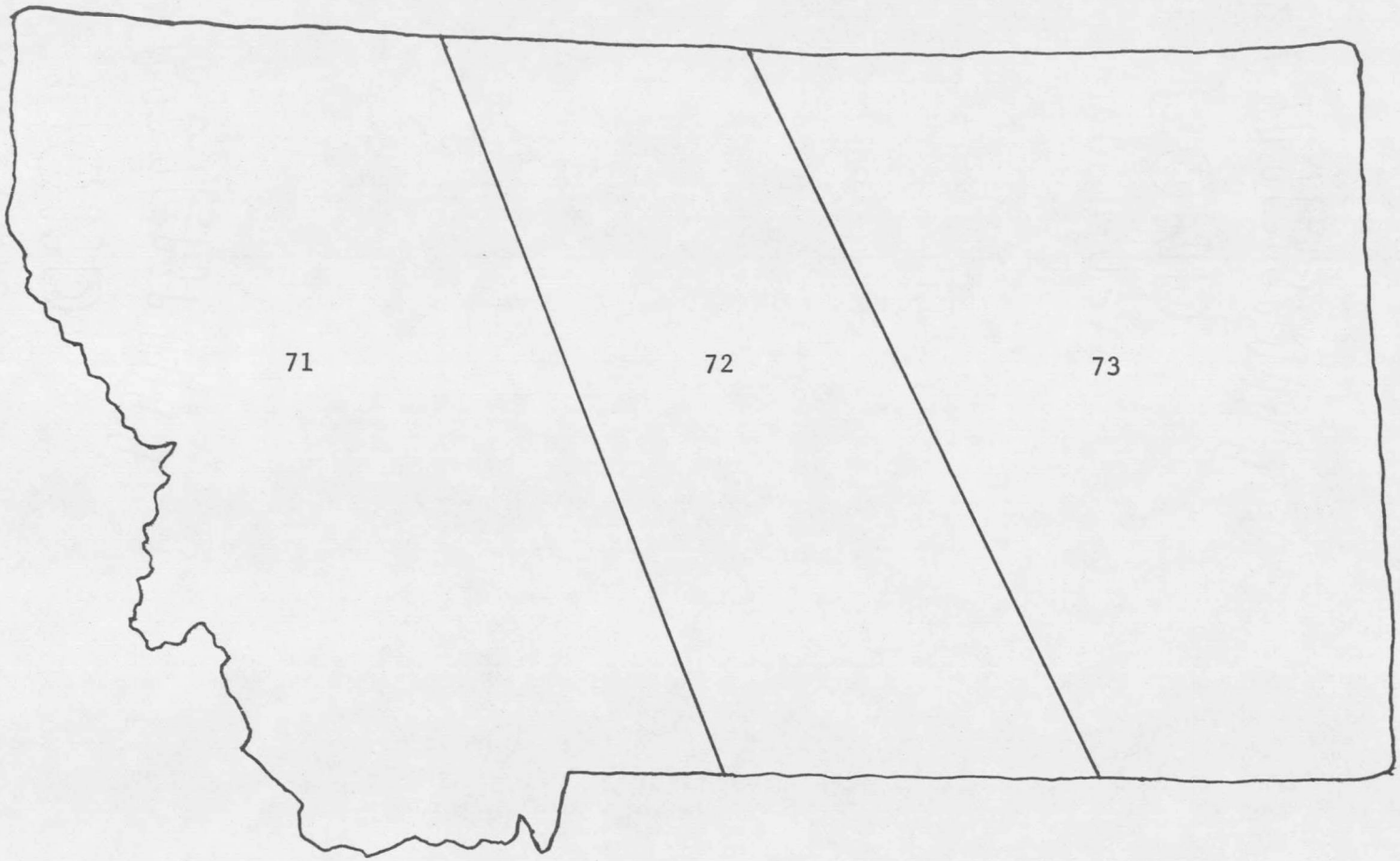


Figure 3. Map of Montana showing division into three regions.

The expectations of the mean squares for the mixed model are shown in table 4. The calculation of the coefficient of the sire variance component (n_4) was by the direct method from the appropriate elements of the inverse matrix for segments of the overall inverse matrix as described by Harvey (1960). The coefficient of the sire x region interaction variance component (n_1) was calculated similarly using formulae given by Genizi (1973). Values for n_2 and n_3 were not calculated since the region effects were assumed fixed and the variance components would not be relevant. The variance components for the sire (σ^2_S), sire x region interaction (σ^2_{SR}) and error (σ^2_E) source of variation were estimated by equating the expected mean squares with the respective observed mean squares from the analyses of variance and solving for the unknown variance components. The total variance per observation (σ^2_T) was estimated by summing the estimated sire, sire x region interaction and error variance componenets ($\hat{\sigma}^2_S + \hat{\sigma}^2_{SR} + \hat{\sigma}^2_E = \hat{\sigma}^2_T$).

Genetic correlation of the sires' progeny performance in the different regions was calculated by the following formula as presented by Yamada (1962):

$$r_g = \frac{\hat{\sigma}^2_S - \frac{1}{K}\hat{\sigma}^2_{SR}}{\hat{\sigma}^2_S + \frac{K-1}{K}\hat{\sigma}^2_{SR}}$$

where K = number of regions.

No correction was made in the denominator of this formula for the difference in genetic variance between regions. Since ratios were

TABLE 4. EXPECTATIONS OF THE MEAN SQUARES

Source	E.M.S.
Sires (S)	$\sigma_E^2 + n_4 \sigma_S^2$
Regions (R)	$\sigma_E^2 + n_2 \sigma_{SR}^2 + n_3 \theta_R^2$
S x R	$\sigma_E^2 + n_1 \sigma_{SR}^2$
Remainder	σ_E^2

used in the analysis of all traits, it was assumed that this difference would be negligible.

The genetic correltation (r_g) was calculated for each trait and analysis in order to assess the average change in performance of genotypes (sires) over the different environments (regions). The estimated sire x region interaction variance component was also expressed as a percentage of the total variance to determine the relative magnitude and importance of σ^2_{SR} for each analysis.

All sires used in the study were given coded identification numbers. Many of the sires represented had small numbers of progeny in some regions. Sires with a large number of missing subclasses were deleted for each analysis. The particular sires represented in each analysis varied from one trait to another. The original sire list with the number of progeny in each region is given in Appendix tables 1-4 for each trait. In general, only 10-13 of the sires with the most progeny and filled subclasses were used in analyzing each trait.

For weaning weight and birth weight, analyses were made using records from all eight regions. Subclasses with less than 20 progeny were excluded for estimation of the sire x region interaction effects. Regions 3, 6, 7 and 8 contained approximately 85% of the records for these two traits. Separate analyses were made using only records from these four regions and excluding subclasses with less than 20 progeny for estimation of the sire x region interaction effects.

Further analyses were made using all records from regions 6 and 7 to compare two very different regions (Texas-Oklahoma vs. Montana). This particular comparison was singled out due to the number of records available and the fact that it represented a fairly extreme comparison with regard to location and cattle management.

Weaning weight and birth weight were also analyzed on a within-Montana basis to investigate sire x region interaction relative to environmental conditions of western, central and eastern Montana. The number of records available for this analysis is shown in table 5.

The number of records available for yearling weight, gestation length and calving ease was limited and there were a large number of missing sire x region subclasses. Adequate numbers were not available to include all regions in the analyses or to study these traits within Montana. Appendix tables 1-4 outline the number of progeny per subclass for all traits. Gestation length and calving ease are listed together in Appendix table 4 because both were recorded or neither was recorded. Records from regions 3, 4, 5, 6 and 7 were included in the analysis for yearling weight, while analyses for gestation length and calving ease were limited to records from regions 3, 6 and 7.

TABLE 5. NUMBER OF PROGENY PER REGION FOR MONTANA

Trait	Region 71 (Western)	Region 72 (Central)	Region 73 (Eastern)
Birth weight	612	714	556
Weaning weight	591	1169	688

RESULTS AND DISCUSSION

Introduction

The results of the analyses are reported separately for each trait studied with some discussion pertaining directly to that trait. This is followed by a general discussion of the importance and implications of the results obtained for the complete study. Several results and observations relevant for all traits are discussed in this introduction.

The region effect was a nonsignificant source of variation for all traits analyzed. This would be expected since the region effect was removed through the use of trait ratios. The values of the coefficients of the variance components (n_1 and n_4) were smaller than the average number of progeny per class or subclass for all traits due to the unequal subclass frequencies. For several analyses, the estimated sire x region interaction variance component was negative and was assumed to be zero for calculation of the percent variance due to the interaction and in calculating the genetic correlation. The analysis of weaning weight within Montana and the analysis of calving ease yielded negative sire and sire x region interaction variance components. Since the sire x region interaction effect was not significant for either analysis, no attempt was made to estimate the genetic correlations.

