EFFECTS OF INBREEDING AND ESTIMATION OF GENETIC PROGRESS UPON PREWEANING TRAITS IN BEEF CATTLE

by

JUAN CARLOS SCARSI

Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Animal Science
(Animal Breeding)

APPROVED:

R. C. Carter, Chairman

K. Hinkelmann

P. B. Siegel

J. A. Gaines

K. P. Bovard

G. W. Litton

M. B. Wise, Dept. Head

June, 1971

Blacksburg, Virginia

ACKNOWLEDGEMENTS

The author is sincerely indebted to many persons who have contributed to this investigation. He is particularly grateful to his graduate committee for their assistance and cooperation. He wishes to express special appreciation to his major professor, Dr. Robert C. Carter, for the opportunity of making this study, guidance during the graduate program, counsel and encouragement offered during numerous personal conferences. The author is also grateful to Dr. James A. Gaines, who reviewed the manuscript and offered many valuable suggestions. He is also indebted to Dr. K. Hinkelmann, Professor of Statistics for the assistance with the statistical analysis of the data. Special gratitude is expressed to Dr. Paul A. Putman, Chief, Beef Cattle Research Branch, Animal Science Research Division, A.R.S., U.S.D.A., Beltsville, Maryland; to Dr. Will T. Butts, Jr., Investigations Leader of the S-10 Technical Committee; and to of the Beef Cattle Research Station, Front Royal, Va., for granting permission to use data from the Front Royal Station. Gratitude is also expressed to Prof. G. W. Litton, Dr. P. B. Siegel and Dr. K. P. Bovard for guidance and assistance during this study. The author is very grateful to the Project F.E.N.U. 121 of the United Nations with Centro Investigaciones Agricolas "A. Boerger" La Estanzuela who granted the author's fellowship and made possible his graduate studies. Finally, the author wishes to express his gratitude to for her assistance with the preparation and typing of this dissertation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

It is important from a practical and theoretical point of view, to have a more accurate evaluation of the effects of inbreeding on economic traits of beef cattle.

Purebred breeders using inbreeding can increase prepotency, improve accuracy in measuring selection traits and have the possibility of avoiding the introduction of genetic defects with the use of closed herds. However, if the effects of inbreeding are harmful, the cost of maintenance of the inbred stock might be prohibitive.

After the earlier results of inbreeding experiments with rats and guinea pigs and the development of inbred lines of swine, several experiment stations started to develop inbred lines in beef cattle. In general, the information reported in the literature indicates that inbreeding adversely affects growth and other economic traits. However, the information available on the magnitude of the inbreeding effects on such traits is limited. Also, it is rather difficult to interpret, because the amount of inbreeding is confounded with years.

The extent to which selection within inbred lines has been effective in preventing inbreeding depression was evaluated in several species with different results. Dickerson _et al_. (1954) analyzed the effect of selection on litter size and growth rate in 49 inbred lines of swine from five different projects and concluded that selection within inbred lines had been ineffective. King (1918) working with albino rats showed that the closest form of inbreeding possible in mammals does not necessarily produce animals that are below normal body size. Wright (1920) suggested that the increase of unfavorable characteristics can be prevented to some extent by sufficiently careful selection. Bell et al. (1955) suggested that selection pressure during the inbreeding process in Drosophila can reduce the expected inbreeding depression. Lush et al. (1949) assumed that inbreeding reduces performance because of the increase in proportion of homozygous recessive individuals and careful selection might prevent much of the inbreeding depression if the rate of inbreeding was slow.

Although many inbred lines of beef cattle have been developed, very few reports are available establishing the inbreeding effects upon each line separately, or the effectiveness of selection practiced during the inbreeding process.

REVIEW OF LITERATURE

Effects of Inbreeding on Preweaning Traits

The fact that both inbreeding of the calf and inbreeding of the dam affect the preweaning performance of the calf is supported by several research reports.

In general, it has been shown that birth weight, average daily gain, weaning weight and weaning score decrease as the coefficients of inbreeding of both the calf and the dam increase. However, the magnitude of this effect varies noticeably from one report to another.

Differences between cattle populations used in each experimental work, level of inbreeding reached, selection practiced during the experimental process and the statistical analysis used for evaluating the experimental results, can explain some of the discrepancies among the reports.

Burgess, Landblom and Stonaker (1954) studied the effect of inbreeding of the calf and the dam on weaning weight of 546 conventional type Hereford calves during 1946-51 in Colorado. The coefficients of inbreeding ranged from 0 to 50% and 0 to 40% for calves and dams, respectively. However, 61% of the calves and 81% of the dams involved in the experiment were in the range of 0 to 10% of inbreeding. The partial regression coefficients of weaning weight on inbreeding of the calf and of the dam estimated within year, age of dam and sex subclasses, were -1.76 and -1.15 lbs., respectively, per one percent increase in inbreeding. There was a significant deviation from linearity for the inbreeding effect of the calf but not for the dam.

Koch (1951) reported partial regression coefficients within year and sex subclasses of weaning weight on inbreeding of calf and dam of -.480 and -2.540, respectively, for one percent increase in inbreeding. The data were from 745 Hereford calves from 180 cows having 2 or more calves during 1938-1948 at Miles City, Montana. The calves involved in the experiment were heifers, steers and bulls, and the mean coefficient of inbreeding for calves and dams was 12.4% and 5.9%, respectively.

Stonaker (1954) studied records from contemporary inbred and outbred progeny born in 1951, 1952 and 1953 at Colorado. The analysis included 284 matings within 12 inbred lines and concurrently 275 matings of their same sires with unrelated, outbred females. The inbreeding coefficients of calves, dams and outbred animals were 30%, 20% and 5%, respectively. Outbred matings exceeded inbred matings by 30% in number of calves raised to weaning and 18% in average weaning weight.

Swiger, Gregory, Koch and Arthaud (1961) investigated the effects of inbreeding on preweaning and postweaning traits with 283 calves raised at Lincoln and 677 at the Fort Robinson Experimental Stations in Nebraska during 1951 through 1955. Two inbred lines of Hereford and one each of Angus and Shorthorn were involved in the experiment. The coefficients of inbreeding for the population at Lincoln were 13% and 10% for calves and dams, respectively. At Fort Robinson the coefficients were 5% and 3% for calves and dams, respectively. Prior to estimating the regressions of each trait on inbreeding of calf and dam, the data were adjusted for differences due to sex effects. The regressions were computed within year-line-age of dam subclasses. For birth weight they found -0.38, -0.03; -0.06 and 0.13 (lbs) per one percent increase in inbreeding of calf and dam at Lincoln and Fort Robinson, respectively. For preweaning daily gain the comparable values were -0.0058, -0.0006, and 0.0000, -0.005 for inbreeding of the calf and dam at Lincoln and Fort Robinson. For weaning weight they were -1.42, -0.15 and -0.05, 0.04 for inbreeding of the calf and dam in each locality, respectively. The average birth weight, daily gain and weaning weight in pounds in each locality were: 71.2 and 74.2; 1.69 and 1.49; 409 and 372. The authors concluded that in general calves with higher than average inbreeding coefficient were below average in performance for the traits studied. The inbreeding effects computed in each locality were not in agreement. The standard errors of the coefficients indicate that sampling variance could account for the discrepancies between stations in some cases, but were not likely in the others. The effect of inbreeding of the dam was negative for all traits at Lincoln but positive for most traits at Fort Robinson. The results at Fort Robinson could not be explained by any variable evaluated in the study and were attributed to chance.

Hoornbeek and Bogart (1966) studied selection and inbreeding in 3 closed Hereford lines and 1 Angus line in Oregon during 1951 to 1962, and found that for preweaning daily gain, the lower percentages of inbreeding were associated with higher suckling gains for both males and females. In postweaning period, mildly inbred calves gain more rapidly than nonbred calves, but there was an indication of decreasing performance as inbreeding increased. Non-inbred dams in the Hereford lines had calves with a higher suckling gain than inbred dams. Male calves in the Angus line did not show the decline in suckling gains associated with inbreeding of dam. On the contrary, Angus females showed a marked decline.

Dinkel, Busch, Minyard and Trevillyan (1968) reported the results of an experiment initiated in 1952 in South Dakota. They analyzed data from 860 Hereford calves from four inbred lines of one sire each. The analysis also included information from a control line started in 1955 as a four-sire line. The selection practiced on all lines was based on net merit index, in which conformation, rate of gain and weaning weight received equal weight. Inbreeding effects were studied separately for each sex under two mating systems: a) all inbred calves from inbred lines, and b) non-inbred calves from the control line. The average inbreeding coefficients of calf and dam were 20%, 9%; 3% and 1% for each mating system, respectively. They reached different levels of inbreeding in their inbred lines, ranging from an average of 23% to 13% in the highest and lowest line, respectively, for inbreeding of calf. The partial linear regression coefficients within year-line-sire subclasses for weaning weight and weaning score of bulls on inbreeding were -.612 and -0.0256 which were significant at the levels of 5% and 1%, respectively. The effect of inbreeding of calf estimated in females was significant only for weaning score. The effect of inbreeding of the dam was not significant for bull calves, but it was significant at the 1% level of probability for weaning weight and weaning score in females, with regressions of -0.7312 and -0.0247 per one percent increase in inbreeding. They also fitted linear and quadratic regressions of the traits on inbreeding of calf and dam. The quadratic effect was significant for both traits in bulls but only for weaning weight of females. The effects of inbreeding of calf and inbreeding of dam were more important in preweaning than in post-weaning traits.

Brinks, Clark and Kieffer (1965) presented the results of performance measured in the Montana Hereford Line 1 from the time that the line was founded in 1933 through 1959, including records of 2,027 calves. The bulls used in the line were selected on the basis of weaning weight and score, performance during a 196-day postweaning test, and in most instances progeny tests. Selection among females was practiced on the basis of 18-month weight and score, fertility, age and production as measured by the weaning weights of their calves. The mean inbreeding of the calves was 16.1, and it was 11.7 for the dams. They found that in general inbreeding of the calf and inbreeding of the dam had a marked detrimental effect on the birth and weaning traits. Inbreeding of the calf had a more pronounced effect on females than on males. The partial regressions were over three times as large for the females as the males for birth weight, preweaning gain and weaning weight. In contrast, inbreeding of the dams had a more detrimental effect on preweaning gain, weaning weight and weaning score of bulls than of heifers. The authors explained that the difference may have been due to the bulls having a greater growth potential that was probably held back more than heifers by the decreased milk supply that is associated with increased inbreeding of dam. Inbreeding of dam showed a negligible effect on birth weight for both sexes and the partial regression coefficients were slightly positive.

No reference was found in the literature about the effect of inbreeding on the milk production of beef cows. However, several authors have studied the effect of inbreeding on milk and butterfat production with dairy herds.

Von Krosigk and Lush (1958) reported the results of intrasire regressions with data collected over a 25-year period in the Iowa State

University dairy herd. Inbreeding of the cows ranged from 0 to 34% with an average of 7.4%. The 534 records available were standardized to a 305-day-2x-ME base. They found that for each one percent increase in inbreeding, butterfat and milk production decreased -1.74 ± 0.57 lb. and -54 ± 17 lb., respectively. There was no evidence of curvilinearity in the effect of inbreeding.

Tyler *et al*. (1949) compared growth and production of inbred and outbred Holstein-Fresian cows. Using 89 records, the estimated coefficients for the intrasire regression of milk and butterfat on inbreeding were -73.8 and -2.32 per 1% of increase in inbreeding, respectively.

The effects of inbreeding on production traits have been evaluated in other species of livestock.

Dickerson *et al*. (1954) investigated the effects of inbreeding on several traits in 38 lines developed at seven of the state experimental stations cooperating in the Regional Swine Breeding Laboratory during 1932 through 1948. The average inbreeding coefficient for all litters was 24%. Inbreeding increased at the rate of 2 to 4 percent per year within lines. The consequences of the inbreeding rise were estimated from intra-season paired comparisons of linecrosses with the parent inbred line. The estimates of change per 10% of inbreeding of litter were 0.02, 0.08, 0.03 and -3.44 pounds in weight per pig at birth, 21, 56 and 154 days of age. The analysis of data from 12 lines during 9 years at the Iowa Station showed that line differences in rate of decline in litter size and litter weight at 154 days of age with inbreeding of litter were less than expected considering sampling error. There was no indication of curvilinear regression on inbreeding.

Bereskin et al. (1970) using 3,389 records of first-parity litters farrowed from 1944 through 1958 at seven Minnesota Experimental Stations observed that inbreeding of litter had a significantly depressing effect on birth weight and weaning weight. Significant curvilinear effects were also found for both traits. Inbreeding of the dam significantly affected birth weight but not weaning weight. They concluded that inbreeding of the dam had a larger effect on litter traits at birth, and inbreeding of litter had more importance for post-farrowing litter traits.

Wright (1929) published the results of a study with inbred families of guinea pigs. He found that after 12 generations of brother-sister mating five strains of guinea pigs were below the average of the control stock in weight, fecundity and vitality of young. There was also a marked differentiation between the lines in these traits. During the following nine years no more decline was observed in the comparisons with the control stock. Genetic differentiation between inbred strains remained during the second period of nine years. With regard to weight, each strain differed significantly from every other strain; however, year trends were not different. The averages fluctuated in almost perfect parallelism as conditions changed from year to year.

Genetic Progress

Only a few workers have evaluated the response to selection in livestock populations. This situation is largely due to the experimental design of most such experiments with large animals. Because of lack of proper control populations or other suitable experimental design it was not possible to determine the amount of the total change due to genetic changes, environmental trends and the effects of inbreeding.

Dickerson (1960) proposed a control population for selection experiments with cattle, sheep and swine where the comparison desired is between response to a given selection program and progress in the breed as a whole. A "control" population representative of the whole breed could be maintained under the same environment as the experimental strain by outcrossing the control herd or flock each year to a fresh sample of sires from breeders herds.

Goodwin, Dickerson and Lamoureux (1960) designed an experimental model based on the replication of generations of progeny from the same parents or grandparents. This approach avoids the assumption that there is no genetic change from relaxed selection, natural selection, inbreeding or random drift. The progenies of unselected repeated matings in successive years have identical expected genotypic means within the limits of Mendelian sampling. This procedure requires the assumption that there is no age change or any parental influence on progeny performance, such as direct maternal influence on nutritional or pathological environment of the young.

However, these procedures cannot be used with accumulated data from populations where no control comparison or planned repeat matings are available.

Smith (1962) attempted to measure genetic change using field records by comparing the change with time of the performance of successive progeny groups of individual sires, with the change in the whole population. The change in the population with time is taken as $t + g$, where t represents environment change and g represents genetic change, while the within sire change is taken as $t + \frac{1}{2} g$. The method was applied to a set of pig records collected over nine years. There was a considerable change with time for age at slaughter, carcass weight, dressing out percentage, carcass length, shoulder fat depth and mid-back fat depth. The last three traits showed a substantial genetic change.

Flower, Brinks, Urick and Willson (1964) evaluated the selection intensity in three closed lines of Hereford cattle. The intensity of selection was defined as the annual selection differential or the average performance of the animals used as parents minus the average performance of the group of animals in which they were born. For preweaning traits the selection differentials were computed on both sires and dams; the resulting selection intensity was greater on the male side. Phenotypic response was measured by the regression of the annual means of traits on years. Environmental changes were estimated using repeat mating. The genetic progress estimated was positive and ranged from 2.16 lb. to 6.51 lb., for weaning weight. For birth weight the values were between -0.04 to 1.71 between lines and crosslines. These estimates were larger than the expected ones.

Brinks, Clark and Kieffer (1965) presented evidence of the genetic progress obtained from selection procedures applied in the development of the Hereford Montana Line 1. Using the repeat mating technique for estimating the environment trends they reported a genetic progress per year of 0.4, 0.87 and 1.23 for birth weight, gain from birth to 180 days of age, and weaning weight and 0.3 point of weaning score, respectively. They concluded that these results indicate that a long term breeding program, combining intense selection and mild inbreeding in a fairly large closed line, should be beneficial in improving the genetic merit of traits associated with growth.

Alexander and Bogart (1961) analyzed data from 280 calves in an experiment combining inbreeding and selection in Oregon during 1952-57. They used three closed lines of Hereford and one of Angus. They found no evidence of a reduction in birth weight, and none in postweaning rate of gain and feed economy during the postweaning performance test, due to inbreeding of the calf. They interpreted this as being due to the compensation of selection for the expected inbreeding depression. On the contrary, however, they found a depressing effect of inbreeding on suckling gain, and an increase in age at 500 and 800 lbs.

Hoornbeek and Bogart (1966) gave a later report of the same experiment. They showed that the Angus line has had a greater and more continued improvement in all traits than any of the three Hereford lines. The general pattern for performance levels of the traits was a marked improvement at first, followed by a plateau, after which there was a decline.

Working with another livestock species Dickerson *et al.* (1954) evaluated selection in developing inbred lines of swine. The effectiveness of selection was studied in data from Iowa, Minnesota, Missouri, Nebraska and Oklahoma using time trends of performance within lines. After removing expected effects of inbreeding they found that selection during development of mildly inbred lines failed to improve measurably the genetic merit of the traits associated with growth and litter size.

King (1918) working with albino rats during fifteen generations of brother-sister mating showed that the closest form of inbreeding possible in mammals does not necessarily produce animals that are below normal body size. The lack of depression due to inbreeding was explained to be due to the use of a strain of animals that seemingly had no inherent defects and by a careful selection of breeding stock.

OBJECTIVES

The objectives of this study were: 1) to study the effects of inbreeding on birth weight, weaning weight, daily gain from birth to weaning and type score at weaning; and 2) to determine the genetic progress in each line of each breed obtained with the selection practiced.

EXPERIMENTAL PROCEDURE

Nature of the Data

Data used in this study were collected in the Aberdeen Angus, Hereford and Shorthorn experimental beef cattle herds at the Beef Cattle Research Station, Front Royal, Virginia.

Beef cattle breeding research was initiated at the Front Royal Station in 1949 in a cooperative project between the Animal Husbandry Department of the Virginia Agricultural Experiment Station and the Animal Husbandry Research Division, Agricultural Research Service, United States Department of Agriculture (U.S.D.A.). This project is a part of the Southern Regional Beef Cattle Breeding Project, S-10, and the National Beef Cattle Breeding Program.

The experimental herds were formed with cattle from different sources over a period of years. In 1949 the Beef Shorthorn herd of approximately 125 head was transferred by the Animal Husbandry Research Division (U.S.D.A.) from Beltsville, Maryland, to Front Royal as the foundation herd of Shorthorn for the project. This herd was established at Beltsville prior to 1930 and for the last 10 years had been kept as a closed herd with linebreeding towards two foundation sires called SNI-A-BAR and Calrossie Lord Rothes. As a consequence, the coefficient of relationship for this particular herd was higher than the others purchased from different sources. The Angus and Hereford herds were established from a wider foundation. A number of head were transferred from the Blacksburg, Virginia herds of the Virginia Agricultural Experiment Station; others were obtained by purchase or lease from a number of purebred herds in Virginia and adjoining states.

The herds of the three breeds were involved in a project designed to compare two major breeding systems with the objective of genetic improvement in traits of economic importance. The two breeding systems were: 1) inbreeding with eventual crossing among the inbred lines, and 2) single traits mass selection. Bovard and Priode (1963) defined the objectives of the selection experiment as: 1) to determine the rate of change in the trait being selected, and 2) to determine correlated changes, if any, in other characteristics ignored in selection.

Four inbred lines were formed in each breed. The initial plan was to develop five inbred lines, but for various practical reasons one line was eliminated in each breed. The inbred lines in the Aberdeen Angus breed are designated as A-1, A-2, A-3, and A-4; in the Hereford breed, H-2, H-3, H-4, and H-5; and in the Shorthorns, S-1, S-2, S-4, and S-5. Two single trait selection lines were formed in the Aberdeen Angus and Shorthorns and three in the Hereford breed. In each of the three breeds there was one line in which the selection was based on type or conformation score alone, designated as line 7 (A-7, H-7, S-7); and one line based on selection for growth rate, designated as line 8. In addition, in the Hereford breed, one line was based on index selection giving equal weight to growth rate and type, designated as H-6.

The foundation bulls were selected by a committee composed of representatives of the two cooperating institutions. The criteria applied was on the basis of their individual performance, or in some cases when data were available, progeny performance, considering growth and conformation. In tables I, II and III are presented the average daily gain and type score for each of the selected foundation bulls through 1961 (Bovard

TABLE I. FOUNDATION SIRES IN ABERDEEN ANGUS INBRED LINES

Line	A-1	A-2	A-3	A-4
Sire	K. B. EILEENMERE 21	ROCK DELUS	BLACKCAP Stamp of Elkton 2	BLACKWOOD Bandy of F R 4
Birth date	May 6, 1948	Dec. 9, 1950	May 4, 1950	March 4, 1952
Performance record				
Average daily gain		2.21	2.56	2.40
Type score		14.2	13.8	13.0
Progeny record				
Number	63	106	84	93
Average daily gain	1.81	1.66	1.66	1.63
Type score	12.0	11.4	11.1	10.8

TABLE II. FOUNDATION SIRES IN HEREFORD INBRED LINES

Line	H-2	H-3	H-4	H-5
Sire	R. F. PERFECT Domino 62	Coastal Beau Rollo 9	N.P.C. Mc. Henry 6497	DOMINION Silver
Birth date	March 2, 1953	Feb. 15, 1951	Sept. 19, 1956	Jan. 8, 1960
Performance record				
Average daily gain	1.88			3.16
Type score	14.5			13.6
Progeny record				
Number	92	94	92	
Average daily gain	1.64	1.69	1.64	
Type score	11.4	10.5	11.6	

TABLE III. FOUNDATION SIRES IN SHORTHORN INBRED LINES

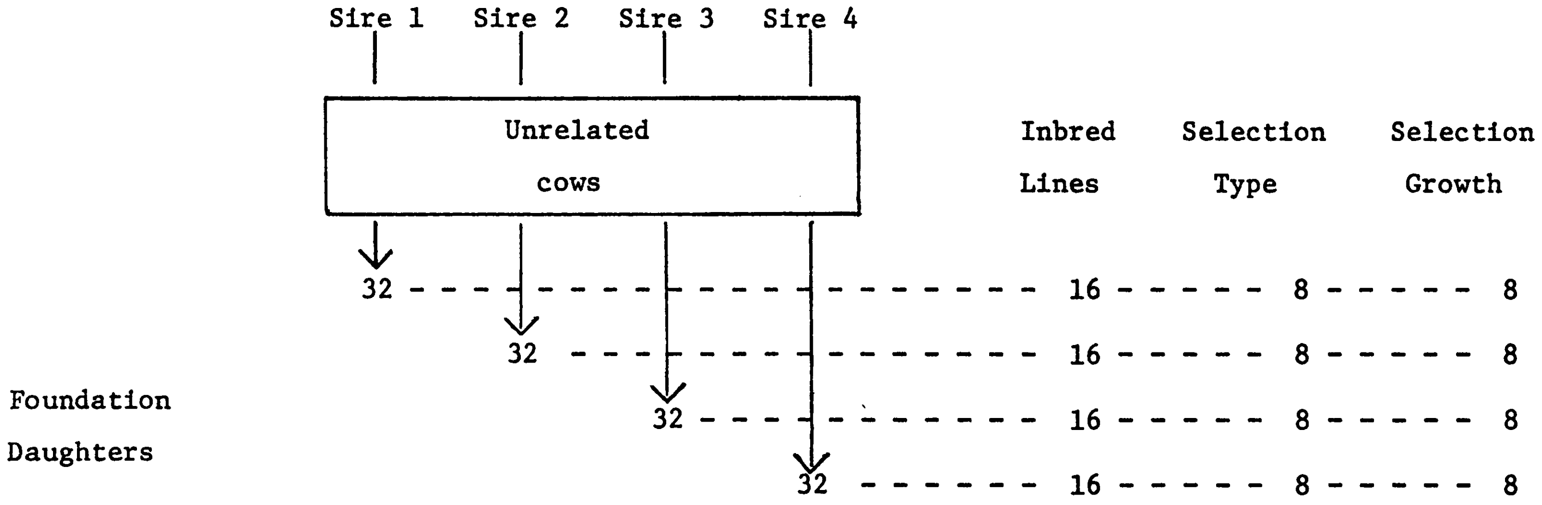
Line	S-1	S-2	S-4	S-5
Sire	WAVERLEY'S Statesman	BARON Kinsman	BRITOMAC Prince Command	PRINCE ERIC
Birth date	March 12, 1945	July 2, 1947	Jan. 10, 1952	March 27, 1951
Performance record				
Average daily gain			2.03	2.25
Type score			15.3	13.8
Progeny record				
Number	11	40	63	107
Average daily gain	1.33	1.46	1.50	1.47
Type score	8.6	10.4	11.5	10.8

and Priode, 1963).

A scheme of the experimental plan used for establishing the different lines in each breed is illustrated in figure 1. Each foundation sire was mated to enough unrelated cows to produce 32 foundation daughters. A random sample of 16 foundation daughters was placed in the corresponding inbred line and the other 16 were randomized equally to each selection line. In the Hereford breed 40 daughters by each foundation sire were used.

