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Experiment Station
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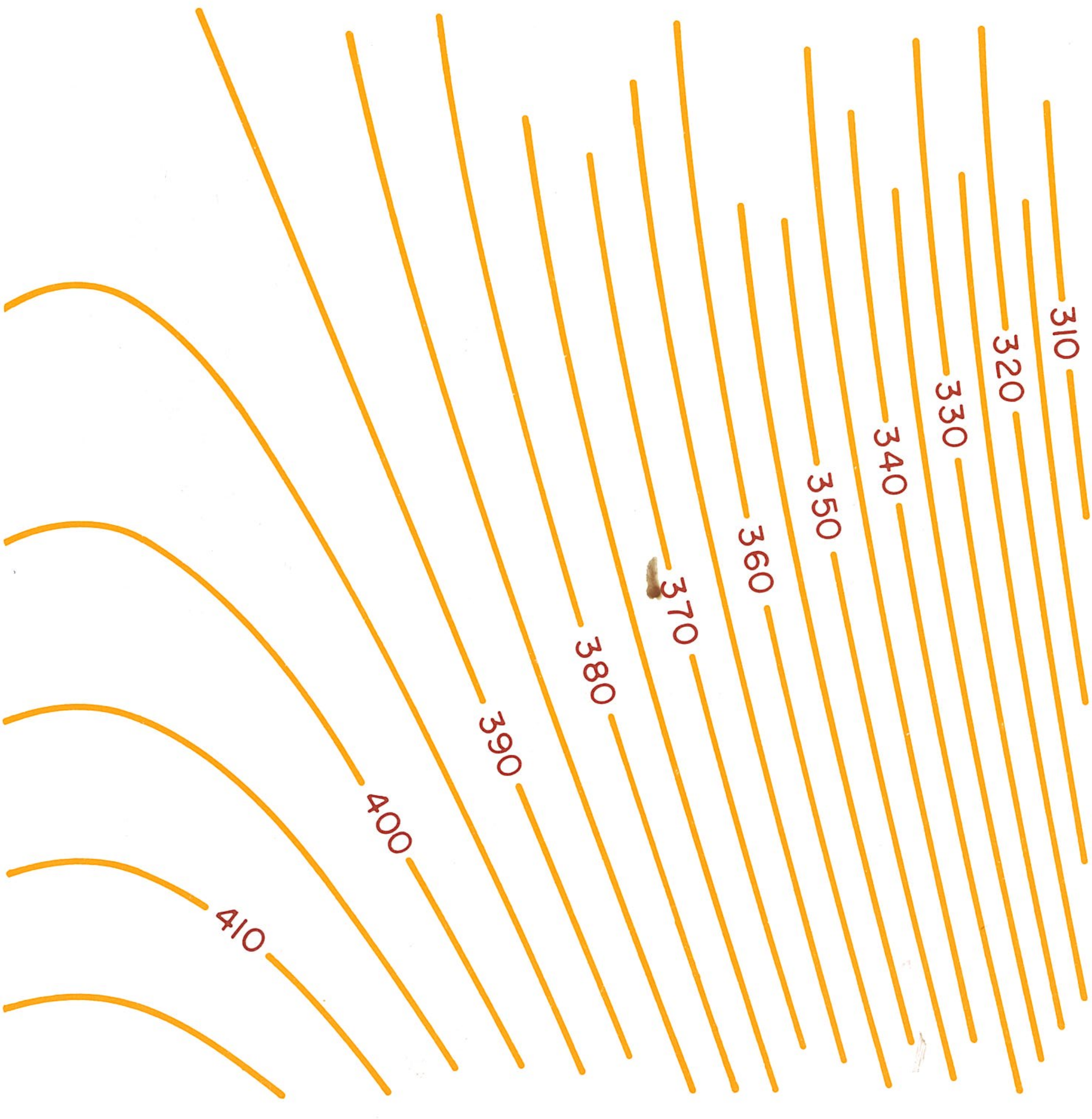
EFFECTS OF INBREEDING ON PERFORMANCE TRAITS OF BEEF CATTLE IN THE WESTERN REGION

Technical Bulletin 123



Authors: J. S. Brinks, Department of Animal Sciences, Colorado State University, Fort Collins; B. W. Knapp, statistician, United States Meat Animal Research Center, Clay Center, Nebraska. Both authors were formerly with the Western Regional Beef Cattle Breeding Project, W-1 and WRCC-1, ARS, USDA. Collaborators are from contributing stations to WRCC-1 and are listed under Research Personnel in this bulletin. G. V. Richardson is biometrician, ARS, USDA, Fort Collins, Colorado.

Cooperating Agencies: The Agricultural Experiment Stations of Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming; the Cooperative State Experiment Station Service, United States Department of Agriculture; and the Agricultural Research Service, United States Department of Agriculture.

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EFFECTS OF INBREEDING ON PERFORMANCE TRAITS OF BEEF CATTLE IN THE WESTERN REGION

J. S. Brinks and B. W. Knapp
In collaboration with
G. V. Richardson
C. B. Roubicek
W. C. Rollins
D. D. Kress
O. F. Pahnish
J. J. Urick
C. M. Bailey
L. A. Holland
R. Bogart
J. A. Bennett
G. E. Nelms

March 1975 5M

Following is a list of research personnel involved with the Western Regional Beef Cattle Breeding Project, W-1 and WRCC-1, since its initiation in 1946.

Research Personnel

Arizona
E. B. Stanley, O. F. Pahnish, C. B. Roubicek, D. E. Ray

California
H. R. Guilbert, P. W. Gregory, W. C. Rollins

Colorado
H. H. Stonaker, J. S. Brinks

Hawaii
O. M. Wayman, E. H. Cobb, D. Reimer

Idaho
C. F. Sierk, R. E. Christian

Montana
F. S. Willson, R. L. Blackwell, D. D. Kress

Nevada
J. F. Kidwell, C. M. Bailey

New Mexico
Marvin Koger, R. L. Blackwell, R. M. Durham, L. A. Holland, Bobby Rankin

Oregon
Ralph Bogart

Utah
J. A. Bennett

Washington
M. E. Ensminger, S. H. Fowler, W. Galgan, C. C. O'Mary

Wyoming
N. W. Hilston, C. B. Roubicek, P. O. Stratton, G. E. Nelms

Agricultural Research Service, USDA
R. T. Clark, C. E. Shelby, J. R. Quesenberry, R. R. Woodward, J. S. Brinks, O. F. Pahnish, B. W. Knapp, G. V. Richardson, N. M. Kieffer, J. J. Urick

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Introduction

The development of inbred lines has received much emphasis in the beef cattle breeding research programs of several western states participating in the Western Regional Project, W-1. Many of these lines were actually begun in the early 1930's and 1940's before the initiation of the W-1 project. The cattle in these closed lines have been selected on performance of economically important traits. The rate of inbreeding among the lines has varied with the station's breeding scheme and the number of animals per line. The increase in inbreeding was held to a minimum in several lines by consciously avoiding close matings. In other lines, inbreeding levels were increased as rapidly as possible. Several lines were discontinued during the period studied for a variety of reasons, but most lines are still in existence.

Inbreeding results from the mating together of individuals that are more closely related than the average relationship in the population to which they belong. The measure of the degree of inbreeding is the coefficient of inbreeding that was derived by Wright (1921) as the correlation between uniting gametes. 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 or population. A consequence of the inbreeding process is that increased homozygosity has generally been associated with a decline in performance in traits associated with general vigor such as reproduction, survival, and growth rate.

The objective of this cooperative study is to describe the effects of inbreeding on various fitness and growth traits. To accomplish this objective, both pooled analyses over all lines and separate analyses by line or by line and sex are used. In addition, both linear and curvilinear effects of inbreeding are examined.

Review of Literature

There is much literature on the effects of inbreeding in both domestic and natural populations. However, only literature on the effects of inbreeding in cattle (primarily beef cattle) is reviewed herein. Early studies before Rollins *et al.* (1949) are not reviewed in most instances. Also, the reader is referred to Dickerson (1972) for a review of both inbreeding and heterosis effects in many species.

Reproduction and Survival

A general phenomenon in mammalian and many other species is that increased inbreeding is associated with a corresponding decrease in fitness in the population (Falconer, 1960). This phenomenon is substantiated by observational data and experimental results. Lower fertility or conception rates and higher pre- and postnatal mortality of individuals are associated, in general, with increases in inbreeding. A brief review of studies relating to this phenomenon in cattle follows.

An increased number of services per conception and greater mortality for inbred calves (15 percent) compared to outbreds (10 percent) was reported by Woodward and Graves (1946) working with Holstein cattle. Regan, Mead, and Gregory (1947) studied abortions, stillbirths, and mortality to 4 months of age in Jersey and Holstein cattle over a range of inbreeding of 0 to 45 percent. Increased inbreeding had no effect on abortions. There was a slight increase in stillbirths and, with increased inbreeding, a rise in the mortality of calves born alive. However, the percentage of mortality varied among inbred progeny of different sires.

Mares *et al.* (1958) studies conception rate and pregnancy loss in parous Holstein cows. Of 513 first inseminations, 58.3 percent resulted in conception, with inbred inseminations of inbred dams averaging 36.8 percent compared with 65.7 percent for outbred matings. Pregnancy loss was 27.4 percent for inbred embryos of inbred dams, 26.0 percent for outbred embryos of inbred dams, 12.9 percent for inbred embryos of outbred dams, and 13.7 percent for outbred embryos of outbred dams. Conneally *et al.* (1963) also reported that inbreeding of the zygote (0-46 percent) and dam (0-40 percent) had a significant deleterious effect on embryonic mortality in dairy cattle.

Stonaker (1954), working with Hereford cattle, reported that outbred matings exceeded inbred matings by 30 percent in number of calves raised to weaning when calves were approximately 30 percent inbred and dams 20 percent inbred. Working with Hereford cattle under range conditions, Rice *et al.* (1961) reported the percentage of cows calving by inbreeding level. There was little difference in calving percentage between cows not inbred and those having less than 10 percent inbreeding. Higher levels of inbreeding, however, were associated with a marked decline in percentage of calf crop born. Davenport *et al.* (1965) reported that inbreeding had a marked effect on percentage of calf crop when all ages of dams were studied. After records of 2-year-old dams were removed, there was no significant difference between inbred and linecross cows; thus, inbreeding effects were more pronounced in younger cows.

On the male side, McNitt (1965) reported that higher levels of inbreeding increased the difference between inbred and linecross means for overall classification, vigor score, percentage alive, and morphology of semen in yearling Hereford bulls. This was in agreement with an earlier study by Harris, Faulkner, and Stonaker (1960). Some lines were affected by increased inbreeding to a larger extent than others.

The literature indicates that increased inbreeding is detrimental to conception rate, embryo loss, and calf loss to weaning, but that variability in response exists among lines.

Milk Production

In beef cattle, variation in milk production among cows has been shown to be the greatest single source of variation in weaning weight of calves. The effect of increased inbreeding of dam on weaning weight of beef calves is reviewed in a subsequent section. A few of the more recent studies on the effect of inbreeding on milk production of dairy cattle follow.

Tyler, Chapman, and Dickerson (1949) reported that increased inbreeding caused a decline in milk production and butterfat in Holstein cattle. However, considerable variation was obtained in the partial regression coefficients of production on inbreeding by sires, indicating that offspring of some sires could be inbred without an apparent decrease in production. Robertson (1954) reported on the effect of inbreeding in 80 heifers resulting from sire-daughter matings in British Friesians. There was no effect on age at first calving or fat percentage, but the effect on yield of 74±24 gallons or a decline of 0.32 percent for each percentage of increase in inbreeding was significant.

Laben *et al.* (1955), working with Holsteins, reported that inbreeding caused a decline in total milk production but did not appear to have an effect on the shape of the lactation curve. There was some evidence that inbreeding had a lesser effect on production in ranges up to 20 percent than in ranges above 25 percent. Von Krosigk and Lush (1958) studied Holsteins that ranged from 0 to 34 percent in inbreeding and averaged 7.4 percent. Milk production decreased 54±17 pounds for each 1 percent increase in inbreeding. Inbreeding affected production mainly through channels other than reducing general size.

Growth Traits

Inbreeding of Calf

Several studies in dairy cattle on the effect of increased inbreeding on growth traits have been reported. Bartlett, Reece, and Lepard (1942) reported that birth weight and size at 5, 10, and 16 months were not significantly different for inbred and outbred heifers in Holsteins. Tyler, Dickerson, and Chapman (1946) reported a regression of birth weight on inbreeding of 0.28 pound per 1 percent inbreeding and that the regressions on inbreeding of height at withers, circumference of bone, heart girth, and width at hips at 6 months and maturity were nonsignificant. Rollins *et al.* (1949), working with weights, heights, and heart girths in Jerseys, reported that increased inbreeding caused a linear decrease in measurements at birth and up to 6 months of age. From 6 to 56 months, inbreds grew more rapidly than outcrosses. Nelson and Lush (1950) reported that birth weight decreased 0.12 pound per percent (lb./%) inbreeding in Holsteins. Apparently, inbreeding slowed rate of growth at early ages but permitted rapid growth to continue longer so that mature size was not decreased, but may even have been increased. Sutherland and Lush (1962), working with the same herd, reported a decrease of -.2 lb./% inbreeding in birth weight. The effect of inbreeding was maximum at 3 years old and diminished at later ages. Foote, Tyler, and Casida (1959) reported a partial regression of birth weight on inbreeding of -6.534 lb./% inbreeding in Holsteins.

Several researchers have reported on the effect of inbreeding on birth weight in beef cattle. Regressions of birth weight on inbreeding of calf in pounds per percent of inbreeding include: -.38 and -.06 (Swiger *et al.* 1961); -.19 (Swiger *et al.* 1962); -.015 (Nelms and Stratton, 1967); and -.13 in males and -.40 in females (Brinks, Clark, and Kieffer, 1965). Alexander and Bogart (1959) reported no significant effect of inbreeding on birth weight in beef cattle.

All literature reviewed indicates a sizeable detrimental effect of inbreeding of calf on suckling gain and weaning weights. Some regression or partial regression values of weaning weights on inbreeding of calf in pounds per percent of inbreeding include: -.48 (Koch, 1951); -1.19 (McCleery and Blackwell, 1954); -1.76 (Burgess, Landblom, and Stonaker, 1954); -.465 (Nelms and Stratton, 1967); -1.38 (Nelms and Stratton, 1964); -1.42 and -.05 in two herds (Swiger *et al.* 1961); -.70 (Swiger *et al.* 1962); -2.11 in females and -.59 in males (Brinks, Clark, and Kieffer, 1963); and -1.35 in males and -.80 in females (Dinkel *et al.* 1968). Alexander and Bogart (1959) reported significant inbreeding effects on suckling gains and age at 300 pounds.

There have been fewer studies reported on the effects of inbreeding on postweaning growth traits. Moore, Stonaker, and Riddle (1961) reported correlations of daily gain and initial weight of bulls with inbreeding values of -.18 and -.30, respectively. Stonaker (1954) observed that outbred bulls exceeded inbreds by 7 percent in final weight and 3 percent in daily gain, but 3 percent more feed per pound of gain was required. A regression value of -2.17 lb./% inbreeding in final weight of bulls was reported by Nelms and Stratton (1964), but there was no inbreeding effect on rate of gain during the test. Alexander and Bogart (1959) also reported no effect of inbreeding on rate and economy of gain in postweaning performance. Brinks *et al.* (1965) reported regression values of -1.67 and -2.30 lb./% inbreeding for 196-day gain and final weights off test in bulls. They also reported detrimental inbreeding effects for weights and gain from weaning to 18 months old in heifers and for measures of mature cow weights. Dinkel *et al.* (1968) reported significant detrimental effects of inbreeding on final weight and negative but nonsignificant effects on daily gain. Bailey *et al.* (1971) reported regression values of -.145 and -.221 lb./% inbreeding for postweaning gain.

Thus, increased inbreeding of the animal is associated with lowered growth, especially during the suckling period and early life of the calf. Smaller detrimental inbreeding effects are apparent in birth weight and in postweaning growth.

Inbreeding of Dam

Inbreeding of dam of the calf may affect calf performance through the pre- and postnatal maternal environment she provides. Regression coefficients of birth weight in pounds per percent of inbreeding of dam in Holsteins of -.10 and 0.14 have been reported by Nelson and Lush (1950) and Foote, Tyler, and Casida (1959), respectively. In beef cattle, Swiger *et al.* (1961) reported small regression coefficients of -.03 and 0.13 in two herds and Swiger *et al.* (1962) also reported slightly positive regression values of 0.009 and 0.096 in male and female birth weights, respectively. Nelms and Stratton (1967) observed no effect of inbreeding of dam on birth weight of calves. Thus, inbreeding of dam appears to be negligible in affecting calf birth weights.