Robertson (1959) stated that a significant interaction could be due to a difference in the between genotype variance or in the true

ranking of genotypes. He presented formulae indicating that the size of the genotype-environment interaction variance component is influenced by the differences in the genetic standard deviations in two environments as well as by the magnitude of the genetic correlation between the genotypes in the environments. It was further shown that an interaction could not be present if the genetic standard deviations (or heritabilities) were equal in the two invironments and if the genetic correlation was unity. Robertson also indicated that estimation of the genetic correlation gives a practical rather than a statistical measure of the significance of the results. This paper suggested that an estimate of r_g equal to or less than 0.8 would be of biological importance in that the average performance for a particular sire, relative to other sires, would not be the same in all environments. In other words, an estimate of 0.8 or lower would indicate changes in the ranking of genotypes among environments whereas a greater genetic correlation would indicate no important changes in ranking.

Birth Weight

The least squares analyses of variance for birth weight are given in table 6. The sire effect was a significant source of variation ($P<.05$) for all analyses. The sire x region interaction effect was not a significant source of variation for any of the analyses except within Montana. For this analysis, the sire x region

TABLE 6. LEAST SQUARES ANALYSES OF VARIANCE FOR BIRTH WEIGHT

Source of variation	All regions		Regions 3,6,7,8		Regions 6 and 7		Montana	
	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares
Sires (S)	12	765.2**	12	795.6**	14	433.1**	13	204.0*
Region (R)	7	39.3	3	42.4	1	168.0	2	3.2
S x R	37[b]	91.8	26[b]	62.3	13[c]	92.3	23[d]	168.2[a]
Remainder	6215	115.6	5343	112.5	2661	116.1	1843	114.1

* $P < .05$
** $P < .01$
a $P = .07$
b Subclasses with less than 20 progeny were not included in the interaction effect.
c One subclass contained no progeny.
d Three subclasses contained no progeny.

interaction source of variation approached significance (P=.07).

Estimates of the variance components and their coefficients with the genetic correlation coefficient for each analysis are presented in table 7. The sire x region interaction variance component accounted for none of the total variance except within Montana where it was 1% of the total. The sire variance component was less than 3% of the total variance for any given analysis.

The genetic correlations were unity (table 7) for all analyses except within Montana, indicating that the average progeny performance for a particular sire, relative to other sires, was essentially the same for all regions. The sire x region interaction for the analysis within Montana approached significance (P=.07) and a genetic correlation of 0.21 was obtained, suggesting that the average performance of the progeny varied among the three regions of Montana.

Inspection of the least squares means for the sire x region subclasses from all analyses except Montana indicated that some individual changes in the ranking of sires did occur. However, in general, bulls ranking above or below average in one region held this same respective ranking in most other regions (Appendix table 7). For the analysis within Montana, definite changes in the ranking of sires were evident from the least squares means for the sire x region subclasses (Appendix table 12). The sire x region interaction least squares constants were also larger in magnitude for this analysis.

TABLE 7. ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR BIRTH WEIGHT

Analysis	n_1[a]	n_4[b]	Variance components			Sire x region component as % of total[c]	Correlation (r_g)[d]
			Sire	Sire x region	Error		
All regions	102.2	294.9	2.2	-0.2	115.6	0.0	1.00
Regions 3,6,7,8	136.1	314.9	2.2	-0.4	112.5	0.0	1.00
Regions 6 and 7	66.4	121.0	2.6	-0.4	116.1	0.0	1.00
Montana	47.2	130.8	0.7	1.1	114.1	1.0	0.21

a Coefficient of the sire x region variance component.
b Coefficient of the sire variance component.
c Negative estimates were assumed zero.
d Negative estimates of the sire x region variance component were assumed zero in calculating the genetic correlation.

The only environmental effects on birth weight are those expressed through maternal influence and those due to the sex of the calf. Petty and Cartwright (1966) reported an average heritability of 0.42 for birth weight from a summary of 28 estimates. Birth weight would not be expected to be influenced by environmental differences to the same degree as traits of lower heritability. Three of the analyses in this study show the sire x region interaction to be nonsignificant. It is difficult to explain the results of the analysis comparing three regions within Montana where the test of significance and genetic correlation indicated an interaction of some importance. It is unlikely that the environmental differences within Montana would be greater than those among regions of the United States. The number of records analyzed may not be adequate to properly assess the importance of sire x region interactions among the three regions of Montana. The results observed may have occurred entirely by chance.

Woodward and Clark (1950) compared the progeny of 11 Hereford sires at two locations in Montana and found no significant sire x location interaction for birth weight. Edwards et al. (1966) reported significant sire x region interactions for birth weight in a study involving the use of Charolais and Hereford bulls on various dairy breeds in England and Wales. Significant genotype x year interactions were reported by Ellis et al. (1965) and Turner and MacDonald (1969) for birth weight in calves of various beef crosses.

Weaning Weight

The sire and sire x region interaction effects were significant sources of variation ($P<.01$) for all the analyses of weaning weight with the exception of the within Montana analysis (table 8).

The estimated variance components and their coefficients are presented in table 9 with the genetic correlation calculated for each analysis. The sire x region interaction component accounted for less than 2% of the total variance for any given analysis. The sire variance component was also a small part of the total variance, being less than 3% of the total for any given analysis.

For all the weaning weight analyses, except Montana, a genetic correlation of less than unity was obtained, indicating that the average performance of a sire's progeny was not the same in the different regions. The genetic correlations obtained (table 9) were in agreement with the statistical results given in table 8. If the analysis of variance indicated a significant interaction, the resulting genetic correlation also indicated a significant and important interaction. The comparison between regions 6 and 7 (Texas and Oklahoma vs. Montana) could be considered the most extreme in the study with regard to differences in cattle management and location. The resulting genetic correlation of 0.52 indicated that a significant and important sire x region interaction effect did occur between these two regions.

TABLE 8. LEAST SQUARES ANALYSES OF VARIANCE FOR WEANING WEIGHT

Source of variation	All regions		Regions 3,6,7,8		Regions 6 and 7		Montana	
	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares
Sire (S)	11	367.5**	11	646.1**	11	797.4**	11	53.2
Region (R)	7	89.3	3	194.1	1	245.5	2	4.4
S x R	54[a]	181.7**	29[a]	290.3**	9[b]	353.6**	22	44.3
Remainder	12860	115.4	11075	114.7	3874	98.0	2412	90.1

** P<.01

a Subclasses with less than 20 progeny were not included in the interaction effect.

b Two subclasses contained no progeny.

TABLE 9. ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR WEANING WEIGHT

Analysis	n_1[a]	n_4[b]	Variance components			Sire x region component as % of total[c]	Correlation (r_g)[d]
			Sire	Sire x region	Error		
All regions	153.6	443.5	0.6	0.4	115.4	0.4	0.54
Regions 3,6,7,8	207.1	545.9	1.0	0.8	114.7	0.7	0.47
Regions 6 and 7	157.2	269.8	2.6	1.6	98.0	1.6	0.52
Montana	53.1	137.1	-0.3	-0.9	90.1	0.0	∞

a Coefficient of the sire x region variance component.
b Coefficient of the sire variance component.
c Negative estimates were assumed zero.
d Negative estimates of the sire x region variance component were assumed zero in calculating the genetic correlation.
∞ Undefined.

With the number of sires represented in the present study, it is unlikely that a genetic correlation of 0.8 or lower could occur without important changes in the ranking of sires from region to region. Several examples calculated using extreme sire progeny mean differences indicated that for a correlation this low to occur without changes in the ranking of sires, the differences between sires would need to be larger than those in the present study. Also, rank correlations calculated for several comparisons of sire performance between two regions for weaning weight ranged from 0.15 to 0.75 indicating that changes in the ranking of sires did occur. Examination of the least squares means for the sire x region subclasses confirmed that definite changes in the ranking of sires occurred among regions (Appendix table 13).

The least squares constants for the sire x region interaction effects for the analysis involving all regions are given in table 10. These constants reflect the magnitude of the differences among subclasses for the interaction effect. Considering the fact that the sire means ranged from approximately 97 to 102, some of the interaction constants are quite large.

Petty and Cartwright (1966) reported heritability estimates of 0.31 for weaning weight and 0.42 for birth weight. Therefore, weaning weight might be expected to be influenced more by environmental differences than birth weight. The results of all the analyses for birth weight and weaning weight for all regions with the exception of Montana confirmed that the sire x region interaction effect was more

TABLE 10. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (ALL REGIONS)

	Regions							
Sire	2	3	4	5	6	7	8	9
1		-0.86		0.43	1.15	0.14	0.86	
2	0.22	1.13	1.49	-0.16	-3.08	-0.52	0.36	0.56
3		-0.24		-0.51		0.75		
4	-0.23	-1.39	0.39	0.14	2.00	0.51	-1.34	-0.08
5	-0.79	-0.27	-0.60	0.12	-0.01	0.05	-0.28	1.78
6	-0.60	-0.24	0.32	-1.72	2.03	-0.24	0.45	
7	-0.32	-0.82			2.45	-1.05	0.83	-1.09
8		-0.09		-0.12		-0.09	0.68	-0.38
9		0.36	-2.51	2.32	-0.60	0.11	1.02	-0.70
10	1.72	0.30	0.97	-0.50	-2.94	0.43	0.11	-0.09
11		0.28	-0.06		0.44	0.31	-0.97	
27		1.84			-1.44	-0.40		

important for weaning weight than for birth weight.