Replacement of the females for the selection lines came from females born within the lines. Initial selection was based on the respective criteria for the line, type, growth rate or index, but little culling was done on the young females themselves. Most were placed in the line. The principal culling of females was based on the performance of their progeny with respect to the proper selection criteria of the line, growth, type or index, or for reproductive performance. Bulls for the selection lines were chosen after a postweaning performance feeding test. Each year from 12 to 20 bull calves of each breed were selected at weaning and placed on a feeding test of 168 days. These bull calves came from all the Front Royal breeding lines and, in addition, a few bull calves were purchased each year from private breeders. At the end of the test the bull of each breed with the fastest growth rate, combining both preweaning and postweaning gains, was selected to go into the growth line of his breed. Similarly the bull with the highest type score or the highest index was chosen for the type or index herd. Each bull so chosen remained in the selection herd for two years being bred to approximately one-half of the females each year.

FIGURE 1. EXPERIMENTAL PLAN



The same scheme was applied in Angus and Shorthorn breeds. In Hereford, 40 foundation daughters were produced by each foundation bull.

Replacement for the inbred herds, both male and female, was exclusively from animals born within the proper line. Selection in the inbred lines was based on the index combining both growth and type. Consideration was also given to selection of replacements that would maximize the rate of increase in inbreeding.

Thirty separate breeding permanent pastures were available for the breeding herds during the mating season. Each year the cows were assigned to the bulls within the line at random. Calving season was primarily spring. Due to an infection of vibriosis it was necessary to use artificial insemination during the years 1959 and 1960. Cattle of similar age and sex were managed as nearly alike as possible and the feeding practices were similar to the commercial herds in the Appalachian Region.

Description of Data

Complete records, birth to weaning, were available for analysis on 4,621 calves (bulls and heifers) born during the period 1950 through 1969. This figure does not include all calves born during this period. Several reasons such as stillbirths, deaths, some crossbreds and steer calves explain the eliminations. All the calf crop of the year 1960 was also eliminated because two different dates of weaning were used. A definite trend was not found between the weights of early and late weaned calves, thus, there was no justification for calculating adjustment factors for differences between the weaning dates. The number of calves that contributed to the analysis were: Aberdeen Angus, 1,571; Hereford, 1,737, and Shorthorn, 1,313.

All calves were weighed and identified at birth. At weaning time in October they were weighed again and graded according to their type and condition. During the first seven years of the experiment the calves were weaned one month older than in the following years. Due to a later breeding date in the more recent years, the calves were about one month younger at weaning. The overall weaning age for lines 7 and 8 in the three breeds was 196 days. The type and condition scores for each animal was the average of individual scores of a team composed of members of the Animal Husbandry Department of the Virginia Polytechnic Institute (V.P.I.) and of the Animal Husbandry Research Division, A.R.S., U. S. Department of Agriculture. The basis of the type scoring system was the Federal-State grade standards for feeder cattle. According to these standards four major grades were used as follows in descending order: fancy, choice, good, medium. Each animal was graded as being in the low, middle or high one-third of these grades. A numerical value was assigned to each grade division as follows: fancy = 17-16-15; choice = 14-13-12; good = 11-10-9; medium = 8-7-6.

Methods and Procedures

Four preweaning traits were considered in this study: birth weight, average daily gain, birth to weaning and 205-day weaning weight and type score at weaning. Weaning weights were adjusted to a 205-day basis by multiplying the average daily gain from birth to weaning by 205 and adding the birth weight.

Inbreeding of the calf and the dam was measured according to Wrights (1922) coefficient. Using this procedure the approximate calendar year to which foundation animals' pedigrees were traced was 1920 for Angus, 1930 for Herefords and 1910 for Shorthorns. Tables IV, V, and VI give means of inbreeding of calves and dams, by years for each line of the

TABLE IV. MEANS OF INBREEDING OF DAMS AND CALVES IN ABERDEEN ANGUS

Years	Inbreeding of Dams %				Inbreeding of Calves %			
	Lines				Lines			
	1	2	3	4	1	2	3	4
51	3				0			
52	1				0			
53	1	4	4		0	0	0	
54	0	0	3		0	0	0	
55	1	0	3	1	15	0	0	1
56	1		2	0	20		0	0
57	0	0	0	1	17	25	1	0
58	2	0	0	0	27	25	5	17
59	5	0	0	2	27	25	25	26
61	18	10	0	0	27	30	25	25
62	20	14	0	0	26	28	24	22
63	19	18	3	3	28	26	19	22
64	25	21	6	5	29	27	21	24
65	24	21	9	8	24	32	21	25
66	22	17	11	13	22	35	22	29
67	24	24	14	16	29	35	22	27
68	27	27	17	15	37	40	25	33
69	25	32	19	19	36	43	29	31

TABLE V. MEANS OF INBREEDING OF DAMS AND CALVES IN HEREFORD

	Inbreeding of Dams %				Inbreeding of Calves %			
	Lines				Lines			
Years	2	3	4	5	2	3	4	5
55	0				0			
56		0				0		
57	0	0			0	0		
58	2	0			2	0		
59	0	0	1		6	4	0	
61	0	0	0		19	25	0	
62	4		0	1	21		6	0
63	0	0	0	2	14	12	9	0
64	5	2	0	0	15	13	13	25
65	8	6	1	0	19	18	16	22
66	6	3	2	0	17	16	22	25
67	10	5	2	2	20	20	16	26
68	12	9	5	4	20	23	21	26
69	12	12	12	13	19	26	29	31

TABLE VI. MEANS OF INBREEDING OF DAMS AND CALVES IN SHORTHORN

Years	Inbreeding of Dams %				Inbreeding of Calves %			
	Lines				Lines			
	1	2	4	5	1	2	4	5
51	10	11			25	25		
52	9	9			24	16		
53	7	7			15	17		
54	8	11		9	22	16		0
55	10	17		5	23	25		0
56	11	16	3	8	24	28	0	0
57	14	16	7	7	28	27	0	0
58	13	20	11	2	29	29	0	14
59	17	27	0	2	34	32	20	17
61	18	23	0	4	31	31	25	27
62	26	27	3	0	38	35	24	24
63	23	26	6	3	40	36	24	26
64	29	33	10	9	38	42	29	24
65	32	29	9	7	44	35	30	24
66	28	32	19	0	41	37	29	20
67	36	33	19	16	49	40	38	25
68	38	34	28	26	50	42	38	28
69	35	34	31	22	47	47	40	29

three breeds. An inspection of these tables reveals that inbreeding of the calves and of the dams increased with years. It is also clear that there is a high degree of correlation between the inbreeding of the calves and the inbreeding of their dams. Since inbreeding increased with years there is also a negative correlation between age and the level of inbreeding of the dams.

Because of these relationships it is difficult to obtain estimates of environmental variations due to years and to ages of dams that are not confounded with inbreeding effects. Since lines 7 and 8 (Type and Growth selection lines) had negligible inbreeding, data from these lines were used to estimate the effect of age of cow on birth weight, average daily gain to weaning, 205-day adjusted weaning weight and weaning type score. These data were analyzed using the Least-Squares and Maximum Likelihood General Purpose Program (L.S.M.L.G.P.) of Harvey (1968). The following model was assumed:

$$Y_{ijklmn} = \mu + S_i + L_j + B_k + Y_l + A_m + (SB)_{ik} + (BA)_{km} + e_{ijklmn}$$

Y_{ijklmn} = is the single observed averaged daily gain, birth weight, weaning weight, type score of the calf.

μ = population mean.

S_i = the effect of i^{th} sex of calf expressed as a deviation from the overall mean μ, $i = 1, 2$.

L_j = the effect of j^{th} line of calf expressed as a deviation from the overall meal μ, $j = 1, 2$.

B_k = the effect of k^{th} breed of calf expressed as a deviation from the overall mean μ, $k = 1, 2, 3$.

Y_l = the effect of l^{th} year of calving expressed as a deviation from the overall mean μ, $l = 1 \ldots\ldots\ldots 19$.

A_m = the effect of m^{th} age of cow expressed as a deviation from the overall mean μ, $m = 2 \ldots\ldots\ldots 10$.

$(SB)_{ik}$ = the effect of the interaction of the i^{th} sex with k^{th} breed.

$(BA)_{km}$ = the effect of the interaction of the k^{th} breed with m^{th} age of dam.

e_{ijklmn} = the random error associated with each observation.

During the 1950 to 1960 period repeat matings were not planned but occurred randomly. However, in the type and growth lines of each breed (two sire lines), matings were repeated in two consecutive years wherever possible. Consequently, the number of full sibs available in that period increased sharply as is shown in table VII. The performance of the calves from repeat matings were adjusted to either a male or female sex basis, in order to estimate the year effects separately for each sex. Adjustment factors for sex were derived from Least Squares Analysis within breed and year with data already adjusted for differences in age of dams. The model included the effects of sex, lines and sex x lines interaction.

The performance of calves from line 7 (type selection line) should give best estimates of year variation with respect to growth rate and weights at standard ages. Inbreeding in these lines was negligible and no intentional selection was practiced for growth. The same should be true for calves with zero inbreeding from non-inbred dams. Year effects were estimated from each of these two sets of observations separately by Least Squares Analysis in each breed.

Linear and quadratic regressions of each trait on inbreeding of the calf and of the dam were estimated, using data adjusted for year differences in each sex separately. Two different models were used. The first included all the lines in each breed. The partial linear and quadratic

TABLE VII. NUMBERS OF REPEAT MATINGS (FULL SIBS) BY BREEDS

	Breeds		
Years	Angus	Hereford	Shorthorn
51-52	13		2
52-53	7	11	13
53-54	2	24	18
54-55	7	1	29
55-56	17	10	22
56-57	11	10	18
57-58	6	10	17
58-59	12	5	11
59-61	9	10	7
61-62	7	4	10
62-63	29	24	20
63-64	28	35	12
64-65	30	32	22
65-66	21	24	20
66-67	35	51	20
67-68	24	52	17
68-69	41	66	30

regression coefficients were obtained absorbing the effects of sires within line. In the second model the two regression coefficients were calculated separately for each line and sex within sire subclasses.

Phenotypic time trends were estimated for each line separately by regressing the unweighted means of the two sexes on years.

The environmental trends were obtained by adding and accumulating deviations between consecutive year to the base year 1952. The year deviations were those estimated from the repeat mating comparisons. The means for each trait for base year 1952 were the Least Squares means for that year.

Estimated genetic progress was obtained by subtracting the environmental regressions from the phenotypic regressions.

RESULTS AND DISCUSSION

Age of Dam Effects

The analysis of variance of the four traits is presented in table VIII. As was expected, age of dam, breed, line and year were highly significant ($P<0.01$) sources of variation for 205-day weaning weight, average daily gain, birth weight and type score. The effect of sex was also highly significant ($P<0.01$) for the first three traits, but not for type score. None of the interactions included in the model showed a significant effect. These results are in agreement with those reported by Cundiff, Willham and Pratt (1966); however, a significant breed x age of dam interaction was reported by Brown (1960) and by Cardellino (1968) for weaning weight. Tables IX, X, XI and XII contain the least squares means and the corresponding standard errors for each trait and age of dam group considered. Weaning weight, average daily gain and birth weight increased with age of dam until cows reached 6 years of age. Type score increased until cows reached 7 years of age. In all cases, the largest differences from the 6-year-old group occurred for the 2-year-old group and the magnitude of the differences decreased in each successive age group. These differences are presented in the second column of tables IX, X, XI and XII and represent the additive correction factors used for adjusting all the weights and scores to a 6-year-old dam basis. An inspection of the magnitude of differences and their corresponding standard errors reveal the lack of significant differences found for 7, 8 and 9 year old groups. Therefore, these groups were not adjusted to a common 6-year-old age of dam basis. In general, the values found are within the range of values presented by Petty and Cartwright (1966).

TABLE VIII. ANALYSIS OF VARIANCE FOR WEANING WEIGHT, AVERAGE DAILY GAIN, BIRTH WEIGHT AND TYPE SCORE OF LINES 7 AND 8 IN ANGUS, HEREFORD AND SHORTHORN BREEDS

		Mean Square			
Source	d.f.	Weaning Weight	A.D.G.	Birth Weight	Type Score
Age of dam	8	71873.20**	1.3229**	1111.94**	9.2581**
Sex	1	1001598.23**	20.2348**	6195.37**	0.7194
Breed	2	76102.74**	2.8487**	5713.82**	15.4599**
Year	18	25550.99**	0.5682**	286.10**	14.9641**
Line	1	177362.41**	3.0724**	3792.72**	127.5658**
Age of dam x breed	16	2032.71	0.0432	96.82	1.5410
Sex x breed	2	403.39	0.0074	36.57	4.4759
Remainder	1534	2320.45	0.0498	60.08	1.5455

** P<.01

TABLE IX. 205 DAY WEANING WEIGHT MEANS AND ADDITIVE AGE OF DAM CORRECTION FACTORS

Age of Dam	No. of Calves	Weaning Weight Means (lbs)	Correction Factors (lbs)
2 years	169	373.81 ± 5.36	63.32 ± 6.31
3 years	337	388.58 ± 2.95	48.55 ± 4.54
4 years	283	412.92 ± 3.14	24.21 ± 4.69
5 years	217	422.46 ± 3.53	14.69 ± 5.69
6 years	186	437.13 ± 3.76	
7 years	142	435.99 ± 4.31	1.14 ± 5.52
8 years	98	432.96 ± 5.25	4.17 ± 6.33
9 years	65	434.66 ± 6.23	2.47 ± 4.73
10 years and older	86	423.93 ± 5.52	13.20 ± 4.33

TABLE X. AVERAGE DAILY GAIN MEANS AND ADDITIVE AGE OF DAM CORRECTION FACTORS

Age of Dam	No. of Calves	Average Daily Gain (lbs)	Correction Factors (lbs)
2 years	169	1.52 ± 0.02	0.27 ± 0.03
3 years	337	1.58 ± 0.01	0.27 ± 0.02
4 years	283	1.68 ± 0.01	0.11 ± 0.02
5 years	217	1.72 ± 0.01	0.07 ± 0.02
6 years	186	1.79 ± 0.01	
7 years	142	1.78 ± 0.02	0.01 ± 0.02
8 years	98	1.78 ± 0.02	0.01 ± 0.03
9 years	65	1.78 ± 0.02	0.01 ± 0.02
10 years and older	86	1.73 ± 0.02	0.06 ± 0.02

TABLE XI. BIRTH WEIGHT MEANS AND ADDITIVE AGE OF DAM CORRECTION FACTORS

Age of Dam	No. of Calves	Birth Weight (lbs)	Correction Factors (lbs)
2 years	169	61.53 ± 0.86	8.27 ± 1.02
3 years	337	64.04 ± 0.47	5.76 ± 0.73
4 years	283	67.11 ± 0.50	2.69 ± 0.75
5 years	217	68.91 ± 0.56	0.89 ± 0.79
6 years	186	69.80 ± 0.60	
7 years	142	69.99 ± 0.69	-0.19 ± 0.88
8 years	98	67.62 ± 0.84	2.18 ± 1.01
9 years	65	69.08 ± 1.00	0.72 ± 0.76
10 years and older	86	68.12 ± 0.88	1.68 ± 0.69

TABLE XII. TYPE SCORE MEANS AND ADDITIVE AGE OF DAM CORRECTION FACTORS

Age of Dam	No. of Calves	Type Score (lbs)	Correction Factors (lbs)
2 years	169	11.15 ± 0.13	0.81 ± 0.16
3 years	337	11.45 ± 0.07	0.51 ± 0.12
4 years	283	11.60 ± 0.08	0.36 ± 0.12
5 years	217	11.78 ± 0.09	0.18 ± 0.13
6 years	186	11.96 ± 0.09	
7 years	142	11.98 ± 0.11	-0.02 ± 0.14
8 years	98	11.84 ± 0.13	0.12 ± 0.16
9 years	65	11.80 ± 0.16	0.16 ± 0.12
10 years and older	86	11.64 ± 0.14	0.32 ± 0.11

Sex Effects

Sex effect was an important source of variation on the four traits studied. The within year analysis of variance showed differences in the degree of importance of sex effects for the traits among breeds and years. For weaning weight and average daily gain the difference between bull calves and heifers was significant ($P<0.05$) in Angus for all the years considered. In Herefords the effect was significant ($P<0.05$) for every year except 1953, 1959 and 1962. In Shorthorns the effect was significant ($P<0.05$) for every year except 1951, 1956 and 1959. The picture for birth weight is not as consistent as for weaning weight and average daily gain. The effect of sex was significantly different ($P<0.05$) only in 12, 11 and 11 years of nineteen years considered for Angus, Hereford and Shorthorn, respectively. No differences due to sex effect in type score were found in Herefords in any of the nineteen years considered. Tables XIII, XIV and XV present the least squares constants for bull calves estimated from the analysis of variance for each breed and year considered. It is noticeable that the least squares constants varied considerably between years and between breeds within years. The overall range of the constants for the traits are within the range of values of the review of literature published by Petty and Cartwright (1966). The least squares constants of tables XIII, XIV and XV were used to estimate the additive correction factors utilized to adjust all the calves from the repeat matings to both a male and female basis.

Phenotypic Performance: Weaning Weight

The annual weaning weight means (unweighted average of the two sexes) are shown graphically for each line by the solid lines of figures 2

TABLE XIII. LEAST SQUARES CONSTANTS[1] FOR SEX, ANGUS BULL CALVES

Years	Number		Weaning Weight (lb.)	Daily Gain (lb.)	Birth Weight (lb.)	Type Score[1]
	M	F				
51	19	23	38.5	0.16	4.94	-0.11
52	25	23	53.5	0.24	2.90	-0.39
53	27	47	20.3	0.08	2.88	-0.56
54	27	39	25.0	0.10	4.22	-0.38
55	54	41	14.6	0.06	2.12	-0.35
56	51	54	19.0	0.08	1.41	-0.28
57	53	55	27.5	0.12	2.97	-0.12
58	36	36	18.9	0.08	1.01	-0.52
59	38	36	19.3	0.08	1.76	-0.29
61	25	27	35.3	0.16	1.50	0.22
62	58	38	39.2	0.18	2.19	-0.005
63	50	48	0.7	0.00	1.80	-0.22
64	53	42	19.1	0.06	2.18	-0.28
65	63	46	36.4	0.15	3.93	0.23
66	46	57	32.9	0.15	2.12	0.09
67	60	58	31.9	0.14	2.75	0.11
68	47	53	23.6	0.10	2.86	0.08
69	64	50	25.1	0.11	1.67	-0.03
Average Standard Error			±6.32	±0.024	±1.13	±0.18
Range of Standard Errors			4.36-8.67	0.02-0.04	0.69-2.31	0.04-0.34

---

[1] Type score, 1 unit = 1/3 of a U.S.D.A. grade.

TABLE XIV. LEAST SQUARES CONSTANTS FOR SEX, HEREFORD BULL CALVES

Years	Number M	Number F	Weaning Weight (lb.)	Daily Gain (lb.)	Birth Weight (lb.)	Type Score[1]
50	22	26	25.5	0.10	3.61	0.29
51	30	34	20.8	0.08	3.55	-0.08
52	36	39	62.0	0.29	2.36	0.03
53	45	47	6.1	0.02	1.04	-0.08
54	50	48	20.9	0.09	1.28	-0.19
55	37	49	26.0	0.11	1.59	-0.12
56	41	47	43.5	0.19	2.78	-0.24
57	48	44	9.6	0.03	1.97	-0.17
58	30	28	37.5	0.17	1.01	0.11
59	46	34	4.8	0.01	2.55	-0.15
61	28	30	31.0	0.13	4.20	-0.43
62	35	31	23.6	0.10	2.04	0.02
63	48	47	28.1	0.12	3.56	-0.16
64	41	47	34.0	0.14	4.05	0.11
65	68	48	23.0	0.10	2.02	-0.05
66	51	53	25.8	0.11	2.09	0.14
67	76	58	24.2	0.10	1.71	0.14
68	69	66	32.7	0.14	2.23	0.15
69	70	73	24.8	0.10	3.01	0.10
Average Standard Error			±7.34	±0.028	±1.08	±0.17
Range of Standard Errors			4.73-12.36	0.02-0.05	0.71-1.43	0.08-0.29

---

[1] Type score, 1 unit = 1/3 of a U.S.D.A. grade.

TABLE XV. LEAST SQUARES CONSTANTS FOR SEX, SHORTHORN BULL CALVES

Years	Number M	Number F	Weaning Weight (lb.)	Daily Gain (lb.)	Birth Weight (lb.)	Type Score[1]
50	22	39	18.5	0.07	2.40	-0.51
51	25	19	5.6	0.02	1.35	-0.76
52	38	36	42.1	0.19	3.17	-0.35
53	37	34	22.6	0.10	1.27	-0.42
54	46	36	27.0	0.11	2.65	0.14
55	59	53	16.6	0.07	2.16	0.14
56	36	48	9.3	0.03	1.55	-0.52
57	49	50	16.3	0.06	2.52	-0.22
58	34	30	30.9	0.14	1.09	-0.19
59	30	38	2.0	-0.002	2.54	-0.21
61	18	18	30.6	0.14	1.73	-0.10
62	40	54	24.1	0.11	1.24	0.07
63	38	43	24.1	0.10	2.54	0.34
64	49	36	26.3	0.11	3.60	-0.48
65	43	31	30.1	0.13	3.17	-0.28
66	43	34	27.9	0.11	3.86	-0.16
67	42	52	28.9	0.12	2.74	0.26
68	49	40	25.9	0.12	0.47	0.01
69	48	29	14.2	0.06	1.45	0.18
Average Standard Error			±6.99	±0.027	±1.09	±0.20
Range of Standard Errors			5.22-8.97	0.02-0.05	0.89-2.04	0.11-0.38

---

[1] Type score, 1 unit = 1/3 of a U.S.D.A. grade.

through 20. The dotted line of each figure represents the annual weaning weight means adjusted for the effects of inbreeding of the calf and inbreeding of the dam. There was a large variation in preweaning and weaning performance among years. In general, most of the graphs are in close agreement with respect to the good and poor years. In Angus and Hereford the coefficients of variation for the yearly means showed in table XVI are higher in the inbred lines than in the selection lines. In Shorthorn only the inbred line S-1 showed a higher coefficient of variation than the selection lines S-7 and S-8. Phenotypic time trends were estimated by the regression of the unweighted means on years. Negative regression coefficients of weaning weight on time found for Angus inbred lines A-1, A-2, A-4 were: -0.464 ± 0.945, -1.1727 ± 1.054 and -0.690 ± 1.906, respectively. Inbred lines A-1 and A-2 are the lines with higher inbreeding in Angus. Table IV shows the average calf and dam inbreeding coefficients for each line and each year considered.

In 1969, the average inbreeding coefficients of calves in lines A-1 and A-2 was 36% and 43% and for dams 25% and 32%, respectively. In both lines weaning weights showed a marked variation between years. Line A-2 showed a continuous decrease in the average weaning weight during the whole experiment. In lines A-3 and A-4 the average coefficients of inbreeding reached in 1969 were 29% and 31% for calves, and 19% and 19% for dams, respectively, for each line. Inbreeding of the calf increased in both lines in 1959 reaching an average of 26%. This average remained relatively constant until 1969 when the calf inbreeding coefficients increased again to 29% and 31% in lines A-3 and A-4, respectively. During the last six years considered, year variations between sex unweighted

TABLE XVI. CV[1] AMONG ANNUAL WEANING WEIGHT MEANS[2] BY LINES

Breed					
Angus		Hereford		Shorthorn	
		Inbred Lines			
A-1	4.76	H-2	9.87	S-1	9.21
A-2	5.08	H-3	6.80	S-2	6.95
A-3	7.34	H-4	5.79	S-4	4.82
A-4	7.26	H-5	2.46	S-5	4.42
		Selection Lines			
A-7	4.34	H-6	2.67	S-7	7.57
A-8	4.04	H-7	3.08	S-8	7.37
		H-8	4.64		

[1] Coefficients of variation in percentage.

[2] Unweighted average of both sexes.

