MONTANA STATE UNIVERSITY

Effects of inbreeding and selection in a closed line of hereford cattle

by Darrell Ian Nevins

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science
Montana State University
© Copyright by Darrell Ian Nevins (1986)

Abstract:
The objectives of this study were to estimate the effect of inbreeding on birth weight, weaning weight and yearling weight in a closed line of Hereford cattle and to evaluate the selection index in use in this line. The Havre Line 4 has been closed since 1976. Mean inbreeding was .15 and .14 for calves and dams, respectively. Inbreeding of calf was increasing at a rate of .005 per year. Estimates of the effect of inbreeding of calf and dam on birth weight were very small and not biologically significant. Inbreeding of calf had no effect on weaning weight of male calves and a -.84 kg/% of calf inbreeding effect on female calf weaning weight. Inbreeding of dam had no effect on weaning weight of female calves and a -.64 kg/% of dam inbreeding effect on male calf weaning weight. Estimates of the effect of inbreeding on yearling weight were very small and not biologically significant. Selection in the Havre Line 4 is based on the index, I = Yearling Weight -3.2 Birth Weight. The purpose of the index is to achieve an acceptable increase in yearling weight while minimizing the correlated increase in birth weight. Genetic trends were estimated by use of frozen semen from sires born in 1975 and 1976 (group 1) and sires born in 1980 and 1981 (group 2) in a common tester herd. Estimates were -.2, 2.3 and 2.8 kg/yr for birth weight, weaning weight and yearling weight, respectively. The index is effectively reducing the trend for larger birth weight but is not increasing yearling weight at the expected rate.

EFFECTS OF INBREEDING AND SELECTION IN A CLOSED LINE OF HEREFORD CATTLE

by

Darrell Ian Nevins

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

of

Master of Science

in

Animal Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1986

MAIN LIB.
N378
N417
Cop. 2

APPROVAL

of a thesis submitted by

Darrell Ian Nevins

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliograghic style, and consistency, and is ready for submission to the College of Graduate Studies.

12/18/86 — D D Kress

Date — Chairperson, Graduate Committee

Approved for the Major Department

12-18-86 — Arthur C. Linton

Date — Head, Major Department

Approved for the College of Graduate Studies

12/18/86 — Henry L Parsons

Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Darrell V. Sims

Date Dec 18, 1986

ACKNOWLEDGEMENTS

I thank my father and mother, Roland and Jessie Nevins. They wanted more for me than they had. A special thank you to Kathy Hanford. Her patience, statistical ability and computor skills made my analyses possible. Last I thank Dr. Don Kress. About four years ago I asked him for a job breeding cows at Havre. He said no. I asked if I could get into graduate school. He said yes. About a year later I found out that Animal Breeding has something to do with the genetics of livestock. This thesis is the result.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF TABLES - Continued

LIST OF TABLES - Continued

LIST OF FIGURES

ABSTRACT

The objectives of this study were to estimate the effect of inbreeding on birth weight, weaning weight and yearling weight in a closed line of Hereford cattle and to evaluate the selection index in use in this line. The Havre Line 4 has been closed since 1976. Mean inbreeding was .15 and .14 for calves and dams, respectively. Inbreeding of calf was increasing at a rate of .005 per year. Estimates of the effect of inbreeding of calf and dam on birth weight were very small and not biologically significant. Inbreeding of calf had no effect on weaning weight of male calves and a -.84 kg/% of calf inbreeding effect on female calf weaning weight. Inbreeding of dam had no effect on weaning weight of female calves and a -.64 kg/% of dam inbreeding effect on male calf weaning weight. Estimates ofthe effect of inbreeding on yearling weight were very small and not biologically significant. Selection in the Havre Line 4 is based on the index, I = Yearling Weight - 3.2 Birth Weight. The purpose of the index is to achieve an acceptable increase in yearling weight while minimizing the correlated increase in birth weight. Genetic trends were estimated by use of frozen semen from sires born in 1975 and 1976 (group 1) and sires born in 1980 and 1981 (group 2) in a common tester herd. Estimates were -.2, 2.3 and 2.8 kg/yr for birth weight, weaning weight and yearling weight, respectively. The index is effectively reducing the trend for larger birth weight but is not increasing yearling weight at the expected rate.

INTRODUCTION

Animal Breeding is the science of improving the genetics of domestic livestock. Two procedures result in changes in the genetic properties of a population, selection of parents and control of the way in which parents are mated. Control of mating may result in inbreeding (Falconer, 1981).

Inbreeding is the mating together of individuals that are related to each other by ancestry (Falconer, 1981). The primary effect of inbreeding is to increase the probability that the two alleles at a particular locus in an individual are identical by descent. This causes an increase in the proportion of homozygous loci in the inbred individual (Brinks and Knapp, 1975).

Increased homozygosity is associated with a decline in performance traits such as reproduction, survival and growth rate (Brinks and Knapp, 1975). The measure of inbreeding is the coefficient of inbreeding (Fx) developed by Wright, (1922). The coefficient of inbreeding is the probability that the two genes at any locus in an individual are identical by descent (Falconer, 1981).

Growth traits, from birth to weaning in beef cattle, are affected by both the genotype of the offspring and the maternal environment provided by the dam (uterine environment, lactation, and other less well-known factors)

(Brinks and Knapp, 1975).

Yearling weight is affected by the genotype of the individual and there is the possibility that inbreeding of dam could have a carryover effect on yearling weight of offspring. Therefore, growth traits may be concurrently affected by both the inbreeding of the dam and the inbreeding of the offspring.

Under dominance theory the relationship between inbreeding (homozygosity) and the level of performance for a trait such as weaning weight should be linear. A non-linear relationship would indicate an epistatic interaction between loci (Falconer, 1981). Analyzing inbreeding as both a linear and a quadratic effect provides some indication whether dominance theory explains the effects of inbreeding.

Artificial selection is the process resulting from the choice of parents. Only the selected parents produce offspring. The response to selection is measured by the change in the population mean, the difference between the offspring of selected parents and the parental generation (Falconer, 1981).

Many early studies of selection were not designed to allow separation of genetic changes from the phenotypic changes (Dalton and Baker, 1979). Techniques of evaluating the genetic trends in beef cattle include maintaining a random bred control population, repeat matings, intra-year comparisons of sire or dam progeny groups and semen storage with evaluations on a common tester herd (Koch et al., 1982).

Selection for higher growth rate has been advocated to increase efficiency in beef production (Barlow, 1979). Dickerson et al. (1974) studied selection criteria including carcass composition, meat quality, optimum economic weight at slaughter of calves, mature size, milk production and calving difficulty of cows to improve efficiency of beef production. An index (I) of I = Yearling Weight - 3.2 Birth Weight was suggested.

Dickerson et al. (1974) predicted the index should result in 56% less increase in birth weight while reducing increase in yearling weight 10% as compared to selection for yearling weight alone. This should be possible since the genetic correlation between birth weight and yearling weight is about .6 (Woldehawariat et al., 1977).

Selection for faster growth (among bulls) will increase birth weights of calves before it increases cow size (Dickerson et al., 1974). Birth weight is the most important factor affecting calving difficulty (Bellows et al., 1971). Two-year-old-dams that experience dystocia wean fewer calves and as 3-yr-olds wean fewer and lighter calves than 2-yr-old dams that do not experience dystocia (Brinks et al., 1973).

The data for this study are from the Havre Line 4 Herefords. The Havre Line 4 is a closed line and herd sires are selected by the index, I = Yearling Weight -3.2 Birth Weight. Therefore, genetic change in this line may be affected by both inbreeding and selection.

The objectives of this study are to estimate the effect of inbreeding on birth weight, weaning weight and yearling weight in the Havre Line 4 and to evaluate the effect of selection based on the selection index on birth weight, weaning weight and yearling weight. To evaluate the selection index a progeny test was performed through the use of frozen semen in a common tester herd.

PART I

THE EFFECT OF INBREEDING ON BIRTH WEIGHT, WEANING WEIGHT AND YEARLING WEIGHT

LITERATURE REVIEW

This section of literature review focuses on the effects of inbreeding of calf (Fx) and inbreeding of dam (Fd) on birth weight, weaning weight and yearling weight in beef cattle.

The Effect of Inbreeding on Birth Weight

Swiger et al. (1961) pooled 283 records from two Hereford lines, one Angus line and one Shorthorn line. Mean inbreeding coefficients were .13 for calves and .10 for dams. Partial regression values of birth weight on inbreeding in kilograms per percent inbreeding were -.17 for Fx and -.01 for Fd. At a separate location 677 records from ten Hereford lines and two Angus lines were pooled. The mean inbreeding coefficient of calves was .05 and the mean inbreeding coefficient of dams was .03. Partial regression values were -.03 kg/% Fx and .06 kg/% Fd for birth weight on inbreeding. Significance levels were not reported for either analysis.

Swiger et al. (1962) pooled 647 records from Hereford Angus and Shorthorn lines. Mean inbreeding coefficients of calves and dams were .09 and .08, respectively. Partial regression values of birth weight on inbreeding were -.03 kg/% Fx and .06 kg% Fd. Significance levels were not reported.

Nelms and Sratton (1967) analyzed 302 records from one Hereford line. Mean inbreeding coefficients were .11 for calves and .05 for dams. Partial regression values of birth weight on inbreeding were -.02 kg/% Fx and -.03 kg/% Fd. Neither Fx or Fd were significant sources of variation in birth weight.

Sutherland and Lush (1962) analyzed 1008 records from a line of Holsteins. Mean inbreeding of calves was .10. Mean inbreeding of dams was not reported. Simple regression values of birth weight on inbreeding of calf were -.10 kg/% Fx of male calves and -.14 kg/% Fx for female calves. Simple regression values of birth weight on inbreeding of dam were -.12 kg/% Fd for male calves and -.13 kg/% Fd for female calves.

Brinks et al. (1965) analyzed 2027 Miles City Line 1 Hereford records. Mean inbreeding of calf and dam were .16 and .12, respectively. Partial regression values for inbreeding of calf on birth weight were -.06kg/% Fx in males and -.18 kg/% Fx in females. Values for inbreeding of dam on birth weight were .004 kg/% Fd and .04 kg/% Fd for males and females, respectively. Significance levels were not reported.