No significant sire x region interaction effect was found for the analysis of weaning weight within Montana. This might be expected since the environmental differences among regions of Montana would be smaller than those among the various regions of the United States. However, this does not explain the results in view of the same effect being a significant source of variation for birth weight among the three regions of Montana. The number of progeny records available from Montana may not be adequate to give a proper evaluation of sire x region interactions in the present study.

Woodward and Clark (1950) found no significant sire x location interaction for preweaning ADG of the progeny of Hereford sires tested at two locations in Montana. Harwin et al. (1966) reported no significant mating systems (inbred or linecross) x year interaction for weaning weight. Significant sire x year and sire x rearing method interactions were reported by Edwards et al. (1966) for 180-day weight of beef and dairy crossbred calves. Turner and MacDonald (1969) studied several beef crosses and found significant sire x year interactions.

Yearling Weight

The sire and sire x region interaction effects were not significant ($P<.17$) for yearling weight (table 11). The sire x region variance component was 2.1% of the total variance (table 12). A

TABLE 11. LEAST SQUARES ANALYSES OF VARIANCE FOR YEARLING WEIGHT, GESTATION LENGTH AND CALVING EASE

Source of variation	Yearling weight[a]		Gestation length[b]		Calving ease[b]	
	df	Mean square	df	Mean square	df	Mean square
Sire (S)	9	68.3	12	5.61**	12	385.5
Region (R)	4	34.6	2	0.76	2	190.0
S x R	22[c]	69.4	19[d]	1.69	19[d]	248.4
Remainder	769	54.0	820	2.05	813	893.6

** P<.01

a Only records from regions 3,4,5,6 and 7 were analyzed.

b Only records from regions 3,6 and 7 were analyzed.

c Fourteen subclasses contained no progeny.

d Five subclasses contained no progeny.

TABLE 12. ESTIMATES OF THE VARIANCE COMPONENTS, THEIR COEFFICIENTS AND GENETIC CORRELATIONS FOR YEARLING WEIGHT, GESTATION LENGTH AND CALVING EASE

Analysis	n_1[a]	n_4[b]	Variance components			Sire x region component as % of total[c]	Correlation (r_g)[d]
			Sire	Sire x region	Error		
Yearling weight	13.4	23.6	0.6	1.1	54.0	2.1	0.25
Gestation length	24.2	33.2	0.1	0.0	2.1	0.0	1.00
Calving ease	24.1	34.5	-14.7	-26.7	893.6	0.0	∞

a Coefficient of the sire x region variance component.
b Coefficient of the sire variance component.
c Negative estimates were assumed zero.
d Negative estimates of the sire x region variance component were assumed zero in calculating the genetic correlation.
∞ Undefined.

genetic correlation of 0.25 was calculated suggesting that the performance of the progeny was not equal in all regions and that changes in the ranking of sires occurred. The least squares means for the sire x region subclasses also indicated that changes in the ranking of the sires occurred. It should be noted that 805 progeny records representing 10 sires and 5 regions were used in the yearling weight analysis. In addition, 14 subclasses contained no progeny and some of the remaining subclasses contained small numbers of progeny.

Pani and Lasley (1972) suggested that genotype-environment interactions may be more important for yearling weight in beef cattle due to their exposure to larger environmental differences following weaning. On the other hand, Petty and Cartwright (1966) reported heritability estimates of 0.31 for weaning weight and 0.41 for yearling weight. Hence, weaning weight might be expected to be influenced more by environmental differences than yearling weight.

Pani et al. (1973) reported significant sire x year interactions for yearling weight in male progeny but not in female progeny. However, in general, previous studies indicated little importance for genotype-environment interactions of the type investigated in the present study for yearling weight (Dillard et al., 1964; Ahlschwede et al., 1969; Klosterman et al., 1968; Brown and Gacula, 1962).

Gestation Length

The number of records available for this analysis was small with 854 progeny and 3 regions represented. The sire effect was a

significant source of variation ($P<.01$) and the sire x region interaction effect was not significant (table 11). The sire x region interaction variance component was small and negative (table 12) and was assumed to account for none of the total variance. A genetic correlation of 1.00 was obtained indicating that the performance of progeny for gestation length was the same in all regions.

The significant sire effect shown for this analysis indicates that the sire does influence the length of time his offspring are carried. Rollins, Laben and Mead (1956) reported heritability estimates of 0.30 and 0.50 for gestation length in cattle. Environmental factors other than maternal and fetal influences may not have any importance in determining gestation length. However, Edwards et al. (1966) reported significant sire x region interactions in a study using Charolais and Hereford bulls on various dairy breeds.

Calving Ease

The least squares analysis of variance for calving ease is presented in table 11. None of the effects tested was significant. The number of progeny records used (847 progeny from three regions) in this analysis was small. This number of records may be inadequate to properly evaluate sire and sire x region interaction effects.

Bellows et al. (1971) reported that birth weight was the most important factor affecting calving difficulty. In view of the results obtained for the sire x region interaction effect on birth weight, it follows that the results for calving ease might be similar.

The sire and sire x region interaction variance components were negative (table 12) and the genetic correlation was not defined.

Little information is available regarding the genetic influences on calving difficulty. Brinks, Olson and Carroll (1973) reported heritability estimates of 0.07 and 0.13 for calving difficulty as a trait of the calf from two analyses of Hereford calving records.

Many of the previous studies on calving difficulty have involved only genotype x sex interactions. Laster et al. (1973) and Burfening et al. (1973) reported significant genotype x sex of the calf interactions for calving ease. Edwards et al. (1966) found significant sire x region interactions for calving difficulty during one of two calving seasons. Further studies are needed to properly evaluate the importance of genotype-environment interactions for calving ease.

Discussion

Butts et al. (1971) reported significant location x origin interactions for birth weight, weaning weight and yearling weight from a study involving the reciprocal transfer of two Hereford herds between Montana and Florida. Records from a seven year period (1962-1968) indicated that performance to yearling ages favored cattle of Montana origin at the Montana location and cattle of Florida origin at the Florida location. The location x origin interactions found in this study are of much greater magnitude than the sire x region interactions reported for the present study. Male and female calves of Montana origin were 8.2 and 17.2 kg heavier, respectively, at weaning than

calves of Florida Origin at the Montana location. At the Florida location, males and females of Florida origin were 20.4 and 12.2 kg heavier, respectively, than calves of Montana origin.

Hull and Gowe (1962) and Carter et al. (1971a,b) suggested that large and important interactions are more likely to occur when the environmental effects are large and the genetic differences are wide. In the study of Butts et al. (1971), opportunity for significant interactions to occur could be considered maximum for cattle of the same breed. Large differences in genotypes (inbred vs. non-inbred) and locations (Montana vs. Florida) are represented in this study. This type of study could also yield "temporary" interactions due to the fact that the animals may require time to adjust to their new environment when physically moved from one location to another. On the other hand, the sire progeny method used in the present study would be a less sensitive method for detecting significant genotype-environment interaction. The sire progeny differences are only one-half of the sire breeding value differences and are the result of mating to 24 different breeds of dams. For these reasons, the opportunity for interaction to occur in the present study should be minimal. Any resulting interaction should be one of the simplest forms of genotype-environment interaction that could occur. From this viewpoint, the results obtained, particularly for weaning weight may have added significance.

It is generally expected that artificial insemination will be used more extensively in the beef industry in future years. The

total of 24 breeds of dams represented in the present study should mean that a broad cross-section of cows have been sampled. The majority of the progeny would be from Hereford, Angus or crossbred dams of these two breeds. These same two breeds and their crosses account for the majority of the commercial beef cow population in the United States. Thus, the results of the present study may have more widespread application than studies involving the transfer of cattle between specific locations.

The significant sire x region interactions reported here for weaning weight could have several implications if caused by changes in the ranking of sires as the results indicated. The results mean that animals could not be selected effectively in one region for use in a different region. This emphasizes the need for evaluating artificial insemination sires in all regions or environments in which their progeny are expected to perform, before the widespread distribution of their semen occurs. Caution must be used in applying the results of progeny tests in one region or environment to performance and selection in different regions or environments. Until the causes of genotype-environment interactions are more fully evaluated, the selection of animals should be made under environmental conditions comparable to those under which they and their progeny are expected to perform.

In the present study, it is interesting to note that no movement of animals occurred, only semen was distributed between regions. All

of the progeny are the result of artificial insemination. As reported earlier, approximately one-third of the progeny changed ownership during the dam's pregnancy or in the period from birth to weaning. Only progeny born and weaned in the same herd were included in the analysis of each trait. This movement of breeding stock is an undesirable practice if adaptation is of major importance and if interactions of the magnitude reported by Butts et al. (1971) occur.