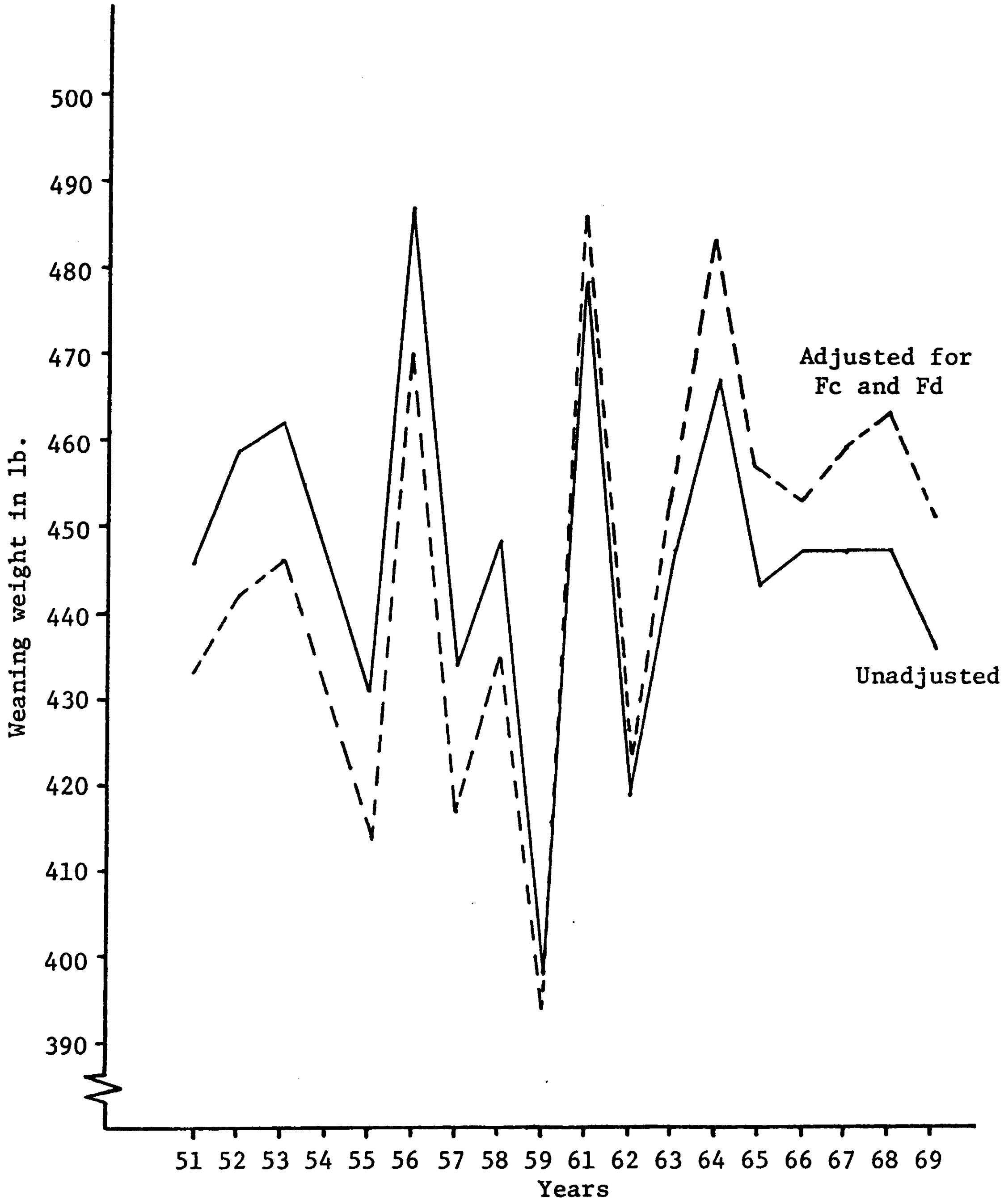


Figure 2. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Angus line 1

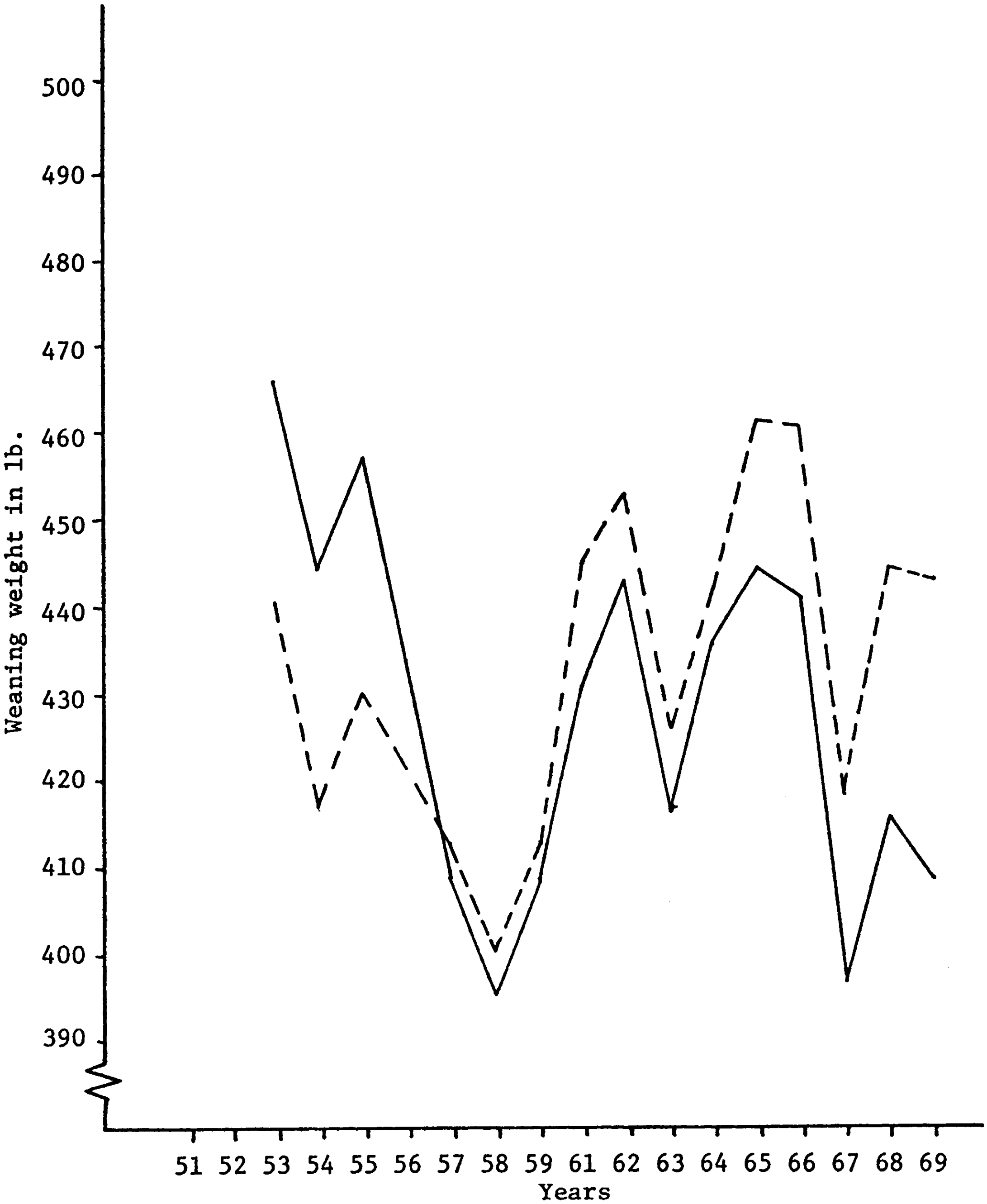


Figure 3. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Angus line 2

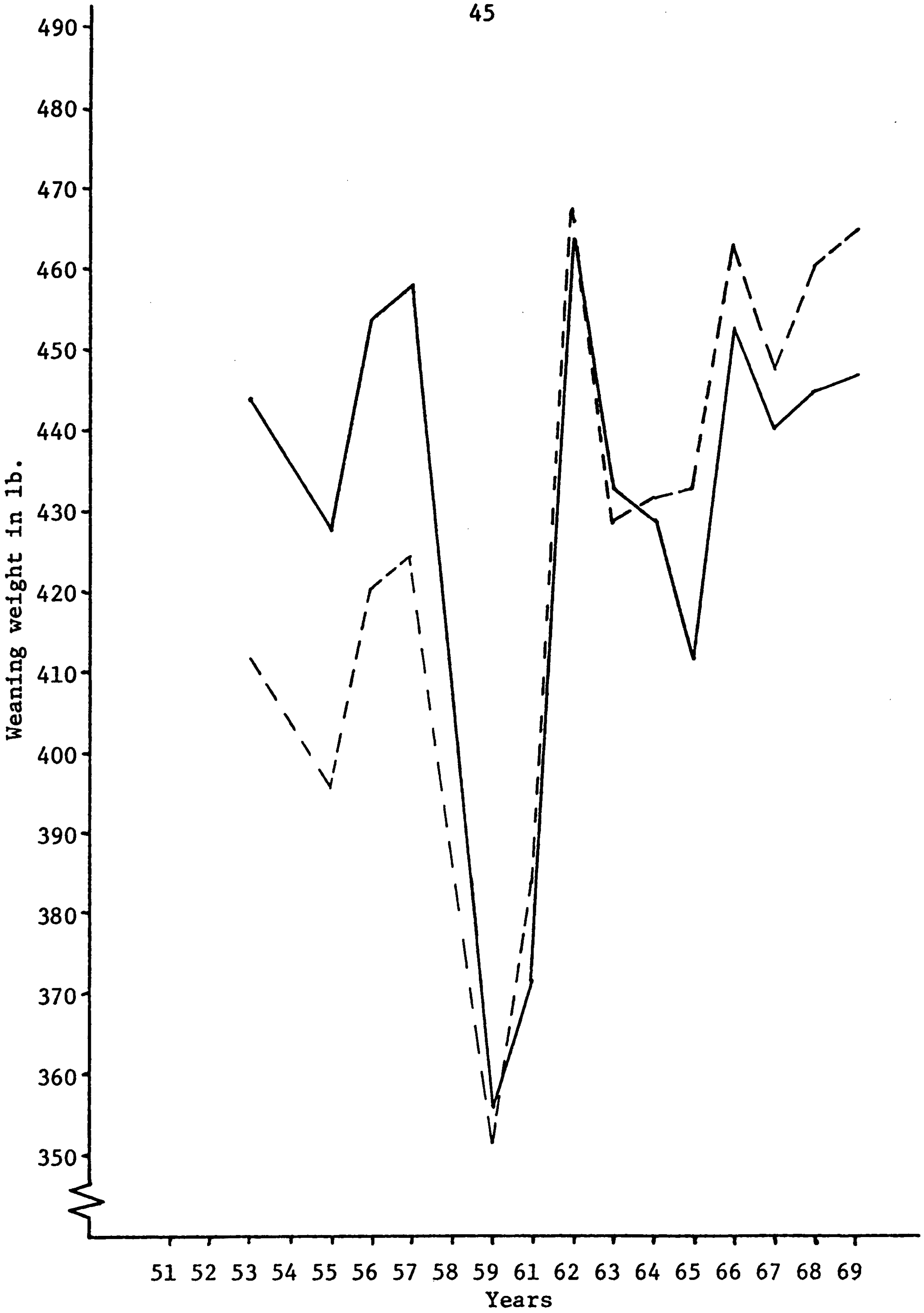


Figure 4. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Angus line 3

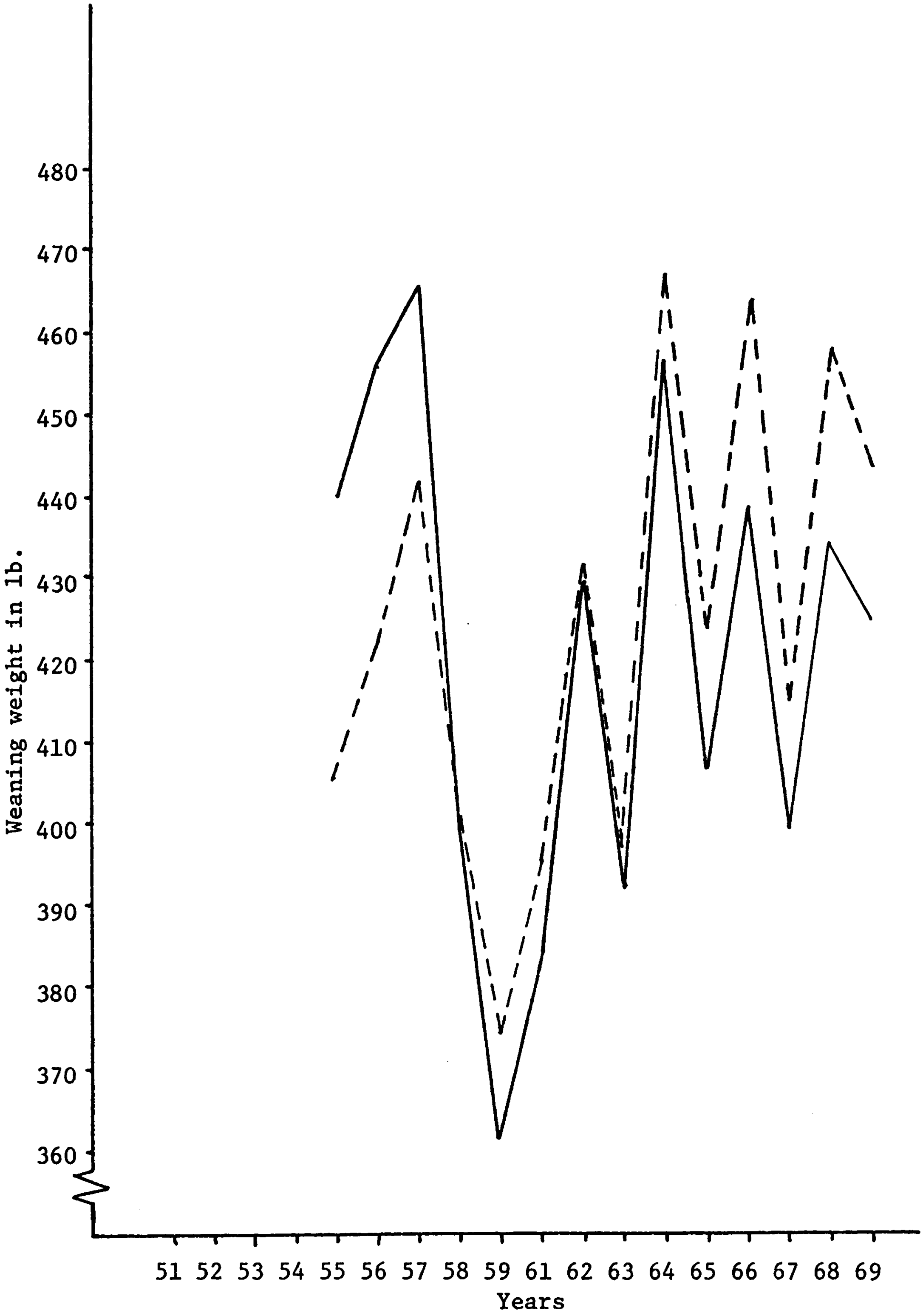


Figure 5. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Angus line 4

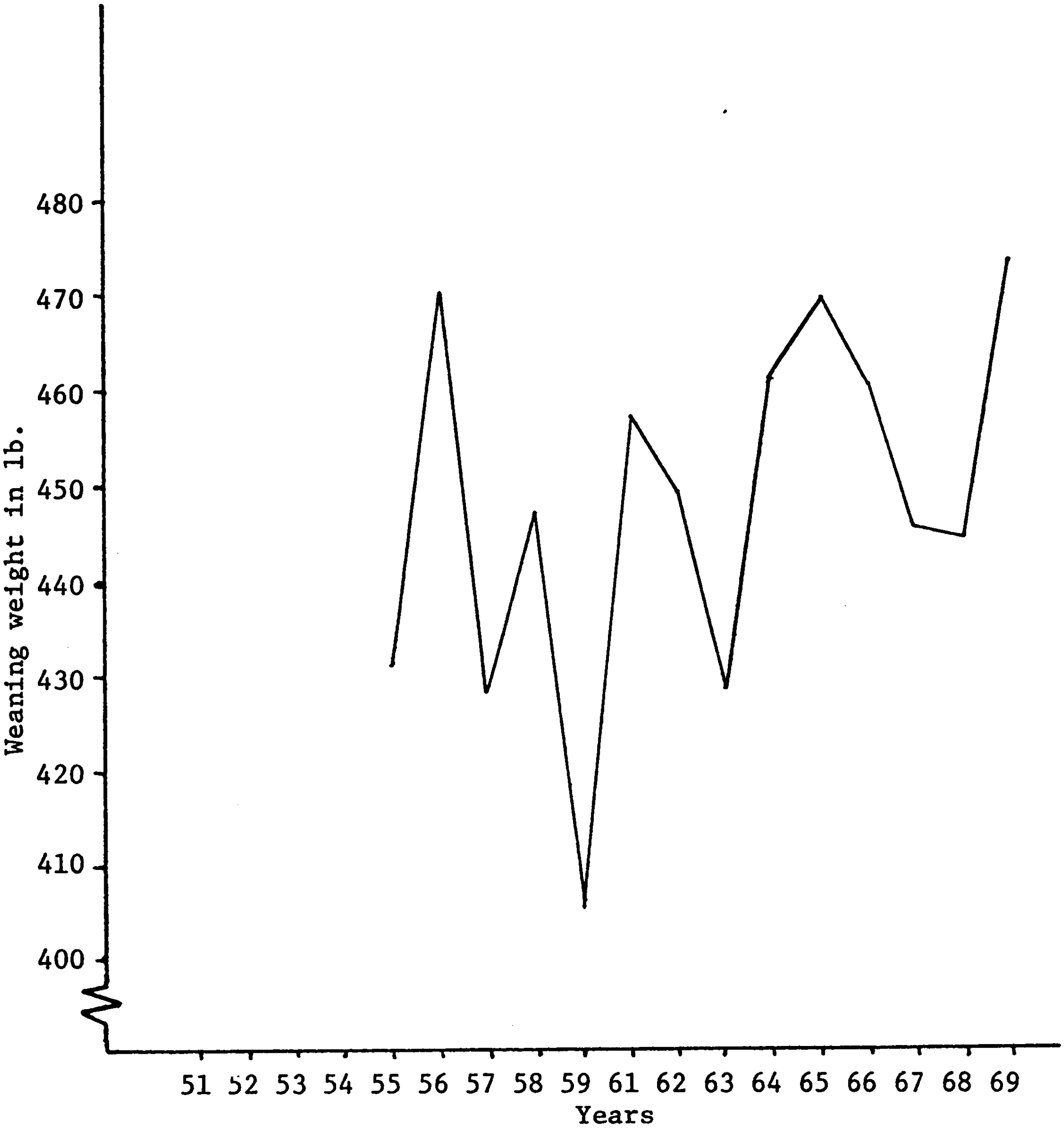


Figure 6. Weaning weights means in Angus line 7

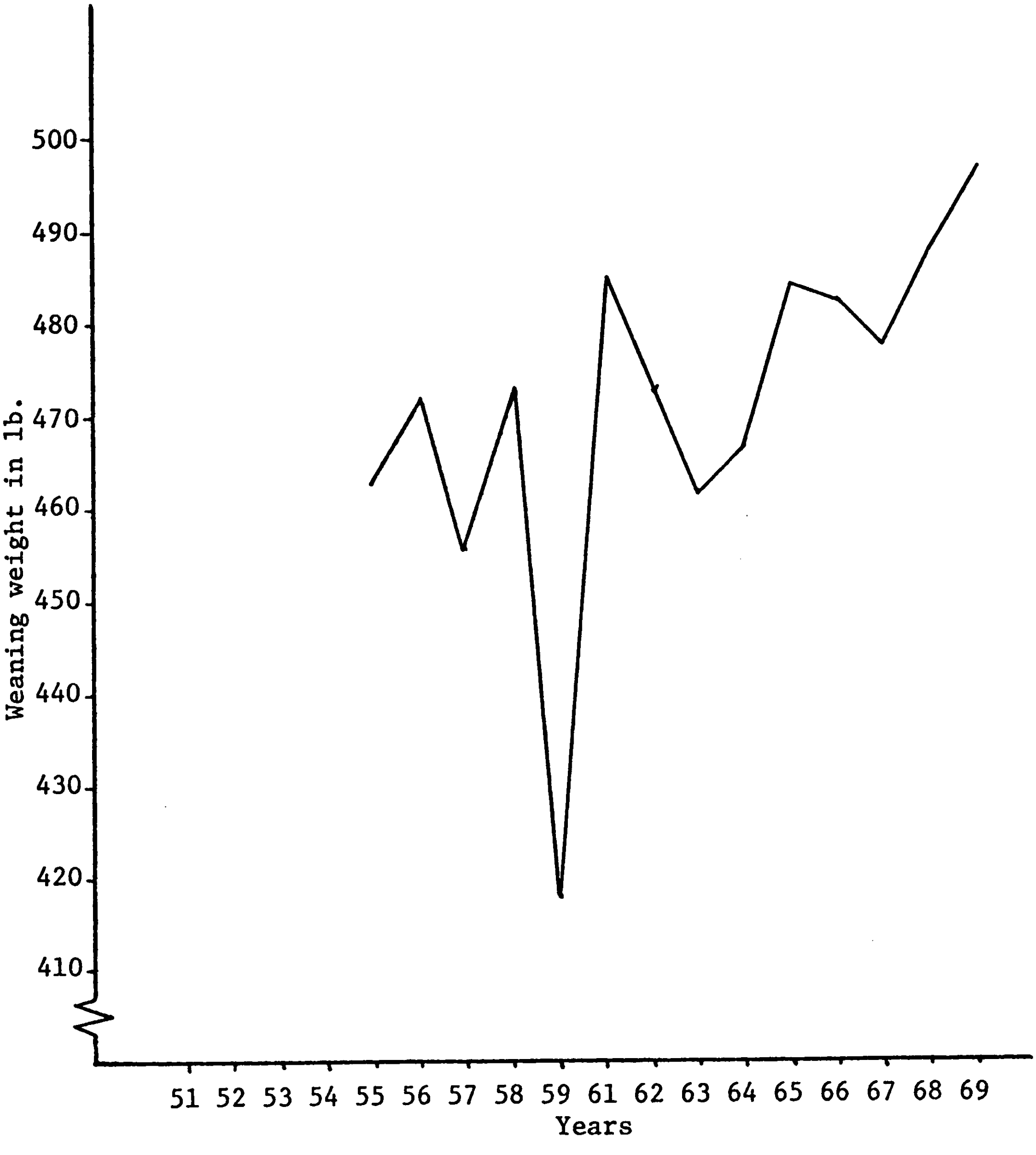


Figure 7. Weaning weights means in Angus line 8

weaning weight means in lines A-1, A-2 and A-4, were lower than in the first part of the experiment. Inbred line A-3 and selection lines A-7 and A-8 showed a positive trend during the whole experiment and the regression coefficients of sex unadjusted weaning weight means on years were 0.544 ± 1.778, 1.685 ± 1.116 and 2.359 ± 0.982, respectively. Unweighted weaning weight means for the year 1969 of lines A-1, A-2, A-3, A-4, A-7 and A-8 were 436, 409, 447, 425, 473 and 498 lb., respectively.

In Herefords three inbred lines and one selection line showed negative phenotypic time trends. The regression coefficients of sex unweighted weaning weights on years were H-2 = -6.856 ± 1.431, H-3 = -1.323 ± 2.118, H-5 = -0.773 ± 1.687 and Type selection line H-7 = -2.047 ± 2.054. Inbred line H-4, index selection H-6 and growth selection line H-8 showed positive regression coefficients of 1.073 ± 2.628, 3.892 ± 1.543 and 5.595 ± 2.664, respectively. It may be seen in table V that the amount of inbreeding for both calves and dams was lower in Herefords than in the other two breeds. In 1969 average calf inbreeding coefficients were H-2 = 19%, H-3 = 26%, H-4 = 29% and H-5 = 31%. For the same year dam inbreeding coefficients averaged 12% for H-2, H-3 and H-4 and 13% for H-5.