Several workers have studied the effect of inbreeding of dam on suckling gains and weaning weight of the calf. Researchers reporting fairly large detrimental effects of inbreeding of dam include: Koch (1951) with a regression value in pounds per percent inbreeding of -2.54; Burgess, Landblom, and Stonaker (1954), -1.15; Brinks *et al.* (1965), -1.88 in males and -.33 in females; and Dinkel *et al.* (1968), -.51 in males and -1.50 in females. Those reporting smaller effects include: Swiger *et al.* (1961) with values of -.15 and 0.04 in two herds and Swiger *et al.* (1962), -.22. McCleery and Blackwell (1954) reported a positive regression of 0.95 and Nelms and Stratton (1964) reported that inbreeding of dam had no effect on weaning weight of calves. Thus, whereas the majority of studies indicate sizeable detrimental effects associated with increased inbreeding of dam, several report little or no effect or in some cases a positive effect. All these indicate variability in response by line of breeding.

There is less information on the effect of inbreeding of dam on postweaning growth of bulls and heifers. However, a few studies indicate no sizeable effect on postweaning daily gain (Nelms and Stratton, 1967; Swiger *et al.* 1961) and some indicate positive regression values (Brinks *et al.* 1965; Dinkel *et al.* 1968); these values indicate a compensatory effect for a poor preweaning environment.

Inbreeding of dam apparently has little effect on birth weight of calves, but has a sizeable detrimental effect on suckling gains and weaning weights followed by little or possibly compensatory gains of calves in the postweaning phase of growth.

Source and Description of Data

The data used in this study were obtained from 48 inbred lines of registered beef cattle developed at 10 separate experiment stations in 8 of the 12 western states contributing to the W-1 Regional Beef Cattle Breeding Project.

Station Description

Data describing the 10 stations involved in the study are presented in Table 1. Information on location, altitude, precipitation, temperature, types of pastures, and stocking rates is presented.

A wide variety of environments exists among stations ranging from lush, irrigated pastures (California; Reno, Nevada; New Mexico; Oregon; and Utah) to dry rolling plains and broken badlands (Miles City, Montana; Knoll Creek, Nevada; and Wyoming) to fairly high native mountain country (Colorado; and Havre, Montana). Stocking rates varied greatly depending on the type of pastures and species of grasses or legumes. A wide range in altitudes exists from 50 feet in California to 7,600 feet in Colorado. The amount of precipitation and average January and July temperatures also varied greatly among stations.

Wide variations also existed in precipitation and temperature within stations among years. The Miles City, Montana, and Wyoming stations have varied in temperatures from a high of 105° F in the summer to -50° F in winter. Other information on variability of environmental effects among and within stations can be observed by studying Table 1.

Cattle Breeding and Management Practices by Station

Information on the breeding season, along with weaning and postweaning cattle rearing practices by station, is presented in Table 2.

The breeding season varied from 45 days at Miles City, Montana, and Wyoming to year around breeding at New Mexico and in the early years at California. All stations except New Mexico and California had specific breeding seasons of 90 days or fewer beginning in the spring and lasting to mid or late summer. Since 1953, California has had a specific breeding season of 60 days in the spring of the year.

Depending on the breeding season practices, most stations weaned the calves on a near date constant basis each year. In the early years of the study, New Mexico and California weaned calves at a nearly constant age (year-long); calves averaged 246 and 240 days old, respectively. The Oregon station weaned calves on a constant weight basis; calves were weaned when they reached 425 to 450 pounds, with an October 15 cutoff date. In later years (1963 and 1964), heifer calves were weaned when they reached 375 to 400 pounds, and bull calves when they reached 425 to 450 pounds. The Utah station weaned calves at nearly an age constant value, from 1947 through 1952; the average weaning age was 205 days. Since 1953, all calves have been weaned on the same date within years. The average age at weaning ranged from 180 days at Wyoming to 246 days at New Mexico.

All stations placed bull calves on a performance test after weaning; most of these tests were for a constant time period. The length of test ranged from 140 days at Colorado, Nevada (both stations), and New Mexico to the longest test of 196 days at Miles City, Montana. Stations performance testing bulls for 168 days included Wyoming; Havre, Montana; and Utah in the early years. The warmup period between weaning and being placed on test was 2 to 4 weeks, in most cases; however, New Mexico had a 2-month warmup period. Most stations weighed calves every 28 days during the test. Bull calves were individually fed at all stations except Wyoming in the later years (since 1958) to obtain individual feed consumption and feed efficiency values. The Oregon station individually fed calves for a gain constant period; calves were required to gain 300 pounds up to 1962, and 350 pounds since 1963. Utah also fed bulls for a gain constant period of 300 pounds since 1952. Although the feed materials in the rations varied greatly among stations, most rations were between 55 and 70 percent total digestible nutrients (TDN). California did not have postweaning data available for the study.

Some stations performance tested heifer calves after weaning using procedures similar to those for bull testing. These stations included Oregon, Nevada (both stations), and Wyoming. Other stations grew out heifers on a low concentrate ration; periodic weighing ranged from every 28 days at Havre, Montana, to every 6 months at Colorado and Miles City, Montana. The Utah station weighed heifer calves on about January 15 and April 15 the first year and on about

January 15 each succeeding year. New Mexico did not obtain weights on females after weaning.

Age at first calving was 2 years at all stations except California, Miles City, and Nevada (both stations), where the first calving was at 3 years old.

Selection and Culling Practices by Station

The selection and culling practices by stations are described in Table 3. Although selection criteria for bulls differed among stations, most criteria emphasized growth traits to a year of age and physical soundness. The Colorado and Oregon stations used a selection index; Colorado's index was based on weaning weight and performance test daily gain and Oregon's on equal emphasis to preweaning gain, performance test gain, feed efficiency, and conformation score at the end of the performance test. Adjusted or unadjusted final weight off test or weight per day of age at the end of the test was used by California; Havre and Miles City, Montana; Utah; and Wyoming. The New Mexico station used weaning weight and pedigree selection for absence of genetic defects. At the Reno, Nevada station selection was for performance test gain in Line 1, gain per 100 units TDN in Line 2, and conformation score at end of test in Line 3. Performance test gain in Line 4 and gain per 100 units TDN in Line 5 were used at the Knoll Creek location.

All bull calves were performance tested with no previous selection being practiced at any station except at California before 1953 and Miles City, Montana before 1963; New Mexico; Havre, Montana; and Utah.

The criteria for heifer selection differed among stations. The Nevada, Oregon, and Wyoming stations used the same testing and selection practices for heifers as that described for bulls. Weight at 12 or 18 months or weight per day of age was used by California; Havre and Miles City, Montana; and Utah. The Colorado station selected approximately the oldest 40 percent at weaning for heifer replacements. The percentage of the heifers entering the breeding herd varied from 25 at Colorado to 85 at Havre and Miles City, Montana, and 100 in the New Mexico "old" line.

Table 1. Station Description

Station location	Altitude (feet)	Precipitation (in) Average	Precipitation (in) Range	Temperature (°F) January	Temperature (°F) July	Pastures Type	Pastures Species	Pastures Stocking rate (Acres/cow)	Pastures Grazing months
Davis, California	50	16	29 (1958) 11 (1959)	45°	75°	Irrigated, improved	Alfala, fescue	.5-1	8
Hesperus, Colorado	7,600	19	31 (1957) 10 (1956)	23°	64°	Native mountain	Shortgrass, midgrass, browse, wheatgrass, oakbrush	20	6.5
Havre, Montana	5,000	20	30 (1964) 13 (1961)	14°	60°	Native mountain	Mountain brome, fescue, wheatgrasses, needlegrass, pinegrass, bluegrass, forbes	20	5.5
Miles City, Montana	2,200	13	19 (1944) 6 (1934)	15°	73°	Plains, broken badlands	Shortgrass, midgrass, browse grama, wheatgrass	31	9
Reno, Nevada	4,400	8	11 (1963) 5 (1961)	31°	69°	Irrigated, improved	Tall fescue, legume, bluegrass	1-2	7
Knoll Creek, Nevada	6,000	10	14 (1963) 7 (1958)	26°	69°	Mountain	Sagebrush, native grass	40	6
Las Cruces, New Mexico	3,900	8	20 (1941) 4 (1964)	41°	80°	Irrigated, improved	Alfalfa, ryegrass		
Corvallis, Oregon	250	40	46 (1961) 33 (1959)	39°	63°	Irrigated, non-irrigated, improved	Subterranean and Ladino clover, orchardgrass alta fescue	2-8	7-8
Logan, Utah		16	20 (1955) 11 (1966)	24°	73°	Irrigated, improved	Orchardgrass, brome, alfalfa, bluegrass, white Dutch clover	1	7
Gillette, Wyoming	4,545	14	22 (1964) 11 (1958)	22°	72°	Rolling plains	Wheatgrasses, blue grama	15	7-8

At all stations, cows were removed from the herd for poor reproduction or physical unsoundness. Some selection pressure was applied to weaning weights of the cow's calves at the California; Havre and Miles City, Montana; Oregon; and Utah stations. Cows were culled at the Miles City station after they reached 10 years of age.

Origin and History of Lines

Information on the origin and history of the lines as to breed, name, year established, number of foundation females and sires, along with a listing of the sires, is presented in Table 4. All of the lines except one Angus (Oregon) and one Shorthorn (Utah) were either Hereford or Polled Hereford cattle. A wide variety in genetic background of the Hereford lines is evident.

Very few foundation sires were used per line in establishing the lines; 32 of the 48 lines were established with one foundation sire. Only two lines (Lines 11 and 14) had more than three foundation sires, and these were developed at the U.S. Range Livestock Experiment Station from other existing inbred lines. The number of foundation cows varied with station and line. Most lines were established with 20 to 35 cows. A notable exception was the Colorado station where most of the 14 lines were established with only six to eight cows per line. Oregon also established two lines (Lines 2 and 3) with only eight cows per line. The other 32 lines were established with 10 or more foundation cows.

Of the original 48 lines that were developed, 27 are still in existence. Twelve lines were discontinued for low performance, genetic abnormalities, or both, in combination with

Table 2. Breeding and Management Practices by Station

Station location	Breeding season (days)		Weaning practices			Postweaning Practices: Bulls			Heifers
	Dates	Length	Type[1]	Dates	Average age (days)	Type of test[2]	Length of test (days)	Type feed	Age at 1st calve (yr)
Davis, California	1944-52, 1953-59, 3/1-4/30	365 60	age date	year-long 10/1-10/31	240	--	--	individual	3
Hesperus, Colorado	6/1-9/1	90	date	10/25-11/5	200	time	140	individual	2
Havre, Montana	6/5-8/5	60	date	10/7-10/28	195	time	168	individual	2
Miles City, Montana	7/1-8/15 to 1945, 6/15-8/1 since 1946	45	date	10/15-10/25	185	time	196	individual	3
Reno, Nevada	5/20-8/5	75	date	11/1-11/30	237	time	140	individual	3
Knoll Creek, Nevada	6/15-9/15 in 1955-61, 6/1 - 8/15 since '61	75-90	date	12/1-12/31 - 1960, 11/1 - 11/30 since	232	time	140	individual	3
Las Cruces, New Mexico	1932-'64	365	age	year-long	246	time	140	individual	2
Corvallis, Oregon	6/1-8/5 or 9/1	65-90	weight[3]	10/15	190	weight	300 lb. to 1963; 350 lb. since	individual	2
Logan, Utah	5/15-8/15	90	1947-52, age; date since 1953	10/15-10/28	205	time 1947-52; weight 1953-'64	168 300 lb.	individual	2
Gillette, Wyoming	5/20-7/20	45-60	date	9/15-10/1	180	time	168	individual to 1958; group 1959-'64	2

[1]Approximate date, age, or weight constant weaning practiced.

[2]Time or weight gain constant performance test.

[3]425 to 450 pounds or October 15 through 1962. 1963 and 1964, female at 375 to 400, male at 425 to 450.

Table 3. Selection and Culling Practices by Station

Station location	Selection Practices: Males: Criteria for bull selection	Males: Percent culled before completion of performance test	Females: Criteria for heifer selection	Females: Percent culled at weaning	Females: Percent heifers entering herd	Females: Criteria for cow culling
Davis, California	Weight for age, conformation, physical soundness	14	12 to 18 month weight	1	71	Open twice consecutively, weaning weight of calves, soundness
Hesperus, Colorado	Individual adjusted weaning weight + 50 (ADG) / Average adjusted weaning weight + 50 (ADG), physical soundness, semen quality	0	Weaning age	60	25	Open, soundness
Havre, Montana	365 day weight, physical soundness conformation	10	Adjusted 18 month weight	5	85	Weight of 1st calf, open, calf weight, soundness
Miles City, Montana	Adjusted final weight off test [Adjusted weaning weight + 196 (ADG)] physical soundness	50 percent through 1963; 0 since 1964	Adjusted 18 month weight	0	85	Open twice, cow age (10 years), calf weight, soundness
Reno, Nevada	Line 1-test gain Line 2-gain/100 units TDN Line 3-conformation score	0	Line 1-test gain; line 2-gain/100 units TDN; Line 3-conformation score	0	50	Open twice, soundness
Knoll Creek, Nevada	Line 4-test gain Line 5-gain/100 units TDN	0	Line 4-test gain; line 5-gain/100 units TDN	0	50	Open twice, soundness
Las Cruces, New Mexico	Weaning weight, freedom of dam of genetic defects. Pedigree selection in "outcross" line for hydrocephalus		Old line-reproduction outcross line-pedigree, weaning weight, conformation	0	100	Failure to conceive after 3 matings, soundness
Corvallis, Oregon	Index[1], physical soundness	0	Index[1]	0	40	Open once except for 2 year olds, weaning weights of calves, soundness
Logan, Utah	Weight/day of age off test, physical soundness, conformation	50	Weight for age at 12 months, conformation	10	25	Open twice, weaning weight of calves, soundness
Gillette, Wyoming	Unadjusted final weight off test, physical soundness	0	Unadjusted final weight off test	0	60	Open, soundness

[1]Equal weight to suckling gain, performance test gain, performance test feed efficiency and performance test conformation score.

Table 4. Origin and History of Lines

Station	Breed	Line	Year Established Closed Termination	Number foundation females	Number foundation males	Name foundation males	Reason for disposal
California	Hereford	Rover	1944 1950	30	1	California Rover 2nd	Experiment completed
Colorado	Polled Hereford	Animas	1952 1952 1960	8	1	President Mischief	Lower production and lack of facilities
Colorado	Polled Hereford	Bonanza	1950 1950 1963	7	1	Numode 2	Dwarfism
Colorado	Hereford	Brae Arden	1946 1926[1]	6	1	Brae Carlos 14th	Continuing
Colorado	Hereford	Colorado	1947 1947	18	1	CSC Dominator 6th	Continuing
Colorado	Hereford	Don	1948 1948	6	1	OXO Roque Domino 401	Continuing
Colorado	Hereford	Ft. Lewis	1946 1946 1956	15	1	Forest Domino	Lower production and lack of facilities
Colorado	Hereford	La Plata	1946 1946 1956	7	1	Baca R Domino 41	Lower production and lack of facilities
Colorado	Hereford	Mesa	1947 1947 1954	12	1	Hiwan Prince C 58	Lower production, compress and dwarfism
Colorado	Hereford	Monarch	1952 1952	6	1	Plus Blanchard 28	Continuing
Colorado	Hereford	Prospector	1947 1947	18	1	Bonvue Prince 17	Continuing
Colorado	Hereford	Royal	1946 1946	34	1	College Royal Dom 3	Continuing
Colorado	Hereford	San Juan	1946 1946	9	1	WHR Flash 74	Continuing
Colorado	Hereford	Tarrington	1955 1955	6	1	Tarrington Onward	Continuing
Colorado	Hereford	Real Prince	1952 1952 1967	8	1	Real Prince 36th	Lower production and lack of facilities
Havre, Montana	Polled Hereford	Line 1	1946 1946	27	2	H.D. Domino 22, King Domino 84	Experiment completed
Havre, Montana	Hereford	Line 2	1947 1947 1972	22	1	Advance Lincoln 28	Experiment completed
Havre, Montana	Hereford	Line 3	1948 1948 1970	25	1	S.S. Flashy Mixer 19th	Experiment completed

[1]Line was closed by private breeder in 1926.