Anderson (1966) analyzed 640 records from three Hereford lines. Mean inbreeding of calf and dam were .15 and .09, respectively. Partial regression values were .01 kg/% Fx for males and -.03 kg/% Fx for females when birth weight was regressed on inbreeding of calf. Values for birth weight on inbreeding of dam were .17 kg/% Fd for males and .06 kg/% Fd for females. Only Fd for males was a significant source of variation in birth weight.

Brinks and Knapp (1975) pooled records from 48 inbred lines in the western United States. Mean inbreeding of calves was .19 and mean inbreeding of dams was .12. When only the linear effect of inbreeding was considered the partial regression coefficients of birth weight on inbreeding were -.04 kg/% Fx and -.10 kg/% Fd for males and -.03 kg/% Fx and .001 kg/% Fd for females. Fx for both males and females were significant sources of variation in birth weight. When both linear and quadratic effects of inbreeding were fitted no partial regressions of inbreeding of calf or dam were significant sources of variation in birth weight.

Table 1. The effect of inbreeding on birth weight.

	b (kg/% Fx)		b (kg/% Fd)	
Swiger et al. (1961)	-.17		-.01	
Swiger et al. (1961)	-.03		.06	
Swiger et al. (1962)	-.09		-.03	
Nelms and Stratton (1967)	-.02		-.03	
	male	female	male	female
Brinks (1965)	-.06	-.18	.004	.04
Anderson (1966)	.01	-.03	.17	.06
Brinks and Knapp (1975)	-.04	-.03	-.10	.001

b (kg/% Fx) = partial regression of birth weight on inbreeding of calf

b (kg/% Fd) = partial regression of birth weight on inbreeding of dam

The Effect of Inbreeding on Weaning Weight

Koch (1951) analyzed 745 records from a line of Herefords. Mean inbreeding of calf was .12 and mean inbreeding of dam was .06. Partial regression values of weaning weight on inbreeding were -.22 kg/% Fx and -1.15 kg/% Fd. Significance levels were not reported.

Burgess et al. (1954) pooled 546 records from several Hereford lines. Mean inbreeding of calf and dam were .12 and .06, respectively. Partial regression values of weaning weight on inbreeding were -.81 kg/% Fx and -.52/kg% Fd. Both Fx and Fd were significant sources of variation in weaning weight.

McCleery and Blackwell (1954) analysed 1455 records from one line of Herefords. Calf inbreeding ranged from 0 to .25 and dam inbreeding ranged from 0 to .16. Partial regression values of weaning weight on inbreeding were -.54 kg/% Fx and .43 kg/% Fd. Fx and Fd were both significant sources of variation in weaning weight.

In the study of Swiger et al. (1961) partial regression values of weaning weight on inbreeding were -.65 kg/% Fx and -.02 kg/% Fx at two locations. Values for weaning weight regressed on inbreeding of dam were -.07 kg/% Fd and .02 kg/% Fd. Significance levels were not reported.

Anderson (1966) found partial regression values of weaning weight on inbreeding of -.12 kg/% Fx for males and -.05 kg/% Fx for females. Values for weaning weight on inbreeding of dam were -.78 kg/% Fd for males and -.07 kg/% Fd for females. Only Fd of males was significant.

The study of Nelms and Stratton (1967) found partial regression values of -.47 kg/% Fx and .27 kg/% Fd for weaning weight on inbreeding. Only Fx was a significant source of variation in weaning weight.

Brinks et al. (1965) found partial regression values for weaning weight on inbreeding of calf of -.21 kg/% Fx for males and -.77 kg/% Fx for females. Values for weaning weight on inbreeding of dam were -.85 kg/% Fd for males and -.20 kg/% Fd for females. Significance levels were not reported. Inbreeding of calf had a larger effect on weaning weight of females. Inbreeding of dam had a larger effect on weaning weight of males. Brinks et al. (1963) hypothesized that males have a greater growth potential and therefore are affected less by inbreeding of calf. Conversely, inbreeding of dam is associated with decreased milk production and males having greater growth potential are affected more by inbreeding of dam.

Dinkel et al. (1968) analyzed 860 records from four Hereford lines. Mean inbreeding of calf was .20 and mean inbreeding of dam was .09. Partial regression values of weaning weight on inbreeding were -.61 kg/% Fx for males and -.36 kg/% Fx for females. Values for inbreeding of dam were -.23 kg/% Fd for males and -.73 kg/% Fd for females. Only Fx of males and Fd of females were significant sources of variation in weaning weight. These results disagree with the hypothesis of Brinks et al. (1963). In a separate analysis, inbreeding was fitted as both a linear and a quadratic effect. Only Fx as a quadratic effect for males and Fd as a linear effect for females were significant sources of variation in weaning weight.

Brinks and Knapp (1975) found partial regression values of weaning weight on inbreeding of -.29 kg/% Fx and -.40 kg/% Fd for males and -.31 kg/% Fx and -.24 kg/% Fd for females. Each of the partial regressions was a significant source of variation in weaning weight. When both linear and quadratic effects of inbreeding were fitted only Fd as a quadratic effect was a significant source of variation in weaning weight.

Table 2. The effect of inbreeding on weaning weight.

	b (kg/% Fx)		b (kg/% Fd)	
Koch (1951)	-1.20		-.22	
Burgess et al. (1954)	-.81		-.52	
McCleery and Blackwell (1954)	-.54		.43	
Swiger et al. (1961)	-.65		-.07	
Swiger et al. (1961)	-.02		.02	
Nelms and Stratton (1967)	-.47		.27	
	male	female	male	female
Anderson (1966)	-.12	-.05	-.78	-.07
Brinks et al. (1965)	-.21	-.77	-.85	-.20
Dinkel et al. (1968)	-.61	-.36	-.23	-.73
Brinks and Knapp (1975)	-.29	-.31	-.40	-.24

b (kg/% Fx) = partial regression of birthweight on inbreeding of calf

b (kg/% Fd) = partial regression of birthweight on inbreeding of dam

The Effect of Inbreeding on Yearling Weight

Several researchers have studied the effect of inbreeding on final weight off postweaning gain test. Final weight may be a different trait in males and females since they are managed separately and fed to gain at different rates.

Brinks et al. (1965) analyzed final weight off postweaning gain test of males and 12-mo weight of females. Partial regression values for final weight of males on inbreeding were -1.04 kg/% Fx and -.39 kg/% Fd. Values for 12-mo weight of females on inbreeding were -1.38 kg/% Fx and -.10 kg/% Fd. Significance levels were not reported.

Nelms and Stratton (1967) analyzed final weight off postweaning gain test of males and females. Partial regression values for final weight on inbreeding were -.15 kg/% Fx and .50 kg/% Fd. Neither Fx or Fd were significant sources of variation in final weight.

Dinkel et al. (1967) analyzed final weight off postweaning gain test. Partial regression values for final weight on inbreeding were -1.09 kg/% Fx and -.004 kg/% Fd for males and -.53 kg/% Fx and -.61 kg/% Fd for females. Fx and Fd for males and Fd for females were significant sources of variation in final weight. When both the linear and quadratic effects of inbreeding were fitted only Fd of females as both a linear and quadratic were significant sources of variation in final weight.

Anderson (1966) found partial regression values for final weight on inbreeding of -.61 kg/% Fx and -.65 kg/% Fd for males and -.17 kg/% Fx and -.19 kg/% Fd for females. None of the regressions were significant sources of variation in final weight.

Brinks and Knapp (1975) found partial regression values for final weight on inbreeding of -.44 kg/% Fx and -.31 kg/% Fd for males and -.25 kg/% Fx and .13 kg/% Fd for females. Only Fx of males was a significant source of variation in final weight. When both linear and quadratic effects of inbreeding were fitted only Fd of males as a quadratic was a significant source of variation in final weight.

Table 3. The effect of inbreeding on yearling weight.

	b (kg/% Fx)		b (kg/% Fd)	
Nelms and Stratton (1967)	-.15		.50	
	male	female	male	female
Brinks et al. (1965)	-1.04	-1.38[a]	-.39	-.10[a]
Dinkel et al. (1967)	-1.09	-.53	-.004	-.61
Anderson (1966)	-.61	-.17	-.65	-.19
Brinks and Knapp (1975)	-.44	-.25	-.31	.13

b (kg/% Fx) = partial regression of yearling weight on inbreeding of calf
b (kg/% Fd) = partial regression of yearling weight on inbreeding of dam
[a] 12-mo weight

Summary

Inbreeding of calf and dam have little effect on birth weight. Inbreeding of calf has a fairly large (approximately -.5 kg/% Fx) detrimental effect on weaning weight. The effect of inbreeding of dam on weaning weight is usually detrimental and varies greatly with line. Inbreeding of calf has a fairly large (approximately -.6 kg/% Fx) detrimental effect on yearling weight. Inbreeding of dam has a smaller (approximately -.14 kg/% Fd) detrimental effect on yearling weight. The response to increased inbreeding varies greatly between inbred lines of beef cattle. Growth traits of a particular line may be greatly affected by inbreeding in a positive or negative manner or may not be affected. The explanation for sex differences in response to inbreeding is not known. There is no strong evidence for a quadratic growth response to inbreeding (Brinks and Knapp, 1975).

MATERIALS AND METHODS

The data for this part of the study were collected at the Northern Agricultural Research Center (NARC) near Havre, Montana from 1976 to 1983.

Site Description

NARC is located 13 km SW of Havre. The area is rolling plains with an approximate elevation of 819 m. Annual precipitation averaged 297 mm from 1951 to 1980 (USDC, 1980). The pastures at NARC are mixed praire grasslands containing *Agropyron desertorum*, *Stipa comata* and *Bouteloa gracilis* (crested wheatgrass, needle and thread and blue grama) as the major forage species.

Experimental Animals

Data were collected on 594 Havre Line 4 Horned Hereford calves. The Havre Line 4 is a subline of the Miles City Line 1. Foundation cows were purchased from the Livestock and Range Research Station at Fort Keogh in 1962 and 1963. The Havre Line 4 consists of approximately 100 cows. The line was closed in 1976.

Selection and Mating System

Each year two sires are selected within the line by utilizing the following index, I = Yearling Weight - 3.2

Birth Weight. Yearling weight and birth weight are corrected for age of dam and yearling weight is corrected to 365 d of age. Correction factors are calculated from within herd data. Sires are used for breeding as yearlings and 2-yr-olds. As yearlings, sires are randomly mated with replacement heifers and cows. Two-yr-old sires are repeat-mated to half the dams that produced their offspring the preceding year. To limit the rate of increase in inbreeding half-sib and son-dam matings are excluded and the two sires selected each year cannot be half-sibs.