Average performance of the Hereford lines through the years is shown graphically by the solid lines in figures 8 through 14. Hereford line H-2 showed a continuous decline during the whole set of years observed. H-3, after a pronounced decline during the early years, started to make progress after 1964; however, it failed to reach the original average weaning weight by 1969. Hereford line H-4 progressed markedly during the first part of the experiment and is the only Hereford inbred line that

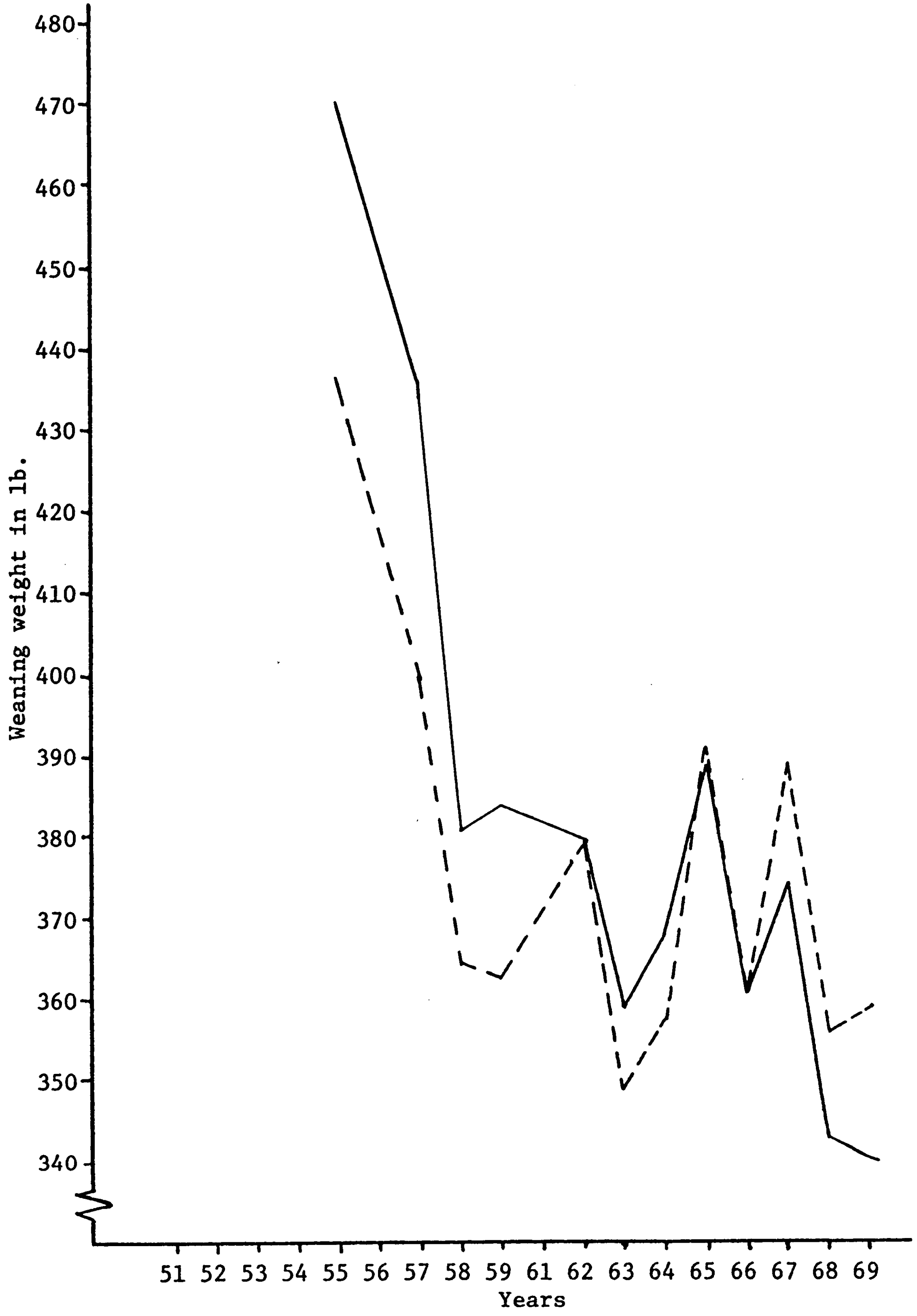


Figure 8. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Hereford line 2

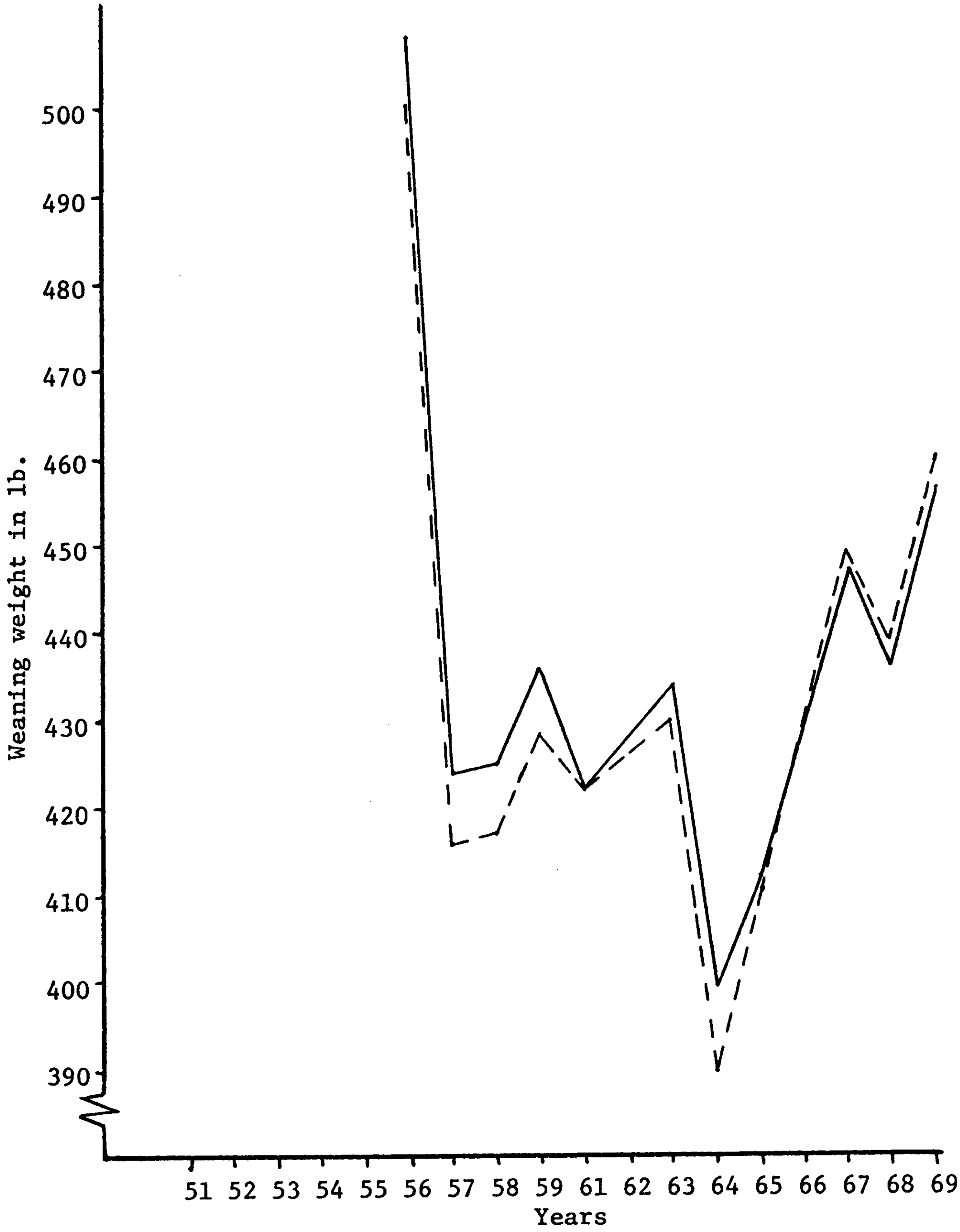


Figure 9. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Hereford line 3

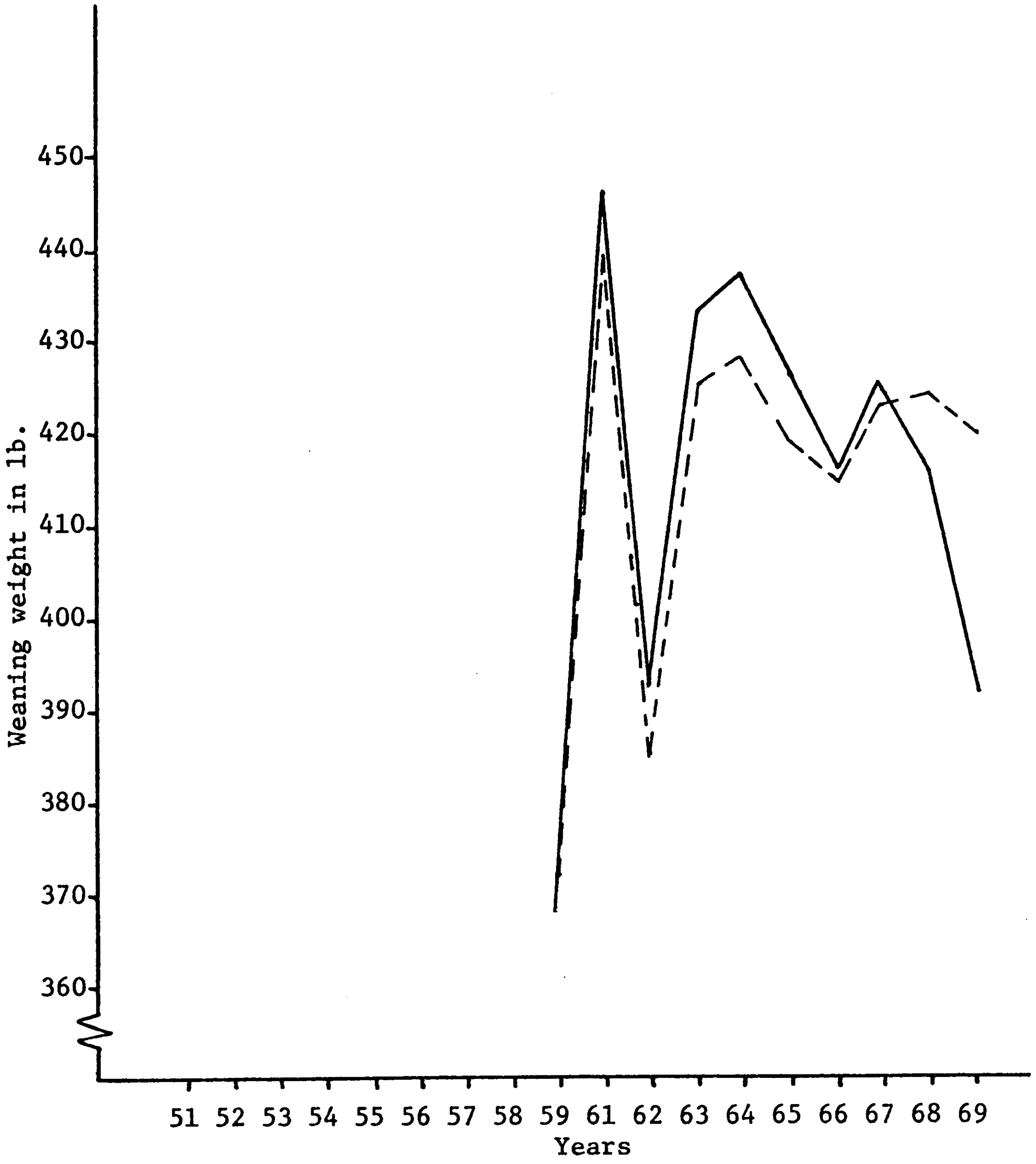


Figure 10. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Hereford line 4

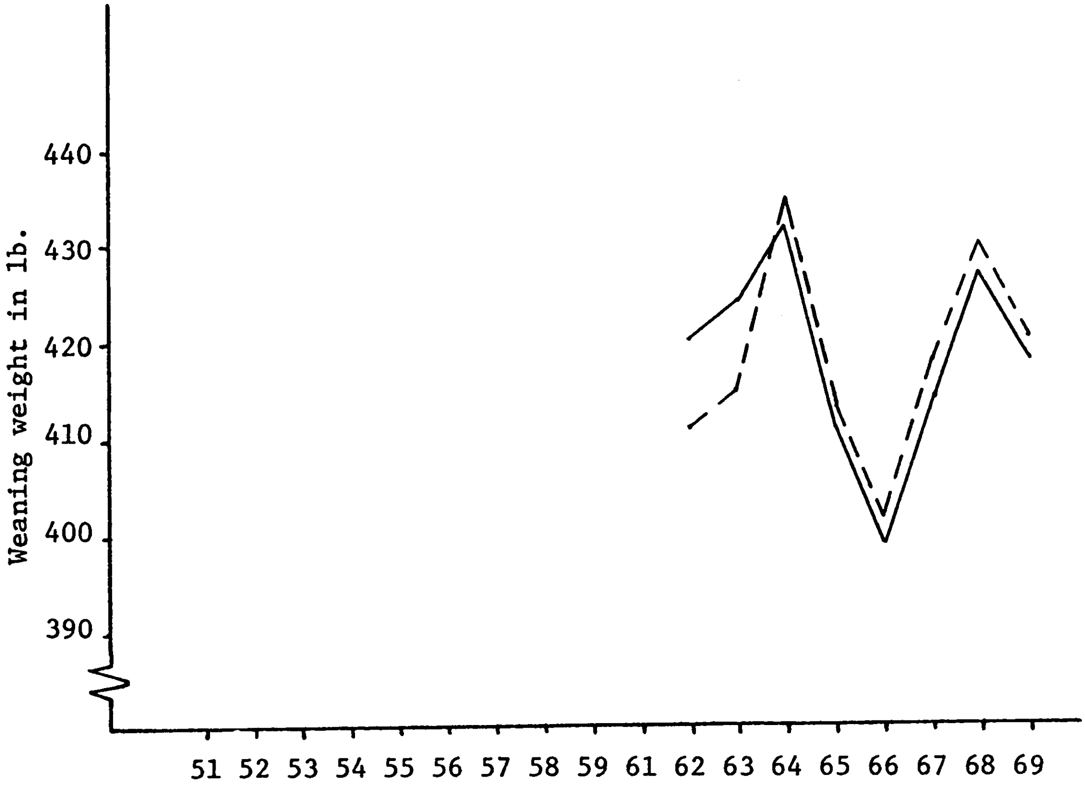


Figure 11. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Hereford line 5

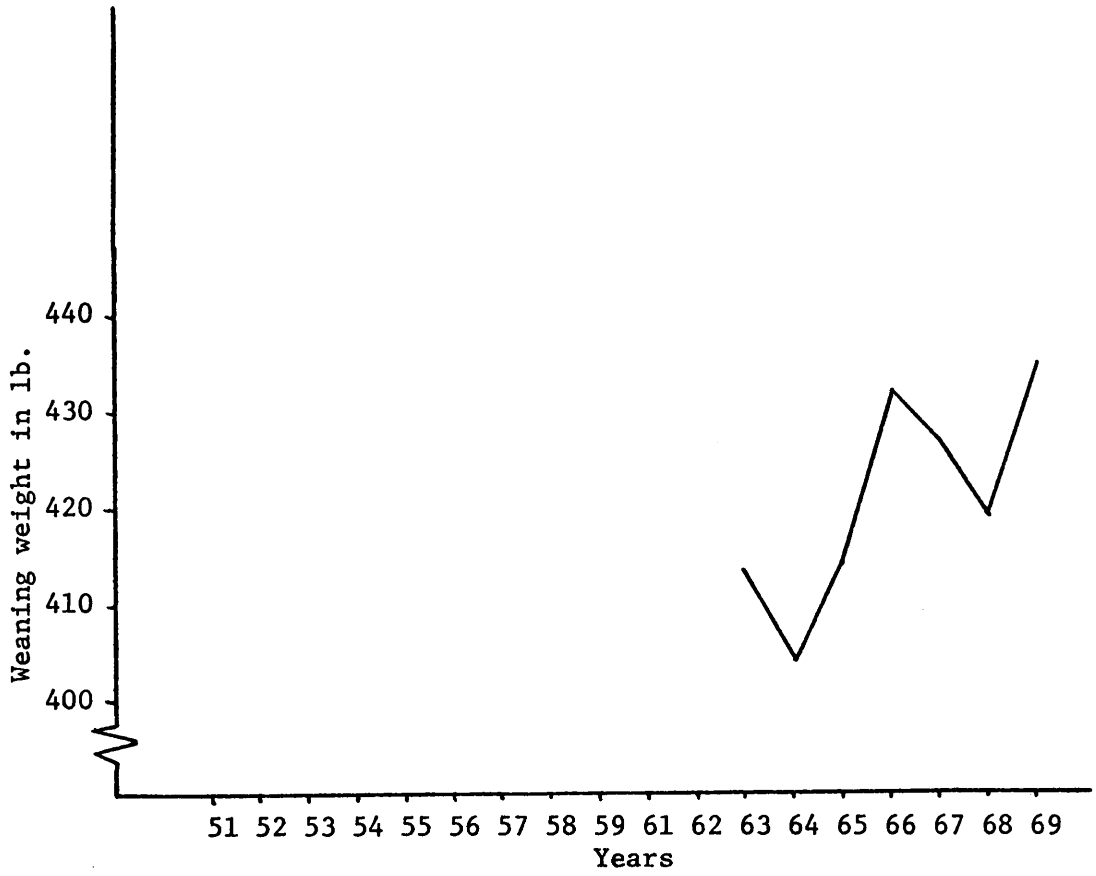


Figure 12. Weaning weight means in Hereford line 6

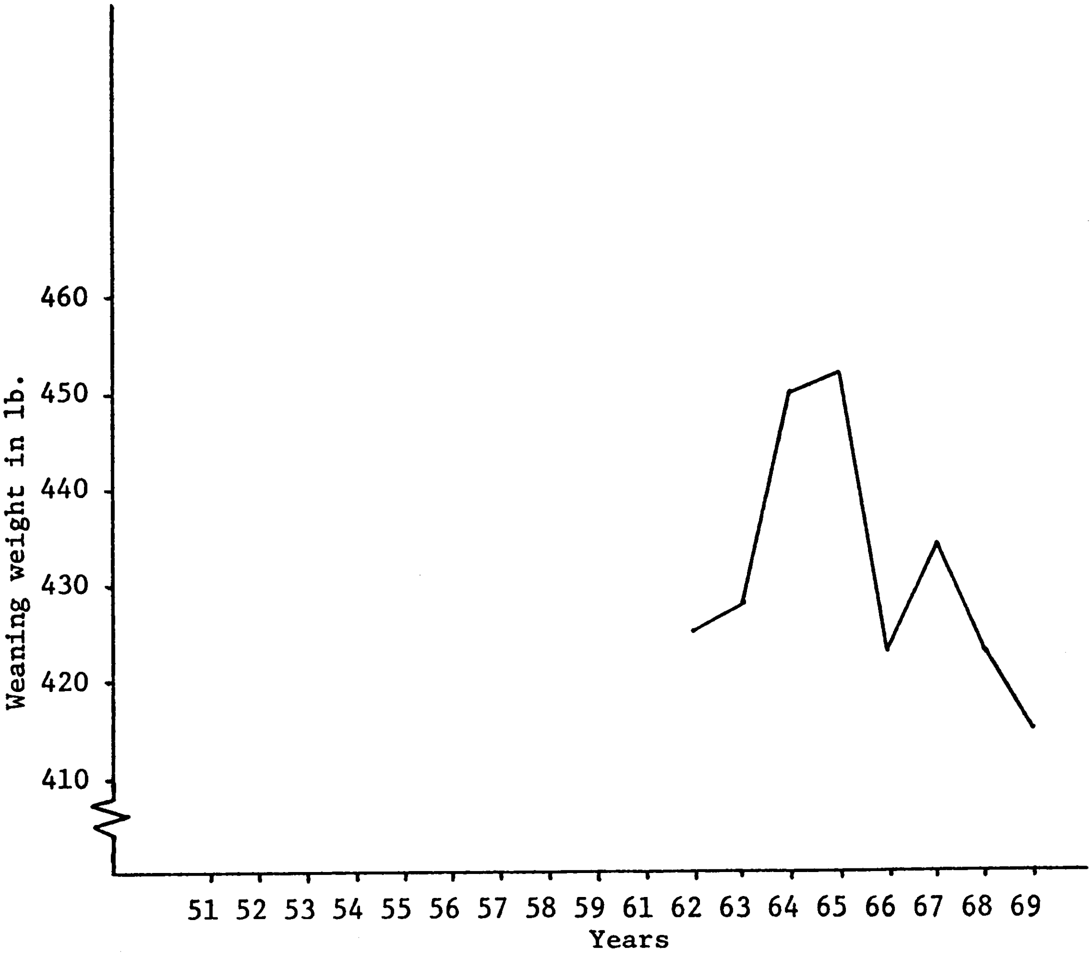


Figure 13. Weaning weight means in Hereford line 7

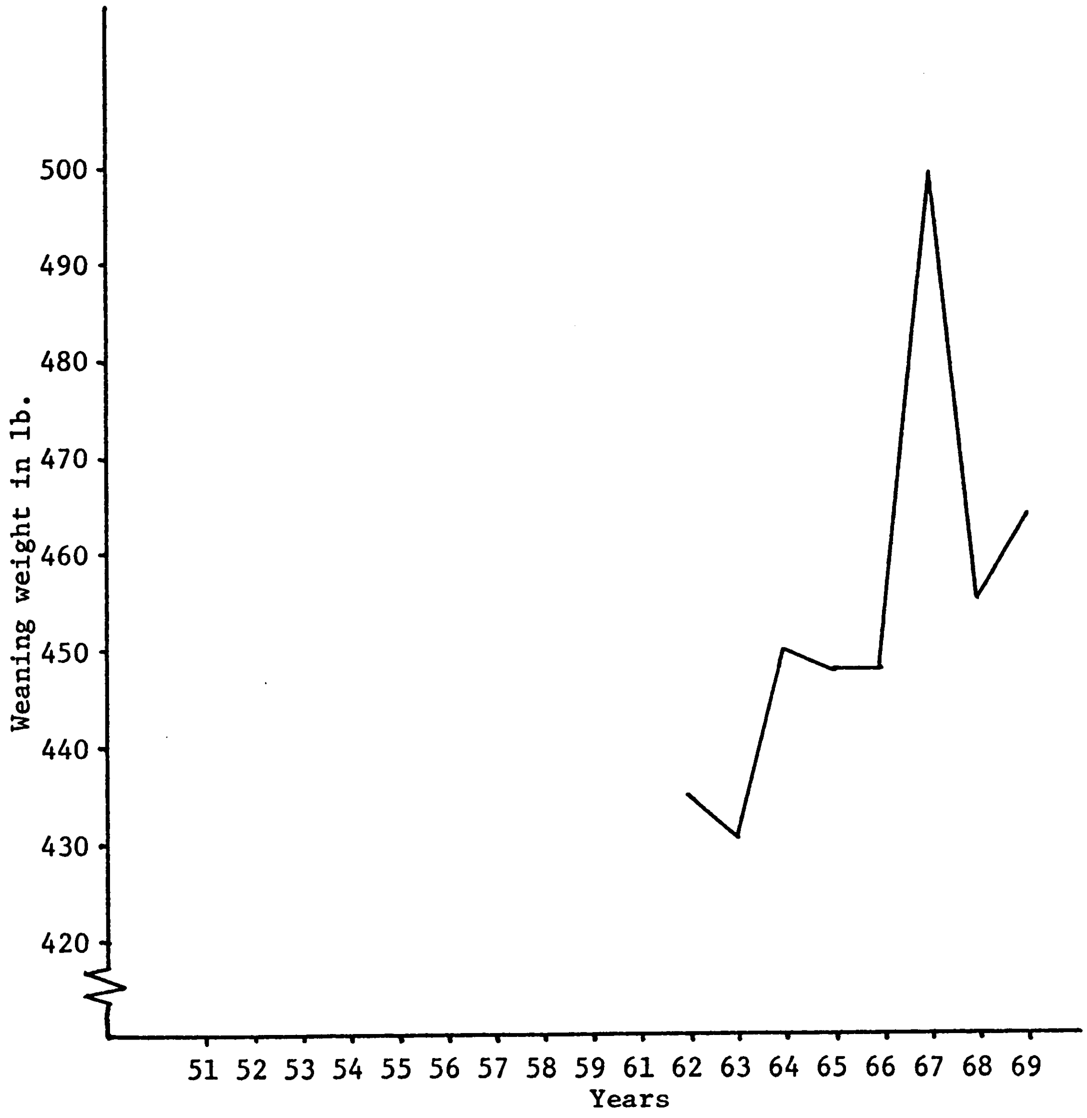


Figure 14. Weaning weight means in Hereford line 8

showed positive phenotypic increase with time. Hereford line H-5 showed improvement in the first two years, declined in the following years, and then started to improve again in 1966. This line presented the lowest coefficient of variation for the yearly means. Selection lines 6 and 8 showed continuous progress during the observed years. However, selection line 7 improved in only the first two years and, thereafter, declined in performance until 1969. There was a noticeable difference in weaning weights between lines at the time each one started. The sex unweighted means for 1969 were H-2 = 340, H-3 = 456, H-4 = 392, H-5 = 418, H-6 = 435, H-7 = 415 and H-8 = 464.

The phenotypic performance of the Shorthorn breed showed a marked difference from the other two breeds in two respects. The first is that the coefficients of regression of the sex unweighted weaning weight means on years of all the lines considered showed a definite positive trend. The second is related to the amount of inbreeding reached in the lines S-1, S-2, S-4; it is higher than in any of the inbred lines previously considered. The average inbreeding of the calf in 1969 were S-1 = 47%, S-2 = 47%, S-4 = 40% and S-5 = 29%. The average inbreeding coefficients for dams in the same year were S-1 = 35%, S-2 = 34%, S-4 = 31% and S-5 = 22%. In line S-1 several bull calves were over 60% inbred by 1969.