Table 4. Origin and History of Lines (continued)

Station	Breed	Line	Year Established Closed Termination	Number foundation females	Number foundation males	Name foundation males	Reason for disposal
Havre, Montana	Hereford	Line 4[2]	1937 1934 1970	22	2	Advance Domino 20th, Advance Domino 54th	Experiment completed
Miles City, Montana	Hereford	Line 1	1934 1934	40	2	Advance Domino 20th, Advance Domino 54th	Continuing
Miles City, Montana	Hereford	Line 2	1935 1935 1952	30	1	Dandy Domino 113	Chronic bloat in feedlot
Miles City, Montana	Hereford	Line 3	1938 1938 1946	30	2	Advance Mixer 2, Double Mixer 8	Low weaning weights; some bloat
Miles City, Montana	Hereford	Line 4	1946 1946	27	1	Husker Mischief 976th	Continuing
Miles City, Montana	Hereford	Line 5	1946 1947 1960	47	1	Young Mischief 595	Low weaning weights
Miles City, Montana	Hereford	Line 6	1948 1948	30	2	Perfect Lad 18, Maude's Mischief 19	Continuing
Miles City, Montana	Hereford	Line 7	1948 1948 1953	30	1	Trailblazer 48	Low weaning weights and low feedlot performance
Miles City, Montana	Hereford	Line 8	1949 1949 1957	20	1	Milton Choice	Low weaning weights
Miles City, Montana	Polled Hereford	Line 9	1950 1950	28	1	Seth Domino	Experiment completed
Miles City, Montana	Hereford	Line 10	1948 1949	27	1	HB Lincoln, Domino 51	Continuing
Miles City, Montana	Hereford	Line 11	1948 1960 1965	18	8	(5 Line 1 Sires) (3 Line 5 Sires)	Hydrocephalic calves
Miles City, Montana	Hereford	Line 12	1951 1954	16	2	L1 Domino 160 (10 x 1) L1 Domino 267	Continuing
Miles City, Montana	Hereford	Line 13	1953 1953 1956	20	1	Bonnie Brae 2	Low weaning weights and low fertility
Miles City, Montana	Hereford	Line 14	1955 1958	64	8	Line 1,4,5,9, 10 and 13 Sires	Continuing
Reno, Nevada	Hereford	Line 1	1955 1957	27	3	LL Mischief Mixer 31, UN Mischief Mixer 6, UN Mischief Mixer 14	Continuing

[2]This is Line 1 Miles City breeding.

Table 4. Origin and History of Lines (continued)

Station	Breed	Line	Year Established Closed Termination	Number foundation females	Number foundation males	Name foundation males	Reason for disposal
Reno, Nevada	Hereford	Line 2	1955 1957	32	3	FHD Domino Prince 15, UN Pioneer Chief 5, UN Domino Prince 12	Continuing
Reno, Nevada	Hereford	Line 3	1955 1957 1970	32	3	Chief Pioneer 104, Diamond Duke, UN Pioneer Chief 12	Experiment completed
Knoll Creek, Nevada	Hereford	Line 4	1955 1957 1970	25	3	Chief Pioneer 103, UN Pioneer Chief 4, KC Mixer 3	Experiment completed
Knoll Creek, Nevada	Hereford	Line 5	1955 1957 1970	30	3	UN Royal Domino 3, UN Mischief Mixer 7, KC Domino 1	Experiment completed
New Mexico	Hereford	"Old"	1932 1932	10	1	Timberline 52	Continuing
New Mexico	Hereford	"Outcross"	1940 1940		1	Dandy Domino 90	Continuing
Oregon	Hereford	Line 1	1948 1950 1962	14	2	Court Lionheart 29, Court Real Lionheart 5-F	Linecrossing initiated
Oregon	Hereford	Line 2	1947 1948 1962	8	1	W.C. Domino Prince 59	Linecrossing study initiated
Oregon	Hereford	Line 3	1947 1948 1962	8	1	Oregon David Domino	Linecrossing study initiated
Oregon	Angus	Line 4	1947 1955	16	3	Prince Sunbeam 16, Missouri General 19, Springmere 300	Continuing
Utah	Hereford	Utah I	1943 1952	25	1	Advance Domino III	Continuing
Utah	Hereford	Utah II	1950	12	1	Publican Domino 184	Continuing
Utah	Shorthorn	Utah	1947 1951	30	2	Kellearn Max Mascot, Roanridge Major Mercury	Continuing
Wyoming	Hereford	Gillette	1953 1953	30	1	Bonnie Brae 36th	Continuing

lack of facilities. The other 10 lines were discontinued because the study was completed (California; Havre, Montana; and Nevada) or they entered a linecrossing experiment and the lines were discontinued (Oregon).

Many of these lines were established before the origin of the W-1 Beef Cattle Breeding Project which was initiated in 1946; the New Mexico and U.S. Range Livestock Experiment Station began lines in the early 1930's. The Colorado Brae Arden line, which was brought to the station in 1946, had actually been closed to outside breeding by a private breeder since 1926. Most of the lines were established at about the time of the initiation of the Regional Project in 1946 or shortly thereafter.

Number of Sires, Dams, and Matings by Lines

The numbers of years, sires, dams, and matings are presented by line in Table 5. A sizeable number of matings were made in most of the lines, although a large range in number of matings exists among lines. The number of matings varied with the length of time the line was in existence and the number of foundation females. The Colorado station had fewer matings per line because of small numbers of foundation females, even though many of the lines were maintained for several years. The Miles City lines generally had much larger numbers of matings due to larger numbers of foundation females and the large number of years the lines were in existence. By far the largest line was Miles City Line 1 where data analyzed covered 31 years, and 53 sires and 872 dams produced 3,034 matings.

The number of years involved per line ranged from 4 to 32 years with an average of 13 years per line. The number of sires and dams per line averaged 11 and 94, and ranged from 2 to 53 sires and 11 to 872 for dams. The numbers of matings per line averaged 298 with a range of 28 to 3,034.

Level and Rate of Inbreeding by Lines

The average inbreeding values for sires, dams, and matings for each line are presented in Table 6. These values are based on the inbreeding coefficients of all sires and dams used, weighted by the number of planned matings per parent because not all planned matings produced a calf. The corresponding numbers of sires, dams, and matings involved in these calculations are listed in Table 5.

Selection for performance was practiced concurrently with the inbreeding process. In all except the Colorado lines, animals were inbred only because the line was closed to outside breeding; in fact, close matings such as half- or full-sibs and sire-daughter matings were avoided. In the Colorado lines, inbreeding was increased as rapidly as possible, especially in the early years when many sire-daughter matings were made.

The average inbreeding values per line for sires, dams, and matings are 13.9, 12.2, and 18.5 percent, respectively. The inbreeding levels of the matings made the final year the line was in existence or the final year of this study (1964) were higher than the values for matings averaged over all years as expected. There was a wide range in inbreeding values among lines. The Colorado lines were the most highly inbred, averaging from 25 to 40 percent for all matings and from 24 to 51 percent in the final year. The Havre, Miles City, New Mexico, California, and Wyoming lines indicate a fair amount of inbreeding, averaging from 10 to 20 percent for all matings and from 15 to 30 percent in the final year. The four Oregon lines averaged from 10 to 15 percent but were somewhat lower in the final years. The Nevada and Utah lines, only slightly inbred, averaged between 4 and 12 percent.

The rate of inbreeding for each line (Table 6) was obtained by dividing the inbreeding value of the matings the final year by the number of years. This calculation yields an average value that probably depicts the pattern of inbreeding increase fairly accurately for all lines except those in Colorado. In the Colorado lines, inbreeding increased rapidly in the early years and then increased only slightly in the later years. The range of increase per year was 0.6 to 9.0 percent, and most of the lines increased between 1 and 5 percent per year. The overall average inbreeding increase per year for all lines was 2.1 percent.

Traits Studied

Several traits of economic importance have been recorded by each station throughout the years (Table 7). The traits in this analysis can be divided into two categories: (1) reproduction or fitness traits and (2) pre- and postweaning growth traits.

The fitness traits dealt with measures of fertility, mortality, abnormalities, and the normal weaning of calves which are subject to natural selection classifications:

a) Open versus pregnant: Open included cows that were pronounced open by pregnancy test or by simply not producing a calf the subsequent calving season. Cows that did not conceive, those losing embryos in the early stages, and undetected abortion of fetuses are included in this classification. The scores assigned to this class for all matings were: 1 = open, 0 = pregnant.

b) Aborted versus born: The aborted class includes cows that were detected to have aborted fetuses. At some stations part of the cows aborting under range conditions probably went undetected. Scores were assigned to all pregnant cows as: 1 = aborted, 0 = calf born.

c) Dead versus alive at birth: The dead at birth class includes calves dead at or near birth including stillborns, those dying during the birth process, and those dead when first observed. Scores were assigned to all calves born as: 1 = dead at birth, 0 = alive at birth.

d) Died birth to weaning: This class includes calves born alive but dying from various causes before normal weaning time or weight. Scores were assigned to all calves born alive as: 1 = died birth to weaning, 0 = weaned live calf.

e) Abnormal versus normal: The abnormal calf class includes dwarfs, hydrocephalus, heart defects, and other abnormalities. Calves in this class also appear in one of the classes b, c, d, or f. Scores were assigned to all pregnant cows as: 1 = abnormal calf or fetus, 0 = normal calf or fetus.

f) Calf weaned versus not weaned: The calf weaned class includes all live calves at the normal time or weight of weaning. Scores were assigned to all pregnant cows as: 1 = weaned, 0 = not weaned.

Table 5. Number of Years, Sires, Dams and Matings by Line

Station and line	Years range	Years number	Sires number	Dams number	Matings number
California					
Rover	1934-58	16	11	143	476
Colorado					
Animas	1952-54 & 57	4	2	11	28
Bonanza	1952-63	13	4	24	86
Brae Arden	1947-64	18	14	50	232
Colorado	1946-64	17	6	45	150
Don	1949-64	15	6	23	112
Ft. Lewis	1945-52	8	4	54	122
La Plata	1947-55	8	5	23	61
Mesa	1950-53	4	2	15	35
Monarch	1951-64	14	6	25	120
Prospector	1946-64	17	6	28	138
Royal	1945-64	19	11	67	200
San Juan	1947-64	17	7	45	202
Tarrington	1955-64	9	4	14	58
Real Prince	1956-64	9	3	20	78
Havre, Montana					
Line 1	1947-64	18	16	114	391
Line 2	1948-64	17	14	133	449
Line 3	1949-64	16	11	97	345
Miles City, Montana					
Line 1	1933-63	31	53	872	3034
Line 2	1935-47	13	8	176	404
Line 3	1938-44	7	3	110	256
Line 4	1946-64	19	13	133	490
Line 5	1946-59	14	8	115	347
Line 6	1948-64	17	9	97	342
Line 7	1948-52	5	2	42	131
Line 8	1949-56	8	3	37	127
Line 9	1950-63	14	9	120	410
Line 10	1948-64	17	14	101	367
Line 11	1960-64	5	7	78	203
Line 12	1951-64	14	15	136	350
Line 13	1953-56	4	12	26	52
Line 14	1955-64	10	16	121	308
Nevada					
Line 1	1955-63	9	9	58	259
Line 2	1955-63	9	9	67	286
Line 3	1955-63	9	9	64	263
Line 4	1955-63	9	10	56	237
Line 5	1955-63	9	9	61	261
New Mexico					
"Old"	1933-64	32	44	151	728
"Outcross"	1940-64	15	26	138	347
Oregon					
Line 1	1958-64	7	8	70	151
Line 2	1958-64	7	8	75	144
Line 3	1958-64	7	9	63	136
Angus	1958-64	7	8	46	142
Utah					
I[1]	1948-65	18	18	99	
II[1]	1953-65	13	25	147	
Shorthorn[1]	1948-65	18	18	97	
Wyoming					
Brae Arden	1954-63	10	14	106	358
AVERAGE	1933-64	13	11	94	305

[1]Numbers pertain only to calf data; reproductive data were not analyzed.

Table 6. Mean Levels and Rate of Inbreeding by Line (percent)

Station and line	Mean values: Sires	Dams	Mating	Final year	Number of years	Average increase per year
California						
Rover	1.7	7.3	12.5	17.3	16	1.1
Colorado						
Animas	27.7	32.3	36.2	35.8	4	9.0
Bonanza	31.7	28.0	37.4	49.0	13	3.8
Brae Arden	36.6	35.8	41.2	45.0	18	2.5
Colorado	24.5	21.0	33.3	53.8	17	3.2
Don	28.7	24.5	35.5	46.9	15	3.1
Ft. Lewis	22.5	14.6	26.8	32.4	7	4.6
La Plata	11.8	11.5	22.2	31.2	8	4.5
Mesa	6.5	4.9	24.9	24.0	4	6.0
Monarch	26.8	23.2	32.7	37.1	14	2.7
Prospector	20.0	18.7	29.2	35.0	17	2.1
Royal	28.2	25.5	34.9	50.7	19	2.7
San Juan	20.9	19.1	27.7	32.9	17	1.9
Tarrington	17.8	14.0	29.1	36.6	9	4.1
Real Prince	22.1	27.9	36.7	44.7	9	5.0
Havre, Montana						
Line 1	9.0	11.1	15.0	18.1	18	1.0
Line 2	10.1	8.8	15.3	20.6	17	1.2
Line 3	8.0	8.3	18.1	26.0	16	1.6
Miles City, Montana						
Line 1	15.9	15.0	18.9	24.1	30	0.8
Line 2	9.9	7.2	14.1	19.2	12	1.6
Line 3	9.9	4.1	6.4	11.3	7	1.6
Line 4	12.6	8.7	16.1	26.3	19	1.4
Line 5	6.4	6.8	12.6	19.8	14	1.4
Line 6	15.3	14.2	22.1	35.6	17	2.1
Line 7	6.7	4.7	13.8	15.5	5	3.1
Line 8	9.0	4.3	11.5	16.0	8	2.0
Line 9	13.7	9.8	15.8	20.9	14	1.5
Line 10	14.7	8.7	16.4	28.6	17	1.7
Line 11	9.4	8.4	16.9	20.2	5	4.0
Line 12	9.2	10.4	14.9	19.9	11	1.8
Line 13	44.4	36.9	40.8	42.9	4	-
Line 14	7.8	4.8	8.3	11.3	9	1.3
Nevada						
Line 1	4.5	1.5	6.9	10.5	9	1.2
Line 2	.7	.8	4.3	9.6	9	1.1
Line 3	4.4	.9	4.0	5.0	9	0.6
Line 4	1.0	1.2	4.4	6.3	9	0.7
Line 5	2.0	.7	4.3	5.2	9	0.6
New Mexico						
"Old"	13.5	12.4	16.9	26.8	32	0.8
"Outcross"	12.1	12.7	17.2	20.0	23	0.9
Oregon						
Line 1	16.1	12.6	10.4	7.0	7	1.0
Line 2	12.4	12.4	10.7	5.9	7	0.8
Line 3	24.3	14.1	14.7	8.4	7	1.2
Angus	9.6	6.2	10.7	11.8	7	1.7
Utah						
Line I[1]	.9	2.7	2.4	4.8	18	0.3
Line II[1]	1.2	4.9	5.9	3.9	13	0.3
Shorthorn[1]	4.0	3.2	7.0	12.9	18	0.7
Wyoming						
Brae Arden	5.2	5.9	12.0	15.7	10	1.6
AVERAGE	13.9	12.2	18.5	23.5	13	2.1

[1]The inbreeding values were calculated from calves weaned rather than matings.

Table 7. Traits Analyzed by Station

Station	Percent open	Percent aborted	Percent dead at birth	Percent died birth to weaning	Percent abnormal	Percent weaned	Birth weight	ADG to wean	Wean weight	Initial weight	ADG test	Final weight
California[1]	X	X	X	X	X	X	X	X	X			
Colorado	X	X	X	X	X	X		X	X	X	X	X
Havre, Montana	X	X	X	X	X	X	X	X	X	X	X	X
Miles City, Montana	X	X	X	X	X	X	X	X	X	X	X	X
New Mexico	X	X	X	X	X	X						
Nevada[2]	X	X	X	X	X	X		X	X	X	X	X
Oregon[2]	X	X	X	X	X	X	X	X	X	X	X	X
Utah							X	X	X	X	X	X
Wyoming[2]	X	X	X	X	X	X	X	X	X	X	X	X

[1]Weaning weight adjusted to 205 days.

[2]Heifers postweaning treatment same as that for bulls.

Table 8. Models for Least Squares Analyses[1]

Variable	Fitness Models 1	2	3	Growth Models 4	5	6	Abbreviated definitions
μ	A	+	A	A	+	+	Overall population mean with equal subclass frequencies and average age and inbreeding.
S_i	A	-	A	A	-	-	Effect of the i^{th} station.
L_{ij}	A	-	A	A	-	-	Effect of the j^{th} line within the i^{th} station.
T_{ijk}	A	+	A	A	+	+	Effect of the k^{th} year born within the j^{th} line and the i^{th} station.
A_l	+	+	A	A	+	+	Effect of the l^{th} age of dam (2,3,4,5,6,7,8, 9,10 +).
b_1Fc_{ijkl}	+	+	+	+	+	+	Linear regression of the trait on inbreeding of calf.
$b_2Fc^2_{ijkl}$	-	-	-	+	-	+	Quadratic regression of the trait on inbreeding of calf.
b_3Fd_{ijkl}	+	+	+	+	+	+	Linear regression of the trait on inbreeding of dam.
$b_4Fd^2_{ijkl}$	-	-	-	+	-	+	Quadratic regression of the trait on inbreeding of dam.
b_5A_{ijkl}	-	-	+	+	+	+	Linear regression of the trait on age of calf.
e_{ijklm}	+	+	+	+	+	+	Residual.