The sire x region interaction component accounted for less than 2% of the total variance for any given analysis of weaning weight. Although this component is a small part of the total variance it could be important biologically on an individual sire basis if changes in the ranking of the sire occur among regions. The least squares means for the sire x region subclasses for all analyses of weaning weight except Montana indicated that in many cases a given sire ranked above average in one region but below average in another region relative to the other sires in the study. This further indicated the errors that could be made in sire selection by attempting to apply the results of progeny tests in one region to performance and selection in a different region. The results also emphasize the need for evaluating sires in all regions in which their progeny are expected to perform. This evaluation should be on a within region basis.

The sire variance component was also a small part of the total variance for weaning weight, being less than 3% of the total for any given analysis. It is possible that the variance among sires used in

the present study is relatively small. With greater variance among the sires represented, it might be expected that the sire x region interaction effect would also show greater variance and follow the among sire variance as it increases or decreases in magnitude.

The commercial beef industry can probably be expected to make greater use of crossbreeding in future production programs. In particular, the use of a crossbred dam should become fairly common. This trend further emphasizes the need for more information on the importance of genotype-environment interactions. The adaptation of particular breeds or breed crosses to each situation or purpose must be recognized in developing specific crossbreeding programs.

Genotype-environment interactions may be more important for reproductive traits which have lower heritabilities and are influenced more by non-genetic variation than most performance traits. Virtually no information is available on the importance of these interactions for reproductive performance in beef cattle. Carter et al. (1971a,b) reported from a study involving the interchange of two breed crosses of sheep between Ontario, Canada and Virgina, U.S.A., that breed cross x location interactions were more important for reproductive traits than for performance traits. The results might be applicable to beef cattle, since sheep and beef cattle are raised over a wide range of climatic conditions and in various production programs. Butts et al. (1971) found some indication of significant location x origin interactions for percent pregnant cows and percent calves

weaned in the beef cattle transferred between Montana and Florida. Both of these traits were lower for cows of Montana origin located in Florida. There is a great need for further studies on the importance of genotype-environment interactions for reproductive traits of beef cattle.

Lerner and Donald (1966) suggested that genotype-environment interactions may be self cancelling, being favorable during one period of an animal's life and unfavorable during a different period. Some evidence that this might occur can be found in the study of Butts et al. (1971) who reported that location x origin interactions were not apparent in traits of five-year-old cows with the exception of reproductive performance.

Until further information is available on the importance and causes of genotype-environment interactions, the beef industry cannot be certain of the best environment in which to select animals. On the basis of present information, it is probably important to firstly, identify the best breeds or breed crosses for a particular situation or purpose and secondly, to find the optimum conditions or environment under which the selection of animals within the breed or cross should be made.

SUMMARY

Data from 38,261 field records obtained from the American Simmental Association were used to evaluate the importance of sire x region interactions in beef cattle and to determine if significant interactions are due to changes in the ranking of sires among regions. Data were analyzed by least squares procedures according to a model containing sire, region and sire x region interaction effects. The traits analyzed were birth weight, weaning weight, yearling weight, gestation length and calving ease. Trait ratios were used in all analyses in order to reduce the error variance among herds and to minimize possible heterogeneity of variances among herds. Only progeny born and weaned in the same herd were included.

The United States was divided into nine regions for this study with one region being deleted due to small numbers. Montana was further sub-divided into three regions to study the interaction within one state for birth weight and weaning weight. The progeny of 10-13 sires were used in each analysis. Birth weight and weaning weight were analyzed using separate analyses of records from all eight regions, four regions containing 85% of the records, two regions (Texas-Oklahoma vs. Montana), and the three regions of Montana. Records from five regions were analyzed for yearling weight and from three regions for gestation length and calving ease. The number of records for these latter three traits was small and may not be adequate to properly assess sire x region interactions.

The region effect was nonsignificant for all traits. The sire effect was significant for all analyses except weaning weight within Montana, yearling weight and calving ease. The sire x region interaction effect was significant for all analyses of weaning weight ($P<.01$) except Montana and approached significance ($P=.07$) for birth weight within Montana. It was not significant for the other analyses. Genetic correlations were calculated from the sire and sire x region interaction variance components for each analysis to assess the average change in sire progeny performance among regions. Correlations were not defined for the within Montana weaning weight or calving ease since both variance components were negative. Correlations of unity were obtained for all analyses of birth weight except Montana and for gestation length indicating that the ranking of sires was essentially the same in all regions. The statistical results indicated no significant interactions for birth weight within Montana and for yearling weight but correlations of 0.21 and 0.25, respectively, were obtained suggesting some changes in the ranking of sires. Correlations of 0.47 to 0.54 for weaning weight suggested that changes in the ranking of sires occurred. This was confirmed from the least squares means for the sire x region subclasses.

The results of the weaning weight analyses may have several implications. The sire x region variance component accounted for less than 2% of the total variance for any given analysis. Although this was a small part of the total, it could be important biologically.

The least squares means for the sire x region subclasses indicated that in many cases a given sire ranked above average in one region but below average in other regions. The results indicated that errors could be made in applying the results of progeny tests in one region to performance and selection in a different region. The need for evaluating sires in all regions and on a within region basis was also suggested.

LITERATURE CITED

Ahlschwede, W. T., E. U. Dillard, J. E. Legates and O. W. Robison. 1969. Sire-environment interaction effects on steer growth. J. Anim. Sci. 28:130 (Abstr.).

Averdunk, G., V. Orel and W. Schmitter. 1968. The influence of testing station on the daily weight gain of young bulls and the interaction between sire and station. Anim. Breed. Abstr. 37: No. 1329.

Beef Improvement Federation. 1972. Guidelines for uniform beef improvement programs. Beef Impr. Fed. USDA Program Aid 1020.

Bellows, R. A., R. E. Short, D. C. Anderson, B. W. Knapp and O. F. Pahnish. 1971. Cause and effect relationships associated with calving difficulty and calf birth weight. J. Anim. Sci. 33:407.

Bonnier, G. A., A. Hansson and A. Skjervold. 1948. Studies on monozygous cattle twins. IX. The interplay of heredity and environment on growth and yield. Acta. Agr. Suecana III:1.

Bradley, N. W., L. V. Cundiff, J. D. Kemp and T. R. Greathouse. 1966. Effects of sex and sire on performance and carcass traits of Hereford and Hereford-Red Poll calves. J. Anim. Sci. 25:783.

Brinks, J. S., R. T. Clark and N. M. Kieffer. 1963. Sex differences in response to inbreeding in a line of Hereford cattle. J. Anim. Sci. 22:816 (Abstr.).

Brinks, J. S., J. J. Urick, O. F. Pahnish, B. W. Knapp and T. M. Riley. 1967. Heterosis in preweaning and weaning traits among lines of Hereford cattle. J. Anim. Sci. 26:278.

Brinks, J. S., J. E. Olson and E. J. Carroll. 1973. Calving difficulty and its association with subsequent productivity in Herefords. J. Anim. Sci. 36:11.

Brown, C. J., C. A. Baugus and S. Sabin. 1961. Evaluation of factors affecting the growth of spring lambs. Ark. Agr. Exp. Sta. Bull. 646.

Brown, C. J. and Maximo Gacula. 1962. Genotype-environment interactions in postweaning rate of gain of beef cattle. J. Anim. Sci. 21:924.

Brumby, P. J. 1961. The causes of differences in production between dairy herds. Anim. Prod. 3:277.

Burdick, J. M. and L. D. McGilliard. 1963. Interactions between sires in artificial insemination and management of dairy herds. J. Dairy Sci. 46:452.

Burfening, P. J., C. M. Saxton, D. D. Kress and D. Vaniman. 1973. Calving ease in Simmental sired calves. Proc. West. Sec. Am. Soc. Anim. Sci. Vol. 24.

Burnside, E. B. and J. C. Rennie. 1968. Evaluation and herd level of milk production. Can. J. Anim. Sci. 48:97.

Burnside, E. B., G. K. MacLeod and D. G. Grieve. 1969. Genotype and environment in calf production. Anim. Prod. 11:285.

Butts, W. T., M. Koger, O. F. Pahnish, W. C. Burns and E. J. Warwick. 1971. Performance of two lines of Hereford cattle in two environments. J. Anim. Sci. 33:923.

Carter, R. C. and C. M. Kincaid. 1959. Estimates of genetic and pheontypic parameters in beef cattle. II. Heritability estimates from parent-offspring and half-sib resemblances. J. Anim. Sci. 18:323.

Carter, R. C., G. M. Carman, F. S. McClaugherty and P.S. Haydon. 1971a. Genotype-environment interaction in sheep. I. Ewe productivity. J. Anim. Sci. 33:556.

Carter, R. C., G. M. Carman, F. S. McClaugherty and P. S. Haydon. 1971b. Genotype-environment interaction in sheep. II. Lamb performance traits. J. Anim. Sci. 33:732.

Davis, Gary A. 1968. Feasibility of selected fall calving alternatives for the range cattle industry of Montana. Masters Thesis. Dept. of Agr. Economics. MSU, Bozeman.