The regression coefficients of sex unweighted year means on years were S-1 = 3.154 ± 1.394, S-2 = 0.601 ± 1.179, S-4 = 2.709 ± 1.069, S-5 = 1.893 ± 1.488, S-7 = 3.922 ± 0.929 and S-8 = 3.703 ± 1.041. All the lines showed a definite phenotypic progress during the period considered. There were wide differences between the lines for average weaning weight at the time that the lines started. Shorthorn inbred S-1 started with

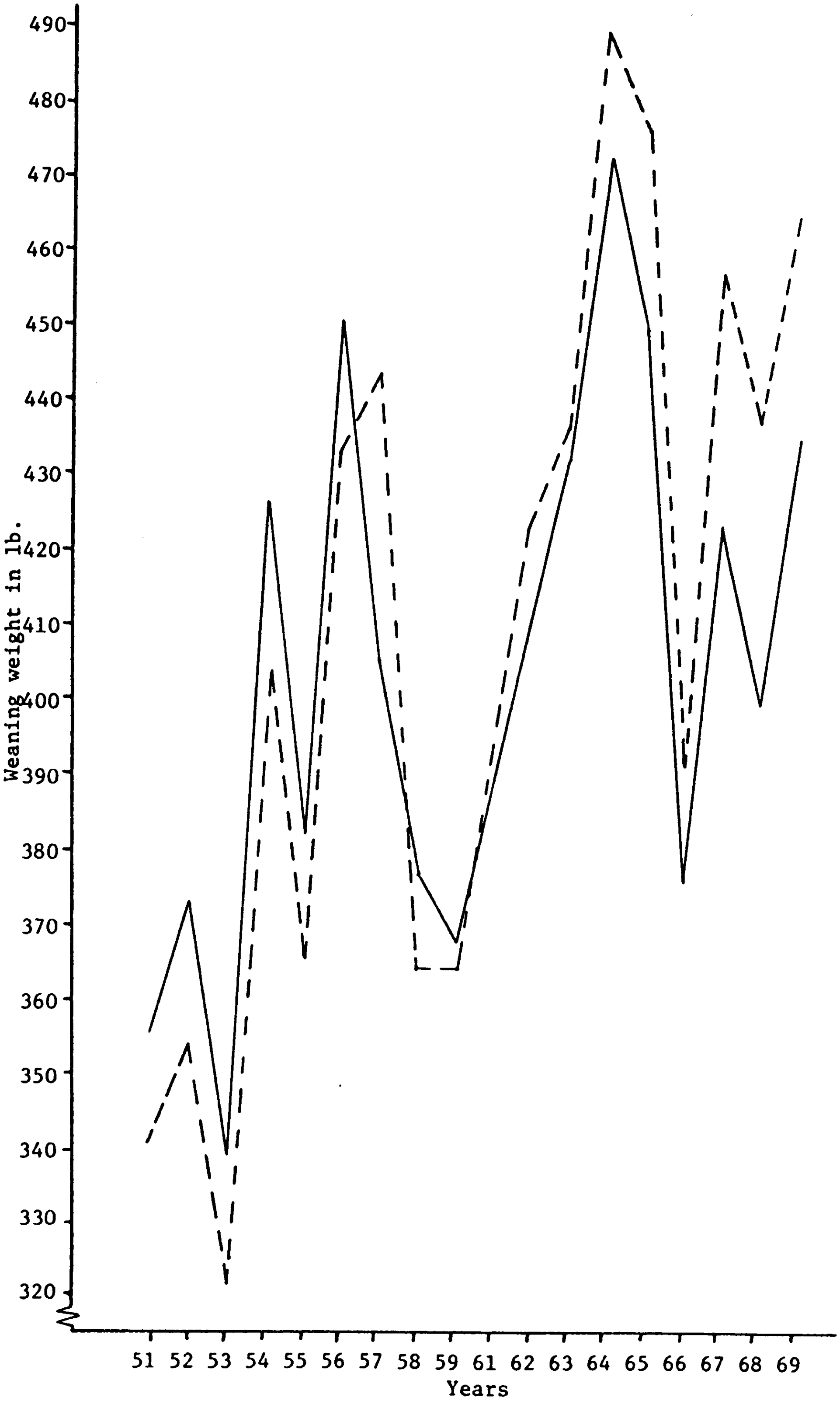


Figure 15. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Shorthorn line 1

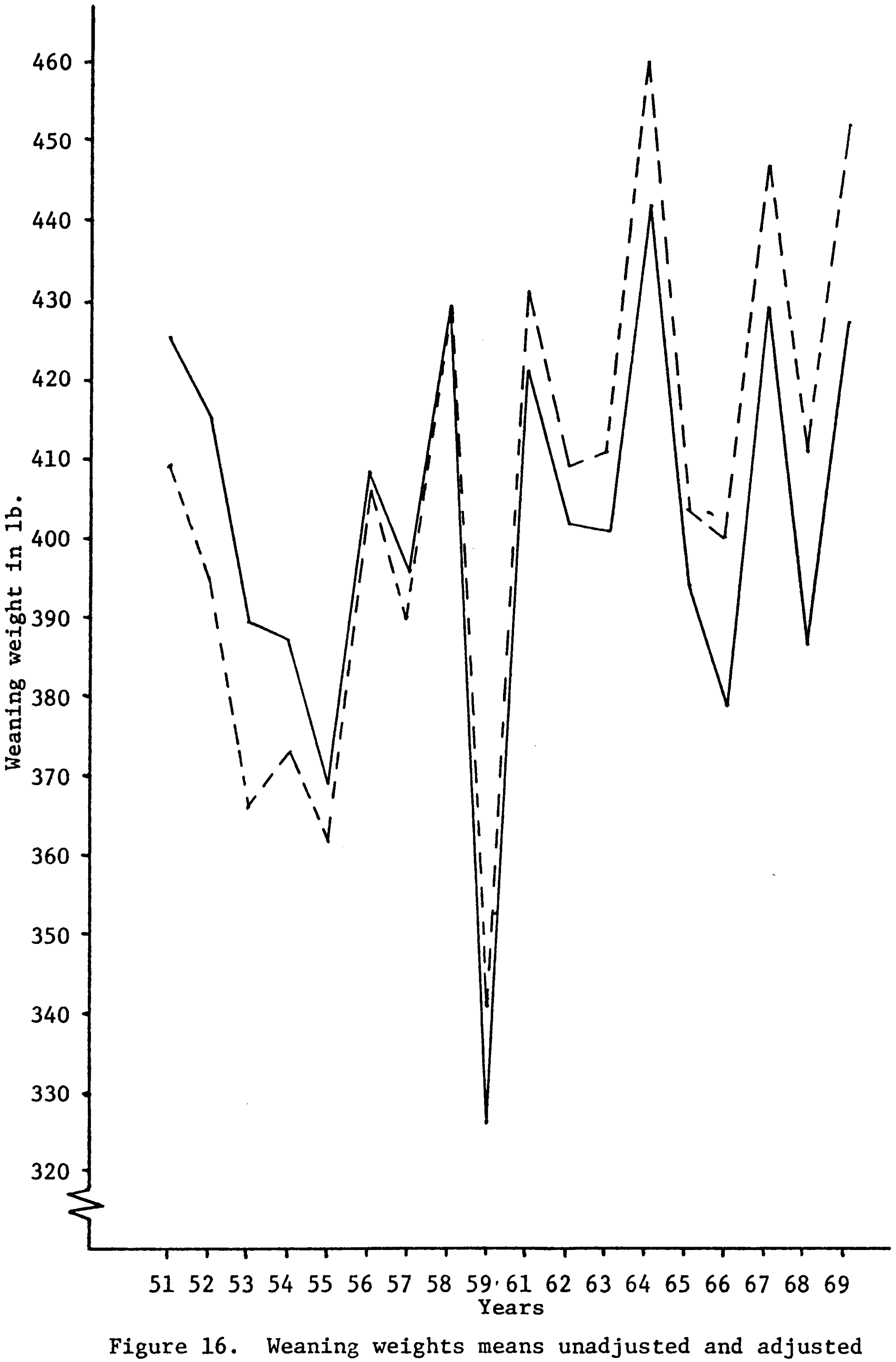


Figure 16. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Shorthorn line 2

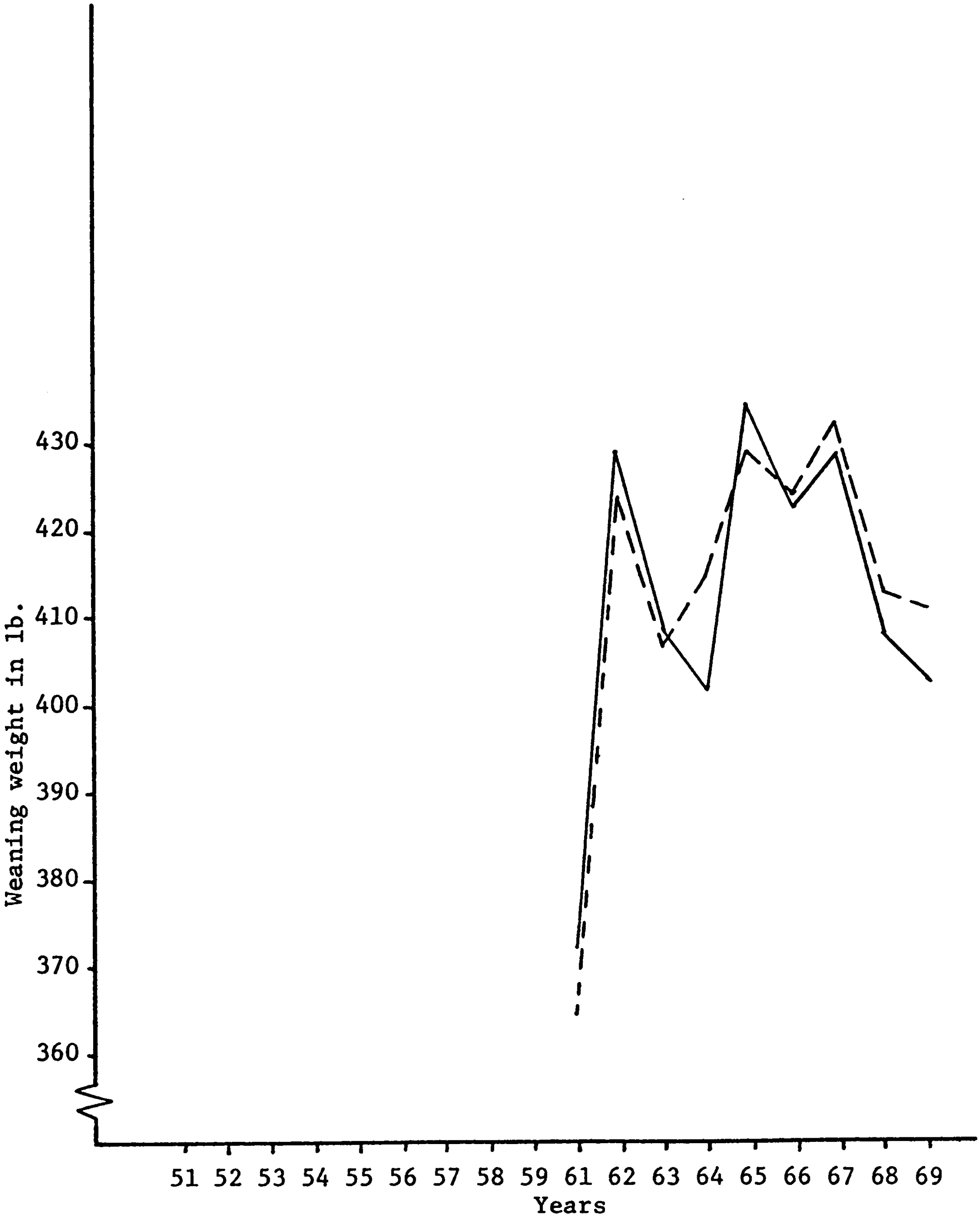


Figure 17. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Shorthorn line 4

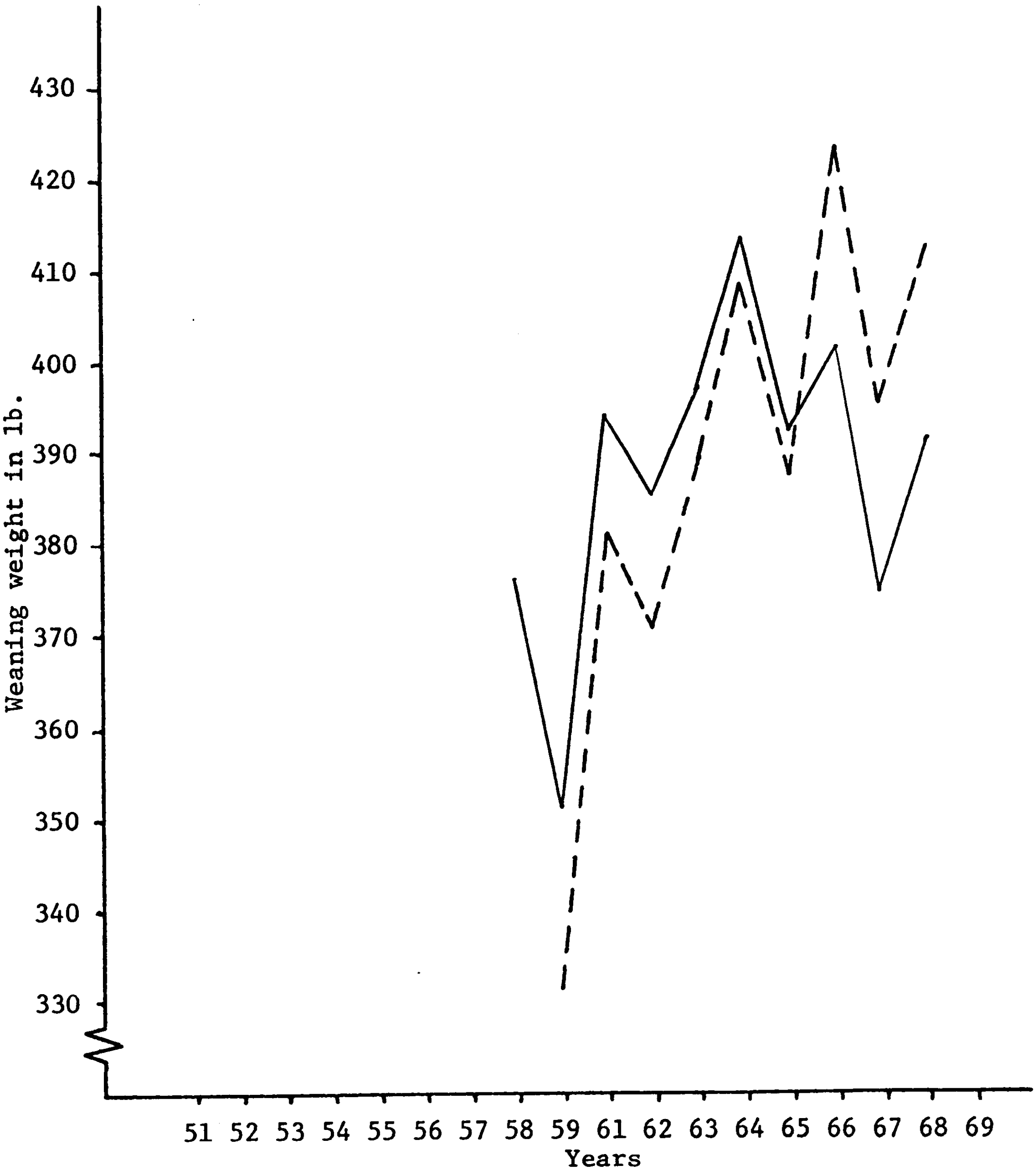


Figure 18. Weaning weights means unadjusted and adjusted for calf and dam inbreeding in Shorthorn line 5

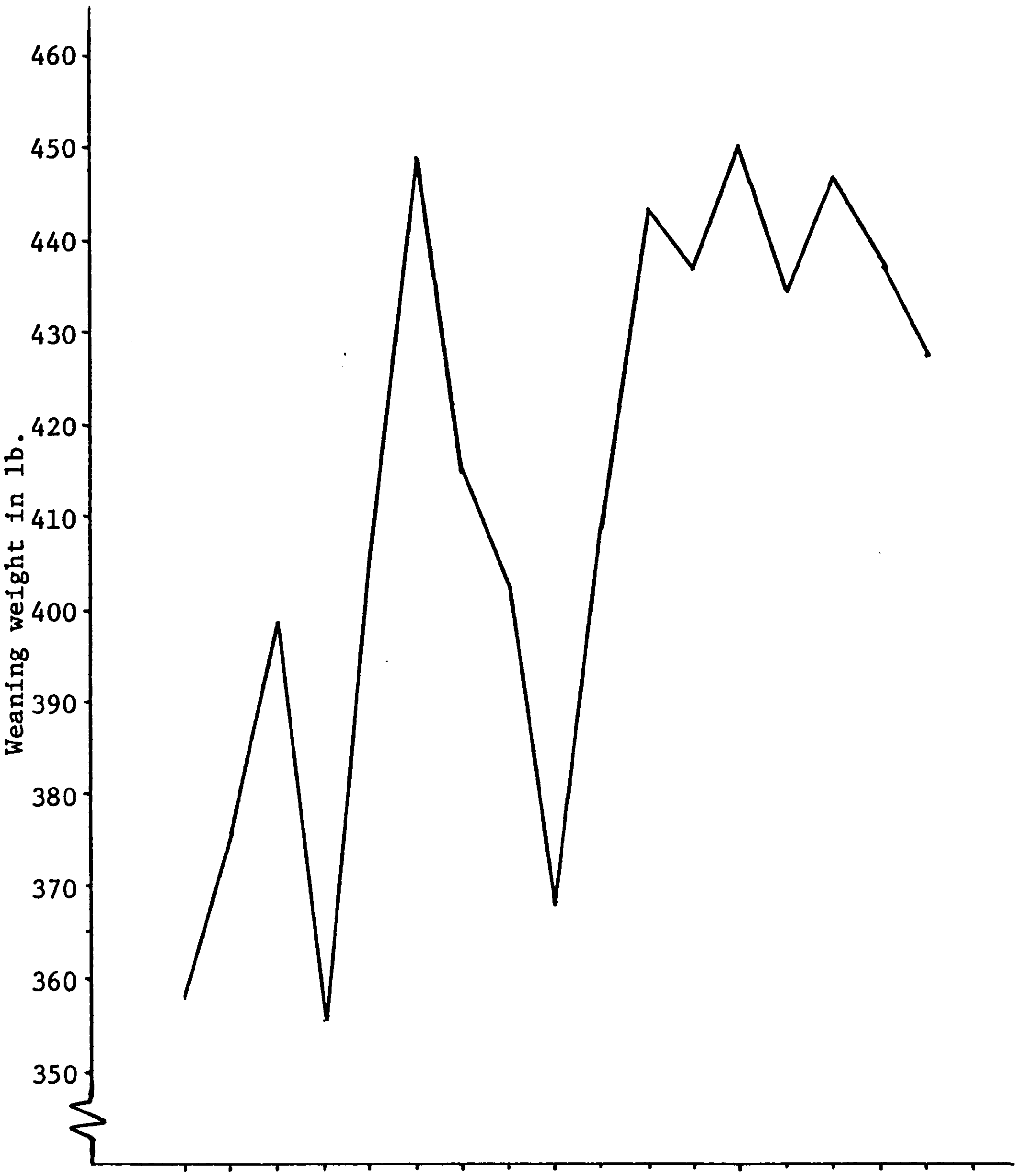


Figure 19. Weaning weight means in Shorthorn line 7

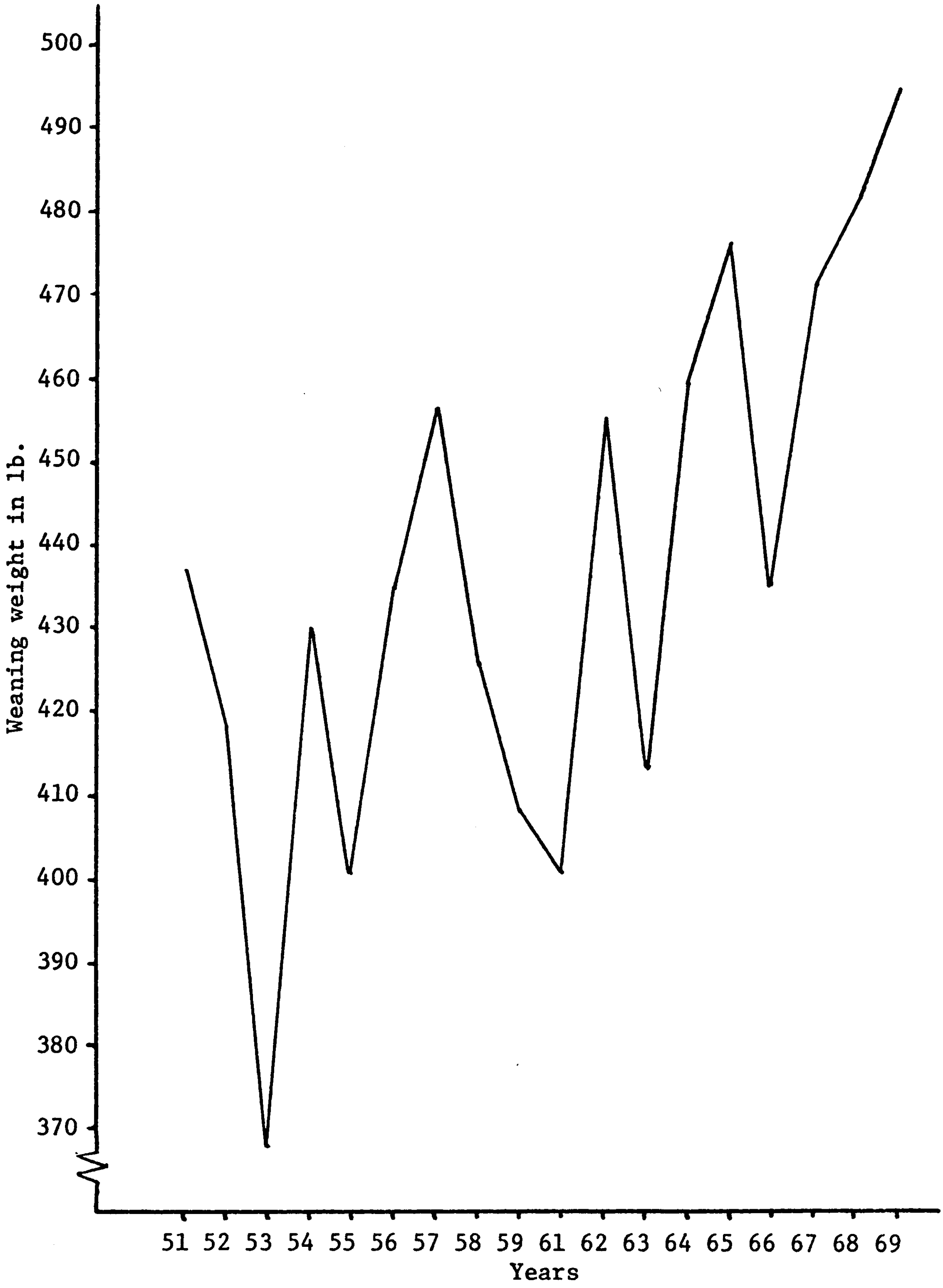


Figure 20. Weaning weights means in Shorthorn line 8

341 lb. and Shorthorn selection line S-8 started with 437 lb. The average weaning weights estimated for 1969 were S-1 = 435, S-2 = 427, S-4 = 403, S-5 = 427 and S-8 = 494. It is of interest that the inbred line S-5, with a lower inbreeding coefficient for both calf and dam, showed lower weaning weights than the other inbred lines with higher inbreeding values.

Environmental Trends

For each breed separately, repeat matings available from all the lines were used to estimate the environmental trend over the years for birth and weaning traits. Environmental variations that affect preweaning traits in beef cattle are extremely difficult to measure accurately in any statistical model. Repeat matings; that is, the comparison of full sibs born in two consecutive years, are only partly an estimate of environmental variation. Segregation and independent assortment can produce serious bias in the year to year estimations. A larger number of repeat matings would produce a better estimate and the average regression over a long period of time should give an idea of the environmental trend.

The environmental difference between two consecutive years was taken as the difference of adjusted calf weights produced by repeat matings after adjustment had been made for age of dam and sex differences. Two analyses of variance were computed in each breed to compare the year estimations from repeat matings. In the first analysis year effects were estimated including only calves born in line 7 of each breed. The second analysis was computed using only those calves which had inbreeding coefficients of zero for both the calf and the dam.

A fairly good agreement was found between the three methods of estimation when the number of repeat matings in each set of consecutive years was ten or higher. Because of low numbers, repeat mating estimations for the years 1953-1954, 1957-1958 and 1961-1962 in Angus were deleted. In Hereford the repeat mating estimates for 1954-1955, 1958-1959 and 1961-1962 were deleted, and the years 1951-1952 and 1961-1962 were deleted in the Shorthorn breed. In those years the estimated year effect used came from the source that had the greater number of observations. For all year estimates in which zero inbred population or line 7 were used, the environmental change was taken as the phenotypic change with the genetic change for that year being set at zero. In the case that some genetic progress did occur, this could bias downward the estimated genetic change.

Figures 21 through 32 show the environmental trends for each trait in the three breeds separately by sex. Environmental trends in Angus and Shorthorn were negative for weaning weight and preweaning average daily gain, but they were positive for Herefords. For birth weight the environmental effects were negative, but positive for type score in the three breeds.

Excluding the graphs corresponding to weaning weight in Angus and birth weight in Shorthorn, the trends in both sexes showed a close agreement for the environmental differences between years during the whole period studied. No satisfactory explanation was found for the two exceptions mentioned.