[1]Each sex was analyzed separately for growth data. (A) indicates variable was absorbed, (+) indicates variable was fitted and (-) indicates variable was not fitted. Models 1, 3 and 4 are the pooled analyses and Models 2, 5 and 6 were used in separate analyses for each line.

Each mating is included in the a class, all pregnant cows in the b, e, and f classes, all calves born in the c class, and all calves born alive in the d class.

When the scoring system of 0 and 1 within each classification is used, the mean value obtained x 100 is the percentage of the class receiving the 1 score. The percentage of the class receiving the 0 score is [(100) - (the mean value x 100)].

The birth and weanling growth traits studied were birth weight, daily gain from birth to weaning, and weaning weight. The postweaning growth traits for bulls from all stations furnishing postweaning data and for heifers from Oregon, Nevada, and Wyoming included initial weight on test, daily gain during the test, and final weight at the conclusion of the test. Selection for these traits was more largely due to deliberate choice of the experimenter, although size undoubtedly would be subject to natural selection as well.

The data available for study differed among stations, and the kinds of data furnished and traits analyzed from each station are described in Table 7.

Statistical Analyses

For the fitness traits, the percentages in each category were calculated by line, station, and overall totals. In addition, the least squares means (percentages) were also obtained along with the within subclass standard deviations and coefficients of variation.

For the pre- and postweaning growth traits, the least squares means by line, station, and overall totals were calculated along with the within subclass standard deviations and coefficients of variation.

All traits were analyzed by least squares procedures, and the various models used are presented in Table 8. For the fitness traits, Model 1 was used for the overall pooled analyses and Model 2 for the separate analyses by line. Inbreeding of the sire was not included as an independent variable in the analyses because of confounding with the station-line-year subclass effects. Models 3 and 4 were used in analyses involving the pre- and postweaning growth traits in the overall pooled analysis of data; Model 4 included the quadratic term for inbreeding of calf and dam. The pre- and postweaning growth traits were analyzed separately by sex.

In addition, separate analyses were made for each line for the growth traits to determine the variability in response to inbreeding by lines. These analyses corresponded with the overall pooled analyses except that station and line were omitted. Models 5 and 6 were used, with Model 6 differing from Model 5 in that the quadratic terms for inbreeding of calf and dam were added.

Results and Discussion

Fitness Traits

Means and Variation

POOLED ANALYSES — The least squares means and standard deviations for the fitness traits are listed Table 9. The percentage of abortions, dead at birth, died birth to weaning, and weaned should total 100 because they were computed as a percentage of pregnant cows and not as a percentage of total matings. The percent open is a percentage of the total matings.

The percent open averaged 16.3; thus 83.7 percent of all matings resulted in pregnancy. Of matings resulting in pregnancy, .5 percent resulted in abortions. This value is probably biased downward because not all abortions would be detected, especially under range conditions. This subject is discussed further under the analyses by line. A total of 3.7 percent of the successful matings resulted in a calf dead at birth and another 5.2 percent died from birth to weaning; thus, 90.7 percent of the calves born were weaned.

The average inbreeding of calf and dam of all matings was slightly higher than the corresponding average for successful matings (Table 9), being 16.9 versus 16.5 and 11.5 versus 11.1, respectively, or .4 percent higher in each case.

ANALYSES BY LINE — The average values in percentage for the six fitness traits by line of breeding are presented in Table 10. Data for the two main fitness traits, percent open and percent weaned (based on total cows pregnant), are easier to interpret than for other fitness traits because of the ease, regularity, and continuity among stations in recording data on these traits.

PERCENT OPEN — Large station and line differences are apparent; the Colorado (most rapid rate and highest level of inbreeding) and Oregon (Hereford lines) stations had among the highest percent open. California and New Mexico, with year around breeding seasons, had the lowest percent open. Lines 11, 12, and 14 from the Miles City station were based on linecross foundations and have among the lowest percentage open for lines at that station; this low percentage open is probably an expression of heterosis in their initial years of existence. The range in percent open was from 4.3 percent for the New Mexico "Outcross" line to 40 percent for the Mesa line of Colorado, which had only 35 matings before it was discontinued.

PERCENT ABORTED — The percent aborted averaged .49 percent over 27 lines (excluding Colorado and Havre, Montana) in the computation. For only the 12 lines reporting some abortions, the average over lines was 1.1 percent. These values are probably biased downwards because not all abortions would be detected, especially under range conditions. Those lines under the most confinement (closest supervision) during the time of possible abortion include the California line, two lines in New Mexico, and Lines 1, 2, and 3 from Nevada (Reno station). In these six lines, the average was 1.4 percent and the range was from .5 to 2.3 percent.

PERCENT DEAD AT BIRTH — The percent dead at birth averaged over 30 lines (Colorado excluded) was 4.1 percent and ranged from .5 to 9.7 percent. Both station and line differences within stations are apparent.

PERCENT DIED BIRTH TO WEANING — The average value over 30 lines (Colorado excluded) was 4.6 percent. Values ranged from .9 to 10.1 percent, and line differences were apparent. The Colorado values include both dead at birth and died birth to weaning and averaged 14.8 percent over lines; this average is substantially higher than the 8.7 percent (4.1 + 4.6) for all other lines.

PERCENT ABNORMAL — The percent abnormal averaged .7 percent for the 44 lines and ranged from none reported to 5.7 percent. There probably was a difference among stations in reporting of abnormals. Of the 24 lines reporting some abnormalities, the average was 1.4 percent.

PERCENT WEANED — Again, station and line within station differences are apparent. The Colorado lines had among the lowest values for percent weaned; the values ranged from 75 to 93 percent. Twenty-two of the 44 lines averaged over 90 percent weaned as a percentage of the successful matings. Many of the lines that had a high percent open or low percent weaned were culled for low productivity after they were in existence only a few years (Animas, Bonanza, Fort Lewis, Mesa, and Real Prince from Colorado and Line 13 from Miles City — Table 4).

Effect of Inbreeding

POOLED ANALYSES — The mean squares for the pooled analysis using Model 1 (Table 8) are listed in Table 11 for the fitness traits. The effects of μ, station, line/station, and year L/S were absorbed and only the mean squares for age of dam along with the linear effects of inbreeding of dam and inbreeding of mating (calf) are presented.

Age of dam effects were highly significant ($P < .01$) for percent open, dead at birth, and weaned and were significant ($P < .05$) for died birth to weaning. The least squares constant estimates for age of dam are listed in Table 12. Percent open was lower, death loss at birth and from birth to weaning was less, and the percent weaned was higher for cows 5 years of age and older than for younger cows. The 2-year-old group had the highest percent open, greatest loss at birth and from birth to weaning, and lowest percent weaned.

The effect of inbreeding of dam was highly significant for percent open ($P < .01$) and was significant for percent weaned ($P < .05$). The partial linear regressions of the fitness traits on inbreeding of dam are shown in Table 13 both in actual and standard units. Increased inbreeding of dam was detrimental to fitness traits in all cases (positive regression coefficients indicate detrimental effects except for percent weaned). The regression coefficient of percent open on inbreeding of dam of .2094 indicates that as inbreeding of dam increased 10 percent, percent open increased 2.1 percent. Likewise, a 10 percent increase in inbreeding of dam was associated with a 1.1 percent reduction in percent weaned. Although not significant, there was a trend for more abortions and more deaths at birth and from birth to weaning to be associated with higher levels of inbreeding of dam.

Inbreeding of mating (calf) had a significant effect ($P < .05$) on percent open, dead at birth, and died from birth to weaning and a highly significant effect ($P < .01$) on percent weaned. The standard partial regressions (Table 13) indicate that inbreeding of dam was more important than inbreeding of mating for percent open, whereas inbreeding of calf was more important for the calf survival traits (dead at birth, died birth to weaning, and weaned). The regression of the traits on inbreeding of mating (calf) indicates that a 10 percent increase in inbreeding was associated with a 1.3 percent increase in percent open, .8 percent more deaths at birth, .8 percent more death loss from birth to weaning, and 1.6 percent fewer calves weaned.

The simple correlation between inbreeding of dam and calf was .29 but varied greatly with line, as discussed below.

ANALYSES BY LINE — The effects of inbreeding of dam and mating (calf) on the fitness traits were studied separately by each line; essentially the same model was used as for the pooled analyses. The independent variables included in the model were years, age of dam, and the linear regressions of the fitness traits on inbreeding of dam and mating (calf). The sum of the partial regressions for inbreeding of dam or inbreeding of calf for percent abortions, dead at birth, and died birth to weaning equals the regression for percent weaned but is of opposite sign.

The partial regression coefficients by line are listed in Table 14 along with the significance levels and the correlation between inbreeding of dam and calf by line. Differences among the regression coefficients in both sign and magnitude is evident among lines both within and between stations. These differences should probably be expected because the foundation stocks were from different sources in most instances and likely differed in initial gene frequencies. Inbreeding, which increased relationship to a sire superior (or inferior) in frequencies of genes affecting fitness traits would be expected to have inbreeding depression offset (or augmented) by the resulting change in gene frequencies. Also, the level of environment differed among stations, and the response to inbreeding may depend on the environment in which the response is measured. For lines where the correlation between inbreeding of calf and dam is high, separation of these two effects is questionable, especially where the regressions are large and of opposite sign such as the Colorado line and Line 13 from Miles City for percent weaned.

The number and percentage of significant ($P < .05$) regressions along with the number and percentage of favorable and unfavorable regressions is summarized in Table 15 for each fitness trait.

Inbreeding of dam had slightly more significant regressions (5) than inbreeding of calf (4) for percent open, whereas inbreeding of calf had more significant regressions for survival traits. This same trend was evidenced in the pooled analyses. Surprisingly, there were about as many significant favorable regressions as unfavorable ones for most traits; that again emphasizes the variability in response to inbreeding by line. For all fitness traits except percent abortions, about 60 percent of the individual regressions were unfavorable and about 40 percent favorable (increased inbreeding associated with increased fitness).

Growth Traits

Means and Variation

The least squares means for the growth traits by sex along with the numbers, standard deviations, and coefficients of variation are listed in Table 16 (Model 3). The standard deviations were computed from the residual mean squares in the least squares analyses. Male calves weighed 3.8 pounds more than heifers at birth; this weight difference is slightly less than the 4.6 pounds reported as a summary value from many studies by Petty and Cartwright (1966). Males gained .09 pounds per day more and weighed 17 pounds more at weaning than heifers. Bulls were also more variable in preweaning daily gain and weaning weight, as evidenced by higher standard deviations and coefficients of variation. Males were managed separately and differently than females in the postweaning analyses; thus, sex differences in the mean values are not meaningful.

The standard deviations of the various traits are similar but somewhat smaller than values reported by Petty and Cartwright (1966) in their summary from many studies. The coefficients of variation for weight ranged from 7.2 percent in final weight of females to 13 percent for weaning weights of males, whereas those for pre- and postweaning average daily gain (ADG) tended to be somewhat higher than weights taken in the same period of life, as expected.

Means and variation for the individual lines are not presented because of space considerations and their limited usefulness to interpreting the inbreeding results.

Effect of Inbreeding — Linear

The mean squares for the pooled analyses using Model 3 (Table 8) are listed in Table 17 for the growth traits. Analyses were run separately by sex of calf, and the effects of μ, station, line/station, years/line/station, and age of dam were absorbed. Only the mean squares for the linear effects of inbreeding of dam, inbreeding of calf, and age of calf are presented. The corresponding linear partial regression coefficients of the traits on inbreeding of dam and inbreeding of calf in actual and standard units, along with the regression of age of calf, are listed in Table 18.

Age of calf effects were highly significant ($P < .01$) for weaning weight in both sexes, as expected; the regression coefficients indicate male and female calves gained 1.62 and 1.61 pounds per day, respectively. Age of calf did not significantly affect preweaning daily gain in either sex. The regression of birth weight on age of calf is actually the regression on date of birth, which was highly significant ($P < .01$) in both sexes. The regressions indicate that for every 10 days earlier in the season the calves were born, the birth weight decreased about ½ pound. Age of calf was highly significant ($P < .01$) for initial and final weights in both sexes, as expected, but was nonsignificant for test daily gain.

The linear effect of inbreeding of dam was highly significant ($P < .01$) for both preweaning ADG and weaning weight in both sexes but was nonsignificant for birth weight in both sexes. As shown by the partial regression coefficients, inbreeding of dam had essentially twice the magnitude of effect on male calves as compared to females on preweaning daily gain. The regression of weaning weight on inbreeding of dam was also much larger than that of males. Apparently, decreased milk production associated with increased inbreeding of dam affected growth of male calves, which have a greater growth potential, more than that of females. This phenomenon was also reported by Brinks *et al.* (1965). A 10 percent inbred dam would be expected to wean a male or female calf weighing 8.8 or 5.3 pounds less than a noninbred dam. Inbreeding of dam was nonsignificant for all three postweaning traits in both sexes, although the regression coefficients were negative for initial weight, as expected, and approached significance for males. Bull calves had a regression of -.68 pounds per 1 percent inbreeding of dam for final weight; this regression was smaller than the corresponding regression at weaning of -.88. The heifer regression on a small population sample was actually positive (.29) and may indicate that the detrimental effect of inbreeding of dam at weaning was completely compensated for by yearling ages.

The linear effect of inbreeding of calf was highly significant ($P < .01$) for all three preweaning traits in both sexes except for birth weight in females, in which the effect was significant ($P < .05$). Although significant, the effect on birth weight was relatively small. A 25 percent inbred calf from a noninbred dam would be expected to weigh 2.3 pounds (male) or 1.7 pounds (female) less than a noninbred calf. Inbreeding of calf had about the same magnitude of effect in both sexes on preweaning daily gain and weaning weight. This effect amounted to about -.003 pounds per day per 1 percent increase in inbreeding for preweaning daily gain and between .6 and .7 pounds per 1 percent increase in inbreeding of calf for weaning weight. Again, a 25 percent inbred calf would gain in pounds about .07 (male) and .08 (female) less per day and weigh 15.9 (male) and 16.8 (female) less at weaning than a noninbred calf. In the postweaning traits, inbreeding of calf for males was significant ($P < .05$) for initial weight and highly significant ($P < .01$) for test ADG and final weight. Although nonsignificant for heifers in a smaller sample, the regressions were negative for all three

Table 9. Least Squares Means and Standard Deviations for Fitness Traits (Pooled Analyses, Model 1)

Trait	Number of observations	Mean	Standard deviation
Open (percent)	13,216	16.3	35.3
Abortions (percent)	11,056	.5	6.9
Dead at birth (percent)	11,056	3.7	18.7
Died birth to weaning (percent)	11,056	5.2	21.3
Weaned (percent)	11,056	90.7	28.6
Inbreeding of calf (percent)	11,056	16.5	6.0
Inbreeding of dam (percent)	11,056	11.1	6.0

Table 10. Means for Fitness Traits by Lines

Station and line	Percent open	Percent abortions	Percent dead at birth	Percent died birth-weaning	Percent abnormal	Percent weaned
California						
Rover	7.6	2.1	6.1	6.4	2.5	85.4
Colorado[1]						
Animas	14.3			20.8		79.2
Bonanza	32.6			8.6		91.4
Brae Arden	22.3			17.4		82.6
Colorado	24.3			17.9		82.1
Don	24.1			12.9		87.1
Ft. Lewis	26.5			7.0		93.0
La Plata	15.0			11.8		88.2
Mesa	40.0			14.3	5.7	85.7
Monarch	18.5			10.3	.7	89.7
Prospector	16.8			20.2		79.8
Royal	31.0			10.1		89.9
San Juan	26.3			15.8		84.2
Tarrington	19.0			14.9		85.1
Real Prince	36.8			25.0		75.0
Havre, Montana						
Line 1	18.0	-	2.2	7.2	1.3	90.6
Line 2	17.4	-	1.1	5.9	.9	93.0
Line 3	25.0	-	2.3	10.1	2.0	87.6
Miles, City, Montana						
Line 1	15.9	.5	3.9	2.8	.3	92.8
Line 2	15.4	1.2	2.9	7.6	.3	88.3
Line 3	21.5	.5	.5	2.5	3.1	96.5
Line 4	16.2	-	4.9	2.2		92.9
Line 5	21.6	-	6.6	3.3	.3	90.1
Line 6	16.7	-	1.4	4.2		94.4
Line 7	26.0	-	2.1	6.2	.8	91.8
Line 8	11.8	-	3.6	7.1	1.6	89.3
Line 9	11.5	-	3.9	7.2	.7	88.9
Line 10	17.2	-	8.6	3.0	.3	88.5
Line 11	15.3	-	5.8	3.5	2.5	90.7
Line 12	7.7	-	3.1	1.9	.6	95.0
Line 13	39.2	-	9.7	6.5		83.9
Line 14	7.8	-	2.1	3.9		94.0
Nevada						
Line 1	16.1	.5	2.3	4.7	1.4	92.5
Line 2	9.7	1.2	4.4	2.8	1.4	91.7
Line 3	16.7	.5	2.4	1.0	2.3	96.2
Line 4	20.6	.6	2.8	2.3		94.4
Line 5	14.0	-	1.8	5.4		92.8
New Mexico						
"Old"	6.2	2.3	5.7	3.4	.1	88.7
"Outcross"	4.3	1.9	6.1	5.4	1.7	86.6
Oregon						
Line 1	24.5	-	7.0	1.8	.7	91.2
Line 2	28.9	-	6.9	5.9	.7	87.1
Line 3	36.8	1.2	2.3	4.7	.7	91.9
Angus	15.5	-	3.3	6.7		90.0
Wyoming						
Brae Arden	7.3	.6	8.4	.9		90.1

[1]Values for percent dead from birth to weaning include percent dead at birth for lines from the Colorado station.

traits and of about the same magnitude as for bulls for test ADG. A 25 percent inbred calf would be expected to weigh in pounds 11.4 (male) and 3.2 (female) less in initial weight, gain .09 (male) and .08 (female) less per day, and weigh 24.2 (male) and 13.9 (female) less in final weight than a noninbred calf.