All yearling heifers are exposed to breeding and those becoming pregnant are retained in the herd. Dams are culled on Most Probable Producing Ability for preweaning gain of calves. Cows which are not pregnant in the fall are culled.

Management

Breeding is by natural service for 45 d beginning June 1. After the breeding season the four sire groups are pastured together on improved pastures for the rest of the year. Winter feed for the cow herd consists of grass hay and corn silage.

Weaning occurs on Oct. 1. After a 2-wk warmup period bull calves go on a 168-d gain test. The ration consists of corn silage, grass hay and an oat-barley concentrate mix. Average gain is 1.1 kg per d.

For 6-wk after weaning heifer calves are pastured on hay field aftermath and then go on a 140-d gain test. The ration consists of corn silage, second cutting alfalfa and barley. Average gain is .6 kg per d.

Data

The data collected on the 594 Havre Line 4 calves weaned from 1976 to 1983 included birth date, birth weight sex of calf, age of dam, sire of calf, weaning weight and final weight off postweaning gain test. Inbreeding was calculated by an algorithm developed by Quaas (1976).

Statistical Analysis

To estimate the effect of calf and dam inbreeding on birth weight, weaning weight and yearling weight the data were analyzed by fixed model least-squares procedures (Harvey, 1977). The effects of inbreeding of calf (Fx) and inbreeding of dam (Fd) were the variables of primary interest in the analysis. The other variables and interactions were fitted to account for known sources of variation and allow better estimates of the effects of inbreeding. The model used to analyze birth weight was as follows:

$$Y_{ijkl} = u + Yr_i + Sx_j + A_k + S_{l(i)} + Yr \times Sx_{ij} + Yr \times A_{ik} + Sx \times A_{jk} + B_{ijkl} + Fx_{ijkl} + Fd_{ijkl} + Sx_j \times Fx_{ijkl} + Sx_j \times Fd_{ijkl} + e_{ijkl}$$

where

Y_{ijkl} = an observation

u = the overall mean

Yr_i = the fixed effect of the ith year

Sx_j = the fixed effect of the jth sex

A_k = the fixed effect of the kth age of dam

$S_{l(i)}$ = the fixed effect of the lth sire nested within the ith year

Yr x Sx_{ij} = the interaction of the ith year and the jth sex

Yr x A_{ik} = the interaction of the ith year and the kth age of dam

Sx x A_{jk} = the interaction of the jth sex and the kth age of dam

B_{ijkl} = the effect of day of birth

Fx_{ijkl} = the effect of inbreeding of calf

Fd_{ijkl} = the effect of inbreeding of dam

Sx_j x Fx_{ijkl} = the interaction of the jth sex of calf and inbreeding of calf

Sx_j x Fd_{ijkl} = the interaction of the jth sex of calf and inbreeding of dam

e_{ijkl} = random error.

The same model with weaning weight as the dependent variable was used to analyze weaning weight. A similar model was used to analyze yearling weight. Final weight off postweaning gain test was the dependent variable and age at yearling weight was included as a covariate.

In preliminary analyses, inbreeding of calf and dam were fitted as both linear and quadratic covariates. Inbreeding of calf and dam as quadratic covariates were not significant sources of variation in any analysis and were not included in final models.

The two-way interactions of age of dam x inbreeding of calf and age of dam x inbreeding of dam were fitted in preliminary analyses. These interactions were not significant for any trait and were not included in final analyses.

RESULTS AND DISCUSSION

Inbreeding

Inbreeding of dam ranged from .06 to .31 with a mean of .14. Inbreeding of calf ranged from .08 to .39 with a mean of .15. Inbreeding of calf increased at a rate of .005 per year. The trend for inbreeding of calf is shown in Figure 1.

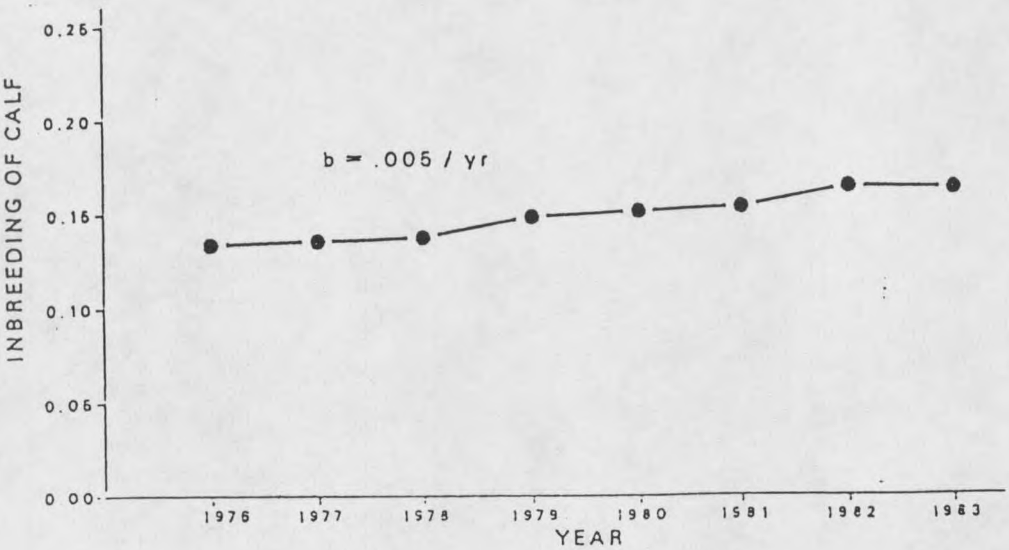

Figure 1. Trend in inbreeding of calves over years.

Birth Weight

The mean birth weight was 36.2 kg. Birth weight was significantly affected by all main effects except sire within year. The least-squares analysis of variance of birth weight is shown in Table 4 and the least-squares means for main effects are shown in Table 5.

Table 4. Least-squares analysis of variance for birth weight.

Source	df	Mean square (kg^2)
Year	7	70[¤¤]
Sex	1	476[¤¤]
Age of dam	3	392[¤¤]
Sire/year	27	21
Year x sex	7	13
Year x age of dam	21	27[¤¤]
Sex x age of dam	3	13
Regressions:		
Day of birth	1	2909[¤¤]
Inbreeding of calf	1	34[a]
Sex x Inbreeding of calf	1	35
Inbreeding of dam	1	45[¤]
Sex x Inbreeding of dam	1	29
Remainder	519	11
R^2		.49

¤¤ $P<.01$
¤ $P<.05$
a $P=.08$

Year was a significant source of variation in birth weight and means ranged from 34.3 kg in 1979 to 37.8 kg in 1983, a difference of 3.5 kg. This is in agreement with Burfening and Kress (1973) who found a significant year effect in a study at the same location.

Sex of calf was a significant source of variation in birth weight and mean male calf birth weight was 37.3 kg and mean female calf birth weight was 35.3 kg. Males were 2.0 kg heavier than females at birth. The sex difference is within the range given by Woldehawariat et al. (1977).

Table 5. Least-squares means for main effects affecting birth weight (kg).

Item	n	Mean	SE
u	594	36.3	±.16
Year			
1976	64	36.0	±.55
1977	69	36.4	±.45
1978	65	35.5	±.45
1979	68	34.3	±.47
1980	68	37.3	±.47
1981	77	37.2	±.44
1982	88	35.8	±.46
1983	95	37.8	±.40
Sex			
Male	302	37.3	±.22
Female	292	35.3	±.23
Age of dam			
2	140	33.6	±.35
3	127	36.2	±.33
4	83	37.3	±.40
5-10	244	38.2	±.25

Age of dam was a significant source of variation in birth weight and means were 33.6, 36.2, 37.3 and 38.2 kg for 2-yr-old, 3-yr-old, 4-yr-old and 5-10-yr-old dams, respectively. Birth weights were lightest for 2-yr-olds, increased with age to mature dams (5-10-yr-old). The effect of age of dam on birth weight is in agreement with Woldehawariat et al. (1977).

The two-way interaction year x age of dam was a significant source of variation in birth weight. Year means for age of dam subclasses changed erratically in rank and magnitude from year to year. The explanation of this interaction was not apparent.

Partial regression values are shown in Table 6. Day of birth as a covariate was a significant source of variation in birth weight. Birth weight increased .06 kg for each one day increase in the calving season. This agrees with Burfening and Kress (1973).

Table 6. Partial regression values of birth weight on inbreeding of calf, inbreeding of dam and day of birth.

Regression	b	SE
Inbreeding of calf (kg/% Fx)	-.0001	±.0001
Inbreeding of dam* (kg/% Fd)	-.0001	±.00004
Day of birth** (kg/d)	-.06	±.01

** P<.01
* P<.05

Inbreeding of calf approached significance as a source of variation in birth weight. Inbreeding of dam was significant. The partial regression values were -.0001 kg/% inbreeding of calf and -.0001 kg/% inbreeding of dam. These small values lack biological significance. Inbreeding had little effect on birth weight in this study. This is in agreement with several studies which have shown little effect of inbreeding of calf on birth weight (Swiger et al., 1962; Brinks et al., 1965 and Brinks and Knapp, 1975). This study agrees with most previous studies where inbreeding of dam has shown little effect on birth weight (Brinks and Knapp, 1975).

Weaning Weight

The mean weaning weight was 203.4 kg. Weaning weight was significantly affected by all main effects except sire within year. The least-squares analysis of variance for weaning weight is shown in Table 7 and the least-squares means for the main effects are shown in Table 8.

Table 7. Least-squares analysis of variance for weaning weight.

Source	df	Mean square (kg^2)
Year	7	5512**
Sex	1	12057**
Age of dam	3	24683**
Sire/year	27	375
Year x sex	7	396
Year x age of dam	21	934**
Sex x age of dam	3	691
Regressions:		
Day of birth	1	59262**
Inbreeding of calf	1	190
Sex x inbreeding	1	1678*
Inbreeding of dam	1	440
Sex x inbreeding of dam	1	1507*
Remainder	519	355
R^2		.67

**P<.01
* P<.05

Year was a significant source of variation in weaning weight and means for year ranged from 176.6 kg in 1978 to 216.8 kg in 1977. Many studies have shown a significant year effect on weaning weight. Anderson (1966) found a significant year effect of a similiar magnitude at the same location.