Effects of Inbreeding

Inbreeding effects were studied for weaning weight, average daily

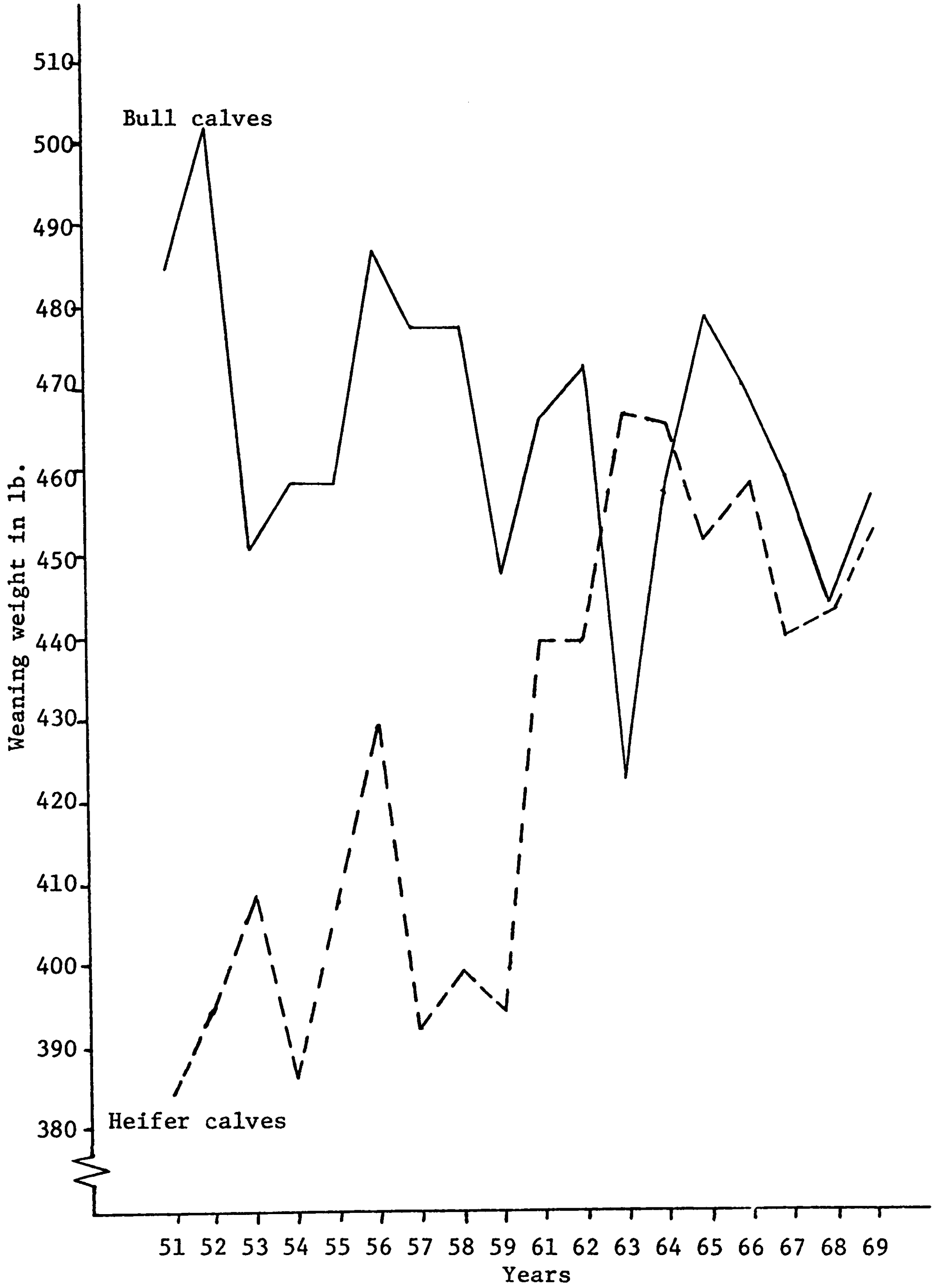


Figure 21. Environmental variation in Angus estimated by repeat matings

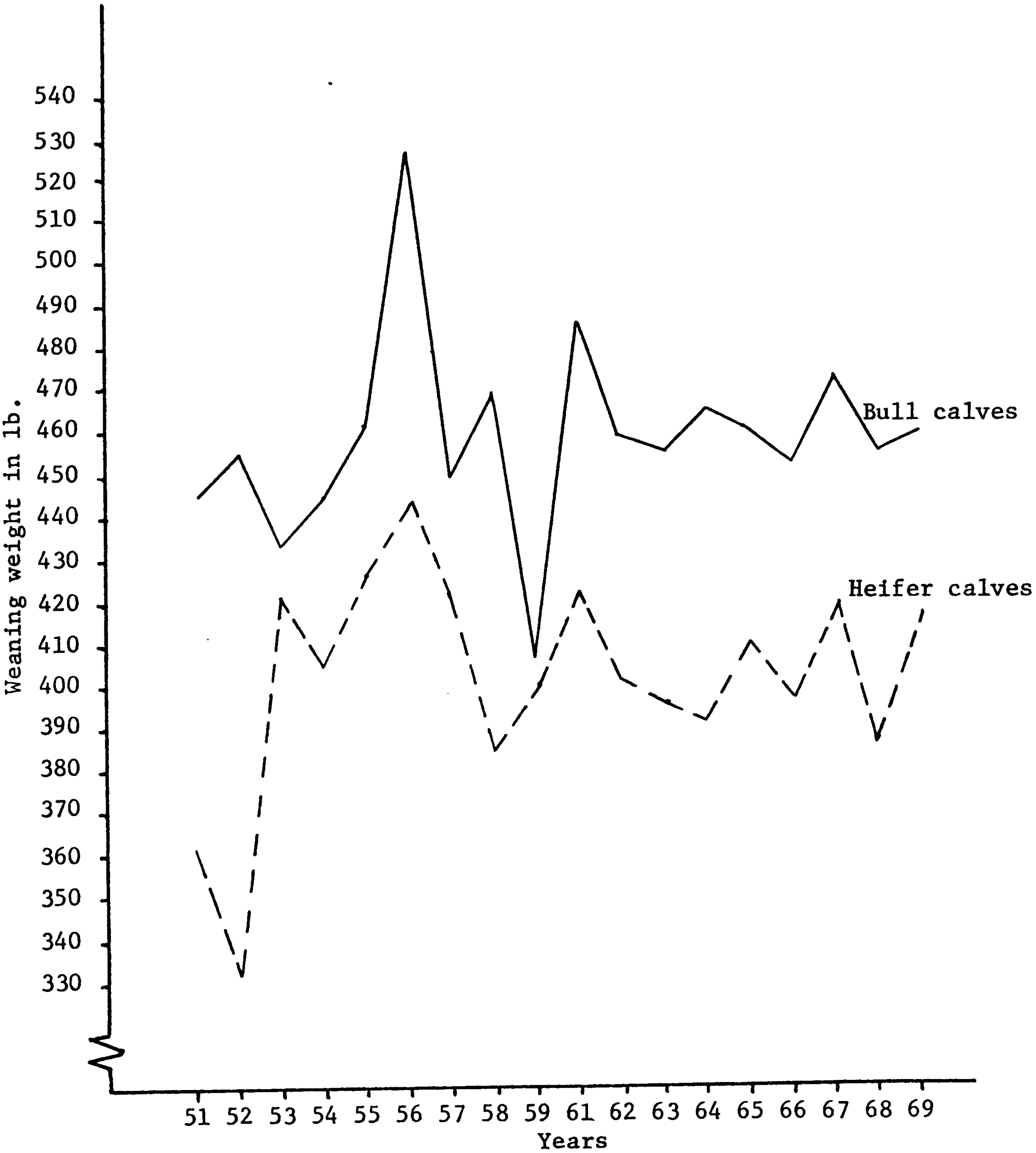


Figure 22. Environmental variations in Hereford estimated by repeat matings

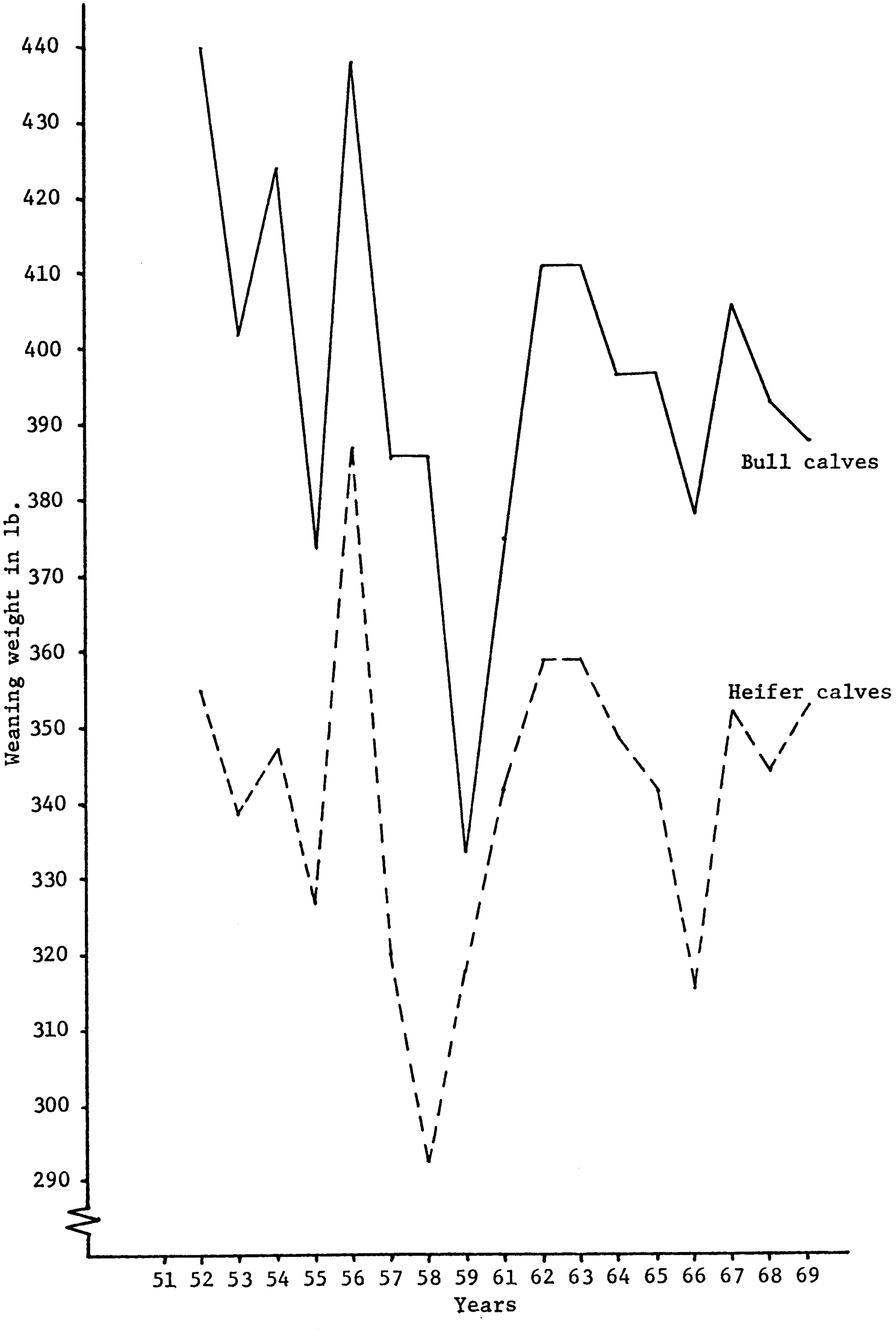


Figure 23. Environmental variations in Shorthorn estimated by repeat matings

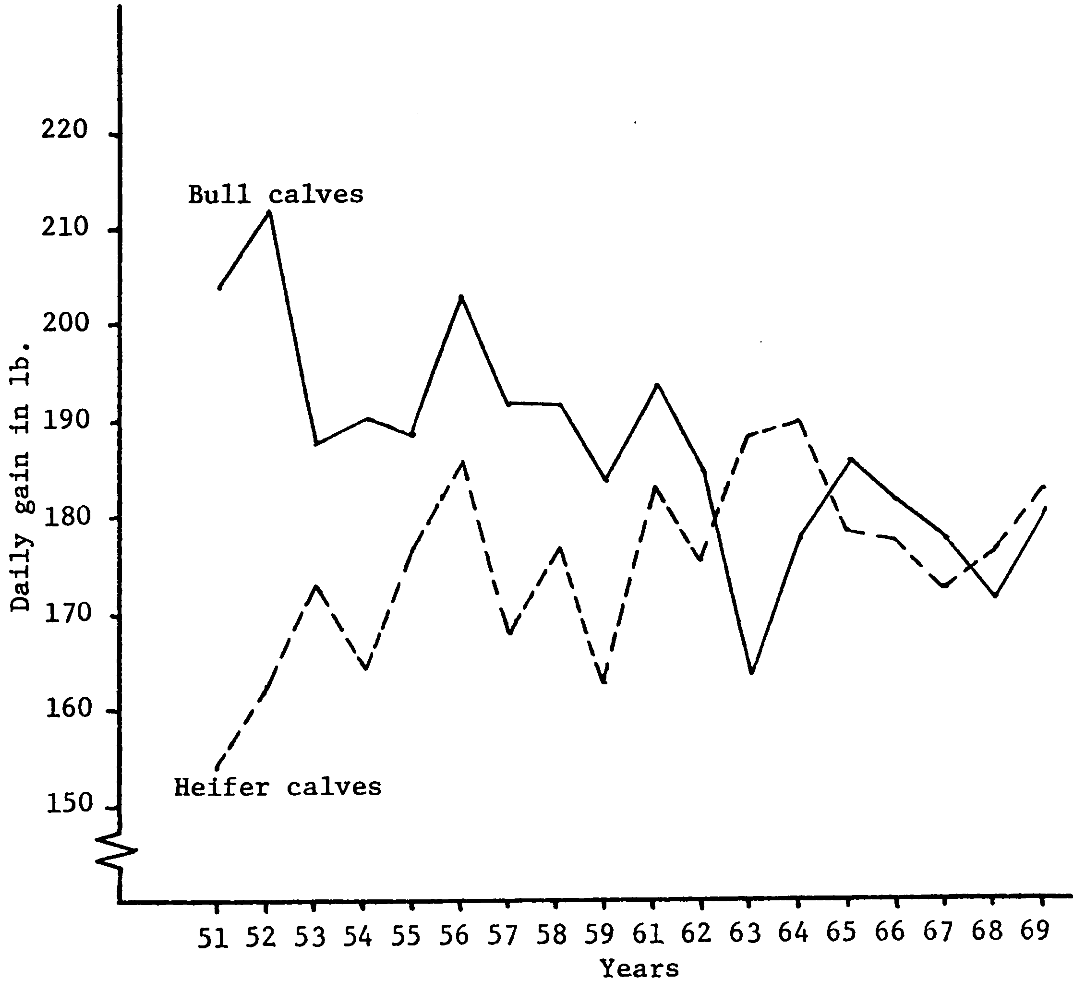


Figure 24. Environmental variation in Angus estimated by repeat matings

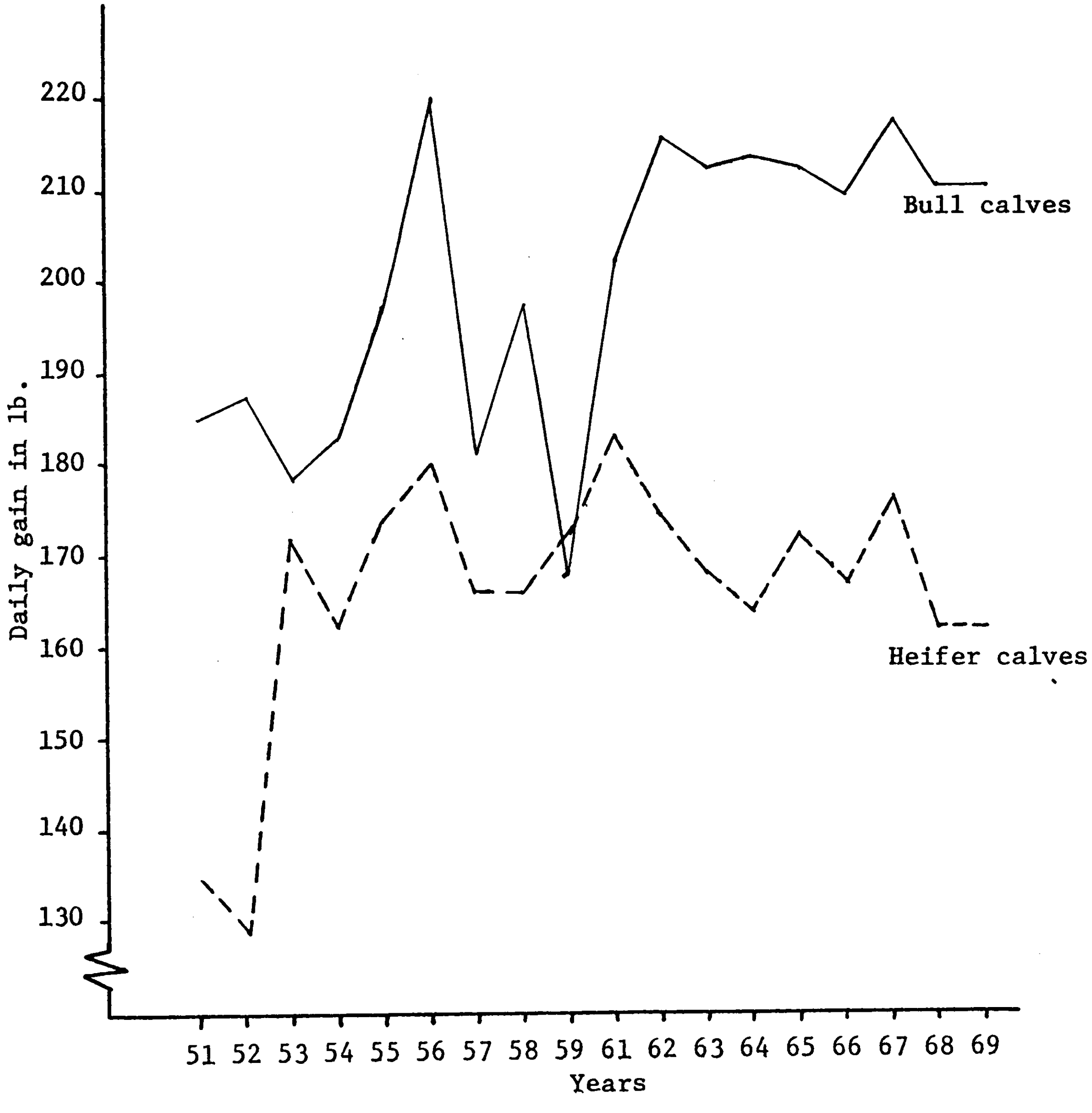


Figure 25. Environmental variation in Hereford estimated by repeat matings

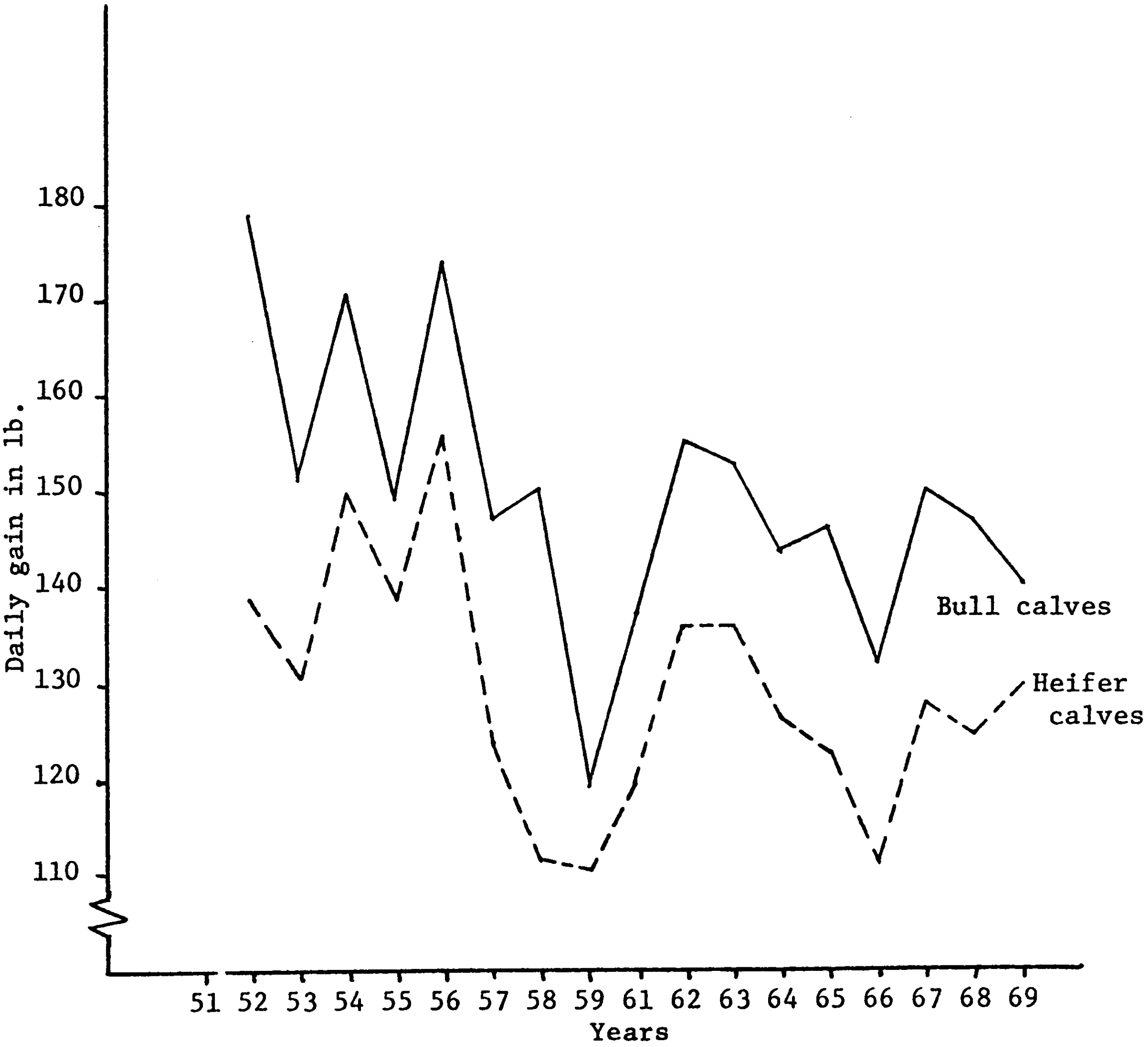


Figure 26. Environmental variation in Shorthorn estimated by repeat matings

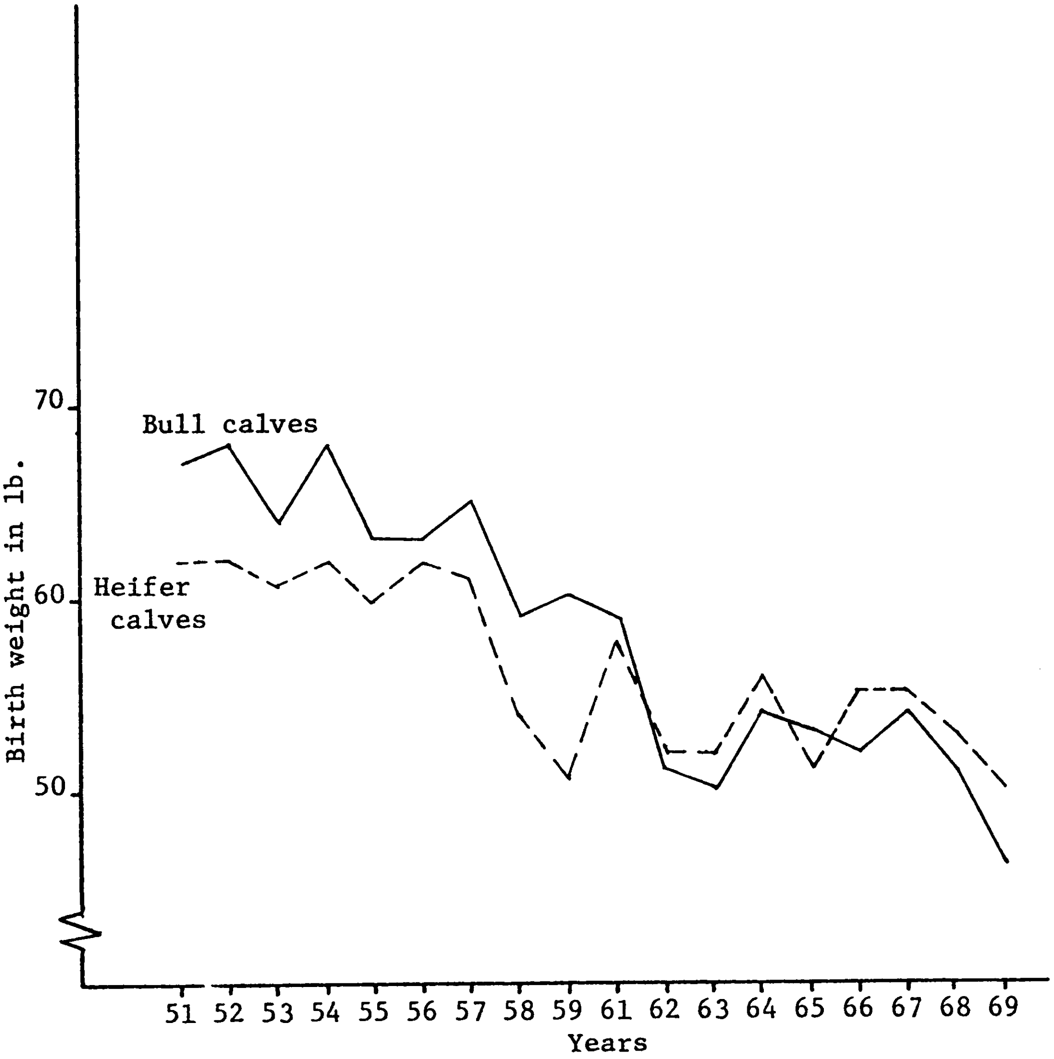


Figure 27. Environmental variation in Angus estimated by repeat matings

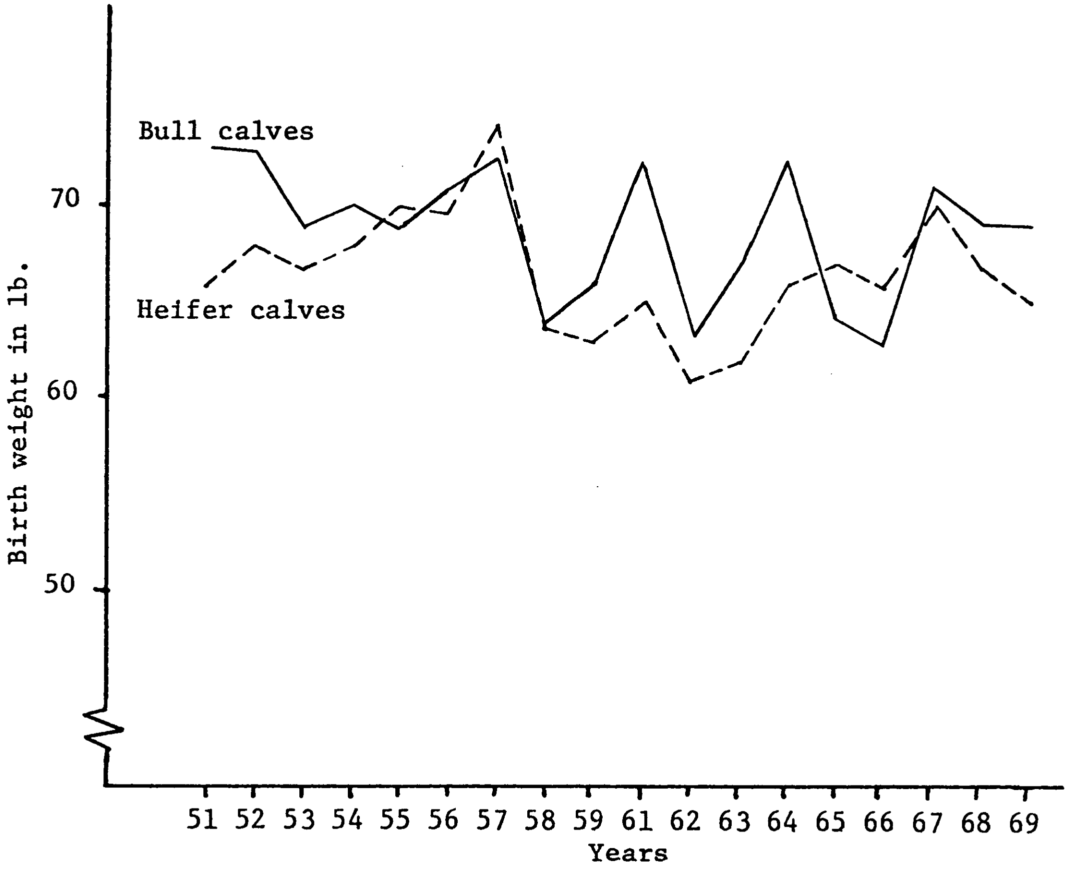


Figure 28. Environmental variation in Hereford estimated by repeat matings

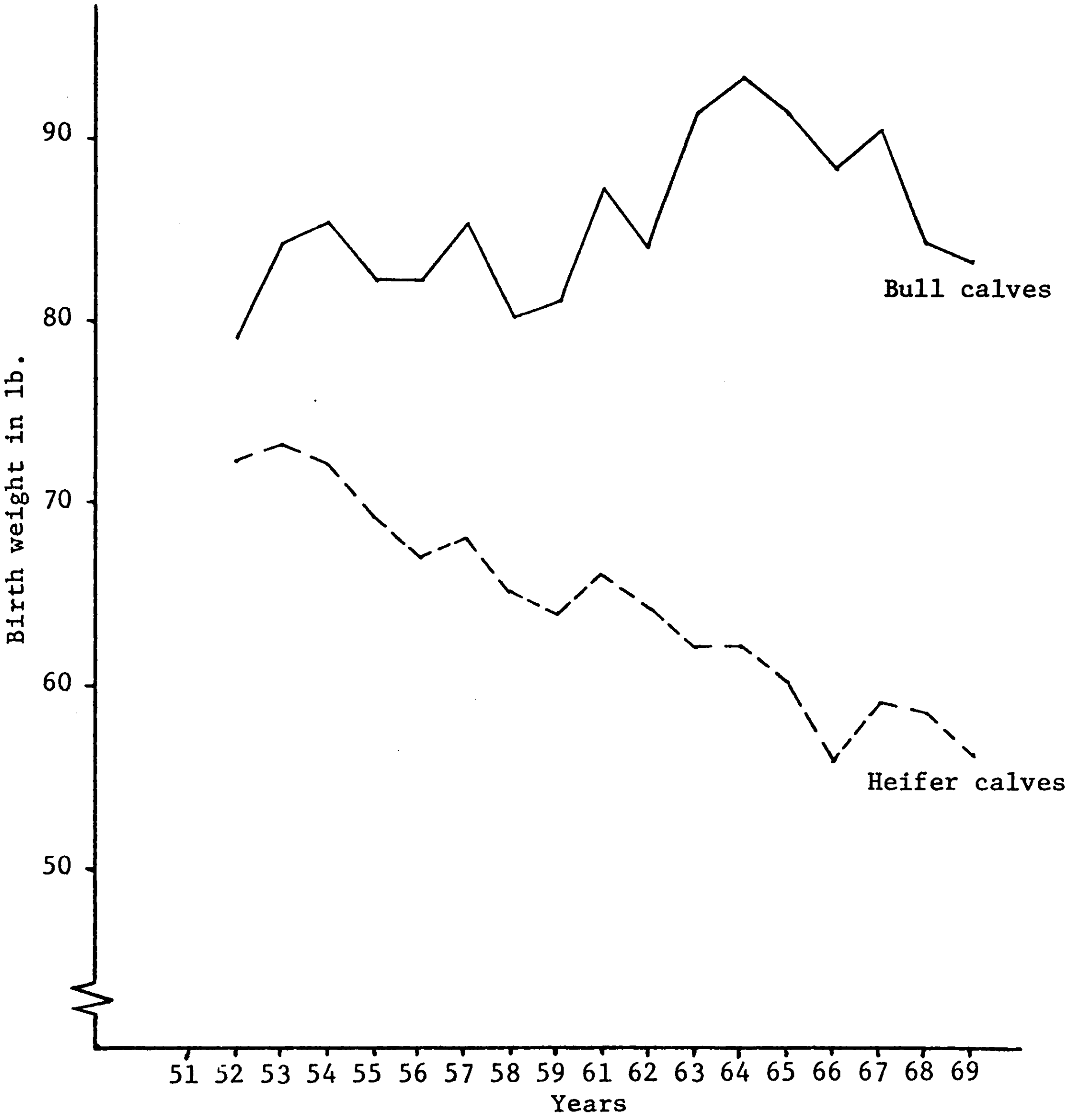


Figure 29. Environmental variation in Shorthorn estimated by repeat matings

Figure 30. Environmental variation in Angus estimated by repeat matings

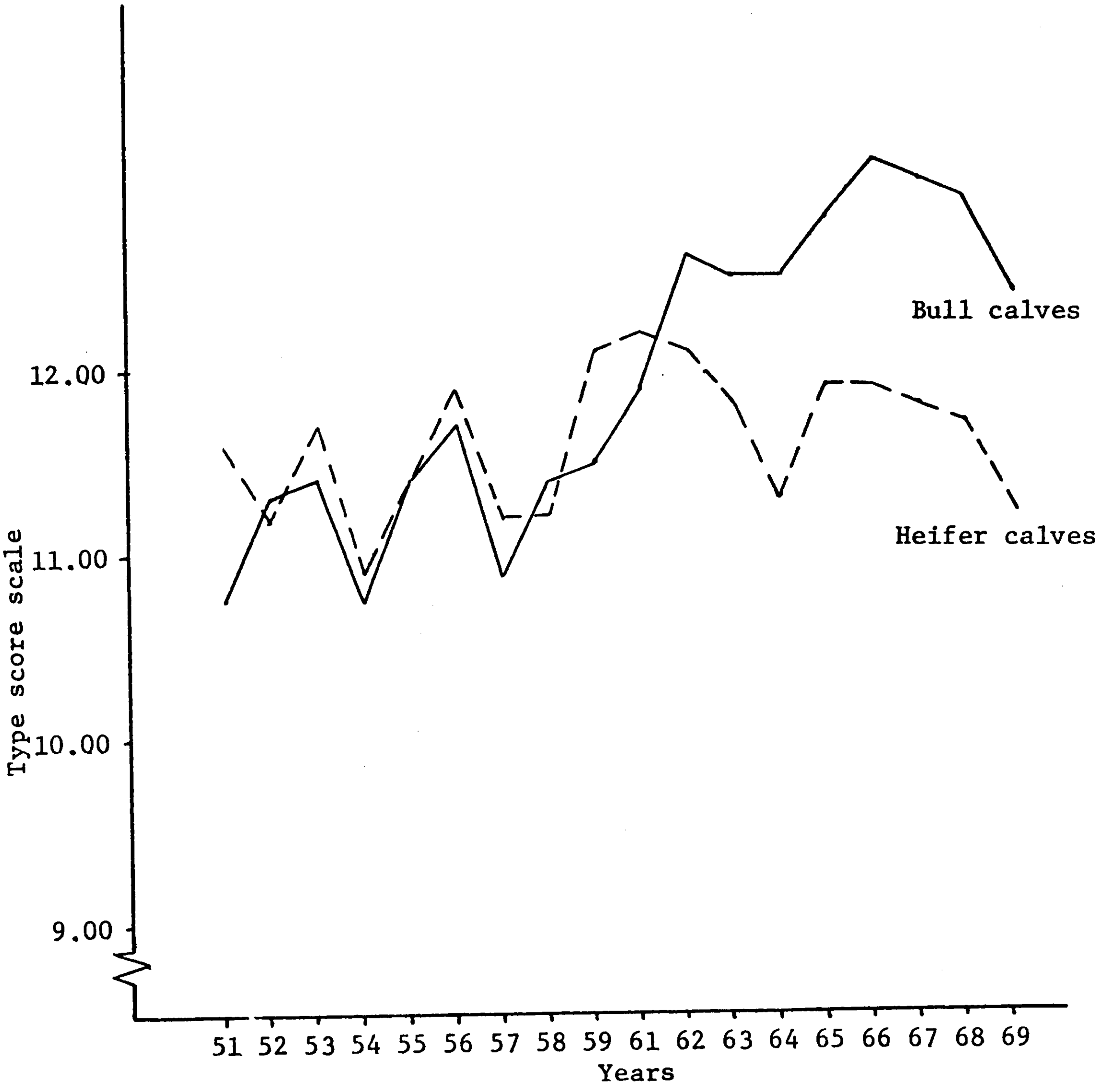


Figure 31. Environmental variation in Hereford estimated by repeat matings

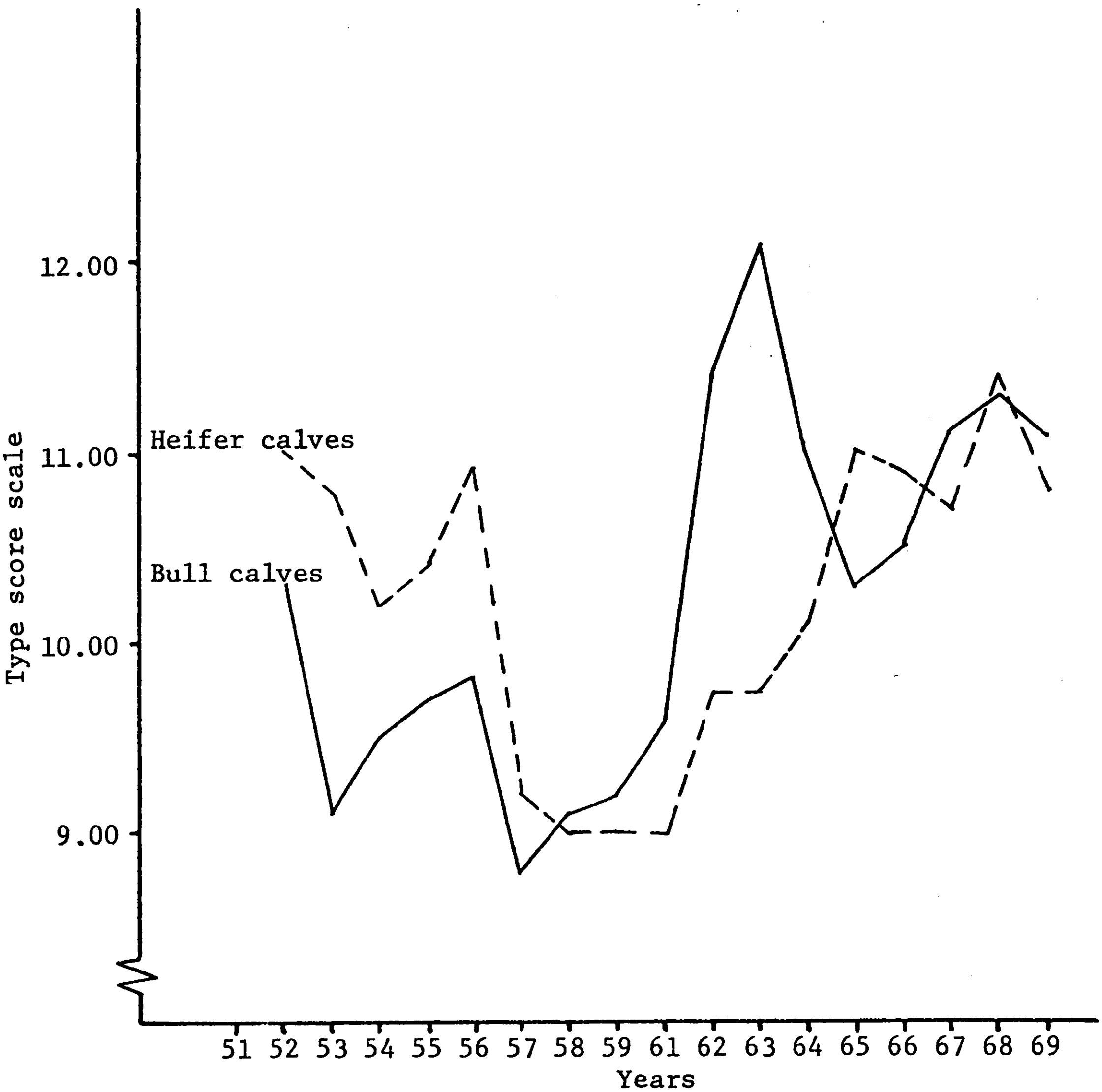


Figure 32. Environmental variation in Shorthorn estimated by repeat matings

gain, birth weight and type score with data adjusted for age of dam differences and for the year to year environmental variations estimated from the repeat mating information. Adjustment for the year to year variation was done separately for each sex in order to partition the confounding between years and inbreeding and to estimate inbreeding effects independent of year effects.

The statistical procedure used for estimating inbreeding effects was the regression of each trait on the inbreeding of calf and of the dam. Inbreeding of calf and dam were continuous independent variables included in all the models. Two mathematical models were used for estimating the regressions. In the first model the effects of calf inbreeding and dam inbreeding were estimated for each breed and sex including all the data from each breed. The partial regression coefficients were obtained absorbing the effects of sires within lines. Linear and quadratic regressions were fitted under this model. In the second model the partial linear and quadratic coefficients were estimated for each line and sex separately within each sire subclass. Tests of significance of the partial regression coefficients were done only for the highest degree of the non-orthogonal polynomial fitted in each model.

The following discussion will concern calf inbreeding (Fc), quadratic effects of calf inbreeding (Fc^2), dam inbreeding (Fd) and quadratic effects of dam inbreeding (Fd^2).

In tables XVII through XX, are presented all the regression coefficients estimated with model one, with the corresponding standard errors and classified by trait, breed and sex.

The effect of Fc on weaning weight was significant at $P<0.01$ in both

TABLE XVII. PARTIAL REGRESSION COEFFICIENTS OF WEANING WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd)

	Breed		
	Angus	Hereford	Shorthorn
Fc			
Linear			
Males	-1.333 ± 0.279**	-0.692 ± 0.299**	0.087 ± 0.304
Females	-0.073 ± 0.248**	-0.764 ± 0.280**	-0.746 ± 0.282**
Quadratic			
Males	0.027 ± 0.015	0.068 ± 0.029*	0.013 ± 0.013
Females	-0.013 ± 0.012	0.015 ± 0.027	0.022 ± 0.013
Fd			
Linear			
Males	0.006 ± 0.284	-1.250 ± 0.441*	-1.104 ± 0.325**
Females	-0.451 ± 0.286	-0.301 ± 0.373	-0.435 ± 0.297
Quadratic			
Males	-0.012 ± 0.021	0.005 ± 0.062	-0.017 ± 0.015
Females	0.025 ± 0.018	-0.029 ± 0.051	-0.025 ± 0.017
No. Observations			
Males	799	875	668
Females	772	862	645

* $P<0.05$

** $P<0.01$

units: Weaning weight (1b)
Inbreeding (1%)

TABLE XVIII. PARTIAL REGRESSION COEFFICIENTS OF AVERAGE DAILY GAIN ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd)

	Breed		
	Angus	Hereford	Shorthorn
Fc			
Linear			
Males	-0.006 ± 0.001**	-0.003 ± 0.001*	0.002 ± 0.001
Females	-0.004 ± 0.001**	-0.002 ± 0.001	-0.0005 ± 0.001
Quadratic			
Males	0.0001 ± 0.053	0.0003 ± 0.0001*	0.0000 ± 0.000
Females	0.0001 ± 0.036	0.0001 ± 0.0001	0.0000 ± 0.000
Fd			
Linear			
Males	-0.0001 ± 0.001	-0.005 ± 0.002*	-0.005 ± 0.001**
Females	-0.002 ± 0.001	-0.0005 ± 0.002	-0.003 ± 0.001*
Quadratic			
Males	0.0000 ± 0.053	0.0000 ± 0.009	-0.0000 ± 0.000
Females	0.0000 ± 0.036	-0.0002 ± 0.0002	-0.0000 ± 0.000

* $P<0.05$

** $P<0.01$

units: Average daily gain (lbs/day)
Inbreeding (1%)

TABLE XIX. PARTIAL REGRESSION COEFFICIENTS OF BIRTH WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd)

	Breed		
	Angus	Hereford	Shorthorn
Fc			
Linear			
Males	-0.008 ± 0.081	-0.187 ± 0.046**	-0.142 ± 0.049**
Females	0.083 ± 0.043	-0.197 ± 0.042**	0.052 ± 0.064
Quadratic			
Males	-0.008 ± 0.004	0.006 ± 0.004	0.001 ± 0.002
Females	-0.0004 ± 0.002	0.001 ± 0.004	0.002 ± 0.003
Fd			
Linear			
Males	-0.020 ± 0.083	-0.074 ± 0.069	-0.022 ± 0.053
Females	0.031 ± 0.049	-0.103 ± 0.056	-0.068 ± 0.067
Quadratic			
Males	0.0007 ± 0.006	0.001 ± 0.009	-0.003 ± 0.002
Females	0.004 ± 0.003	0.012 ± 0.007	-0.002 ± 0.002

* P<0.05
** P<0.01
units: Birth weight (lb); Inbreeding (1%)

TABLE XX. PARTIAL REGRESSION COEFFICIENTS OF TYPE SCORE ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd)

	Breed		
	Angus	Hereford	Shorthorn
Fc			
Linear			
Males	-0.015 ± 0.007*	-0.008 ± 0.007	0.0006 ± 0.007
Females	-0.0008 ± 0.008	-0.028 ± 0.007**	0.0000 ± 0.008
Quadratic			
Males	0.0000 ± 0.0004	0.001 ± 0.0006	0.0009 ± 0.0003**
Females	0.0001 ± 0.0003	0.0006 ± 0.001	-0.0003 ± 0.0004
Fd			
Linear			
Males	-0.001 ± 0.007	-0.007 ± 0.009	-0.033 ± 0.008**
Females	-0.027 ± 0.007**	0.006 ± 0.009	-0.027 ± 0.009**
Quadratic			
Males	-0.0002 ± 0.0005	0.0008 ± 0.001	-0.0003 ± 0.0003