Dickerson, G. E. 1962. Implications of genetic-environmental interaction in animal breeding. Anim. Prod. 4:47.

Dillard, E. U., J. E. Legates, T. N. Blumer, R. G. Petersen, O. W. Robison and J. H. Gregory. 1964. Genotype-environment interactions in beef cattle. J. Anim. Sci. 23:848 (Abstr.).

Dunlop, A. A. 1962. Interactions between heredity and environment in the Australian Merino. I. Strain x location interactions in wool traits. Aust. J. Agr. Res. 13:503.

Dunlop, A. A. 1963. Interactions between heredity and environment in the Australian Merino. II. Strain x location interactions in body traits and reproductive performance. Aust. J. Agr. Res. 14:690.

Edwards, J., D. Jobst, J. Hodges, M. Leyburn, L. K. O'Connor, A. MacDonald, G. F. Smith and P. Wood. 1966. The Charolais report. The results of field trials in England and Wales to compare Charolais bulls with bulls of British beef breeds when crossed with dairy cows. Anim. Breed. Abstr. 35: No. 94.

Ellis, G. F., Jr., T. C. Cartwright and W. E. Kruse. 1965. Heterosis for birth weight in Brahman-Hereford crosses. J. Anim. Sci. 24:93.

Falconer, D. S. 1952. The problem of environment and selection. Amer. Nat., 86:293.

Falconer, D. S. and M. Latyszewski. 1952. The environment in relation to selection for size in mice. J. Genetics, 51:67.

Falconer, D. S. 1960. Selection of mice for growth on high and low planes of nutrition. Genetical Res. 1:91.

Fowler, S. H. and M. E. Ensminger. 1960. Interactions between genotype and plane of nutrition in selection for rate of gain in swine. J. Anim. Sci. 19:434.

Freeman, A. E. 1969. Estimates of genotype by environment interaction and effects of contemporaneity upon growth and production from cattle twins. J. Dairy Sci. 52:926 (Abstr.).

Genizi, A. 1973. A note on estimating the interaction component of variance from unbalanced data. Mimeograph.

Haldane, J. B. S. 1946. The interaction of nature and nuture. Annals of Eugenics 13:197.

Hammond, J. 1947. Animal breeding in relation to nutrition and environmental conditions. Biol. Rev. 22:195.

Hansson, A., E. Brannang and O. Claesson. 1953. Studies on monozygous cattle twins. XIII. Body development in relation to heredity and intensity of rearing. Acta. Agr. Scand. 3:61.

Harvey, W. R. 1960. Least squares analysis of data with unequal subclass numbers. U.S.D.A., A.R.S. 20-8.

Harwin, G. O., J. S. Brinks, H. H. Stonaker. 1966. Genetic and environmental interactions affecting the weaning weights of Hereford calves. J. Anim. Sci. 25:779.

Hull, P. and R. S. Gowe. 1962. The importance of interactions detected between genotype and environmental factors for characters of economic significance in poultry. Genetics 47:143.

King, J. W. B. and G. B. Young. 1955. A study of three breeds of sheep wintered in four environments. J. Agr. Sci. 45:331.

King, J. W. B., J. H. Watson and G. B. Young. 1959. Genotype-environment interactions in the wintering of lambs. J. Agr. Sci. 53:156.

Klosterman, E. W., V. R. Cahill and C. F. Parker. 1968. A comparison of the Hereford and Charolais breeds and their crosses under two systems of management. Ohio Agr. Res. and Dev. Center. Res. Bull. 1011.

Knapp, Bradford, Jr. and R. W. Phillips. 1942. Differences in performance between sexes in offspring of beef bulls. J. Anim. Sci. 1:346 (Abstr.).

Koger, M. and J. H. Knox. 1945. The effect of sex on weaning weight of range calves. J. Anim. Sci. 4:15.

Kress, D. D., E. R. Hauser and A. B. Chapman. 1971. Genetic-environmental interactions in identical and fraternal twin beef cattle. I. Growth from 7 to 24 months of age. J. Anim. Sci. 33:1177.

Kress, D. D. and R. P. Webb. 1972. Sex x sire interactions in beef cattle. Proc. West. Sec. Am. Soc. Anim. Sci. Vol. 23.

Laster, D. B., H. A. Glimp, L. V. Cundiff and K. E. Gregory. 1973. Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. J. Anim. Sci. 36:695.

Legates, J. E., F. J. Verlinden and J. F. Kendrick. 1956. Sire by herd interaction in production traits in dairy cattle. J. Dairy Sci. 39:1055.

Legates, J. E. 1962. Heritability of fat yields in herds with different production levels. J. Dairy Sci. 45:990.

Lerner, I. M. and H. P. Donald. 1966. Modern Developments in Animal Breeding. Academic Press, London and New York.

Lush, J. L. 1945. Animal Breeding Plans. Iowa State College Press. Ames, Iowa.

Lytton, V. H. and J. E. Legates. 1966. Sire by region interaction for production traits in dairy cattle. J. Dairy Sci. 49:874.

Mao, I. L. and E. B. Burnside. 1969. Sire by herd environment interaction for milk production. J. Dairy Sci. 52:1055.

Mason, I. L. and Alan Robertson. 1956. The progeny testing of dairy bulls at different levels of production. J. Agr. Sci. 47:367.

McBride, G. 1958. The environment and animal breeding problems. Anim. Breed. Abstr. 26:349.

McDaniel, B. T. and E. L. Corley. 1967. Relationships between sire evaluations at different herdmate levels. J. Dairy Sci. 50:735.

Morley, F. H. W. 1956. Selection for economic characters in Australian Merino sheep. VII. Interactions between genotype and plane of nutrition. Aust. J. Agr. Res. 7:140.

Osman, A. H. and G. E. Bradford. 1965. Effects of environment on phenotype and genetic variation in sheep. J. Anim. Sci. 24:766.

Osman, A. H. and G. E. Bradford. 1967. Genotype-environment interaction and compensatory growth in sheep. J. Anim. Sci. 26:1239.

Pahnish, O. F., E. B. Stanley, R. Bogart and C. B. Roubicek. 1961. Influence of sex and sire on weaning weights of Southwestern range calves. J. Anim. Sci. 20:454.

Pahnish, O. F., R. L. Roberson, R. L. Taylor, J. S. Brinks, R. T. Clark and C. B. Roubicek. 1964. Genetic analyses of economic traits measured in range-raised Herefords at preweaning and weaning ages. J. Anim. Sci. 23:562.

Pani, S. N. and J. F. Lasley. 1972. Genotype x environment interactions in animals. Mo. Agr. Exp. Sta. Res. Bull. 992.

Pani, S. N., G. F. Krause and J. F. Lasley. 1973. Genotype x environment interactions in beef sire evaluation: The importance of sire by year interactions for postweaning traits. J. Anim. Sci. 36:622.

Petty, Robert R., Jr. and T. C. Cartwright. 1966. A summary of genetic and environmental statistics for growth and conformation traits of young beef cattle. Dept. Tech. Report No. 5. Texas Agr. Exp. Sta.

Radomska, M. J. 1965. Comparative studies of some methods of progeny testing rams. I. Analysis of methods. Anim. Breed. Abstr. 34: No. 3049.

Robertson, Alan. 1959. The sampling variance of the genetic correlation coefficient. Biometrics 15:469.

Robertson, Alan, L. K. O'Connor and J. Edwards. 1960. Progeny testing dairy bulls at different management levels. Anim. Prod. 2:141.

Rollins, W. C. and K. A. Wagnon. 1956. A genetic analysis of weaning weights in a range beef herd operated under optimum and sub-optimum nutritional regimes. J. Anim. Sci. 15:125.

Rollins, W. C., R. C. Laben and S. W. Mead. 1956. Gestation length in an inbred Jersey herd. J. Dairy Sci. 39:1578.

Sagebiel, J. A., G. F. Krause, B. Sibbit, L. Langford, J. E. Comfort, A. J. Dyer and J. F. Lasley. 1969. Dystocia in reciprocally crossed Angus, Hereford and Charolais cattle. J. Anim. Sci. 29:245.

Skjervold, H. and K. Gravir. 1961. Interaction between genotype and environment in selection for rate of gain in cattle. The Agr. College of Norway. Inst. of Anim. Genet. and Breed. Rep. No. 150.

Tanner, J. E., R. R. Frahm and J. V. Whiteman. 1969. Sire-sex interactions and sex differences in cattle. J. Anim. Sci. 29:112 (Abstr.).

Thrift, F. A., D. D. Kratzer and J. D. Kemp. 1970. Effect of sire, sex and sire x sex interactions on beef cattle performance and carcass traits. J. Anim. Sci. 30:182.

Turner, J. W. and R. P. MacDonald. 1969. Preweaning performance of crossbred beef calves. J. Anim. Sci. 28:131 (Abstr.).

Urick, J. J., J. S. Brinks, O. F. Pahnish, B. W. Knapp and T. M. Riley. 1968. Heterosis in postweaning traits among lines of Hereford cattle. J. Anim. Sci. 27:323.