The correlations between inbreeding of dam and calf for pre- and postweaning analyses for males were .16 and .14, respectively, and for females were .18 and .24, respectively. When the relative effects of inbreeding of dam with inbreeding of calf were compared, inbreeding of dam had a greater effect for male calves but a slightly less effect for females than inbreeding of calf for preweaning ADG and weaning weight. This same result was reported by Brinks et *al.* (1965) in the Miles City Line 1 study. Inbreeding of calf had a much larger effect than inbreeding of dam on postweaning gain and final weight, as might be expected.

Effects of Inbreeding — Linear and Quadratic

The mean squares for the pooled analyses using Model 4 (Table 8) are presented in Table 19 along with the significance levels for the quadratic effects. Significance levels for linear effects were presented in Table 17. The partial regression coefficients for the linear and quadratic effects of inbreeding of dam and inbreeding of calf resulting from these analyses are listed in Table 20. The model was the same as that in the preceding section except the quadratic effects of inbreeding of dam and calf were added. Age of calf significance levels and regressions were similar, as in the preceding section, and are not discussed further.

The quadratic effect of inbreeding of dam was nonsignificant for birth weight in both sexes, and the linear and quadratic regression coefficients are similar for both sexes. For preweaning daily gain and weaning weight, the quadratic term was highly significant ($P < .01$) for males. The quadratic term for inbreeding of dam was also significant ($P < .05$) for males for test ADG and final weight. Although this effect was nonsignificant for females, the regression coefficients are in a similar direction in general but of smaller magnitude for the preweaning traits. Inbreeding of dam effect on growth traits apparently is curvilinear in response to increased inbreeding, especially in male calves.

For inbreeding of calf, the quadratic term was nonsignificant for all growth traits. This effect is apparently linear in its effect on these traits.

A three-dimensional portrayal of the linear plus curvilinear effects of inbreeding of dam and calf for weaning weight is presented in Figures 1 (male) and 2 (female). Also, a two-dimensional contour plot of the same data is shown in Figures 3 and 4. The larger and more curvilinear effect of inbreeding of dam on males than on females can be visualized by studying these figures.

When the results from the two models (linear versus linear and quadratic) are compared, inbreeding of dam effect on preweaning growth and weaning weight apparently is curvilinear. All quadratic terms for inbreeding of calf were nonsignificant and the response to this effect apparently is linear. The total effect of inbreeding at any combination of levels of inbreeding of dam and calf was about the same for the two models.

Analyses by Line — Linear

The linear effects of inbreeding of calf and dam on the growth traits were studied separately by line and sex using Model 5 (Table 8). This model included the independent variables μ, years, ages of dam, and the partial linear regressions of the growth traits on inbreeding of calf, inbreeding of dam, and calf age.

The regression coefficients, along with the number per line, level of significance, and correlations between inbreeding of dam and calf are listed in Table 21. As with the fitness traits, there appear to be large differences among lines in their response to inbreeding. The level of significance depends considerably on the number of observations per line. The smaller Colorado lines did not show significant inbreeding effects, although in most cases the magnitude of the regression values were larger than those of the larger lines which were significant.

A summary listing the total number of individual line regressions per trait along with the number of significant, favorable, and unfavorable regressions was compiled (Table 22). For birth weight, there were 24 individual line regressions for each sex for both inbreeding of calf and dam. Of the regressions on inbreeding of calf, only 3 of the 24 (13 percent) were significant for each sex, and one of these (female) was a favorable regression. Sixty-seven percent (males) and 58 percent (females) of the regression values were unfavorable. In the pooled analysis, this regression was highly significant ($P < .01$) for males and significant ($P < .05$) for females, although the magnitude of the coefficients was small. The regressions of birth weight on inbreeding of dam showed a similar trend, although only slightly over half (50 percent for males and 62 percent for females) of the values were unfavorable. This effect was nonsignificant in the pooled analyses.

For preweaning daily gain, more of the regressions on inbreeding of dam were significant than those on inbreeding of calf, although about the same percentages were in the unfavorable direction (62 to 79 percent). These individual regressions agreed with the pooled analyses where both inbreeding of calf and dam had highly significant negative effects. Weaning weight showed similar results as preweaning gain.

For the postweaning growth traits, there were 25 individual regressions for males and only 10 for females. Initial weight results are similar to those for weaning weight except fewer regressions were significant because of smaller numbers.

For test ADG, the regression values tended to be favorable for the effect of inbreeding of dam (64 percent for males and 70 percent for females) and thus indicated some compensatory effect. Apparently, the poorer preweaning environment associated with increased inbreeding of dam provided a postweaning environment for more rapid gain. For final weight, about one-half of the regression values (60 percent for males and 40 percent for females) were favorable and thus indicated that the detrimental preweaning inbreeding of dam effects were nearly compensated for by final weight. In the pooled analyses, the effect of inbreeding of dam was nonsignificant for both test ADG and final weight for both sexes.

Inbreeding of calf continued to show a detrimental effect on postweaning growth, with 70 to 80 percent of the regression values even unfavorable for test ADG and final weight.

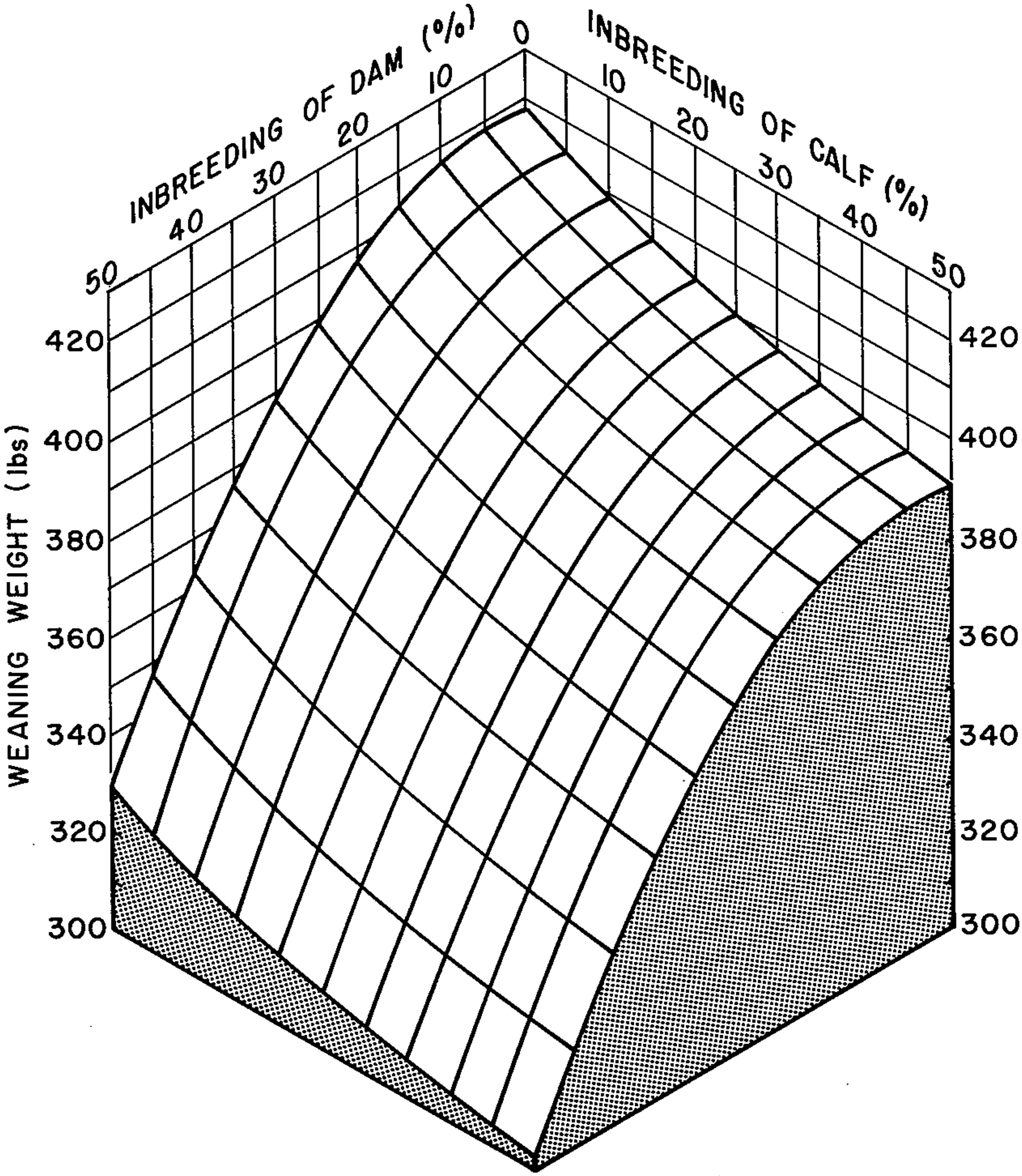

Figure 1. Three-dimensional portrayal of linear and quadratic joint effects of inbreeding of calf and inbreeding of dam on weaning weight of male calves.

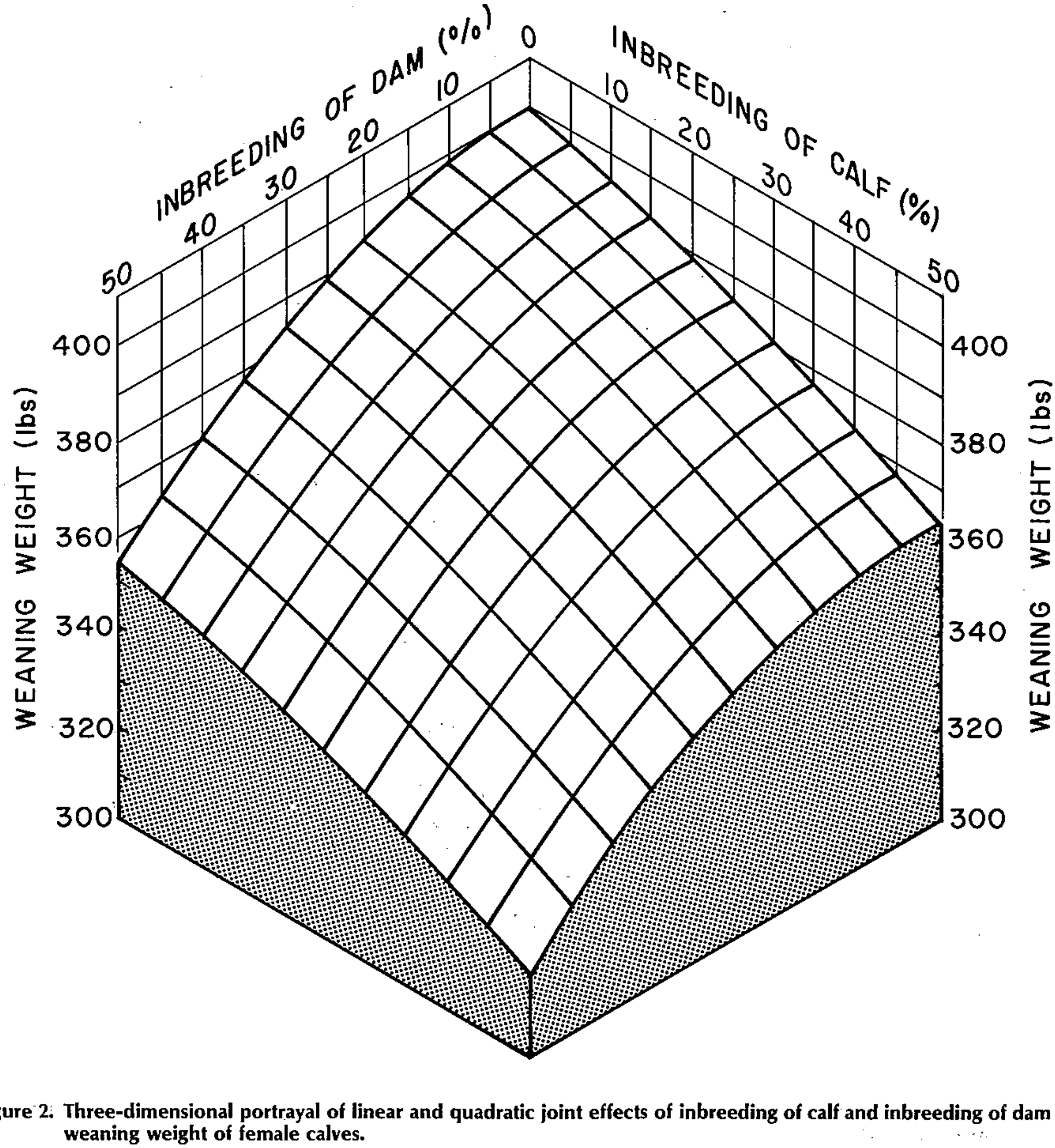

Figure 2. Three-dimensional portrayal of linear and quadratic joint effects of inbreeding of calf and inbreeding of dam on weaning weight of female calves.

Table 11. Mean Squares for Fitness Traits (Pooled Analyses, Model 1).

Source	D.F.	Percent open	D.F.	Percent abortions	Percent dead at birth	Percent died birth to weaning	Percent weaned
Dam age	8	.907**	8	.008	.418**	.249*	1.298**
FX Dam	1	1.739**	1	.002	.021	.170	.362*
FX calf	1	.658*	1	.001	.190*	.215*	.856**
Residual	12,658	.124	10,504	.005	.035	.045	.080

* P < .05
** P < .01

Table 12. Least Squares Constants for Age of Dam for Fitness Traits (Pooled Analyses, Model 1)

Age of dam	Percent open	Percent abortions	Percent dead at birth	Percent died birth to weaning	Percent weaned
2	7.48	.15	6.52	5.46	-11.82
3	-.48	.17	1.24	.63	-2.04
4	-.70	.03	-.01	.04	-.06
5	-1.25	.31	-1.87	-.75	2.31
6	-2.73	-.30	-1.32	-1.19	2.81
7	-1.82	-.17	-1.62	-1.31	3.10
8	-2.40	-.45	-1.62	-.76	2.82
9	-1.87	.09	-1.13	-1.51	2.55

When inbreeding of calf effects from the individual line analyses were summarized, 72 to 80 percent of the regression values were unfavorable for growth traits from preweaning gain through final weight. Also, only 2 of the 39 significant regressions for these traits were in the favorable direction. The effect of inbreeding of calf on birth weight was not so severe; only 67 percent (males) and 58 percent (females) of the regressions were unfavorable.

Inbreeding of dam had little effect on birth weight in most lines; two of the seven significant regressions were favorable and only 50 percent (males) and 62 percent (females) of the regressions were unfavorable. This effect was detrimental for preweaning growth and weaning weight; 62 to 72 percent of the regressions were unfavorable. However, this detrimental preweaning effect was compensated for in the postweaning phase when 64 percent (males) and 70 percent (females) of the regressions were favorable for test ADG.

Analyses by Line — Linear and Quadratic

The linear and quadratic partial regression coefficients by sex for each line for the growth traits on inbreeding of calf and dam are presented in Table 23. The significance levels for the quadratic effect only are also listed.

For birth weight there were 48 individual regressions. Of these, the quadratic term for inbreeding of calf and of dam was significant ($P < .05$) in four (8.3 percent) and six (12.5 percent) instances, respectively. For preweaning ADG and weaning weight, the quadratic term for inbreeding of calf was significant ($P < .05$) in seven instances (9.1 percent). Similar values for inbreeding of dam were 8 (10.4 percent) for ADG and 13 (16.9 percent) for weaning weight. Thus, for the preweaning traits, the quadratic term was somewhat more important for inbreeding of dam than for calf; this result agrees with the pooled analyses.