Females	0.0001 ± 0.0005	-0.0002 ± 0.0007	0.0003 ± 0.0005

* $P<0.05$

** $P<0.01$

units: Type score (1/3 of a U.S.D.A. grade)
Inbreeding (1%)

sexes in Angus and Hereford. In Shorthorns the effect was significant $P<0.01$ for females only. The regression coefficients of weaning weight on Fc for both male and female Angus and Herefords were negative and ranged between -0.692 ± 0.299 to -1.333 ± 0.279. Shorthorn females also showed a negative regression coefficient of -0.746 ± 0.282; however, for male Shorthorns the value was positive, 0.087 ± 0.304 and nonsignificant.

The effect of Fd on weaning weight was negative and significant ($P<0.01$) in male Herefords, -1.250 ± 0.441, and in male Shorthorns, -1.104 ± 0.325; and positive in male Angus, 0.006 ± 0.284. Females of the three breeds showed nonsignificant negative regression coefficients on inbreeding.

The only quadratic regression coefficient that was significant ($P<0.05$), was for Fc^2 in Hereford males.

In the Hereford and Shorthorn breeds the effect of Fc was greater in females than in males, however the reverse situation was present in Angus. The effects for Fd were greater in males than in females in Hereford and Shorthorn breeds but in Angus breed again the reverse situation was found.

A fair comparison of the results of this study with those reported in the literature is somewhat difficult for several reasons. Most of the authors did not remove the confounding between years and inbreeding. This is an important point for the Front Royal inbred lines because inbreeding coefficients increased sharply in most of the inbred lines and yielded the highest inbred beef cattle population reported in the United States.

In addition, most of the inbreeding research reported was done with the Hereford breed. Only two papers, Dinkel _et al_. (1968) and Brinks _et al_. (1965) reported separate regression coefficients for each sex.

The report from Nebraska, Swiger et al. (1961) includes one line of Angus and one of Shorthorns, however, they did not report separate estimations of Fc and Fd effects for each breed and sex.

In general and with the limitations already explained the range of values of the weaning weight regressions observed in this study are within the range of values reported in the literature. Working with the Hereford breed, Burgess et al. (1958), Koch (1951), Swiger et al. (1961) reported regression values for Fc and Fd of: -1.76, -1.15; -0.48, -2.54; -1.42, -0.15, respectively. Brinks et al. (1965) and Dinkel et al. (1968) reported regression coefficients for Fc in Hereford bull calves of -0.269, -0.621 and for females -0.956 and -0.364, respectively.

The different effects of Fc and Fd in each sex found in this study in the Hereford and Shorthorn breeds are in agreement with those reported by Brinks et al. (1965). However, Dinkel et al. (1968) found opposite effects for Fc and Fd than those reported by Brinks et al. (1965), and the results in this study for Hereford and Shorthorn breeds.

Two hypotheses have been discussed in regard to the differences between the two sexes. Stonaker (1963) discussed the hypothesis that genetic differences between the two sexes may exist as a consequence of differences in the sex chromosomes. Brinks (1965) concluded that the effects of maternal environment could mask response to inbreeding, especially in male calves. Bulls having a greater growth potential, may be retarded more than heifers by the decreased milk supply that is associated with increasing inbreeding of dam. A similar hypothesis was suggested previously by Carter and Kincaid (1959), to explain the higher values of heritability of weaning weight found for heifers in comparison with those obtained for steers.

Quadratic effects of Fc on weaning weight was found only for Hereford males 0.068 ± 0.029. Dinkel et al. (1968) reported a quadratic effect of Fc on weaning weight for bull calves of -0.0313 and of Fd^2 on weaning weight of females of 0.040 lb. per 1% of inbreeding, both of which were significant ($P<0.05$). In the present study quadratic effects of Fc and Fd on weaning weight were not significant in the females of either of the three breeds.

Calf inbreeding affected the average daily gain of male Angus and Herefords -0.006 ± 0.001, -0.003 ± 0.001, respectively, but not Shorthorn bull calves. Angus females showed a regression coefficient of -0.004 ± 0.001 for average daily gain on Fc. The corresponding estimates for Hereford and Shorthorn females were negative but not significant. The regression coefficients for both Angus and Hereford males were larger than for the females of the same breeds. Average daily gain of Shorthorn females had a tendency to be more depressed than for males, for which the regression coefficient was positive and nonsignificant.

Inbreeding of dam showed a significantly depressing effect on average daily gain of Hereford and Shorthorn bull calves, -0.005 ± 0.002 and -0.005 ± 0.001, respectively, and in female Shorthorns, -0.003 ± 0.001. The other regression coefficients were negative and nonsignificant. With the exception of the Angus, Fd depressed the average daily gain more in males than in females. The only quadratic effect that showed significance for this trait was Fc^2 in Hereford males, 0.0003 ± 0.0001. Separate linear and quadratic coefficients of regression of average daily gain on Fc and Fd for bull and female calves have not been published for beef cattle populations. Swiger et al. (1961) reported estimations obtained within year, line and sex subclasses of -0.0006 and -0.0006 for Fc and Fd, respectively. Hoornbeek _et al_. (1966) reported that as the dam became more inbred, suckling gains of their calves declined. Brinks _et al_. (1965) reported separate estimates by sexes of suckling gain, measured as 180-day gain, Fc, -0.464 and -1.708, and Fd, -1.887 and -0.431, for males and females, respectively.