Van Vleck, L. D., L. H. Wadell and C. R. Henderson. 1961. Components of variance associated with milk and fat records of artificially sired Holstein daughters. J. Anim. Sci. 20:812.

Van Vleck, L. D. 1963. Genotype and environment in sire evaluation. J. Dairy Sci. 46:983.

Vesely, J. A. and O. W. Robison. 1969. Genotype-sex interaction in sheep. J. Anim. Sci. 28:132 (Abstr.).

Wadell, L.H. and L. D. McGilliard. 1959. Influence of artificial breeding on production in Michigan dairy herds. J. Dairy Sci. 42:1079.

Warwick, E. J., R. E. Davis and R. L. Hiner. 1964. Response of monozygotic bovine twins to high and low concentrate rations. J. Anim. Sci. 23:78.

Wiggans, G. R. and L. D. Van Vleck. 1970. Sire effects in different housing systems. J. Dairy Sci. 53:545.

Wilson, L. L., J. H. Ziegler, J. L. Watkins, C. E. Thompson and H. R. Purdy. 1969. Influence of sex and sire on growth and carcass traits of beef cattle. J. Anim. Sci. 28:607.

Wiltbank, J. N., C. W. Kasson and J. E. Ingalls. 1969. Puberty in crossbred and straightbred beef heifers on two levels of feed. J. Anim. Sci. 29:602.

Woodward R. R. and R. T. Clark. 1950. The repeatability of performance of several Hereford sires as measured by progeny records. J. Anim. Sci. 9:588.

Yamada, Yukio. 1962. Genotype by environment interaction and genetic correlation of the same trait under different environments. Jap. Jour. Genet. 37:498.

APPENDIX

APPENDIX TABLE 1. NUMBER OF PROGENY PER SIRE AND REGION FOR BIRTH WEIGHT BEFORE DELETIONS

	Regions								
Sire No.	2	3	4	5	6	7	8	9	Total
1		62		13	10	27	26		138
2	21	152		24	44	107	69	6	423
3		53			5	75			133
4	118	301	13	62	281	307	156	98	1336
5	51	290		58	67	208	87	50	811
6	21	160	5	15	71	87	63	9	431
7	5	218		7	13	146	29	16	434
8	9	85		28	4	84	33	39	282
9	17	270	11	26	116	153	118	2	713
10	29	232	15	50	92	519	173	21	1131
11		76			29	55	3	13	176
12		6		1	1	1	7	14	30
13		4		1				1	6
14					1				1
15						4			4
16		1		9	22		3		35
17				1		12	5		18
18		41				4			45
19		9			45				54
21				13		3	1		17
22		1		5		2			8
23		54	1	10	14	33	1	4	117
24		31				9			40
25	5	5				5			15
27		42	4	9	18	55	12	7	147
28		13			22	26		9	70
29		4		4					8
30		25			10				35
31	1	1			1		13		16
32		1		3	9				13
33		43						3	46
34		13							13
36		5			2	13			20
37						18			18
38				5		5			10
39						3			3
40		6			6				12
41		5			1		6		12
42							4		4

APPENDIX TABLE 1. (CONTINUED)

Sire No.	Regions 2	3	4	5	6	7	8	9	Total
43						4			4
44						3			3
45						1			1
46						20			20
47						6			6
48			4						4
49		4			1				5
51		5							5
53		1							1
Total	277	2219	53	344	885	1995	809	292	6874

APPENDIX TABLE 2. NUMBER OF PROGENY PER SIRE AND REGION FOR WEANING WEIGHT BEFORE DELETIONS

	Regions								
Sire No.	2	3	4	5	6	7	8	9	Total
1	8	226	4	20	31	62	25	3	379
2	71	508	54	22	90	258	99	21	1123
3	1	144	4	40	5	101	6	2	303
4	54	1208	170	96	359	431	248	98	2664
5	155	910	73	108	206	367	109	43	1971
6	22	308	29	67	189	86	74	3	778
7	36	389		7	161	126	49	30	798
8	14	868	4	41	13	84	51	37	1112
9	18	580	23	24	155	288	105	22	1215
10	65	632	36	150	118	514	220	47	1782
11	7	368	27	6	100	78	48	13	647
12		10	24	5	2	2	9	2	54
13		4		2		2			8
14						1	12		13
15		2				5			7
16		2		18	13		2		35
17				1		12	5		18
18		20		1		13			34
19		43							43
20						3			3
21		1		9		5			15
22		19		4		2			25
23		44		7	18	17	2	4	92
24		37			6				43
25	2	36				6	1		44
26		1							1
27	6	38	9	17	21	53	10	7	161
28		19	2	7	41	15		9	93
29		3		6	3				12
30		26	2						28
31	1				1		8		10
32				4	9				13
33		27						3	30
34		28							28
35			5						5
36		8				13			21
37						18			18
38				5		4			9
39						3			3

APPENDIX TABLE 2. (CONTINUED)

Sire No.	Regions 2	3	4	5	6	7	8	9	Total
40		16		1					17
41		1					6	4	11
42							3		3
43						3			3
45						1			1
46						20			20
47						6			6
48			4			1			5
49		6							6
51		1							1
54		1							1
Total	460	6534	470	668	1541	2600	1092	348	13713

APPENDIX TABLE 3. NUMBER OF PROGENY PER SIRE AND REGION FOR YEARLING WEIGHT BEFORE DELETIONS

	Region								
Sire No.	2	3	4	5	6	7	8	9	Total
1		4	1	3			2		10
2	3	98	2	3	6	17	2		131
3		4				1			5
4		50	28	5	6	15	5	2	111
5	3	190			6	20	1		220
6		21	5		5	7		4	42
7		53			1	2			56
8		89				5			94
9		57		5	9	26	3		100
10		22	3	5	6	25	11		72
12				1					1
18		6							6
21				1					1
23		13		1					14
24		4							4
27		11		3					14
30		1							1
33		3						-	3
Total	6	625	39	27	39	118	24	6	884

APPENDIX TABLE 4. NUMBER OF PROGENY PER SIRE AND REGION FOR GESTATION LENGTH AND CALVING EASE BEFORE DELETIONS

Sire No.	Region 2	3	4	5	6	7	8	9	Total
1		12							12
2	4	36	1	1	27	8			77
3					2				2
4	2	8	14	6	53	71	7		161
5	29	47		13	26	67			182
6		43			7	14	17		81
7		110			1	30			141
8	2	22			2				26
9	5	9			27	2			43
10	3	20		13	13	7	7	4	67
11					3				3
12					4	17			21
13						2			2
14					1	3			4
15						4			4
16					18				18
17		4				3			7
18		34			1				35
19					45				45
20						3			3
21		13				5			18
22						50			50
23		33			1	19			53
24		6				9			15
25						6			6
27		35		4		71			110
28				2	3	27			32
30		13			10				23
32					5				5
33		26							26
36				3	2				5
37					1	10			11
38						3			3
40					6				6
41		5			1				6
44						3			3
45						1			1
46						20			20
47						6			6

APPENDIX TABLE 4. (CONTINUED)

Sire No.	Region 2	3	4	5	6	7	8	9	Total
49					1				1
50		1							1
51		7							7
52		5							5
53		1							1
54		6							6
55		2							2
Total	45	498	15	42	260	461	31	4	1356

APPENDIX TABLE 5. LEAST SQUARES SIRE AND REGION MEANS AND STANDARD ERRORS FOR THE VARIOUS TRAITS

Sire	Birth weight	Weaning weight	Yearling weight[a]	Gestation length[b]	Calving ease[b]
1	99.6±1.0	100.6±0.9	103.8±3.1		
2	96.8±0.7	99.2±0.5	99.6±1.5	100.1±0.2	104.3±4.3
3	100.6±1.0	100.8±0.7	101.5±4.2		
4	101.4±0.4	100.3±0.3	100.0±1.0	99.9±0.2	98.2±3.9
5	101.0±0.5	100.6±0.4	103.1±1.3	100.2±0.1	99.7±2.7
6	97.8±0.6	100.0±0.6	101.4±1.5	99.6±0.2	98.5±4.9
7	100.4±0.7	101.7±0.6	99.4±3.1	100.2±0.5	99.9±10.2
8	99.2±0.7	99.7±0.6	100.3±1.8	100.1±0.5	103.3±11.1
9	100.4±0.6	100.1±0.6	98.8±1.2	100.3±0.4	100.6±8.0
10	102.2±0.5	99.0±0.4	98.8±1.3	100.2±0.2	101.1±5.2
11	99.5±0.8	100.1±0.6			
16					
17				99.6±0.6	111.8±11.6
23	100.9±1.0			100.2±0.5	101.4±10.4
24				100.2±0.4	95.1±8.3
27	100.7±0.9	97.1±0.9		100.9±0.2	102.1±3.6
28					
30				100.1±0.3	91.4±6.4
Region					
2	100.8±0.8	100.0±0.6			
3	100.3±0.3	100.1±0.2	99.3±0.6	100.0±0.1	100.0±2.3
4	99.2±1.6	99.8±0.6	102.5±2.2		
5	100.0±0.7	100.4±0.5	100.6±1.8		
6	99.8±0.5	99.2±0.4	100.8±1.6	100.1±0.2	99.7±5.3
7	100.1±0.3	99.9±0.3	100.2±1.2	100.2±0.2	102.3±3.4
8	100.4±0.5	100.2±0.4			
9	99.7±0.8	99.8±0.7			

a Records from regions 3, 4, 5, 6 and 7 were analyzed.

b Records from regions 3, 6 and 7 were anlayzed.