For the postweaning traits of test ADG and final weight, there were 34 individual regressions. The quadratic term for inbreeding of calf was significant ($P < .05$) in five (14.7 percent) and three (8.8 percent) instances for the two traits, respectively. Similar values for inbreeding of dam were 4 (11.8 percent) and 2 (5.9 percent), respectively. Slightly more quadratic terms were significant for inbreeding of calf than of dam for postweaning growth traits, but throughout there is no strong evidence for a quadratic response to inbreeding.

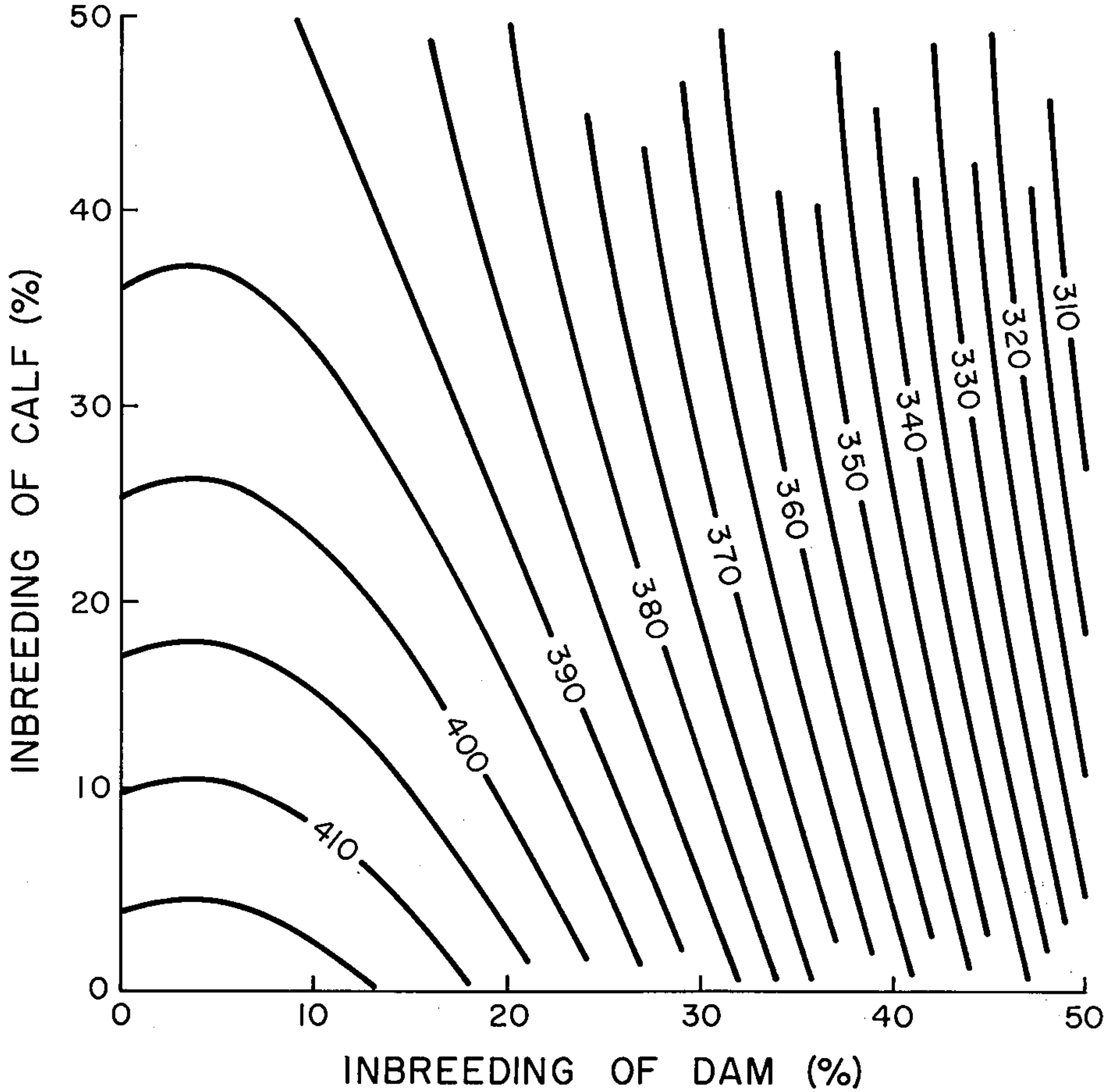

Figure 3. Two-dimensional plot of linear and quadratic joint effects of inbreeding of calf and inbreeding of dam on weaning weight of male calves.

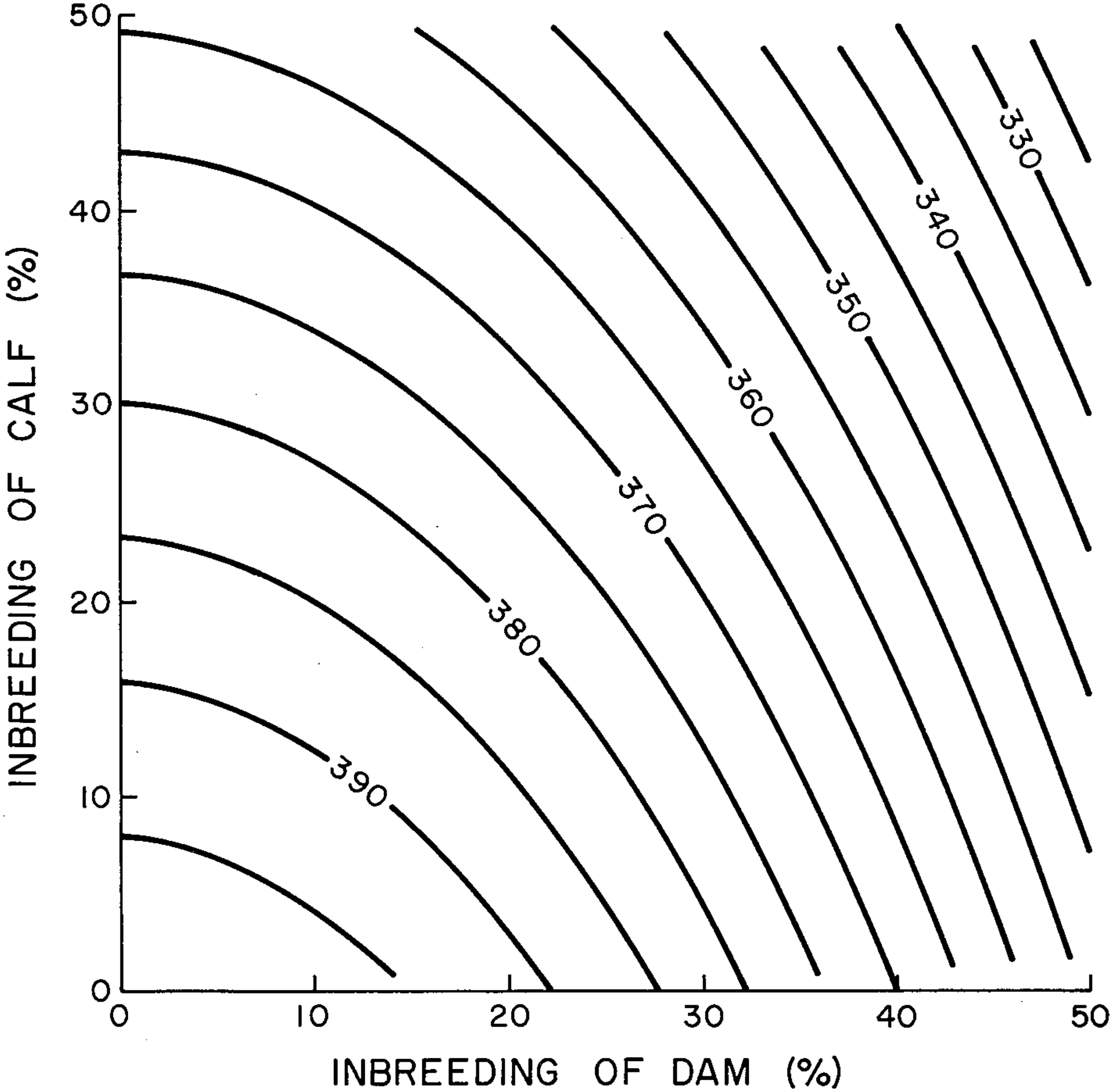

Figure 4. Two-dimensional plot of linear and quadratic joint effects of inbreeding of calf and inbreeding of dam on weaning weight of female calves.

Table 13. Partial Regression Coefficients for Linear Effects of Inbreeding of Calf and Dam for Fitness Traits (Pooled Analyses, Model 1)

Source	Open (percent) b	Open (percent) β[1]	Aborted (percent) b	Aborted (percent) β[1]	Dead at birth (percent) b	Dead at birth (percent) β[1]	Died birth to weaning (percent) b	Died birth to weaning (percent) β[1]	Weaned (percent) b	Weaned (percent) β[1]
Inbreeding of calf	.1287*	.0219	.0045	.0039	.0775*	.0249	.0825*	.0232	-.1645**	-.0345
Inbreeding of dam	.2094*	.0356	.0081	.0070	.0255	.0082	.0734	.0207	-.1070*	-.0224

[1]6.0 percent used for standard deviations of Fc and Fd[1], standard deviations for fitness traits shown in Table 9.
* P < .05.
**P < .01.

Summary and Conclusions

The purpose of this cooperative study was to determine the effects of increased inbreeding on various fitness and growth traits. Both pooled analyses over all lines and separate analyses by line were used to study both linear and curvilinear effects of inbreeding of calf and of dam.

Data were from 48 inbred lines from 10 experiment stations located in eight western states participating in the W-1 Regional Beef Cattle Breeding Project. The lines averaged 305 matings, 94 dams, and 11 sires per line and were in existence an average of 13 years. The average inbreeding values per line were 13.9 percent for sires, 12.2 percent for dams, and 18.5 percent for matings (calves). However, there was considerable variation around these average values.

The traits studied were divided into the two categories of fitness traits associated with reproduction and survival and growth traits from birth through yearling ages.

The following summary of results and conclusions are drawn from the study.

Fitness Traits

1. The least squares mean from the pooled analyses for percent open was 16.3. This result indicates that 83.7 percent of all matings resulted in pregnancy. Of matings resulting in pregnancy, 0.5 percent resulted in abortions, 3.7 percent died at birth, 5.2 percent died from birth to weaning, and 90.7 percent of calves born were weaned.
2. There were large differences in means for fitness traits among stations and lines associated with differences in rate and degree of inbreeding. More rapid and higher levels of inbreeding were associated with lower performance for all fitness traits.
3. Increased inbreeding of calf and of dam had a detrimental effect on all fitness traits studied. Inbreeding of calf was slightly more important than inbreeding of dam for all traits except percent open. The partial regressions of traits on inbreeding of calf were: percent open, .1287; percent aborted, .0045; percent dead at birth, .0775; percent dead birth to weaning, .0825; and percent weaned, -.1645. Corresponding regressions on inbreeding of dam were: .2094, .0081, .0255, .0734, and -.1070.
4. The response to inbreeding of calf and of dam by line varied greatly, as evidenced by both the sign and magnitude of the partial regression coefficients both within and among stations. The percent of the partial regressions by line that were unfavorable was about 60 percent for all traits except percent abortions for inbreeding of both calf and of dam.

Growth Traits

1. The least squares means from the pooled analyses for males in pounds were: birth weight, 76.9; preweaning daily gain, 1.71; weaning weight, 406; initial weight at test, 451; test daily gain, 2.09; and final weight, 795. Corresponding values for females were: 73.1, 1.62, 389, 431, 1.54, and 660. Males were more variable than females in preweaning daily gain and weaning weight, as evidenced by their larger standard deviations and coefficients of variation.
2. Increased inbreeding of calf had a detrimental effect for all growth traits studied when only the linear effect of inbreeding was considered. Partial regression coefficients of traits on inbreeding in pounds per percent inbreeding were: birth weight, -.0934; preweaning daily gain, -.002735; weaning weight, -.6370; initial test weight, -.4574; test daily gain, -.003482; and final weight, -.9687. Correspond-

ing values for females were -.0661; -.003147, -.6715, -.1283, -.003259, and -.5548.

3. Increased inbreeding of dam had a detrimental effect for all traits in males, and in all but birth weight and postweaning growth in females. The largest detrimental effect was found for preweaning daily gain in both sexes, as determined by standard partial regression coefficients. This effect is presumably due to decreased milk production associated with increased inbreeding of dam. The partial regression coefficients for males corresponding to traits listed above were: -.170, -.004865, -.8808, -.4173, -.002050, and -.6777. For females the coefficients were: .0016, -.002492, -.5288, -.0123, .001279, and .2946.

4. Increased inbreeding of dam had about twice the detrimental effect on preweaning daily gain of male as for female calves. It is postulated that male calves, having more growth potential, are handicapped more than females by decreased milk production associated with increased inbreeding of dam. Thus, the magnitude of effects of inbreeding may depend on the level of environment provided the inbred population.

5. When both the linear and quadratic effects of inbreeding of calf and of dam were considered, the quadratic term for inbreeding of dam was significant for preweaning daily gain, weaning weight, test daily gain and final weight of bulls, but was nonsignificant for growth traits in females. The quadratic term for inbreeding of calf was nonsignificant for all growth traits in both sexes.

6. A differential response to increased inbreeding of calf and of dam by line was again evident when only the linear effects of inbreeding were considered. For inbreeding of calf, 72 to 80 percent of the individual line regression coefficients were unfavorable for all growth traits except birth weight. The effects were less severe for inbreeding of dam; 62 to 72 percent of the regressions were unfavorable for preweaning daily gain and weaning weight. This detrimental preweaning effect was compensated for in postweaning daily gain in which 64 percent (males) and 70 percent (females) of the regressions were favorable.

7. There was no strong evidence for a quadratic growth response to inbreeding of calf or of dam. The largest proportion of significant quadratic effects (16.9 percent) was for the effect of inbreeding of dam on weaning weight.

The results of this study corroborate previous reports that, in general, increased inbreeding is detrimental to performance in fitness and growth traits. The results also document the magnitude of the inbreeding effects. More important, however, the results indicate that the response to increased inbreeding varies with the individual lines; some lines show little or no detrimental effects in certain traits whereas other lines are affected greatly. The differential response is probably due to different initial gene frequencies in the lines and to the combination of the inbreeding plus concurrent selection processes operating with different degrees of success in the individual lines.

From an observational standpoint, relatively small inbred lines apparently can be developed and maintained without their loss due to highly detrimental effects of inbreeding in fitness traits. Although some cost through lower performance is associated with the maintenance of these lines, the cost does not appear to be prohibitive if the use of inbred lines is warranted in the production of seed stock in beef cattle.

Table 14. Partial Regression Coefficients of Fitness Traits on Inbreeding of Calf and Dam by Line (Model 2)

Station and line	Percent open		Percent abortions		Percent dead at birth		Percent died birth to weaning		Percent weaned		Correlation
	Fd[a]	Fm[a]	Fd	Fc[a]	Fd	Fc	Fd	Fc	Fd	Fc	$r_{Fd\ Fc}$
California											
Rover	.156	-.435*	.193	.008	-.040	.277*	-.004	-.017	-.149	-.628*	.45
Colorado											
Animas	4.066	.179					-2.433	.385	2.433	-.385	-.24
Bonanza	-1.232	.275					-.782	.878	.782	-.878	.83
Brae Arden	.198	-.385					.081	-.173	-.081	.173	.52
Colorado	.526	-.528					1.066	-1.741*	-1.066	1.741**	.71
Don	-2.648**	.703					.258	-.515	-.258	.515	.72
Ft. Lewis	.714	-.050					1.400	-.263	-1.400	.263	.74
La Plata	-.087	.596					-1.182	.781	1.182	-.781	.54
Mesa	-1.313	-21.739**									-.11
Monarch	-1.112**	1.149**					.877	-.221	-.877	.221	.32
Prospector	.218	-.292					.158	.832	-.158	-.832	.61
Royal	-1.047*	-.332					-.362	-.245	.362	.245	.85
San Juan	.137	.636					.029	-.282	-.029	.282	.68
Tarrington	-.135	-2.280*					1.390	1.643	-1.390	-1.643	.72
Real Prince	-.328	1.339					1.490	-2.708*	-1.490	2.708	.71
Havre, Montana											
Line 1	.454	.406			.044	.018	.035	-.123	-.079	.106	.56
Line 2	.759	-.190			-.078	-.007	-.660*	.215	.739*	-.208	.63
Line 3	.598	.303			.019	-.243	-.393	.692*	.374	-.449	.56
Miles City, Montana											
Line 1	.530**	.285	-.050	.020	.030	.164	-.029	.062	.049	-.246*	.61
Line 2	.225	.029	.050	-.073	.046	.317	.288	-.098	-.385	-.145	.34
Line 3	-.534	-.669	-.073	-.031	-.008	-.153	.017	.310	.063	-.127	-.23
Line 4	-.169	.075			-.032	-.004	.087	.081	-.055	-.077	.42
Line 5	-.091	.881			-.640*	.857*	.109	.040	.532	-.897	.41
Line 6	.603	.100			.133	.049	.272	-.049	-.406	.000	.77
Line 7	.277	1.184			-.757	.424	.861	.432	-.103	-.855	.62
Line 8	-.930	.729			.032	-.686	.065	-.017	-.098	.703	.46
Line 9	.251	.219			.059	.156	.190	.142	-.248	-.298	.43
Line 10	.869	.184			.393	.519	-.210	.433*	-.182	-.951**	.62
Line 11	.582	.154			-.208	.822*	.151	.571	.057	-1.392**	.30
Line 12	.134	.351			-.103	-.197	.006	-.062	.096	.259	-.16
Line 13	2.132	.289			-1.320	1.719	-.446	-.158	1.766	-1.562	.84
Line 14	-.371	-.443			.003	-.030	-.038	-.317	.034	.348	.02
Nevada											
Line 1	1.091	-.283	-.085	.216**	.590*	.152	.086	.359	-.591	-.727*	.31
Line 2	.389	-.228	-.066	-.147	1.190**	.472	-.131	.461*	-.993	-.786*	.28
Line 3	.105	-.099	-.031	-.030	-.263	.262	.349	.017	-.056	-.249	.15
Line 4	-.887	-.011	-.076	-.083	-.554	.033	1.079**	.156	-.449	-.107	.14
Line 5	-.517	.237			-.224	.006	-.133	.214	.357	-.220	.25
New Mexico											
"Old"	-.146	.132	-.050	-.156*	.172	-.430	.040	.056	-.163	.529*	.63
"Outcross"	.185	-.197	.231	-.163	.027	-.585	-.123	-.319	-.135	1.068*	.19
Oregon											
Line 1	-.010	.017			-.085	.243	-.155	.067	.240	-.311	-.04
Line 2	1.327*	-.055			.148	1.077**	.107	-.213	-.255	-.863	-.08
Line 3	.819	.018	.023	.225	-.243	-.051	.531	.260	-.311	-.433	.22
Angus	.027	.532			-.154	-.037	-.104	.699	.259	-.663	.13
Wyoming											
Brae Arden	.187	-.314	-.040	.245**	.475	-.404	.033	-.099	-.468	.258	.45

[a] Fd, Fm and Fc percent inbreeding of dam, mating, and calf, respectively.
* $P < .05$
** $P < .01$

Table 15. Significance and Variability in Response to Inbreeding for Fitness Traits by Line.