Sex of calf was a significant source of variation in weaning weight and mean weaning weight was 207.7 kg for males and 192.0 for females. The 15.7 kg difference due to sex is in agreement with Woldehawariat et al. (1977).

Table 8. Least-squares means for main effects affecting weaning weight (kg).

Item	n	Mean	SE
u	594	199.9	±1.3
Year			
1976	64	198.6	±4.6
1977	69	216.8	±3.5
1978	65	176.6	±3.4
1979	68	193.2	±3.0
1980	68	214.7	±3.1
1981	77	208.1	±3.7
1982	88	190.8	±4.5
1983	95	200.0	±3.0
Sex			
Male	302	207.7	±1.7
Female	292	192.0	±2.0
Age of dam			
2	140	176.6	±2.0
3	127	198.3	±1.8
4	83	210.3	±2.2
5-10	244	217.8	±1.4

Age of dam was a significant source of variation in weaning weight and means were 177, 198, 210 and 218 kg for 2-yr-old, 3-yr-old, 4-yr-old and 5-10-yr-old dams respectively. This effect of age of dam on weaning weight is in agreement with Woldehawariat et al., (1977).

The two-way interaction year x age of dam was an important source of variation in weaning weight. Weaning weights of calves from 2-yr-old dams were affected more by year than calves from mature dams as shown in Figure 2.

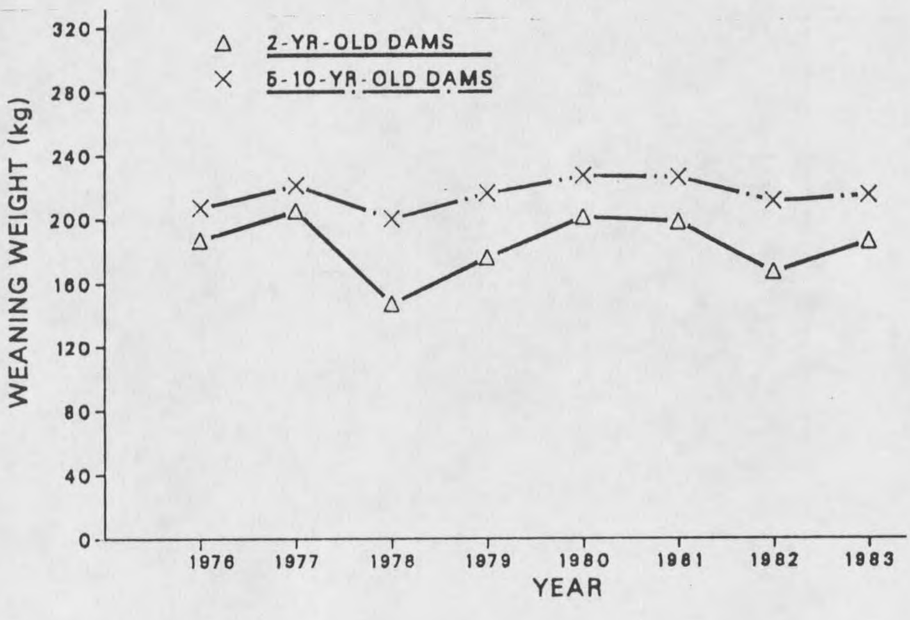

Figure 2. Year x age of dam interaction for weaning weight.

Day of birth as a covariate was a significant source of variation in weaning weight. Weaning weight increased .89 kg for each one day decrease in day of birth. This agrees closely with the study of Urick (1958) at the same location.

Inbreeding of calf and dam when pooled over sex were not significant sources of variation in weaning weight. However, the two-way interactions sex x inbreeding of calf and sex by inbreeding of dam were significant. Male weaning weight decreased .64 kg for each one percent increase in inbreeding of dam. Female weaning weight decreased .84 kg for each one percent increase in inbreeding of calf. Partial regression values are shown in Table 9.

Table 9. Partial regression values of weaning weight on sex x inbreeding of calf, sex x inbreeding of dam and day of birth.

Regression	b	SE
Inbreeding of calf (kg/% Fx)	-.22	±.30
Sex x inbreeding of calf* (kg/% Fx)		
Male	.39	±.46
Female	-.84	±.36
Inbreeding of dam (kg/% Fd)	-.22	±.20
Sex x inbreeding of dam* (kg/% Fd)		
Male	-.65	±.29
Female	.20	±.28
Day of birth** (kg/d)	-.89	±.07

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

Inbreeding of calf had a detrimental effect on weaning weight of females. Several studies have found a sizeable detrimental effect of inbreeding of calf on both sexes (Swiger et al., 1962; Dinkel et al., 1968, Brinks et al., 1965 and Brinks and Knapp, 1975). Inbreeding of dam had a detrimental effect on weaning weight of males. Studies have found a detrimental effect of inbreeding of dam on weaning weight of both sexes (Brinks et al., 1965; Anderson, 1966 and Dinkel et al., 1968), a positive effect (McCleery and Blackwell, 1954) and no effect (Nelms and Stratton, 1964). The response of weaning weight to increased inbreeding varies by line and selection criteria.

Weaning weight of males was more greatly affected by inbreeding of dam while weaning weight of females was more greatly affected by inbreeding of calf. This agrees with Brinks et al. (1963). This similarity is probably to be expected because Brinks et al., (1963) used Miles City Line 1 Hereford data and the Havre Line 4 is a subline of the Line 1.

Yearling Weight

The mean yearling weight was 350 kg. All main effects were significant sources of variation in yearling weight except sire within year. The least-squares analysis of variance is shown in Table 10 and the least-squares means for main effects are shown in Table 11.

Year was a significant source of variation in yearling weight and means for yearling weight ranged from 316 kg in 1978 to 381 kg in 1980. This 65 kg variation due to year agrees with Anderson (1966).

Sex of calf was a significant source of variation in yearling weight and mean yearling weight for males was 398 kg and mean yearling weight for females was 298 kg. The 100 kg difference due to sex is larger than the range given by Woldhawariat et al. (1977). Sex effect in this analysis is a combination of sex and environment. The two sexes are managed separately and males are fed to gain at a higher rate.

Table 10. Least-squares analysis of variance for yearling weight.

Source	df	Mean square (kg^2)
Year	7	15620**
Sex	1	1047412**
Age of dam	3	26626**
Sire/year	27	2020
Year x sex	7	3716**
Year x age of dam	21	726
Sex x age of dam	3	1650
Regressions:		
Age at yearling weight	1	96437**
Inbreeding of calf	1	6120**
Sex x inbreeding of calf	1	875
Inbreeding of dam	1	2016
Sex x inbreeding of dam	1	6196**
Remainder	493	841
R^2		.82

**P<.01

Age of dam was a significant source of variation in yearling weight and means were 332, 347, 357 and 359 kg for 2-yr-old, 3-yr-old, 4-yr-old and 5-10-yr-old dams. The weaning weight differences due to age of dam were maintained through yearling weight.

The two-way interaction year x sex was a significant source of variation in yearling weight. Male means were more varied than means for females. Males apparently respond differently to environmental differences of year than females.

Table 11. Least-squares means for main effects affecting yearling weight (kg).

Item	n	Mean	SE
u	568	347.7	±1.4
Year			
1976	62	335.5	±4.9
1977	67	344.4	±4.0
1978	56	316.2	±4.3
1979	65	345.8	±4.2
1980	68	381.1	±4.1
1981	75	355.1	±3.9
1982	83	345.5	±4.1
1983	92	357.9	±3.5
Sex			
Male	284	397.7	±2.0
Female	284	297.7	±2.0
Age of dam			
2	124	324.0	±3.2
3	124	345.7	±2.9
4	82	358.7	±3.5
5-10	238	362.3	±2.2

Age at yearling weight was a significant source of variation in yearling weight and the partial regression value was 1.2 kg/day. Each 1 day increase in age resulted in a 1.2 kg increase in yearling weight. Inbreeding of calf was a significant source of variation in yearling weight. The partial regression value is small, -.001 kg/% Fx, and lacks biological significance. A completely inbred individual would decrease only .1 kg in yearling weight. Regression values are shown in Table 12.

Table 12. Partial regression values of yearling weight on inbreeding of calf, sex x inbreeding of calf, inbreeding of dam, sex x inbreeding of dam and age yearling weight.

Regression	b	SE
Inbreeding of calf** (kg/% Fx)	-.001	±.0005
Sex x inbreeding of calf (kg/% Fx)		
Male	-.0008	±.0007
Female	-.001	±.0006
Inbreeding of dam (kg/% Fd)	-.0003	±.0003
Sex x inbreeding of dam** (kg/% Fd)		
Male	-.002	±.0006
Female	.0004	±.0004
Age at weaning weight** (kg/d)	1.2	±.1

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

The two-way interaction sex x inbreeding of dam was also significant. The partial regression values were -.0008 kg/% Fd and -.002 kg/% Fd for males and females, respectively. Again these small values lack biological significance. Selection for increased yearling weight in the Havre Line 4 may be masking the possible effect of inbreeding on yearling weight. Previous studies of the effect of inbreeding on yearling weight have generally found a detrimental effect (Brinks and Knapp, 1975).

Summary

The effect of inbreeding of calf and inbreeding of dam on birth weight, weaning weight and yearling weight were estimated in the Havre Line 4 Herefords. Inbreeding of calf and dam had little effect on birth weight. Inbreeding of calf caused a -.84 kg/% Fx decrease in female weaning weight. Inbreeding of dam caused a -.64 kg/% Fd decrease in male weaning weight. Inbreeding of calf and dam had little effect on yearling weight.

PART II

THE EFFECT OF SELECTION FOR AN INDEX ON BIRTH WEIGHT, WEANING WEIGHT AND YEARLING WEIGHT

LITERATURE REVIEW

This section of literature review focuses on the response to selection for the growth traits, weaning weight and yearling weight, and the correlated response in birth weight in beef cattle.

Response to Selection for Growth

Flower et al. (1964) studied selection response in three closed lines of Herefords. Sire selection was by sequential selection for increased weaning weight and postweaning weight gain followed by progeny testing in a common tester line. Genetic trends were estimated by subtracting environmental trends (calculated from repeat matings) from phenotypic trends. After 6 yr of selection the genetic increases were .33 and 1.91 kg/yr for birth weight and weaning weight, respectively.