APPENDIX TABLE 6. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (ALL REGIONS)

	Regions							
Sire	2	3	4	5	6	7	8	9
1		-0.78				0.08	0.70	
2	-0.87	0.84			-0.83	-0.18	1.04	
3		0.45				-0.45		
4	-1.47	1.18	0.00	-1.09	0.30	0.17	-0.46	1.37
5	-0.84	-0.17		0.18	0.78	0.31	-0.07	-0.19
6	-0.72	0.91			0.38	-0.40	-0.17	
7		-0.37				-0.82	1.19	
8		-0.01		-0.50		1.34	-0.85	0.02
9		-0.50		-1.07	1.38	0.67	-0.48	
10	3.90	-1.20		2.48	-1.95	-1.13	- .90	-1.20
11		-0.39			-0.06	0.45		
23		-0.24				0.24		
27		0.28				-0.28		

APPENDIX TABLE 7. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (ALL REGIONS)

Sire	Regions 2	3	4	5	6	7	8	9
1		99.0±1.3				99.7±2.0	100.7±2.0	
2	96.6±2.2	97.8±0.9			95.7±1.6	96.7±1.0	98.2±1.3	
3		101.3±1.5				100.3±1.2		
4	100.7±1.0	102.9±0.6	100.6±1.6	100.3±1.3	101.5±0.6	101.7±0.6	101.4±0.9	102.5±1.1
5	100.9±1.5	101.0±0.6		101.2±1.4	101.5±1.3	101.4±0.7	101.3±1.1	100.5±1.5
6	97.8±2.2	98.9±0.8			97.9±1.3	97.4±1.1	98.0±1.3	
7		100.3±0.7				99.7±0.9	102.0±1.9	
8		99.4±1.2		98.7±1.9		100.6±1.2	98.7±1.8	98.9±1.7
9		100.2±0.6		99.3±2.0	101.6±1.0	101.1±0.9	100.3±1.0	
10	106.9±1.9	101.3±0.7		104.8±1.5	100.1±1.1	101.2±0.5	101.8±0.8	100.8±2.2
11		99.3±1.2			99.2±1.9	100.0±1.4		
23		100.9±1.4				101.2±1.7		
27		101.2±1.5				100.5±1.3		

APPENDIX TABLE 8. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (REGIONS 3, 6, 7, 8)

	Regions			
Sire	3	6	7	8
1	-0.90		0.15	0.75
2	0.78	-1.20	-0.29	0.71
3	0.44		-0.44	
4	0.92	0.00	-0.08	-0.84
5	-0.34	0.58	0.13	-0.37
6	0.91	0.18	-0.56	-0.53
7	-0.65		-1.02	1.67
8	-0.22		1.14	-0.92
9	-0.79	1.16	0.43	-0.80
10	0.10	-0.61	0.18	0.33
11	-0.33	-0.11	0.44	
23	-0.28		0.28	
27	0.36		-0.36	

APPENDIX TABLE 9. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (REGIONS 3,6,7,8)

	Regions			
Sire	3	6	7	8
1	99.2±1.6		100.1±2.0	101.1±2.0
2	97.7±0.9	95.5±1.6	96.4±1.0	97.8±1.3
3	101.3±1.4		100.3±1.2	
4	102.8±0.6	101.5±0.6	101.6±0.6	101.3±0.8
5	101.0±0.6	101.5±1.3	101.3±0.7	101.2±1.1
6	98.7±0.8	97.6±1.2	97.1±1.1	97.5±1.3
7	100.4±0.7		99.8±0.9	102.9±1.9
8	99.6±1.1		100.7±1.1	99.1±1.8
9	100.1±0.6	101.7±1.0	101.2±0.9	100.4±1.0
10	101.3±0.7	100.2±1.1	101.2±0.5	101.8±0.8
11	99.1±1.2	98.9±1.9	99.7±1.2	
23	101.0±1.4		101.4±1.7	
27	102.0±1.5		101.1±1.3	

APPENDIX TABLE 10. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS, MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT REGIONS 6 and 7)

	Constants		Means	
Sire	Region 6	Region 7	Region 6	Region 7
1	0.70	-0.70	102.1±3.4	99.7±2.1
2	-1.20	1.20	95.0±1.6	96.4±1.0
3	0.35	-0.35	101.9±4.8	100.2±1.2
4	-0.59	0.59	101.4±0.6	101.7±0.6
5	-0.47	0.47	101.4±1.3	101.3±0.7
6	-0.33	0.33	97.4±1.3	97.1±1.2
7	0.77	-0.77	102.3±3.0	99.8±0.9
8	0.34	-0.34	102.4±5.4	100.7±1.2
9	-0.30	0.30	101.6±1.0	101.2±0.9
10	-1.07	1.07	100.1±1.1	101.2±0.5
11	-1.08	1.08	98.7±2.0	99.8±1.4
16	0.00		100.7±2.3	
23	1.12	-1.12	100.4±2.9	100.7±1.9
27	-1.54	1.54	99.3±2.5	101.4±1.4
28	3.30	-3.30	101.8±2.3	94.2±2.1

APPENDIX TABLE 11. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR BIRTH WEIGHT (MONTANA)

Sire	Regions 71	72	73
1	-2.72	5.89	-3.16
2	-2.09	0.53	1.56
3	-0.97	-1.24	2.21
4	2.71	-2.63	-0.08
5	-0.46	0.46	
6	2.31	-3.38	1.07
7	-1.10	0.35	0.75
8	-0.82	-0.93	1.75
9	1.25	1.65	-2.90
10	-0.15	0.84	-0.69
11	0.55	-0.14	-0.41
23		-3.14	3.14
27	0.65	-0.65	
28	0.85	2.40	-3.25

APPENDIX TABLE 12. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT (MONTANA)

Sire	Regions 71	72	73
1	93.5±4.4	102.4±2.4	93.3±7.5
2	94.6±1.6	97.5±1.4	98.5±3.8
3	99.3±1.8	99.4±2.2	102.8±2.4
4	104.4±1.1	99.3±1.0	101.8±1.0
5	100.6±1.2	101.8±0.9	
6	99.9±3.2	94.5±1.7	98.9±1.7
7	99.8±1.2	100.6±2.1	100.3±1.6
8	98.7±6.2	98.9±2.2	101.5±1.4
9	102.0±1.1	102.7±1.9	98.1±1.8
10	100.9±0.8	102.2±0.8	100.6±0.7
11	100.2±4.0	99.8±1.7	99.5±3.8
23		95.4±4.8	101.7±2.0
27	102.4±6.2	101.4±1.5	
28	95.6±2.8	97.5±10.7	91.8±3.4

APPENDIX TABLE 13. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (ALL REGIONS)

	Regions							
Sire	2	3	4	5	6	7	8	9
1		99.9±0.7		101.4±2.3	101.0±1.9	100.7±1.3	100.0±2.1	
2	99.5±1.3	100.5±0.5	100.5±1.5	99.5±2.3	95.4±1.1	98.7±0.7	99.8±1.1	99.7±2.3
3		100.7±0.9		100.7±1.7		101.6±1.1		
4	100.1±1.4	99.1±0.3	100.5±0.8	100.9±1.1	101.6±0.6	100.8±0.5	99.2±0.7	100.2±1.1
5	99.8±0.9	100.5±0.4	99.9±1.2	101.2±1.0	99.9±0.7	100.7±0.6	100.6±1.0	102.3±1.6
6	99.4±2.2	99.9±0.6	100.1±2.0	98.7±1.3	101.3±0.8	99.7±1.1	100.7±1.2	
7	101.5±1.8	101.1±0.5			103.5±0.8	100.7±0.9	102.8±1.5	100.6±1.9
8		99.8±0.4		100.0±1.6		99.6±1.2	100.7±1.5	99.2±1.7
9		100.6±0.4	97.4±2.2	102.8±2.2	98.8±0.9	100.2±0.6	101.4±1.0	99.3±2.2
10	100.8±1.3	99.5±0.4	99.8±1.8	98.9±0.9	95.3±1.0	99.5±0.5	99.4±0.7	98.8±1.6
11		100.6±0.6	99.8±2.0		99.8±1.1	100.4±1.2	99.4±1.5	
27		99.2±1.6			94.9±2.1	96.7±1.4		

APPENDIX TABLE 14. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (REGIONS 3, 6, 7, 8)