Trait		Total regressions number	Significant regressions number	Significant regressions percent	Favorable regressions number	Favorable regressions percent	Unfavorable regressions number	Unfavorable regressions percent
Open (percent)	Fd	44	5[c]	11	17	39	27	61
	Fm	44	4[c]	9	18	41	26	59
Abortions (percent)	Fd	12	0	0	8	67	4	33
	Fc	12	3[a]	25	7	58	5	42
Dead at birth (percent)	Fd	30	3[a]	10	15	50	15	50
	Fc	30	4	13	12	40	18	60
Died, birth to weaning (percent)	Fd	43	2[a]	5	16	37	27	63
	Fc	43	5[b]	12	19	44	24	56
Weaned (percent)	Fd	43	1[a]	2	16	37	27	63
	Fc	43	9[c]	21	16	37	27	63

[a] 1 Favorable

[b] 2 Favorable

[c] 3 Favorable

Table 16. Least Squares Means and Variation for Growth Traits (Pooled Analyses, Model 3).

Trait	Sex	Number	Mean	Standard deviation	Coefficient of variation (percent)
Birth weight (pound)	M	3912	76.9	7.74	10.1
	F	3796	73.1	7.54	10.3
Preweaning average (pound)	M	4866	1.71	.237	13.9
	F	4717	1.62	.213	13.1
Weaning weight (pound)	M	4866	406	52.6	13.0
	F	4717	389	48.3	12.4
Initial weight (pound)	M	2688	451	42.6	9.4
	F	948	431	39.2	9.1
Test average (pound)	M	2688	2.09	.232	11.1
	F	948	1.54	.194	12.6
Final weight (pound)	M	2688	795	59.3	7.5
	F	948	660	47.5	7.2

Table 17. Mean Squares for Linear Effects of Inbreeding and Age on Growth Traits (Pooled Analysis, Model 3)

Source	Preweaning D.F.	Birth weight	D.F.	Preweaning ADG	Weaning weight	Postweaning D.F.	Initial test weight	Test ADG	Final weight
Males									
Inbreeding of dam (linear)	1	15.2	1	1.3475**	44171**	1	4279	.1033	11285
Inbreeding of calf (linear)	1	441.9**	1	.4489**	24338**	1	6141*	.3558**	27549**
Weaning age (linear)	1	1963.2**	1	.0174	1691588**	1	520952**	.0163	471328**
Residual	2513	59.0	2902	.0556	2154	1375	1424	.0536	3142
Females									
Inbreeding of dam (linear)	1	.1	1	.3529**	15893**	1	1	.0120	637
Inbreeding of calf (linear)	1	217.2*	1	.5892**	26834**	1	156	.1010	2927
Weaning age (linear)	1	1231.3**	1	.0513	1581097**	1	68809**	.0317	59503**
Residual	2412	56.4	2781	.0448	1742	424	1388	.0377	2119

* P < .05
** P < .01

Table 18. Partial[1] and Standard Partial[2] Regression Coefficients for Linear Effects of Inbreeding and Age on Growth Traits (Pooled Analyses, Model 3).

Source	Birth weight b	Birth weight β	Preweaning ADG[3] b	Preweaning ADG[3] β	Weaning weight b	Weaning weight β	Initial test weight b	Initial test weight β	Test ADG[3] b	Test ADG[3] β	Final weight b	Final weight β
Males												
Inbreeding of dam	-.0170	-.0099	-.4865**	-.0924	-.8808**	-.0754	-.4173	-.0441	-.2050	-.0398	-.6777	-.0514
Inbreeding of calf	-.0934**	-.0543	-.2735**	-.0519	-.6370**	-.0545	-.4574*	-.0483	-.3482**	-.0676	-.9687**	-.0735
Weaning age	-.0597**		-.0165		1.6221**		1.4144**		-.0250		1.3453**	
Females												
Inbreeding of dam	.0016	.0010	-.2492**	-.0527	-.5288**	-.0493	-.0123	-.0014	.1279	.0297	.2946	.0279
Inbreeding of calf	-.0661*	-.0394	-.3147**	-.0665	-.6715**	-.0626	-.1283	-.0147	-.3259	-.0756	-.5548	-.0525
Weaning age	-.0498**		.0290		1.6132**		.7721**		-.0524		.7180**	

1 Units in pounds per 1 percent inbreeding.
2 Standard deviation of Fc and Fd = 4.5%, standard deviation of dependent variables shown in Table 16.
3 $\times 10^{-2}$.
* P < .05.
** P < .01.

Table 19. Mean Squares for Linear and Quadratic Effects of Inbreeding and Age on Growth Traits (Pooled Analyses, Model 4)

	Preweaning					Postweaning			
Source	D.F.	Birth weight	D.F.	Preweaning ADG	Weaning weight	D.F.	Initial test weight	Test ADG	Final weight
				Males					
Inbreeding of dam									
Linear	1	.1	1	.2583	7881	1	66	.0112	38
Quadratic	1	41.3	1	.5734**	20364**	1	3548	.2621*	16159*
Inbreeding of calf									
Linear	1	307.1	1	.4820	24920	1	7961	.4006	27861
Quadratic	1	21.4	1	.0286	986	1	1613	.0447	1712
Weaning age	1	1946.8**	1	.0189	1688014**	1	520044**	.0174	469942**
Residual	2511	59.0	2900	.0554	2149	1373	1422	.0535	3134
				Females					
Inbreeding of dam									
Linear	1	12.3	1	.2479	5486	1	2414	.2737	1266
Quadratic	1	32.6	1	.0000	3324	1	3435	.2801**	760
Inbreeding of calf									
Linear	1	181.7	1	.4487	19779	1	774	.0223	3612
Quadratic	1	.1	1	.0013	294	1	661	.0413	720
Weaning age	1	1204.7**	1	.0517	1584250**	1	69616**	.0268	59840**
Residual	2410	56.4	2779	.0448	1742	422	1386	.0371	2126

* P < .05
** P < .01
For significance of linear effects see Table 17.

Table 20. Partial Regression Coefficients for Linear and Quadratic Effects of Inbreeding on Growth Traits (Pooled Analyses, Model 4).

Source	Birth weight	Preweaning ADG[1]	Weaning weight	Initial test weight	Test ADG[1]	Final weight
			Males			
Inbreeding of dam						
Linear	.0019	-.2612	-.4562	-.0694	.0904	.0529
Quadratic	-.002031	-.022026**	-.041507**	-.030700	-.026384*	-.065514*
Inbreeding of calf						
Linear	-.0856	-.3098	-.7045	-.6049	-.4291	-1.1317
Quadratic	-.001241	.003836	.007125	.014120	.007428	.014545
Weaning age	-.0594**	-.0172	1.6208**	1.4132**	-.0258	1.3434**
			Females			
Inbreeding of dam						
Linear	.0186	-.2494	-.3709	1.1269	1.1999	.8160
Quadratic	-.002005	.000023	-.017041	-.099719	-.090042	-.046916
Inbreeding of calf						
Linear	-.0676	-.3072	-.6449	-.3610	-.1940	-.7801
Quadratic	.000069	.000628	-.002933	.024000	-.018977	.025040
Weaning age	-.0493**	.0292	1.6172**	.7769**	-.0482	.7203**

1 x 10^{-2}
* P < .05
** P < .01
For significance of linear regression coefficients see Table 18.

Table 21. Partial Regressions on Inbreeding of Calf and Dam for Growth Traits by Line (Model 5)

Line	Sex	Number	Birth weight Fc	Birth weight Fd	Preweaning ADG[1] Fc	Preweaning ADG[1] Fd	Weaning weight Fc	Weaning weight Fd	Number	Initial test weight Fc	Initial test weight Fd	Postweaning[1] ADG Fc	Postweaning[1] ADG Fd	Final weight Fc	Final weight Fd
Colorado															
Bonanza	M	24			1.522	2.185	3.145	4.731							
	F	27			-.889	-.499	-1.511	-.212							
Brae Arden	M	76			-.033	-.463	-.158	-1.076	53	-.437	1.212	1.065	2.755	1.188	4.687
	F	70			-1.179	.002	-1.644	.491							
Colorado	M	41			.118	-1.131	.173	-2.419							
	F	45			.171	-1.357	.405	-2.357							
Don	M	34			-1.149	-.421	-.986	-2.345							
	F	38			-.479	-.480	-1.133	.039							
Ft. Lewis	M	48			-2.122	.511	-4.685	1.551							
	F	28			-.074	.668	-3.550	3.010							
La Plata	M	25			1.519	.334	2.249	-.071							
	F	20			-1.741	-3.447	-3.308	-6.463							
Monarch	M	46			-1.304	2.372	-1.836	3.165							
	F	40			1.254	-.066	2.959	-1.021							
Prospector	M	46			2.246**	-.817*	5.533**	-1.755*	34	1.962	-3.112	2.171	-.985	5.025	-4.356
	F	45			2.521	-.933	3.710	-2.688							
Royal	M	54			-.708	-.700	-.043	-2.242	43	-.144	.175	-.534	.597	-.655	.764
	F	67			1.143	-.814	1.124	-1.220							
San Juan	M	60			-1.284	-.811	-2.455	1.195	46	-.331	.828	-.099	1.198	-.148	1.947
	F	56			-.114	.400	.047	-.802							
Havre, Montana															
Line 1	M	114	-.014	.128	-.076	.397	-.071	.839							
	F	86	.027	-.052	.019	-.514	.418	-1.326							
Line 2	M	138	.067	.029	-.102	-.768*	-.217	-1.337							
	F	111	.403*	.696	-.271	-1.762*	-.026	-2.325							
Line 3	M	90	-.113	-.151	-.275	.316	-.798	.405							
	F	81	-.202	.550	.357	-2.204**	.557	-3.555*							
Miles City, Montana															
Line 1	M	1156	-.172**	-.064	-.255	-1.143**	-.728*	-2.129**	544	-.212	-1.121**	-.909**	-.030	-1.996**	-1.186
	F	1119	-.163**	-.003	-.228	-.553**	-.566	-.992**							
Line 2	M	148	-.107	.040	-.193	-1.386**	-.601	-2.205**							
	F	150	-.223	-.289*	-.232	-.710*	-.652	-1.438*							
Line 3	M	94	-.191	.427	-1.117	-.984	-2.405	-1.306							
	F	88	.245	.220	-.797	-.946**	-1.217	-1.440*							
Line 4	M	188	-.028	.044	-.092	-.617*	-.214	-1.048*	100	-.631	.033	-.197	-.361	-1.008	-.686
	F	169	-.077	.114	-.853**	.355	-1.698**	.791							
Line 5	M	114	.185	-.503**	.022	-1.167**	.317	-2.660**	53	-1.394	-.609	.792	1.544	.155	2.417
	F	128	-.374	-.241	-.291	-1.155**	-1.007	-2.211*							
Line 6	M	131	-.105	-.229	-.226	-.190	-.435	-.686	67	-.235	-.904	-.499	.466	-1.183	.022
	F	118	-.535**	-.112	-1.613**	.486	-3.404**	.652							
Line 7	M	46	-.618*	1.257**	-2.488*	.254	-5.259*	1.798							
	F	43	.059	-.304	-2.529**	.668	-4.711**	1.171							
Line 8	M	54	-.200	-.116	-1.529*	-1.047	-3.197*	-2.251							
	F	44	.083	.036	-.529	-.888	-.832	-1.732							
Line 9	M	155	-.064	-.024	-.237	-.381	-.482	-.737							
	F	152	-.030	.122	-.185	-.024	-.374	.109							
Line 10	M	126	.149	-.510*	-.320	-1.336	-.553	-2.772	76	-1.062	3.594	.947	-1.079	.789	1.483
	F	120	-.076	-.015	-.127	.349	-.348	.475*							

Table 21. Partial Regressions on Inbreeding of Calf and Dam for Growth Traits by Line (Model 5) (continued)

Line	Sex	Number	Birth weight		Preweaning ADG[1]		Weaning weight		Number	Initial test weight		Postweaning[1] ADG		Final weight	
			Fc	Fd	Fc	Fd	Fc	Fd		Fc	Fd	Fc	Fd	Fc	Fd
Miles City, Montana (cont.)															
Line 11	M	67	-.130	.184	-.791	-.645	-1.638	-.962	46	-1.336	-1.465	-.721	.308	-2.720	-.864
	F	57	.030	.021	-.489	-1.771**	-.868	-3.345**							
Line 12	M	108	.044	-.239	-1.473*	.208	-2.766*	.017	59	-1.871	1.213	-.310	.189	-2.468	1.594
	F	163	.212	-.008	-.314	-.537*	-.295	-.998*							
Line 14	M	100	-.125	.417	-.516	.250	-.951	.941	51	-1.645	3.590	-.702	-.315	-3.036	3.009
	F	127	-.081	-.083	-.197	-.564*	-.516	-1.100*							
Nevada															
Line 1	M	100			-.753	.473	-1.838	1.354	100	-2.043	1.880	-.156	.360	-2.240	2.363
	F	98			-.157	-1.253	-.490	-2.456	98	-.430	-2.400	.319	-1.485**	.005	-4.448**
Line 2	M	115			-.717	-2.093**	-1.800*	-5.146**	115	-2.026*	-5.399**	-.835*	-.598	-3.185**	-6.236*
	F	111			-.399	-.040	-.963	.076	111	-.419	.342	.214	-.500	-.108	-.342
Line 3	M	100			-1.323**	-1.541*	-3.047**	-3.354*	100	-3.232**	-3.486*	-.450	1.079	-3.869**	-1.983
	F	93			.068	-.874	.245	-1.972	93	.239	-1.838	-.648	.242	-.678	-1.495
Line 4	M	78			.131	.170	.075	.505	78	.298	.463	-.291	-.247	-.119	.131
	F	87			-.058	.197	-.135	.476	87	-.082	.577	-.487*	.171	-.760	.824
Line 5	M	107			-.263	.347	-.660	.803	107	-.255	.393	-.607	.459	-1.114	1.042
	F	96			-.293	-.767	-.597	-1.906	96	-.581	-1.122	-.432	.105	-1.179	-.980
Oregon															
Line 1	M	71	.272	.274	.681	-.784	1.462	-1.211	71	-.198	-.270	-.807	.695	-.305	.193
	F	73	.412	.061	-1.388*	1.379*	-2.232	2.560	73	-.194	-.075	-.641	1.722*	-1.183*	1.537**
Line 2	M	68	-.269	.249	-.182	-.856	-.451	-1.004	68	-.609*	-.824**	-1.232	2.052*	-.263	.276
	F	65	.063	.651**	-.777	.458	-1.917	1.533	65	-.290	.014	-.940	.454	-2.484*	.999
Line 3	M	60	-.069	.003	.160	-1.027*	.309	-1.924*	60	.349	-.226	-.874	.351	.078	-.214
	F	58	-.052	-.034	.686	-.824	1.266	-1.789	58	-.378*	-.088	-.406	-.627	.129	-.337
Angus	M	86	.263	-.340*	-.456	-.800	-.744	-1.596*	86	.315	-.179	-1.281	.090	-.434	-.289
	F	123	-.092	-.088	-.338	-.759	-.693	-1.589	123	.111	-.504*	-.123	.050	.048	-.359
Utah															
Line 1	M	183	-.338*	-.073	-1.970**	.352	-4.378**	.699	94	-1.104	-.225	-.724	-1.202	-3.159	-2.436
	F	165	-.109	-.002	-.392	-.418	-.908	-.760							
Line 2	M	259	.017	-.185	-.178	.040	-.197	.102	135	-.854	.191	.401	-.263	-2.083*	-.863
	F	239	-.055	-.207*	-.537**	-.365	-.994**	-.775							
Line 3	M	193	-.103	.094	.058	-.221	.051	-.377	104	.939	.735	.126	.724	1.370	1.969
	F	173	-.109	-.030	-.416	-.405	-.902	-.985							
Wyoming															
Brae Arden	M	157	.015	-.111	-.709**	.082	-1.268*	.001	156	-1.165*	-.296	-.062	.454	-1.270	.472
	F	144	.066	-.037	-.337	.617*	-.485	1.092*	144	-.908	1.644**	-.021	.029	-.943	1.698*