Brinks et al. (1965) studied the effectiveness of selection for increased weights, gains and conformation score in the Miles City Line 1. Repeat matings were used to estimate environmental trends. Sires used in the line were selected on weaning weight and conformation score, performance during a postweaning gain test and (usually) a progeny test. After 25 yr of selection genetic trend for birth weight was .19 kg/yr and genetic trend for weaning weight was .56 kg/yr. Due to small numbers of repeat matings for postweaning traits, genetic trends were not estimated for them. It was concluded that substantial genetic progress was obtained for growth traits.

Newman et al. (1973) studied the response to selection for greater unadjusted yearling weight in two replicate lines of Shorthorns. Genetic trends were measured as deviations from unselected control line means. Ten yr of selection resulted in genetic responses of 4.8 and 4.1 kg/yr in male yearling weight in the two lines. Genetic response in female yearling weight in the two lines was 3.3 and 2.3 kg/yr, respectively. It was concluded that selection was highly effective in changing yearling weight.

Koch et al. (1974) studied selection response in three lines of Herefords selected for increased weaning weight, yearling weight and an index of yearling weight and muscling score. Genetic trends were measured by offspring regression on selection in parents. After 8 of selection genetic trends were .18, 1.05 and 2.58 kg/yr for birth weight, weaning weight and yearling weight, respectively in the weaning weight line. The responses in the yearling weight line were .23, .77 and 3.09 kg/yr for birth weight, weaning weight and yearling weight, respectively. Genetic response in the index line was .23, .68 and 2.37 kg/yr for birth weight, weaning weight and yearling weight, respectively. It was concluded that genetic correlations between growth traits are fairly large. Applying negative selection on birth weight to decrease death loss associated with large birth weight was suggested.

Chevraux and Bailey (1977) studied the response to selection for increased postweaning gain in a closed line of Herefords. Genetic changes were estimated by regression on dam birth year. After 19 yr of selection genetic change was 2.6 kg/yr for weaning weight and 4.5 kg/yr for postweaning gain.

Frahm et al. (1985) studied selection response in two lines of Herefords. Single trait selection was applied for increased weaning weight and yearling weight. An unselected Angus line was maintained as a control. Genetic trends were measured as deviations from the control line and by a crossbred progeny test using frozen semen from two foundation sires and two selected sires born in the sixth yr of selection. Due to small numbers of progeny, selected sires were considered a group and compared to foundation sires. Selected sire progeny minus foundation sire progeny differences were .28, 2.2 and 4.01 kg/yr for birth weight, weaning weight and yearling weight, respectively. In the weaning weight line genetic trends were estimated as deviations from the control line and were .3, 1.0 and .6 kg/yr for birth weight , weaning weight and yearling weight, respectively. In the yearling weight line genetic trends were .2, .9 and 1.0 kg/yr for birth weight, weaning weight and yearling weight, respectively. It was concluded that substantial increase for growth rate had occurred as a result of selection for weaning weight and yearling weight and some attention should be given to minimizing the correlated response of increased birth weight.

Irgang et al. (1985) studied the response to single trait selection for increased weaning weight and postweaning gain in two lines of Herefords. A nonselected Hereford line was used as a control. Estimated genetic responses in weaning weight were 1.1 and .6 kg/yr for bulls and heifers, respectively in the weaning weight line and 1.4 and 1.2 kg/yr in the postweaning gain line. Responses in postweaning gain was .0 and .2 kg/yr for bulls and heifers, respectively, in the weaning weight line. Responses were .9 and .3 kg/yr for bulls and heifers, respectively, in the postweaning gain line.

Anderson et al. (1985) studied the response to selection for the index, I = Yearling Weight - 3.2 Birth Weight in the Havre Line 4. Genetic trends were estimated from repeat matings. Increases due to the selection index were -.4, 3.2 and 1.6 kg/yr for birth weight, weaning weight, and yearling weight, respectively. It was concluded that through the use of the selection index, some improvement in weaning weaning weight and yearling weight can be realized while the correlated increase in birth weight can be retarded.

Aaron et al. (1986) studied the response to selection for weaning weight, yearling weight and a combination of weaning weight and progeny weaning weight in three lines of Angus cattle. An unselected Angus line was maintained as a control. In the weaning weight line after 16 yr of selection estimated responses were .2, 1.0 and 1.8 kg/yr for birth weight, weaning weight and yearling weight, respectively. In the yearling weight line estimated responses were .4, 1.3 and 3.0 kg/yr for birth weight, weaning weight and yearling weight, respectively. After 15 yr of selection in the combination line estimated responses were .3, 1.7 and 2.2 kg/yr for birth weight, weaning weight and yearling weight, respectively. It was concluded that selection for yearling weight was most effective in increasing both weaning weight and yearling weight and some attention should be given to minimizing the correlated increase in birth weight.

Summary

Selection for increased weaning weight and yearling weight is effective in beef cattle. Selection for these two growth traits results in genetic improvement. Birth weight increases as a correlated response to selection for increased growth. Selection for increased yearling weight while limiting increase in birth weight should be possible since the genetic correlation between birth weight and yearling weight is about .6 (Woldehawariat et al., 1977). The study of Anderson et al., (1985) used Havre Line 4 data and concluded that the selection index, I = Yearling Weight - 3.2 Birth Weight, increased yearling weight while limiting the increase in birth weight.

Table 13. Responses and correlated responses to selection for growth.

	Selection criteria	Response (kg/yr)			
		BW	WW	YW	PWG
Flower et al. (1964)	WW and PWG	.3	1.9		
Brinks et al. (1965)	WW, CS and PWG	.2	.6		
Newman (1973)	YW			3.9	
Newman (1973)	YW			3.2	
Koch et al. (1974)	YW	.2	.8	3.1	
Koch et al. (1974)	WW	.2	1.0	2.6	
Koch et al. (1974)	YW and MS	.2	.7	2.4	
Chevraux and Bailey (1977)	PWG		2.6		4.5
Anderson et al (1985)	YW-3.2 BW	-.4	3.2	1.6	
Frahm et al. (1985)	WW	.3	1.0	.6	
Frahm et al. (1985)	YW	.2	.9	1.0	
Frahm et al. (1985)	YW and WW	.3	2.2	4.0	
Aaron et al. (1986)	WW	.2	1.0	.8	
Aaron et al. (1986)	YW	.4	1.3	3.0	
Aaron et al. (1986)	WW and PWW	.3	1.7	2.2	

BW = birth weight, WW = weaning weight, YW = yearling weight, PWG = postweaning gain, CS = condition score, MS = muscling score and PWW = progeny weaning weight

MATERIALS AND METHODS

The data for this part of the study were collected during 1984 and 1985 at the Red Bluff Research Ranch, Norris, Montana and the Montana State University Livestock Center, Bozeman, Montana. Both facilities are operated by the Department of Animal and Range Sciences, Montana State University.

Site Descriptions

The Red Bluff Research Ranch is located near Norris, Montana 56 km west of Bozeman, Montana on the northwest slope of the Madison range. The elevation ranges from 1,400 to 1,900 m and the annual precipitation averages 350 to 406 mm, USDA-SCS (1976). Agropyron smithii and Festuca idahoensis (Bluebunch Wheatgrass and Idaho Fescue) account for 70% of the principle plant community (Turner, 1985).

The Montana State University Livestock Center is located on the southwest edge of Bozeman in the Gallatin Valley. The elevation is about 1370 m and the annual precipitation averages 406 to 457 mm, USDA-SCS (1976). The subirrigated improved pastures include Poa pratensis, Bromus inermis, Lotus corniculatus and Onobrychis viciafolia (Kentucky Bluegrass, Smooth Brome, Birdsfoot trefoil and Sainfoin) as the major forage species.

<u>Sires</u>

The sires used in this study were Havre Line 4 Horned Herefords from the Northern Agricultural Research Center near Havre, Montana. The Havre Line 4 is a subline of the Miles City Line 1. The Line 4 has been closed at Havre since 1976. Two herd sires per year were selected within the line based on the selection index, I = Yearling Weight - 3.2 Birth Weight (Dickerson et al., 1974). Yearling weight and birth weight are adjusted for age of dam and yearling weight is corrected to 365 d of age. Use of the index was initiated for sires born in 1975.

Eight sires were used through frozen semen to measure genetic progress resulting from the selection index. The eight sires were considered two groups. The first group consisted of the four sires selected in 1975 and 1976 and the second group consisted of the four sires selected in 1980 and 1981.

Calving occurred in March and April at the Northern Agricultural Research Center. All calves were weighed within 24 h of birth, at weaning and at the end of postweaning gain test. Male calves were placed on a 168-d gain test after weaning. Male calves were fed to gain approximately 1.1 kg/d (Anderson et al., 1985).

Test Dams

The Montana State University cow herd was managed by the Red Bluff Research Ranch and the Montana State University Livestock Center. Three-year-old and older dams were maintained at Red Bluff and replacement heifers and 2-yr-old dams were maintained at Bozeman. Female replacement calves were trucked to Bozeman after weaning.

At the Montana State University Livestock Center replacement females were wintered on mixed grass-alfalfa hay ad libitum and .9 kg of ground barley per head per day. Replacement females weighed approximately 330 kg at the beginning of the breeding season, which began May 20 and ended June 30. Bred yearling heifers were summered on improved pastures.

The pregnant replacement females were wintered on mixed grass-alfalfa hay provided ad libitum. Beginning 60 d prior to calving, .9 kg of ground barley per head per day was fed. Second cutting alfalfa ad libitum and .9 kg of ground barley per head were fed for 45 d post calving. Calves were weaned in mid-November.

After weaning their first calves the 2-yr-old-dams were moved to Red Bluff. At Red Bluff the cow herd was wintered on range and supplemented grass hay when snow cover restricted grazing. Beginning 45 d prior to calving .9 kg of barley pellots per head per day were fed. Alfalfa hay ad libitum and 1.8 kg of barley pellets per head were fed for

45 d post calving. The breeding season began June 1 and ended July 15.

The cow herd consisted of Angus, Hereford, Angus X Hereford and Tarantaise X cows. In 1979 and 1980 Tarantaise sires were used. In other years Angus and/or Hereford sires were used to produce the test dams used in this study.