	Regions			
Sire	3	6	7	8
1	-0.50	1.14	0.36	-1.00
2	1.64	-2.52	-0.01	0.89
3	-0.46		0.46	
4	-1.34	2.07	0.55	-1.28
5	-0.15	0.13	0.16	-0.14
6	-0.77	1.53	-0.73	-0.03
7	-1.21	2.10	-1.41	0.52
8	-0.18		-0.26	0.44
9	0.15	-0.81	-0.11	0.77
10	0.81	-2.38	0.93	0.64
11	0.09	0.40	0.32	-0.81
27	1.92	-1.66	-0.26	

APPENDIX TABLE 15. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (REGIONS 3, 6, 7, 8)

	Regions			
Sire	3	6	7	8
1	99.9±0.7	100.6±1.9	100.6±1.4	99.4±2.1
2	100.5±0.5	95.4±1.1	98.7±0.7	99.8±1.1
3	100.6±0.9		101.4±1.0	
4	99.1±0.3	101.6±0.6	100.8±0.5	99.2±0.7
5	100.5±0.4	99.9±0.7	100.7±0.6	100.6±1.1
6	99.9±0.6	101.3±0.8	99.8±1.1	100.7±1.2
7	101.1±0.5	103.5±0.8	100.8±1.0	102.9±1.5
8	99.8±0.4		99.6±1.2	100.5±1.5
9	100.6±0.4	98.7±0.9	100.2±0.6	101.3±1.0
10	99.5±0.4	95.4±1.0	99.5±0.5	99.4±0.7
11	100.6±0.6	100.0±1.1	100.7±1.2	99.8±1.5
27	98.9±1.7	94.4±2.3	96.6±1.5	

APPENDIX TABLE 16. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS, MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (REGIONS 6 and 7)

	Constants		Means	
Sire	Region 6	Region 7	Region 6	Region 7
1	0.33	-0.33	100.5±1.8	100.5±1.2
2	-1.30	1.30	95.4±1.0	98.7±0.6
3		0.00		101.4±1.0
4	0.72	-0.72	101.6±0.5	100.8±0.5
5	-0.05	0.05	99.9±0.7	100.7±0.5
6	1.10	-1.10	101.3±0.7	99.8±1.1
7	1.72	-1.72	103.4±0.8	100.7±0.9
8		0.00		99.4±1.0
9	-0.39	0.39	98.7±0.8	100.2±0.6
10	-1.71	1.71	95.3±0.9	99.5±0.4
11	0.01	-0.01	100.0±1.0	100.7±1.1
27	-0.45	0.45	95.3±2.1	97.0±1.4

APPENDIX TABLE 17. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR WEANING WEIGHT (MONTANA)

Sire	Regions 71	72	73
1	-1.10	0.92	0.18
2	-0.01	-1.16	1.17
3	-2.31	0.29	2.02
4	-0.66	0.21	0.45
5	-0.12	0.10	0.02
6	1.73	-0.26	-1.47
7	-0.49	1.19	-0.70
8	2.78	-2.10	-0.68
9	-0.50	0.84	-0.34
10	0.10	0.14	-0.24
11	-0.42	1.03	-0.61
27	0.99	-1.20	0.21

APPENDIX TABLE 18. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR WEANING WEIGHT (MONTANA)

Sire	Regions 71	72	73
1	99.1±3.9	100.9±1.5	100.1±2.2
2	99.6±1.5	98.2±0.7	100.4±1.8
3	98.6±2.2	101.0±2.2	102.5±1.1
4	100.3±1.1	100.9±0.6	101.0±0.8
5	100.7±1.0	100.7±0.6	100.5±2.0
6	102.2±2.6	100.0±1.6	98.6±1.6
7	100.4±1.6	101.9±1.4	99.9±1.4
8	103.5±5.5	98.4±2.2	99.7±1.2
9	99.8±0.9	100.9±0.9	99.6±1.1
10	99.8±0.9	99.6±0.7	99.1±0.7
11	100.3±1.4	101.5±1.9	99.8±3.6
27	98.4±2.2	96.0±1.7	97.3±9.5

APPENDIX TABLE 19. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR YEARLING WEIGHT[a]

Sire	Regions 3	4	5	6	7
1	-6.16	6.33	-0.17		
2	1.64	2.94	-1.16	-0.60	-2.82
3	0.92				-0.92
4	-1.69	-2.16	-1.34	-1.01	6.20
5	-0.11			-0.78	0.89
6	0.52	-3.81		-3.26	0.032
7	1.41			0.66	-2.07
8	1.01				-1.01
9	1.50		0.08	-1.60	0.02
10	0.97	-3.29	2.59	0.06	-0.32

[a] Only records from regions 3, 4, 5, 6 and 7 were included in the analysis.

APPENDIX TABLE 20. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR YEARLING WEIGHT[a]

Sire	Regions 3	4	5	6	7
1	96.3±3.7	112.0±7.4	103.6±4.2		
2	99.9±0.7	104.4±5.2	98.4±4.2	99.2±3.0	96.4±1.8
3	101.0±3.7				100.1±7.4
4	96.9±1.0	99.6±1.4	98.5±3.3	99.1±3.0	105.7±1.9
5	101.5±0.5			102.4±3.0	103.5±1.6
6	100.5±1.6	99.4±3.3		104.8±3.3	101.0±2.8
7	99.4±1.0			100.2±7.4	96.9±5.2
8	99.9±0.8				98.8±3.3
9	98.9±1.0		98.7±3.3	97.3±2.4	98.4±1.4
10	98.4±1.6	97.4±4.2	101.4±3.3	99.1±3.0	98.1±1.5

[a] Only records from regions 3, 4, 5, 6 and 7 were included in the analysis.

APPENDIX TABLE 21. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR GESTATION LENGTH[a]

Sire	Regions 3	6	7
2	-0.14	-0.29	0.43
4	-0.12	0.44	-0.32
5	0.04	0.03	-0.07
6	-0.37	0.03	0.34
7	0.17	0.11	-0.28
8	0.16	-0.16	
9	0.12	-0.43	0.31
10	0.10	0.01	-0.11
17	-0.36		0.36
23	0.09	0.13	-0.22
24	0.23		-0.23
27	0.21		-0.21
30	-0.13	0.13	

a Only records from regions 3, 6 and 7 were included in the analysis.

APPENDIX TABLE 22. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR GESTATION LENGTH[a]

Sire	Regions 3	6	7
2	99.9±0.2	99.8±0.3	100.6±0.5
4	99.7±0.5	100.3±0.2	99.6±0.2
5	100.1±0.2	100.2±0.3	100.2±0.2
6	99.1±0.2	99.6±0.5	100.0±0.4
7	100.3±0.1	100.3±1.4	100.0±0.3
8	100.2±0.3	100.0±1.0	
9	100.3±0.5	99.9±0.3	100.7±1.0
10	100.2±0.3	100.2±0.4	100.1±0.5
17	99.2±0.7		100.1±0.8
23	100.2±0.2	100.3±1.4	100.0±0.3
24	100.3±0.6		100.0±0.5
27	101.0±0.2		100.8±0.2
30	99.9±0.4	100.2±0.4	

[a] Only records from regions 3, 6 and 7 were included in the analysis.

APPENDIX TABLE 23. LEAST SQUARES SIRE X REGION INTERACTION CONSTANTS FOR CALVING EASE[a]

Sire	Regions 3	6	7
2	-1.84	-5.22	7.06
4	-2.11	4.18	-2.07
5	2.11	0.59	-2.70
6	-2.45	1.14	1.31
7	0.65	0.94	-1.59
8	2.46	-2.46	
9	-3.15	5.53	-2.38
10	4.63	-1.78	-2.85
17	-10.96		10.96
23	2.29	-0.60	-1.69
24	4.00		-4.00
27	2.03		-2.03
30	2.34	-2.34	

[a] Only records from regions 3, 6 and 7 were included in the analysis.

APPENDIX TABLE 24. LEAST SQUARES SIRE X REGION INTERACTION MEANS AND STANDARD ERRORS FOR CALVING EASE[a]

Sire	Regions 3	6	7
2	101.6±5.0	98.2±5.7	113.1±10.5
4	95.2±10.6	101.5±4.1	97.9±3.5
5	100.9±4.4	99.5±5.9	98.8±3.6
6	95.2±4.6	98.8±11.3	101.6±8.3
7	99.7±2.9	100.0±29.9	100.1±5.6
8	104.9±6.4	100.0±21.1	
9	96.6±9.9	105.3±5.7	100.0±21.1
10	104.8±6.9	98.5±8.3	100.0±11.3
17	100.0±14.9		124.5±17.2
23	102.8±5.2	100.0±30.0	101.5±6.9
24	98.2±12.2		92.8±10.6
27	103.2±5.1		101.8±3.5
30	92.9±8.3	88.2±9.4	

[a] Only records from regions 3, 6 and 7 were included in the analysis.

MONTANA STATE UNIVERSITY LIBRARIES
3 1762 10015103 2

N378
N924
cop. 2