[1] $\times 10^{-2}$

* $P < .05$

** $P < .01$

Table 22. Significance and Variability in Response to Inbreeding for Growth Traits by Line

Trait		Sex	Total regressions number	Significant regressions number	Significant regressions percent	Favorable regressions number	Favorable regressions percent	Unfavorable regressions number	Unfavorable regressions percent
Birth weight	Fc	M	24	3	13	8	33	16	67
		F	24	3[a]	13	10	42	14	58
	Fd	M	24	4[a]	17	12	50	12	50
		F	24	3[a]	13	9	38	15	62
Preweaning ADG	Fc	M	39	7[a]	18	9	23	30	77
		F	39	5	13	8	21	31	79
	Fd	M	39	9	23	15	38	24	62
		F	39	11[b]	28	11	28	28	72
Weaning weight	Fc	M	39	9[a]	23	11	28	28	72
		F	39	4	10	9	23	30	77
	Fd	M	39	9	23	15	38	24	62
		F	39	10[b]	26	13	33	26	67
Initial weight	Fc	M	25	4	16	5	20	20	80
		F	10	1	10	2	20	8	80
	Fd	M	25	4	16	12	48	13	52
		F	10	2[a]	20	4	40	6	60
Test ADG	Fc	M	25	2	8	6	24	19	76
		F	10	1	10	2	20	8	80
	Fd	M	25	1[a]	4	16	64	9	36
		F	10	2[a]	20	7	70	3	30
Final weight	Fc	M	25	4	16	6	24	19	76
		F	10	2	20	3	30	7	70
	Fd	M	25	1	4	15	60	10	40
		F	10	3[b]	30	4	40	6	60

[a] 1 Favorable

[b] 2 Favorable

Table 23. Partial Regressions (Linear and Quadratic) on Inbreeding of Calf and Dam for Growth Traits by Line

Line	Sex	Birth weight Fc L	Birth weight Fc Q1	Birth weight Fd L	Birth weight Fd Q1	Preweaning ADG Fc L1	Preweaning ADG Fc Q2	Preweaning ADG Fd L	Preweaning ADG Fd Q1	Weaning weight Fc L	Weaning weight Fc Q1	Weaning weight Fd L1	Weaning weight Fd Q2	Test ADG Fc L1	Test ADG Fc Q2	Test ADG Fd L1	Test ADG Fd Q2	Final weight Fc L	Final weight Fc Q1	Final weight Fd L	Final weight Fd Q1
California																					
Line 1	M					.026	-3.193	-.088	1.306	-.432	-7.273	-.019	.262								
	F					-.097	-2.641	-.501	.493	-.178	-7.250	-.502	-1.518								
Colorado																					
Line 3	M					-.883	-12.388	-.251	-3.831	-.416	-4.314	-.376	-11.713*								
	F					.051	-3.669	-.972	-2.087	.296	-19.724	-3.072	-7.548								
Line 4	M					1.417	-11.979	-2.892	-3.299	1.666	-9.413	-4.985	-10.204								
	F					.518	1.965	-.894	5.797	1.178	4.260	-1.635	7.791								
Line 5	M					1.379	9.104	-1.574	-7.074	.512	8.215	-1.641	-10.098								
	F					.207	-9.957	-.459	-.429	-1.923	24.319	-3.137	-9.870								
Line 6	M					.425	.796	3.998	-14.522	-5.402	-5.646	10.665	-25.908								
	F					-2.115	-.811	1.625	-2.821	-4.639	-1.887	2.792	-2.900								
Line 7																					
	F					1.017	7.673	.169	-21.411	3.219	-11.014	-1.950	-38.313								
Line 9	M					1.118	20.262	-3.576	-28.982	2.220	-6.231	1.270	19.598								
	F					.363	-11.186	6.405	-33.635	.219	-13.354	9.413	-54.226								
Line 10	M					1.835	2.845	-.915	7.705	3.962	11.747	-2.952	18.650								
	F					2.376	3.737	-.934	1.998	5.344	-17.034	-2.256	12.824								
Line 11	M					1.408	5.186	-.573	-1.393	1.387	4.764	-1.565	1.591								
	F					-1.117	-3.005	-.636	-2.108	-.493	-7.084	-1.921	-1.898								
Line 12	M					.005	-3.184	.060	2.114	-.144	1.929	-.244	-3.099								
	F					-2.405	10.765	-.972	2.591	-7.114	48.882**	5.335	-28.213**								
Havre, Montana																					
Line 1	M	.127	-1.621	-.008	1.804	.092	-2.453	.347	-.081	.386	-6.257	.557	2.715	-1.837	19.315**	.639	-1.599	-1.509	5.769	.626	-.458
	F	-.142	1.965	.004	-.107	.774	-9.981	-.412	-4.250	1.663	-15.633	-1.176	-8.068								
Line 2	M	.038	.428	.002	.081	-.534	6.494*	-1.265	1.823	-1.033	11.688*	-2.495	5.388	.679	6.721	4.941	-25.837**	-.102	12.226	6.034	-37.145*
	F	.305	1.552	.131	4.269	-.534	5.697	-.398	-13.617	-.555	10.638	-.380	-20.150								
Line 3	M	-.106	.500	-.154	-.067	-.060	2.733	-.790	6.679	-.393	6.798	-1.700	12.446	-.241	-1.337	1.129	-11.163	-.203	9.530	-.035	-10.017
	F	-.241	-1.722	.630	-.356	1.296	4.182	-4.503	20.816	.406	6.060	-8.180	41.503								
Miles City, Montana																					
Line 1	M	-.108	-.817	-.063	.028	-.107	-1.823	-1.134	-.135	-.367	-4.637	-2.067	-.721	-.911	-.021	.070	-2.523	-1.973	-.333	-1.079	-2.769
	F	-.155	-.106	.000	-.048	-.026	-2.235	-.764	4.017**	-.233	-4.062	-1.312	6.456**								
Line 2	M	-.090	.112	-.165	2.032	.384	-18.236**	.472	-16.076**	.457	-32.261**	.759	-25.133*								
	F	-.241	2.308	-.177	-1.943	-.226	-4.732	-.257	-4.053	-.663	-4.676	-.507	-9.665								
Line 3	M	-.125	-.534	1.590	-11.876	1.819	-17.942*	.929	-16.957	3.853	-36.783*	3.232	-41.111*								
	F	-1.271	5.767*	.491	-2.857	-2.187	5.070	1.483	-19.529**	-4.108	11.327	3.464	-39.221**								
Line 4	M	-.041	.560	.021	.352	-.323	4.407	-.460	-2.035	-.490	8.534	-.747	-3.785	-.231	.873	-.608	2.573	-1.308	6.053	.503	-12.031
	F	.049	-1.601*	.232	-1.153	-.929	1.482	.871	-7.710*	-1.755	1.650	1.933	-16.298*								
Line 5	M	.262	-.330	-.099	-5.159*	.042	2.435	-.176	-13.223*	.457	3.232	-.273	-30.431*	-.864	20.353	1.406	22.171	-2.273	30.729	3.321	4.105
	F	-.517	.987	-.556	3.846	-.591	3.423	-.901	-4.202	-1.788	7.285	-2.291	-.685								
Line 6	M	-.372	3.032**	.020	-2.780	.528	-4.840	-.800	14.820*	.678	-5.492	-1.544	22.599	-.918	-.882	.694	-9.659	-2.270	-4.327	.520	-27.262
	F	-.702	3.230**	.050	-3.964*	-1.548	1.879	.450	.566	-3.685	7.229	.874	-4.406								
Line 7	M	-.602	-.961	1.063	7.518	-2.205	1.717	-.562	38.027	-5.241	7.260	-.122	51.557								
	F	-.090	-8.185	-.148	11.335	-2.540	-6.246	.469	14.627	-4.925	-16.605	1.078	29.850								
Line 8	M	-.199	-.877	.277	-5.930	-1.410	9.691	-1.992	16.555	-3.084	16.062	-3.247	16.071								
	F	.029	5.073	.856	-15.290	-.579	1.468	-1.853	19.294	-1.090	9.678	-2.232	10.099								
Line 9	M	-.135	.996	.120	-1.422	-.196	-1.316	-.472	.909	-.433	-.994	-.728	-.032								
	F	-.142	1.650	.283	-1.812	-.237	-.509	.130	-2.090	-.561	.630	.551	-5.252								
Line 10	M	.189	-.434	-.348	-1.106	-.196	.638	-.876	-2.699	-.613	1.807	-2.071	-5.099	.920	2.929	-1.662	16.911	-.637	15.260	4.022	-18.861
	F	-.095	-1.154	-.218	3.390	.163	2.164	.661	-5.881	-.364	3.241	.725	-5.491								
Line 11	M	-.547	6.510	-.541	12.607*	-1.499	11.261	-1.570	13.061	-2.907	20.698	-2.865	31.361	-.589	-3.042	-.354	17.174	-5.481	33.635	-5.300	87.529
	F	.139	-2.427	-.023	2.426	-1.001	7.149	-2.169	17.719	-1.771	12.954	-4.407	41.435								
Line 12	M	-.052	1.396	-.153	-1.973	-1.992	9.788	.375	-3.768	-3.754	18.476	.364	-7.861	1.185	-13.796	-.347	7.727	1.021	-35.634	1.143	4.513
	F	.396	-2.584	.161	-2.289	-.113	-2.953	-.757	10.605**	.425	-8.734	-1.221	19.470**								
Line 14	M	-.181	.280	.650	-4.792	-1.000	4.858	4.078	-60.607**	-1.989	8.900	6.889	-94.705*	-1.017	7.432	-2.242	63.282	-4.031	17.585	.196	102.234
	F	-.133	.260	.039	-.464	.148	-4.849	.384	-3.779	.286	-9.614	.974	-8.186*								
Nevada																					
Line 1	M					-.845	1.346	1.741	-13.769	-2.197	4.596	5.349	-45.423	.499	-6.848	2.247	-25.768	-1.775	-4.031	8.663	-77.006
	F					-.356	.168	.369	-10.116	-.906	.713	.558	-18.695	.459	-3.241	.201	-9.382	-.236	-3.232	.578	-29.875
Line 2	M					-1.173	2.998	-4.909	24.843	-2.346	5.540	-10.161	46.382	-.339	-4.877	-6.116	53.656	-3.615	4.579	-24.110	168.928
	F					-.110	-4.487	-4.405	42.817	-.696	-8.128	-10.226	103.422	.272	-1.456	-1.591	11.170	-.207	-1.862	-15.190	145.408
Line 3	M					-2.123	8.602	-2.032	2.586	-4.836	19.236	-4.542	5.815	-.655	2.112	.068	5.842	-5.760	20.310	-3.462	7.464
	F					-1.365	16.527*	-.695	-1.933	-2.949	37.179*	-1.779	-3.442	-1.593	10.978*	.059	.250	-4.638	46.061**	-1.647	-2.199
Line 4	M					.628	-4.963	-.001	3.499	1.489	-13.260	-1.855	24.175	-.182	-.991	.237	-4.750	2.023	-19.968	-.729	9.661
	F					.437	-3.872	-.438	7.411	.826	-7.955	-.055	5.005	.508	-8.214*	-.971	12.092	.648	-11.631	-.702	16.061
Line 5	M					.371	-4.414	2.263	-11.665	.758	-9.872	5.302	-27.316	.171	-5.376	-.098	3.295	1.487	-18.029	3.286	-13.785
	F					-.477	1.541	-3.261	23.881	-.899	2.553	-8.248	61.042	-1.135	5.526	-5.645	55.192*	-2.351	9.383	-14.115	126.243

Table 23. Partial Regressions (Linear and Quadratic) on Inbreeding of Calf and Dam for Growth Traits by Line (continued)

Line	Sex	Birth weight				Preweaning ADG				Weaning weight				Test ADG				Final weight			
		Fc		Fd		Fc		Fd		Fc		Fd		Fc		Fd		Fc		Fd	
		L	Q^1	L	Q^1	L^1	Q^2	L	Q^1	L	Q^1	L^1	Q^2	L^1	Q^2	L^1	Q^2	L	Q^1	L	Q^1
Oregon																					
Line 1	M	.467	-2.966	.329	-.426	-1.413	19.436**	-.926	.951	.949	11.922	-3.315	11.683	-1.146	3.363	1.444	-3.817	-.375	.897	.249	-.259
	F	.377	-.154	.487	-5.318	-1.680	.406	2.028	-4.171	-2.534	2.797	3.937	-18.101	-.819	-.243	3.608	-23.663**	-1.445	2.182	2.876	-17.453*
Line 2	M	-.146	-3.344	.657	-6.107*	-.652	10.077	-1.108	10.426	-.096	-7.529	-1.075	1.806	-1.125	-4.886	3.605	-23.925*	-.141	-3.457	.778	-7.561
	F	.056	-.567	.325	4.594*	-.563	-1.897	-1.239	14.698	-1.930	-3.847	-.254	24.943	-.548	-11.119	.281	-1.308	-1.909	-17.326	.304	4.228
Line 3	M	-.025	-.404	-.036	1.347	-.274	2.758	-1.278	5.789	.030	2.498	-2.100	6.167	.103	-8.804	.629	-9.848	.367	-2.607*	-.190	-.873
	F	-.099	.529	.141	-2.140	.387	5.769	-.202	-8.863	.652	11.150	-.278	-19.464	-.558	-2.771	.751	-15.891	.117	-.723	-.139	-2.235
Angus	M	.127	1.024	-.734	4.373*	.492	-7.165	.325	-9.131	-.790	.895	-.467	-12.921	-2.713	12.662*	.262	-3.190	-.706	2.348	-.379	.792
	F	-.120	.424	-.173	1.584	.022	-1.696	-1.535	18.459	-.416	-2.205	-4.584	53.458**	.466	-8.381*	.428	-8.125	-.046	1.343	-.430	1.478
Utah																					
Line 1	M	-.423	.647	-.175	.562	-2.801	6.624	-.689	5.565	-6.489	15.872	-1.471	12.019	.073	-4.477	-1.817	3.326	-5.183	12.696	-5.310	17.095
	F	.136	-1.753	-.015	.031	-2.105	12.616*	-1.071	4.182	-3.920	22.238*	-2.103	8.672								
Line 2	M	-.039	.144	-.051	-1.160	-.611	1.207	.724	-6.357	-1.217	2.719	1.950	-14.542*	.193	.563	-.828	5.109	-5.369	7.946**	.061	-3.805
	F	-.059	.010	-.192	-.153	-.969	.836	-.587	1.838	-1.561	1.117	-.665	-.963								
Line 3	M	-.034	-.621	.110	-.113	-.622	6.018	-.646	2.986	-1.393	12.971	-1.335	6.517	1.144	-7.764	-.223	7.083	.049	9.556	-2.517	34.990
	F	-.252	.931	-.278	1.387	-.051	-3.775	-.277	-.113	-.426	-5.844	-1.038*	1.186								
Wyoming																					
Line 1	M	.091	-1.030	.166	-4.490	-.857	1.056	-.394	7.567	-1.294	.409	-.062	.996	.261	-1.151	1.226	-15.481	.040	-6.670	-.153	-2.040
	F	.070	.183	-.065	.454	.002	11.212**	1.336	-16.030	.158	18.637**	2.362	-27.730	.053	2.618	-.094	1.505	-.280	20.715	2.110	-12.910

^{1} x 10^{-2} ^{2} x 10^{-4} * $P < .05$ ** $P < .01$

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