Yearling replacement heifers at Bozeman were randomly assigned to the eight Havre Line 4 sires within breed type (Angus, Angus X Hereford, Hereford, Tarantaise X and Simmental X (a Simmental sire was used at Bozeman from 1982 to 1984). The older cows at Red Bluff were randomly assigned to the eight Havre Line 4 sires within age of cow.

Data

The data collected on the 169 progeny calves born at Red Bluff and Bozeman included sire, age of dam, birth weight, calving difficulty score, day of birth and sex. Weaning weight was taken on 159 progeny calves. Yearling weight was taken on 149 progeny. Gestation length was calculated from breeding date and day of birth.

All calves born at Bozeman were from 2-yr-old dams. Age of dam at Red Bluff was pooled into 3, 4, 5-10 and 11 and older age groups.

Birth weights were taken within 24 h of birth. Calving difficulty was scored from 1 to 5 where

1 = No difficulty, no assistance

2 = Minor difficulty, some assistance

3 = Major assistance, mechanical assistance

4 = Caesarean

5 = Abnormal presentation.

Calving difficulty scores of 5 were not included in the analysis of calving difficulty. Abnormal presentations have not been shown to have a genetic relationship with calving difficulty (BIF, 1981).

Weaning weights for the 1984 progeny calves were taken November 1 and November 2 at Bozeman and Red Bluff, respectively. In 1985 weaning weights were taken October 17 at Bozeman and October 18 at Red Bluff.

Weaning age of the 20 progeny calves weaned at Bozeman averaged 241 d in 1984. The 21 progeny calves weaned at Red Bluff averaged 231 d of age at weaning in 1984. Weaning age in 1985 averaged 212 d for 66 progeny calves at Bozeman while 52 progeny calves at Red Bluff averaged 215 d of age at weaning.

Age at yearling weight of the 85 progeny steers averaged 375 d. Yearling weight of stocker steers was taken April 1 in 1985 and March 8 in 1986. Yearling weight of feedlot steers was taken April 1 in 1985 and April 5 in 1986.

Age at yearling weight averaged 383 d for the 12 progeny females in 1985 and 389 d for the 52 progeny females in 1986. Yearling weights were taken April 1 in 1985 and

April 5 in 1986.

In both 1984 and 1985 the steer progeny were split into two groups postweaning. The 43 steer progeny produced during the 2 years by 2-yr-old dams at Bozeman were wintered on 8.2 kg of grass hay per head per day and gained .5 kg per day. The 42 steer progeny produced during the 2 yr by older dams at Red Bluff were finished in a feedlot. After a 21 d adjustment period they were placed on full feed for 180 d before slaughter. The ad libitum ration was 85% concentrate consisting of 20% beet pulp and 80% barley. Roughage made up 15% of the diet and consisted of grass hay. Average daily gain was 1.5 kg.

Postweaning in 1984 the 12 female progeny were placed on a barley and grass hay ration and fed to gain .6 kg per head per day. In 1985 the 52 female progeny were placed in a nutrition study for 60 d. Three rations were fed and daily gains were small (.007 to .01 kg/d). Following the study the heifers were placed on growing rations of hay and corn or hay and distillers dried grains. Daily gains were 1.3 kg per head per day.

Progeny

One hundred sixty nine progeny were born (44 in 1984 and 125 in 1985) and the progeny data were analyzed to evaluate the sire selection index. Calving dates ranged from February 20 to March 11. The progeny were raised on pasture without creepfeed. The progeny produced at Red Bluff were included in growth implant studies in both 1984 and 1985. Preliminary analyses were performed to determine if adjustments were needed to correct weaning weight to a non implant basis.

<u>Preliminary Analysis of Weaning Weight of Calves Produced at Red Bluff</u>

The 115 calves produced at Red Bluff in 1984 included 22 progeny test calves. The 1984 calves from Red Bluff were randomly assigned to one of four growth implant treatments; negative control, 1/4 dose "Steer-oid"[1], 1/2 dose "Steeer-oid" and full dose "Steer-oid". Weaning weight of all 115 calves was analyzed by fixed model least-squares procedures (Harvey, 1977) to estimate the effect of growth implant treatment. Implant was a significant source of variation in weaning weight. Implant treatment means were tested by linear orthogonal contrasts. The full dose "Steer-oid" treatment differed significantly from the other three treatments and resulted in a 9.1 kg increase in weaning weight. Weaning weights of the five progeny receiving the full dose implant were corrected to a non implant basis by subtracting 9.1 kg. The analysis of variance for 1984 weaning weight and least-square means for implant treatment are presented in Tables 14 and 15.

[1] Anchor, 20 mg estridiol benzoate and 200 mg progesterone

Table 14. Least-squares analysis of variance for 1984 weaning weight at Red Bluff.

Source	df	Mean Square (kg^2)
Sex	1	70
Age of dam[a]	6	252**
Implant level	3	538**
Regressions:		
Birth weight	1	48
Age at weaning	1	2617**
Weight at implant	1	16548**
Remainder	101	117
R^2		.85

**P<.01

[a] age of dam groups were 3,4,5,6,7,12 and 13

Table 15. Least-squares means and standard errors for implant treatment at Red Bluff in 1984.

Treatment	Total no.	No. progeny test calves	Weaning weight (kg) ± standard error
Negative control	29	5	231.5 ± 2.1[a]
1/4 dose	28	7	230.5 ± 2.3[a]
1/2 dose	29	5	230.2 ± 2.3[a]
Full dose	29	5	239.8 ± 2.1[b]

[a,b] means with differing superscripts differ at the .01 level

The 1985 Red Bluff calf crop was randomly assigned to one of three growth implant treatments; 1/4 dose "Steer-oid", 1/2 dose "Steer-oid" and "Ralgro"[2]. Of the 124 calves, 52 were progeny test calves. Weaning weight of all

[2] International Minerals & Chemical Corporation, zeranol

124 calves was analyzed by fixed model least-squares procedures (Harvey, 1977) to estimate the effect of growth implant treatment. Implant treatment was not a significant source of variation in weaning weight. Analysis of variance of 1985 weaning weight and least-squares means are presented in Tables 16 and 17.

Table 16. Least-squares analysis of variance for 1985 weaning weight at Red Bluff.

Source	df	Mean squares (kg^2)
Sex	1	1360*
Age of dam[a]	5	924**
Implant level	2	.13
Fistula	1	2822**
Regressions:		
Birthweight	1	641
Age at weaning	1	5979**
Weight at implant	1	30324**
Remainder	111	241
R^2		.76

*P<.05
**P<.01
[a] age of dam groups were 3,4,5,6,7 and 8

In 1985, 16 dams of Red Bluff calves received rumen fistulae as part of a nutrition study. Ten fistulated dams produced progeny test calves. Seven of the eight test sires produced offspring from these dams. Fistulation treatment was included as an independent variable in the weaning weight analysis to estimate the effect of dam fistulation on calf weaning weights. Fistulation was a significant source of variation in weaning weight. Fistulation treatment means were tested by linear orthogonal contrasts. Offspring of fistulated dams weaned 15.1 kg heavier than offspring of intact dams.

Table 17. Least-squares means and standard errors for fistulation treatment at Red Bluff in 1985.

Treatment	Total no.	No. progeny test calves	Weaning weight (kg)
Fistulated dams	16	10	252.5 ± 4.2[a]
Intact dams	108	42	237.4 ± 1.6[b]

[a,b] means with differing superscripts differ at the .001 level

In a further analysis of all progeny calves (1984 progeny corrected for implant) weaning weight was analyzed by mixed model least-squares (SAS, 1982). Fistulated dams as a main effect was not significant. Therefore, weaning weights were not corrected for effect of dam fistulation. This analysis of variance is presented in Table 18.

Table 18. Least-squares analysis of variance for weaning weight of progeny calves at Red Bluff in 1984 and 1985.

Source	df	Mean squares (kg^2)
Group	1	1492
Sire/group	6	494
Sex	1	2427*
Year	1	16
Age of dam[a]	4	1249*
Fistula	1	67
Calving dificulty	3	862
Regressions:		
Gestation length	1	761
Birth weight	1	11805**
Day of birth	1	3761**
Remainder	133	416
R^2		.49

* P<.05
** P<.01
a age of dam groups were 2,3,4,5-10 and 11

<u>Preliminary Analysis of Weaning Weight of Progeny Calves Produced at Bozeman</u>

The Bozeman progeny were not implanted in 1984. In 1985 steer progeny at Bozeman were implanted twice with "Ralgro". A preliminary analysis was performed to determine if adjustments were needed to correct 1985 Bozeman weaning weights to a non implant basis.

Weaning weight of Bozeman calves for both years (20 progeny were produced in 1984 and 66 were produced in 1985) was analyzed by mixed model least-square procedures (Harvey, 1977). The two-way interaction of sex by year was fitted to estimate effect of 1985 implants on weaning weight. The sex by year interaction was not a significant source of variation. Therefore the difference between steer and heifer calves was not significantly different in 1984 and 1985. Steer progeny weaning weights for 1985 were not adjusted. Analysis of variance is presented in Table 19.

Table 19. Least-squares analysis of variance for weaning weight at Bozeman.

Source	df	Mean square (kg^2)
Year	1	1105
Sex	1	407
Group	1	180
Sire/group	6	870*
Sex x Year	1	54[a]
Regressions:		
Birthweight	1	4202**
Age at weaning	1	2304*
Remainder	71	377
R^2		.35

* $P<.05$
** $P<.01$
[a] $P=.71$

Statisical Analysis

The progeny calf data were pooled and analyzed by mixed model least-squares procedures, (Harvey, 1977). The basic model was as follows:

$$Y_{ijklm} = u + G_i + S_{j(i)} + Sx_k + Yr_l + AD_m + e_{ijklm}$$

where

Y_{ijklm} = an observation

u = the overall mean

G_i = the fixed effect of the ith sire group

$S_{j(i)}$ = the random effect of the jth sire within the ith sire group

Sx_k = the fixed effect of the kth sex

Yr_l = the fixed effect of the lth year

AD_m = the fixed effect of the mth age of dam

e_{ijklm} = random error.

Group of sire was tested for significance by the sire/group mean square term. All other effects were tested against the error term. The basic model was used to analyze gestation length. The other dependent variables analyzed were birth weight, calving difficulty, weaning weight, and yearling weight. Birth weight was analyzed by adding day of birth as a covariate to the basis model. Calving difficulty was analyzed by adding birth weight and gestation length to the basic model as a covariates. Weaning weight was analyzed by adding day of birth as a covariate to the basic model. Steer yearling weight was analyzed with age at yearling weight added as a covariate. Female yearling weight was analyzed within year. For females born in 1985 the two nutrition regimes were added as main effects.

Group of sire (group 1 = sires born in 1975 and 1976, group 2 = sires born in 1980 and 1981) was the independent variable of primary interest in these analyses. The other variables were fitted to account for known sources of variation and to allow better estimates of the effect of group of sire. Because of the small number of records all two-way interactions were assumed to be nonsignificant. Age of dam and location were completely confounded in these data since all 2-yr-old dams were located at Bozeman. The effect of age of dam and location can not be estimated separately. Therefore, location was omitted from the model.

Heritability (h^2) was estimated by the paternal half-sib procedure, (Falconer, 1981). Heritability was calculated as four times the sire variance component (half-sibs have one-fourth their sires' genes in common) divided by the sire variance component plus the environmental variance component

$$h^2 = \frac{4\,\sigma_s^2}{\sigma_s^2 + \sigma_e^2}.$$

Postweaning management varied greatly within and between years and sexes. Therefore, heritability was not estimated for yearling weight.

RESULTS AND DISCUSSION

Gestation Length

The mean gestation length was 281 d. The least-squares analysis of variance is presented in Table 20 and least-squares means are presented in table 21.

Table 20. Least-squares analysis of variance for gestation length.

Source	df	Mean square (d^2)
Group	1	50[a]
Sire/group	6	15
Sex of calf	1	74*
Year	1	112**
Age of dam	4	11
Remainder	155	15
R^2		.16

[a] P=.12
* P<.05
** P<.01

Sex of calf and year were significant sources of variation affecting gestation length. Male calf gestation length was 1.3 d greater than female calf gestation length. This agrees with the study of Bellows et al., (1971). Gestation length in 1984 was 1.9 d greater than in 1985.

Table 21. Least-squares means and standard errors for main effects affecting gestation length.

Effect	n	Mean ± SE (d)
Sex of calf		
Male	94	282.2 ± .8
Female	75	280.9 ± .8
Year		
1984	44	282.5 ± .8
1985	125	280.6 ± .8
Group		
1	88	281.0 ± .8
2	81	282.2 ± .8

Group of sire was not an important source of variation in gestation length. The least-squares mean for group 2 (sires born in 1981 and 1982) was 1.2 d greater than the least-squares mean for group 1 (sires born in 1975 and 1976). This suggests a positive genetic trend for gestation length. Dickerson et al. (1974) predicted that the selection index, I = Yearling Weight - 3.2 Birth Weight, would result in a shorter gestation period.

Birth Weight

The mean birth weight was 37.1 kg. Least-squares analysis of variance is presented in Table 22 and least-squares means are presented in Table 23.

Sex and age of dam were significant sources of variation in birth weight. Male birth weight was 2 kg greater than female birth weight. This agrees with

Woldehawariat et al. (1977). Age of dam means were confounded with location. The least-squares means for 2-yr-old dams at Bozeman cannot be compared with means for other age groups at Red Bluff. The age of dam effect for Red Bluff dams is in agreement with the study of Kress et al. (1979).

Table 22. Least-squares analysis of variance for birth weight.

Source	df	Mean square (kg^2)
Group	1	1[a]
Sire/group	6	186
Sex of calf	1	2271**
Year	1	421
Age of dam	4	554**
Regression:		
Day of birth	1	29
Remainder	154	129
R^2		.57

[a] P=.93
** P<.01

Group of sire was not an important source of variation in birth weight. The group 1 (sires born in 1975 and 1976) progeny were .5 kg heavier than group 2 (sires born in 1980 and 1981) progeny. This suggests a negative genetic trend for birth weight. Anderson et al., (1985) estimated the genetic trend for birth weight in the Havre Line 4 by the repeat mating method and found it to be negative.

Table 23. Least-squares means and standard errors for main effects affecting birth weight.

Effect	n	Mean ± SE (kg)
Sex of calf		
Male	94	37.6 ± .7
Female	75	35.6 ± .8
Age of dam		
2	94	36.3 ± .5
3	2	35.4 ± 2.4
4	11	38.3 ± 1.1
5-10	58	38.5 ± .5
11	4	34.3 ± 1.8
Group		
1	88	36.9 ± .7
2	81	36.4 ± .7

Calving Difficulty

Mean calving difficulty score was 1.2. Calving difficulty scores of 5 were not included in the analysis. The least-squares analysis of variance is presented in Table 24 and least-squares means are presented in Table 25.

Male progeny calving difficulty score was .2 units greater than female progeny calving difficulty score. This agrees with the study of Bellows et al., (1971). The age of dam means are confounded with location. The 2-yr-old dams at Bozeman did experience more calving difficulty than older dams at Red Bluff. This agrees with Laster et al., (1973).

Table 24. Least-squares analysis of variance for calving difficulty.

Source	df	Meansquare (score^2)
Group	1	.08[a]
Sire/group	6	.29
Sex of calf	1	1.47*
Year	1	.01
Age of dam	4	10.64**
Regressions		
Gestation length	1	.14
Birth weight	1	4.11
Remainder	148	.36
R^2		.48

[a] P=.62
* P<.05
** P<.01

Table 25. Least-squares means and standard errors for main effects affecting calving difficulty score.

Effect	n	Mean ± SE (score)
Sex of calf		
Male	93	1.3 ± .1
Female	71	1.1 ± .1
Age of dam		
2	92	2.0 ± .1
3	2	1.1 ± .4
4	10	.8 ± .2
5-10	56	.9 ± .1
11	4	1.1 ± .3
Group		
1	85	1.18 ± .2
2	79	1.22 ± .2

Birth weight was an important source of variation in calving difficulty score. The partial regression value in units per kg was .05. Each 1 kg increase on birth weight caused a .05 unit increase in calving difficulty score. This is in agreement with Bellows et al. (1971).

Group of sire was not a significant source of variation in calving difficulty score. Group 2 sires progeny calving difficulty score was .04 units greater than group 1 progeny calving difficulty score. This is not consistent with the trend for heavier birth weight in group 2 progeny.

Weaning Weight

The mean weaning weight was 250 kg. The least-squares analysis of variance is presented in Table 26 and least-squares means are presented in Table 27.

Sex of calf and age of dam were significant sources of variation in weaning weight. Male progeny were 13.4 kg heavier than female progeny. This agrees with Woldehawariat et al. (1977). Age of dam least squares means were 230.6. 251.1, 273.9, 255.2 and 241.5 kg for 2-yr-old, 3-yr-old, 4-yr-old, 5-10-yr-old and 11-yr-old and older dams, respectively. Because of confounding of age of dam and location the mean for 2-yr-olds cannot be compared with means for older dams. The progeny of 4-yr-old dams were the heaviest at weaning. Most studies (Woldehawariat et al., (1977) have found that 5 to 10-yr-old dams wean the heaviest calves. The different result in this study may be caused by sampling error because only 10 4-yr-old dams produced progeny.

Table 26. Least-squares analysis of variance for weaning weight.

Source	df	Mean square (kg^2)
Group	1	1259[a]
Sire/group	6	466
Sex of calf	1	6524*
Year	1	120
Age of dam	4	6485*
Regression:		
Day of birth	1	2499**
Remainder	144	499
R^2		.35

[a] P=.15
* P<.05
** P<.01

Day of birth was a significant source of variation in weaning weight. The partial regression coefficient was -.43 kg per d. Each 1 d increase in day of birth caused a .43 kg decrease in weaning weight. This agrees with the study of Anderson (1966).

Group of sire was not a significant source of variation in weaning weight. Group 2 (sires born in 1980 and 1981) progeny were 5.7 kg heavier at weaning than group 1 (sires born in 1975 and 1976) progeny. This suggests a positive genetic trend for weaning weight. Anderson et al., (1985) found a positive trend in the Havre Line 4.

Table 27. Least-squares means and standard errors for main effects affecting weaning weight.

Effect	n	Mean ± SE (kg)
Sex of calf		
Male	89	257.2 ± 4.7
Female	70	243.8 ± 5.1
Age of dam		
2	86	230.6 ± 2.9
3	2	251.1 ± 16.1
4	10	273.9 ± 7.7
5-10	58	255.2 ± 3.2
11	3	241.5 ± 13.4
Group		
1	84	247.6 ± 4.8
2	75	253.3 ± 5.0

Yearling Weight

Mean yearling weight of steer progeny was 372 kg. The least-squares analysis is presented in Table 28 and least-squares means are presented in table 29.

Age of dam was the only main effect significantly affecting yearling weight of steer progeny. Age of dam, location and postweaning management are confounded. Steer progeny from 3-yr-old and older dams at Red Bluff were fed out to slaughter. The yearling weight of Red Bluff progeny steers was 131.1 kg heavier than yearling weight of Bozeman progeny steers which were wintered on grass.

Table 28. Least-squares analysis of variance for steer yearling weight.

Source	df	Meansquare (kg^2)
Group	1	950[a]
Sire/group	6	809
Age of dam[b]	1	294286 **
Year	1	148
Regression:		
age at yearling weight	1	5170*
Remainder	74	1278
R^2		.81

[a] P=.39
[b] age of dam groups were 2 and 3-13
** P<.01
* P<.05

Table 29. Least-squares means and standard errors for main effects affecting yearling weight.

Effect	n	Mean ± SE (kg)
Age of dam		
2	43	307.6 ± 6.1
3-11	42	438.7 ± 6.3
Group		
1	42	369.6 ± 5.7
2	43	376.7 ± 6.4

Age at yearling weight was a significant source of variation in steer yearling weight. The partial regression value was .72 kg per d. Each 1 d increase in age at yearling weight caused a .72 kg increase in yearling weight.

Group of sires was not a significant source of variation in steer yearling weight. Yearling weight of group 2 progeny was 7.1 kg heavier than yearling weight of group 1 progeny. This suggests that the genetic trend for yearling weight is positive. This agrees with the study of Anderson et al. (1985).

Female progeny yearling weight was analyzed within year. Mean yearling weight was 338 kg in 1985 and 311 kg in 1986. Least-squares analyses of variance for the two years is presented in Tables 30 and 31 and group least-squares means are presented in Table 32.

Table 30. Least-squares analysis of variance for yearling weight of female progeny born in 1984.

Source	df	Mean square (kg^2)
Group	1	16
Sire/group	3	140
Age of dam[a]	2	1330
Regression:		
Age at yearling weight	1	1708
Remainder	4	1049
R^2		.49

[a] age of dam groups were 2 and 3-13

None of the main effects was a significant source of variation in yearing weight of females born in 1984. Yearling weight of group 1 female progeny was 3.5 kg heavier than yearling weight of group 2 progeny.

Table 31. Least-squares analysis of variance for yearling weight of female progeny born in 1985.

Source	df	Mean square (kg^2)
Group	1	40
Sire/group	6	75
Age of dam[a]	3	510
Nutrition trial 1	2	306
Nutrition trial 2	1	15679**
Regression:		
Age at yearling weight	1	33
Remainder	37	196
R^2		.76

[a] age of dam groups were 2,3,4 and 5-9
** $P<.01$

Table 32. Least-squares means for female yearling weight.

Year	n	Mean ± SE (kg)
1984		
Group 1	5	346.3 ± 29.1
Group 2	7	342.8 ± 16.7
1985		
Group 1	32	317.9 ± 5.6
Group 2	20	317.1 ± 6.2

The only significant source of variation in yearling weight of female progeny born in 1985 was the second nutrition trial. Yearling weight of group 1 female progeny were .8 kg heavier than group 2 female progeny. The small number of female progeny born in 1984 and the management differences of female progeny born in 1985 prevent meaningful sire group comparisons.

Heritability

Heritabilities for gestation length, birth weight, calving difficulty and weaning weight are presented in Table 33. The heritability estimates are much lower than those usually reported (Woldehawariat et al., 1977).

Table 33. Heritabilities of dependent variables.

Trait	$h^2 \pm SE$
Gestation length	.01 ± .11
Birth weight	.03 ± .12
Calving difficulty	-.04 ± .11
Weaning weight	.05 ± .15

Summary

The purpose of the selection index, I = Yearling Weight -3.2 Birth Weight, is to achieve an acceptable increase in yearling weight while minimizing the correlated increase in birth weight. The estimates of the genetic trends were -.2, 2.3 and 2.8 kg/yr for birthweight, weaning weight and yearling weight (steer progeny only), respectively. Anderson et al., (1985) found estimates of -.4 kg/yr, 3.2 kg/yr and 1.6 kg/yr for birth weight, weaning weight and yearling weight, respectively. Single trait selection for increased yearling weight has resulted in genetic trends of about 2.9 kg/yr with a correlated response in birth weight of about .3 kg/yr. The weighted average responses of this study and Anderson et al. (1985) are -.4, 2.7 and 1.8 kg/yr for birthweight, weaning weight and yearling weight, respectively.

Therefore, the selection index is very effective in minimizing the trend for larger birth weight but results in a smaller than expected response in yearling weight.

Table 34. Summary of response and correlated responses to selection for yearling weight (kg/yr).

	BW	WW	YW
Anderson et al. (1985)	-.4	3.2	1.6
Progeny test[a]	-.2	2.3	2.8
Weighted average of Anderson et al. (1985) and progeny test[b]	-.4	2.7	1.8
Average from literature[c]	.3	1.0	2.9
Expected response[d]	.3	1.8	3.6

BW = birth weight, WW = weaning weight and YW = yearling weight

[a] group 2 - group 1 means / 5 x 2

[b] weighted by number of observations

[c] uncorrected mean

[d] h^2 x selection intensity x phenotypic standard deviation, based on Woldehawariat et al. (1977)

LITERATURE CITED

LITERATURE CITED

Aaron, D. K., R.R. Frahm and D.S. Buchanan. 1986. Direct and correlated responses to selection for increased weaning or yearling weight in Angus cattle. II. Evaluation of response. J. Anim. Sci. 62:66.

Anderson, D. C. 1966. Some factors affecting performance in three closed lines of Hereford cattle. M.S. thesis. Montana State University., Bozeman, MT.

Anderson, D. C., D. D. Kress, D. E. Doornbos, K. J. Hanford and A. C. Linton. 1985. Genetic trend in beef cattle selected for greater yearling weight and moderate birth weight. 1985. Proc. West. Sec. Am. Soc. Anim. Sci. 36:43.

Barlow, Roger. 1979. Short term responses to selection for high and low yearling gain in Angus cattle. Selection Experiments in Laboratory and Domestic Animals. Commonwealth Agricultural Bureau. UK.

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.

BIF. 1981. Guidelines for uniform beef improvement programs. USDA Extension Service. Program Aid 1020.

Burfening. P. J. and D. D. Kress. 1973. Heterosis for most probable producing ability in Hereford cows. J. Anim. Sci. 36:7.

Burgess, J. B., N. L. Landblom and H. H. Stonaker. 1954. Weaning weights of Hereford calves as affected by in breeding, sex and age. J. Anim. Sci. 13:843.

Brinks, J. S., R. T. Clark and N. M. Kieffer. 1963. Sex differences in response to inbreeding in a line of Hereford cattle. Proc. West. Sec. An. Soc. Anim. Sci. 14:(V)1.

Brinks, J. S. , R. T. Clark and N. M. Kieffer. 1965. Evaluation of response to selection and inbreeding in a closed line of Hereford cattle. USDA. Tech. Bul. 1323.

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.

Brinks, J. S. and B. W. Knapp. 1975. Effects of inbreeding on performance traits of beef cattle in the western region. Tech. Bul. 123. Colorado State University.

Chevraux, D. J. and C. M. Bailey. 1977. Selection for postweaning growth rate in a closed line of Hereford cattle. J. Anim. Sci. 44:352.

Dalton, D. C. and R. L. Baker. 1979. Selection experiments with beef cattle and sheep. Selection Experiments in Laboratory and Domestic Animals. Commonwealth Agricultural Bureaux. UK.

Dickerson, G. E., Niklaus Kunzi, L. V. Cundiff, R. M. Koch, V. H. Arthaud and K. E. Gregory. 1974. Selection criteria for efficient beef production. J. Anim. Sci. 39:659.

Dinkel, C. A. , D. A. Busch, J. A. Minyard and W. R. Trevillyan. 1968. Effects of inbreeding on growth and conformation of beef cattle. J. Anim. Sci. 27:313.

Falconer, D. S. 1981. Introduction to Quantitative Genetics (2nd Ed.) Longman, London.

Flower, A. . J. S. Brinks, J.J. Urich and F.S. Wilson. 1964. Selectin intensities and time trends for performance traits in range Hereford cattle under mass and recurrent selection. J. Anim. Sci. 23:189

Frahm, R. R., C. G. Nichols and D. S. Buchanan. 1985. Selection for increased weaningoryearling weightin Hereford cattle. II.Direct and correlated responses. J. Anim. Sci. 60:1385.

Harvey, W.R. 1977. User's guide to LSML 76 mixed model least-squares and maximum likelihood computor program. Ohio State Univ., Columbus (Mimeo.).

Irgang, R., E. U. Dillard, M. W. Tess and O. W. Robison. 1984. Selection for weaning weight and postweaning gain in Hereford cattle. II. Response to selection. J. Anim. Sci. 60:1142.

Koch, R. M. 1951. Size of calves at weaning as a permanent characteristic of range Hereford cows. J. Anim. Sci. 10:768.

Koch, R. M., K. E. Gregory and L. V. Cundiff. 1974. Selection in beef cattle II. Selection Response. J. Anim. Sci. 39:459.

Koch, R. M., K. E. Gregory and L. V. Cundiff. 1982. Critical analysis of selection methods and experiments in beef cattle and consequences upon selection programs applied. Proc. 2nd World Congress on Genetics Applied to Livestock Production. Madrid, Spain.

Kress, D.D., P. J. Burfening, D. C. Anderson and R. L. Blackwell. 1979. Heterosis among closed lines of Hereford cattle. II. Preweaning growth and survival. J. Anim. Sci. 49:958.

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.

McCleery, N. B. and R. L. Blackwell. 1954. A study of the effect of mild inbreeding on weaning weight and grade of range calves. Proc. West. Sec. Am. Soc. Anim. Sci. 5:223.

Nelms, G. E. and P. O. Stratton. 1967. Selection practiced and phenotypic change in a closed line of beef cattle. J. Anim. Sci. 26:274.

Newman, J. A., G. W. Rahnefield and H. T. Fredeen. 1973. Selection intensity and response to selection for yearling weight in beef cattle. Can. J. Anim. Sci. 53:1.

Quaas, R. L. 1976. Computing the diagonal elements and inverse of a large numerator relationship matrix. Biometrics. 32:949.

Sutherland, T. M. and J. L. Lush. 1962. Effects of inbreeding on size and type of Holstein-Friesan cattle. J. Dairy. Sci. 45:390.

Swiger, L. A., K. E. Gregory, R. M. Koch and V. A. Arthaud. 1961. Effect of inbreeding on performance traits of beef cattle. J. Anim. Sci. 20:626.

Swiger, L. A., R. M. Koch, K. E. Gregory, V. H. Arthaud, W. W. Rowden and J. E. Ingalls. 1962. Evaluating pre-weaning growth of beef calves. J. Anim. Sci. 21:781.

Turner, M. E., 1985. The forage intake of supplemented cows grazing winter foothill rangelands of Montana. M. S. thesis. Montana State University, Bozeman, MT.

United States Department of Agriculture (USDA). Soil Conservation Service (SCS). 1976. Climax vegetation of Montana: based on soils and climate. USDA-SCS. Bozeman, MT.

United States Department of Commerce. 1982. Monthly normals of temperature, precipitation and heating and cooling degree days 1951-1980. Montana Climatology of the United States. No. 81 (by state).

Urick, J. J. 1958. Effect of age of cow, sex and calf of weaning weights of Hereford calves. M. S. thesis. Colorado State University, Ft. Collins, Colo.

Woldehawariat, G. M., M. A. Talamantes, R. R. Petty, Jr. and T. C. Cartwright. 1977. A summary of genetic and environmental statistics for growth and conformation characters of beef cattle. Texas Agr. Exp. Sta. Tech. Rep. 103.

Wright, Sewall. 1922. Coefficients of inbreeding and relationship. American Natural. 55:330.

MONTANA STATE UNIVERSITY LIBRARIES
3 1762 10013279 2

AMERICAN BINDERIES