The effect of Fc on birth weight shown in table XIX, was significant; -0.187 ± 0.046 and -0.197 ± 0.042 for both male and female Herefords; and male Shorthorns, -0.142 ± 0.049. The effect of Fd on birth weight showed a nonsignificant negative trend in all the regressions with the exception of Angus females, which showed a positive trend. Quadratic regression coefficients were not significant in either sex in the three breeds. Brinks _et al_. (1965) reported a negative effect of Fc on birth weight of male and female calves of -0.128 and -0.401, respectively. The effect of Fd was positive in both sexes and the regression coefficients reported were 0.009 and 0.096 for male and female calves, respectively. Swiger _et al_. (1961) presented coefficients of regression of birth weight on Fc and Fd estimated in two localities of -0.380, -0.06 and -0.03, 0.13 in Fort Robinson and Lincoln, Nebraska, respectively.

Partial regression coefficients of type score on inbreeding of the calf and of the dam, estimated in the three breeds, are presented in table XX. The regression coefficients of Fc were negative in both sexes in the Angus and Hereford breeds; however, in Shorthorn the regressions were positive but not significant. The effect of Fc was greater in Hereford females, -0.028 ± 0.007, than in Hereford bull calves, -0.008 ±

0.007. In Angus a reverse effect was observed. The regression coefficients were -0.015 ± 0.007 and -0.008 ± 0.008 for males and females, respectively. The effect of Fd on type score was significant ($P<0.01$) in Angus females and in male and female Shorthorns. The regression coefficients for females of the Angus and Shorthorn breeds were equal, -0.027. With the exception of the Angus breed, the effect of Fd was greater in male than in female calves. The only significant quadratic effect was the regression of score on Fc for Shorthorn males, 0.0009 ± 0.0003. Brinks *et al.* (1965) reported that the effect of Fc on type was negative only in Hereford females and for Fd the reverse situation was observed. Dinkel *et al.* (1968) reported a negative effect of Fc on both males and females. The sex differences were not significant. A quadratic effect of Fd^2 on type score of male calves was reported by Dinkel (1968).

To compare the estimates of inbreeding effects for the whole breed with those from each line, the second model of analysis was used. As was explained, in this model calf and dam inbreeding were included as continuous independent variables and the regressions were estimated for each line and sex separately within sire subclasses. All the linear and quadratic regressions are presented in tables XXI through XXXII. The number of observations from which each regression coefficient was estimated are included in only the first tables corresponding to each breed. The same number of observations is valid for the four traits in the following tables.

Comparing the regression coefficients for weaning weight presented in tables XVII and XXI, it is possible to see the discrepancies between the two systems of estimating inbreeding effects. Using model one, Angus

TABLE XXI. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF WEANING WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN ANGUS

Line	No. Observations	Fc		Fd	
		Linear	Quadratic	Linear	Quadratic
A-1					
M^1	97	0.054 ± 0.592	-0.016 ± 0.033	-0.277 ± 0.737	0.099 ± 0.050
F^2	80	0.479 ± 0.673	0.027 ± 0.038	-2.148 ± 0.879*	0.149 ± 0.059*
A-2					
M	99	-1.168 ± 0.490**	0.014 ± 0.022	-0.371 ± 0.489	-0.038 ± 0.034
F	87	-1.298 ± 0.448**	-0.035 ± 0.019	-0.056 ± 0.550	0.039 ± 0.031
A-3					
M	99	-1.653 ± 1.161	0.167 ± 0.074*	0.436 ± 0.866	-0.031 ± 0.082
F	63	-1.581 ± 0.890	-0.130 ± 0.059*	-1.017 ± 0.979	-0.127 ± 0.064
A-4					
M	77	-2.813 ± 0.769**	0.091 ± 0.056	2.335 ± 1.118	-0.054 ± 0.073
F	65	-0.769 ± 0.649	0.096 ± 0.035**	0.568 ± 0.802	-0.059 ± 0.134
A-7					
M	146	0.205 ± 1.140	-0.061 ± 0.280	0.004 ± 0.961	0.134 ± 0.137
F	140	-0.421 ± 1.095	-0.099 ± 0.161	-0.927 ± 0.695	-0.140 ± 0.139
A-8					
M	141	-1.934 ± 0.846*	0.004 ± 0.117	-1.077 ± 0.758	0.117 ± 0.121
F	167	-1.054 ± 0.856	-0.053 ± 0.085	-1.614 ± 0.988	0.227 ± 0.111*

* $P<0.05$
** $P<0.01$
1 = males; 2 = females
units: Weaning weight (lb); Inbreeding (1%)

TABLE XXII. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF WEANING WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN HEREFORD

Line	No. Observations	Fc		Fd	
		Linear	Quadratic	Linear	Quadratic
H-2					
M[1]	89	-0.153 ± 0.940	0.139 ± 0.077	-3.673 ± 0.917**	0.255 ± 0.142
F[2]	60	-2.826 ± 0.825**	0.208 ± 0.098*	-0.466 ± 0.839	0.180 ± 0.148
H-3					
M	75	0.123 ± 0.974	0.230 ± 0.121	-0.657 ± 1.405	0.268 ± 0.261
F	63	-0.664 ± 0.873	0.044 ± 0.071	0.865 ± 1.047	-0.084 ± 0.104
H-4					
M	81	-0.011 ± 0.888	-0.157 ± 0.079	-2.292 ± 1.251	0.134 ± 0.145
F	44	0.170 ± 0.991	-0.055 ± 0.237	-3.362 ± 1.833	0.561 ± 1.195
H-5					
M	77	-0.736 ± 0.503	0.125 ± 0.131	1.201 ± 1.072	-0.405 ± 0.389
F	55	-0.254 ± 0.464	-0.056 ± 0.81	-0.175 ± 0.719	-0.270 ± 0.176
H-6					
M	70	1.471 ± 3.174	-0.447 ± 0.632	-2.131 ± 4.339	-0.895 ± 1.029
F	68	-2.340 ± 2.205	-0.268 ± 0.855	0.068 ± 3.933	-1.188 ± 1.070
H-7					
M	77	-2.670 ± 1.602	2.041 ± 0.190	-3.281 ± 1.341*	0.185 ± 0.234
F	89	-0.629 ± 1.564	0.167 ± 0.208	-1.287 ± 1.561	-0.024 ± 0.214
H-8					
M	97	-1.477 ± 1.139	0.088 ± 0.192	0.989 ± 1.634	0.133 ± 0.853
F	83	-0.454 ± 1.438	-0.030 ± 0.236	1.152 ± 1.597	-0.674 ± 0.608

* $P<0.05$
** $P<0.01$
1 = males; 2 = females
units: Weaning weight (lb); Inbreeding (1%)

TABLE XXIII. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF WEANING WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN SHORTHORN

Line	No. Observations	Fc		Fd	
		Linear	Quadratic	Linear	Quadratic
S-1					
M[1]	89	1.352 ± 0.992	0.012 ± 0.047	-2.287 ± 1.088*	-0.058 ± 0.042
F[2]	73	-0.042 ± 1.361	-0.096 ± 0.078	-1.583 ± 1.494	0.081 ± 0.070
S-2					
M	64	-1.022 ± 0.983	-0.071 ± 0.065	-1.042 ± 0.811	0.042 ± 0.038
F	65	0.918 ± 0.900	-0.012 ± 0.050	-1.281 ± 0.822	-0.021 ± 0.037
S-4					
M	47	0.653 ± 0.972	-0.044 ± 0.048	0.317 ± 0.852	-0.032 ± 0.046
F	40	-0.404 ± 0.481	0.025 ± 0.030	-0.574 ± 0.431	-0.021 ± 0.022
S-5					
M	45	0.219 ± 0.709	0.033 ± 0.057	-1.771 ± 0.810*	0.371 ± 0.242
F	43	-1.752 ± 0.838*	0.103 ± 0.062	-0.740 ± 0.773	0.071 ± 0.147
S-7					
M	128	-1.661 ± 1.164	-0.034 ± 0.180	-0.663 ± 1.651	0.156 ± 0.265
F	139	-1.887 ± 1.069	-0.053 ± 0.147	-0.617 ± 1.034	-0.046 ± 0.159
S-8					
M	152	-0.767 ± 0.931	-0.170 ± 0.110	-1.551 ± 0.960	-0.189 ± 0.115
F	178	-0.820 ± 0.827	0.133 ± 0.091	0.186 ± 0.736	-0.113 ± 0.120

* $P<0.05$

1 = males; 2 = females

units: Weaning weight (lb); Inbreeding (1%)

TABLE XXIV. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF AVERAGE DAILY GAIN ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN ANGUS

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
A-1				
M^1	0.001 ± 0.003	-0.0001 ± 0.000	-0.001 ± 0.003	-0.0004 ± 0.0002*
F^2	-0.004 ± 0.002	0.027 ± 0.038	-0.005 ± 0.002	-0.150 ± 0.059*
A-2				
M	-0.005 ± 0.002**	0.0004 ± 0.001	-0.001 ± 0.002	-0.0001 ± 0.0001
F	-0.006 ± 0.002**	0.0001 ± 0.0009	0.0003 ± 0.002	0.0001 ± 0.0001
A-3				
M	-0.008 ± 0.005	-0.015 ± 0.006*	0.001 ± 0.003	-0.0001 ± 0.0003
F	-0.006 ± 0.004	-0.0007 ± 0.0002*	-0.005 ± 0.004	-0.0005 ± 0.0002
A-4				
M	-0.013 ± 0.003**	0.0004 ± 0.0002	0.011 ± 0.005	-0.0002 ± 0.0003
F	-0.002 ± 0.002	0.0003 ± 0.0001*	0.002 ± 0.003	-0.0003 ± 0.0006
A-7				
M	0.001 ± 0.005	-0.0007 ± 0.001	-0.001 ± 0.004	0.0009 ± 0.0006
F	-0.002 ± 0.004	-0.0004 ± 0.007	-0.005 ± 0.003	-0.0007 ± 0.0006
A-8				
M	-0.007 ± 0.003	-0.00001 ± 0.0006	-0.004 ± 0.003	-0.0002 ± 0.0002
F	-0.004 ± 0.002	-0.0006 ± 0.0005	-0.008 ± 0.004	0.0005 ± 0.0002

* $P<0.05$

** $P<0.01$

1 = males; 2 = females

units: Average daily gain (lb/day); Inbreeding (1%)

TABLE XXV. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF AVERAGE DAILY GAIN ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN HEREFORD

Line	Fc		Fd	
	Linear	Quadratic	Linear	Quadratic
H-2				
M[1]	-0.002 ± 0.004	0.0008 ± 0.0003	-0.016 ± 0.004**	0.0010 ± 0.0006
F[2]	-0.016 ± 0.004**	0.0011 ± 0.0004*	-0.006 ± 0.004	0.0007 ± 0.0007
H-3				
M	-0.0002 ± 0.006	0.0011 ± 0.0005*	-0.001 ± 0.006	0.0014 ± 0.001
F	-0.002 ± 0.004	0.0004 ± 0.0003	0.005 ± 0.005	-0.0005 ± 0.0005
H-4				
M	-0.004 ± 0.004	-0.0004 ± 0.0003	-0.006 ± 0.005	0.0004 ± 0.0006
F	0.002 ± 0.004	-0.0002 ± 0.001	-0.012 ± 0.008	0.003 ± 0.005
H-5				
M	-0.002 ± 0.002	0.0006 ± 0.0006	0.005 ± 0.005	-0.0018 ± 0.001
F	0.002 ± 0.002	-0.0001 ± 0.0004	-0.0003 ± 0.003	-0.0013 ± 0.008
H-6				
M	0.009 ± 0.014	-0.0024 ± 0.002	-0.011 ± 0.020	-0.0044 ± 0.004
F	-0.010 ± 0.010	-0.0004 ± 0.003	0.004 ± 0.018	-0.0067 ± 0.004
H-7				
M	-0.011 ± 0.007	0.0011 ± 0.0009	-0.014 ± 0.006	0.0007 ± 0.001
F	-0.002 ± 0.007	0.0010 ± 0.0009	-0.007 ± 0.007	-0.0001 ± 0.0009
H-8				
M	-0.006 ± 0.005	0.0002 ± 0.0008	0.003 ± 0.007	0.0007 ± 0.003
F	-0.003 ± 0.006	0.00007 ± 0.001	0.005 ± 0.007	-0.0031 ± 0.002

* $P<0.05$
** $P<0.01$
1 = males; 2 = females
units: Average daily gain (lb/day); Inbreeding (1%)

TABLE XXVI. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF AVERAGE DAILY GAIN ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN SHORTHORN

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
S-1				
M[1]	0.008 ± 0.004	0.012 ± 0.047	-0.009 ± 0.005	-0.058 ± 0.042
F[2]	0.003 ± 0.006	-0.096 ± 0.078	-0.006 ± 0.007	0.081 ± 0.070
S-2				
M	-0.005 ± 0.004	-0.072 ± 0.065	-0.004 ± 0.003	0.042 ± 0.038
F	0.005 ± 0.004	-0.012 ± 0.050	-0.005 ± 0.003	-0.021 ± 0.037
S-4				
M	0.003 ± 0.004	-0.0002 ± 0.0002	0.001 ± 0.004	-0.0001 ± 0.0002
F	0.001 ± 0.002	0.0000 ± 0.0000	-0.003 ± 0.001*	-0.0001 ± 0.0001
S-5				
M	0.002 ± 0.003	0.0001 ± 0.0002	-0.008 ± 0.003	0.002 ± 0.001
F	-0.007 ± 0.003	0.0005 ± 0.0002*	-0.002 ± 0.003	-0.0004 ± 0.0006
S-7				
M	-0.008 ± 0.005	-0.035 ± 0.180	-0.003 ± 0.007	0.156 ± 0.265
F	-0.009 ± 0.004	-0.053 ± 0.147	-0.003 ± 0.004	-0.047 ± 0.159
S-8				
M	-0.002 ± 0.004	-1.551 ± 0.960	-0.008 ± 0.004*	-0.190 ± 0.115
F	-0.003 ± 0.003	0.186 ± 0.736	-0.007 ± 0.003	-0.113 ± 0.120

* P<0.05
** P<0.01
1 = males; 2 = females
units: Average daily gain (lb/day); Inbreeding (1%)

TABLE XXVII. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF BIRTH WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN ANGUS

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
A-1				
M^1	-0.062 ± 0.170	-0.010 ± 0.009	-0.179 ± 0.211	-0.003 ± 0.014
F^2	0.085 ± 0.093	-0.011 ± 0.005*	-0.020 ± 0.122	-0.003 ± 0.008
A-2				
M	0.077 ± 0.112	-0.011 ± 0.005*	-0.102 ± 0.112	0.008 ± 0.007
F	0.228 ± 0.079*	-0.0009 ± 0.003	-0.061 ± 0.087	0.015 ± 0.005
A-3				
M	-0.215 ± 0.309	-0.026 ± 0.020	0.294 ± 0.230	0.019 ± 0.022
F	0.173 ± 0.133	-0.014 ± 0.009	-0.234 ± 0.146	-0.002 ± 0.010
A-4				
M	-0.038 ± 0.077	-0.005 ± 0.005	-0.029 ± 0.112	0.003 ± 0.007
F	0.199 ± 0.091*	0.003 ± 0.005	0.010 ± 0.112	0.012 ± 0.020
A-7				
M	0.054 ± 0.360	0.075 ± 0.088	-0.229 ± 0.304	0.005 ± 0.043
F	-0.073 ± 0.220	-0.018 ± 0.032	0.152 ± 0.140	0.021 ± 0.028
A-8				
M	0.039 ± 0.395	0.025 ± 0.054	0.006 ± 0.354	-0.078 ± 0.056
F	-0.251 ± 0.119*	0.005 ± 0.017	0.031 ± 0.202	0.006 ± 0.023

* $P<0.05$

** $P<0.01$

1 = males; 2 = females

units: Birth weight (lb); Inbreeding (1%)

TABLE XXVIII. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF BIRTH WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN HEREFORD

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
H-2				
M^1	-0.018 ± 0.139	0.002 ± 0.011	-0.229 ± 0.135	0.036 ± 0.021
F^2	0.053 ± 0.121	-0.015 ± 0.015	-0.308 ± 0.124	0.007 ± 0.022
H-3				
M	0.096 ± 0.135	-0.002 ± 0.017	-0.289 ± 0.195	-0.027 ± 0.037
F	-0.156 ± 0.143	0.001 ± 0.011	0.070 ± 0.172	0.011 ± 0.017
H-4				
M	-0.242 ± 0.111*	-0.012 ± 0.010	0.090 ± 0.157	0.023 ± 0.018
F	-0.125 ± 0.157	0.010 ± 0.037	-0.150 ± 0.290	-0.035 ± 0.190
H-5				
M	-0.237 ± 0.063	0.007 ± 0.016	0.155 ± 0.134	-0.047 ± 0.049
F	-0.305 ± 0.065**	-0.0006 ± 0.012	0.196 ± 0.101	-0.009 ± 0.026
H-6				
M	-0.493 ± 0.392	0.056 ± 0.078	0.159 ± 0.535	0.047 ± 0.127
F	-0.341 ± 0.319	-0.169 ± 0.122	-0.738 ± 0.569	0.101 ± 0.152
H-7				
M	-0.327 ± 0.193	-0.041 ± 0.022	-0.309 ± 0.161	0.018 ± 0.028
F	-0.275 ± 0.241	-0.037 ± 0.031	-0.340 ± 0.240	-0.039 ± 0.032
H-8				
M	-0.308 ± 0.184	0.026 ± 0.031	0.346 ± 0.265	-0.044 ± 0.137
F	0.027 ± 0.214	-0.019 ± 0.035	0.0009 ± 0.237	-0.020 ± 0.091

* $P<0.05$
** $P<0.01$
1 = males; 2 = females
units: Birth weight (lb); Inbreeding (1%)

TABLE XXIX. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF BIRTH WEIGHT ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN SHORTHORN

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
S-1				
M[1]	-0.009 ± 0.139	0.014 ± 0.006	-0.352 ± 0.153*	-0.0005 ± 0.006
F[2]	0.278 ± 0.263	0.008 ± 0.015	-0.111 ± 0.289	-0.003 ± 0.013
S-2				
M	-0.059 ± 0.170	0.004 ± 0.011	-0.109 ± 0.140	0.004 ± 0.006
F	-0.042 ± 0.132	-0.007 ± 0.007	-0.075 ± 0.120	-0.001 ± 0.005
S-4				
M	-0.051 ± 0.126	-0.007 ± 0.006	0.070 ± 0.110	-0.001 ± 0.006
F	0.034 ± 0.093	-0.005 ± 0.006	-0.127 ± 0.084	-0.0001 ± 0.004
S-5				
M	-0.079 ± 0.122	-0.006 ± 0.010	-0.079 ± 0.140	-0.026 ± 0.043
F	-0.154 ± 0.205	0.0001 ± 0.015	-0.203 ± 0.189	-0.013 ± 0.037
S-7				
M	-0.328 ± 0.145	0.003 ± 0.024	0.029 ± 0.227	-0.043 ± 0.036
F	-0.051 ± 0.220	0.083 ± 0.041*	-0.297 ± 0.298	-0.032 ± 0.045
S-8				
M	0.073 ± 0.341	-0.0001 ± 0.017	0.184 ± 0.150	-0.022 ± 0.018
F	0.055 ± 0.134	0.033 ± 0.024	0.101 ± 0.196	0.034 ± 0.032

* $P<0.05$

** $P<0.01$

1 = males; 2 = females

units: Birth weight (lb); Inbreeding (1%)

TABLE XXX. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF TYPE SCORE ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN ANGUS

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
A-1				
M^1	-0.001 ± 0.014	0.000 ± 0.000	-0.006 ± 0.017	0.023 ± 0.001
F^2	0.020 ± 0.017	-0.0005 ± 0.001	-0.039 ± 0.022	-0.001 ± 0.001
A-2				
M	-0.015 ± 0.011	-0.0008 ± 0.0005	-0.009 ± 0.011	-0.0007 ± 0.0008
F	-0.020 ± 0.011	-0.0002 ± 0.0005	-0.015 ± 0.014	0.0015 ± 0.0008
A-3				
M	-0.012 ± 0.027	0.004 ± 0.001*	-0.003 ± 0.020	-0.002 ± 0.001
F	-0.036 ± 0.025	-0.003 ± 0.001	-0.065 ± 0.027	-0.003 ± 0.001
A-4				
M	-0.056 ± 0.019**	0.002 ± 0.001	0.060 ± 0.027	0.00003 ± 0.001
F	-0.008 ± 0.016	0.002 ± 0.0008	0.006 ± 0.020	-0.006 ± 0.003
A-7				
M	0.076 ± 0.029**	-0.005 ± 0.007	-0.004 ± 0.024	0.006 ± 0.003
F	-0.047 ± 0.034	0.004 ± 0.004	-0.021 ± 0.021	-0.009 ± 0.004*
A-8				
M	-0.005 ± 0.019	-0.001 ± 0.002	-0.025 ± 0.017	0.002 ± 0.002
F	-0.001 ± 0.017	-0.001 ± 0.002	-0.052 ± 0.030	0.005 ± 0.003

* P<0.05

** P<0.01

1 = males; 2 = females

units: Type score 1/3 of a U.S.D.A. grade; Inbreeding (1%)

TABLE XXXI. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF TYPE SCORE ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN HEREFORD

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
H-2				
M[1]	-0.009 ± 0.018	0.002 ± 0.001	-0.030 ± 0.017	-0.031 ± 0.022
F[2]	-0.061 ± 0.002**	0.006 ± 0.002**	-0.011 ± 0.019	0.002 ± 0.003
H-3				
M	-0.038 ± 0.020	0.003 ± 0.002	0.072 ± 0.029	-0.006 ± 0.005
F	-0.014 ± 0.024	0.003 ± 0.001	0.014 ± 0.028	-0.001 ± 0.002
H-4				
M	-0.008 ± 0.018	-0.004 ± 0.001*	-0.009 ± 0.025	-0.004 ± 0.002
F	-0.017 ± 0.021	0.004 ± 0.005	-0.031 ± 0.039	-0.008 ± 0.020
H-5				
M	-0.011 ± 0.007	0.001 ± 0.002	0.026 ± 0.016	-0.009 ± 0.006
F	-0.014 ± 0.011	-0.002 ± 0.001	-0.006 ± 0.017	-0.011 ± 0.004
H-6				
M	-0.017 ± 0.053	-0.014 ± 0.010	-0.012 ± 0.072	-0.002 ± 0.017
F	-0.032 ± 0.048	0.008 ± 0.018	0.032 ± 0.086	-0.031 ± 0.023
H-7				
M	-0.027 ± 0.027	0.006 ± 0.003	-0.027 ± 0.023	-0.003 ± 0.003
F	0.017 ± 0.031	0.004 ± 0.004	-0.034 ± 0.031	-0.001 ± 0.004
H-8				
M	-0.005 ± 0.022	-0.004 ± 0.003	-0.042 ± 0.031	-0.006 ± 0.016
F	-0.063 ± 0.027*	0.005 ± 0.004	0.019 ± 0.030	-0.023 ± 0.011*

* $P<0.05$
** $P<0.01$
1 = males; 2 = females
units: Type score 1/3 of a U.S.D.A. Grade; Inbreeding (1%)

TABLE XXXII. PARTIAL LINEAR AND QUADRATIC REGRESSION COEFFICIENTS OF TYPE SCORE ON INBREEDING OF THE CALF (Fc) AND INBREEDING OF THE DAM (Fd) IN SHORTHORN

	Fc		Fd	
Line	Linear	Quadratic	Linear	Quadratic
S-1				
M[1]	0.020 ± 0.020	0.001 ± 0.0009	-0.033 ± 0.022	-0.0002 ± 0.0008
F[2]	-0.017 ± 0.031	-0.004 ± 0.001*	-0.012 ± 0.035	0.003 ± 0.001
S-2				
M	0.017 ± 0.026	0.001 ± 0.001	-0.062 ± 0.021**	-0.0002 ± 0.001
F	0.010 ± 0.025	-0.0009 ± 0.001	-0.034 ± 0.023	0.0007 ± 0.001
S-4				
M	0.030 ± 0.020	-0.0004 ± 0.001	-0.032 ± 0.018	0.00006 ± 0.0009
F	0.018 ± 0.016	0.0003 ± 0.001	-0.050 ± 0.014	0.0003 ± 0.0007
S-5				
M	-0.010 ± 0.020	0.001 ± 0.011	-0.023 ± 0.023	0.005 ± 0.007
F	-0.025 ± 0.025	-0.002 ± 0.001	0.002 ± 0.002	0.001 ± 0.004
S-7				
M	0.026 ± 0.017	0.0008 ± 0.004	-0.017 ± 0.037	0.006 ± 0.005
F	-0.028 ± 0.023	-0.0035 ± 0.004	-0.016 ± 0.030	0.005 ± 0.004
S-8				
M	-0.035 ± 0.046	-0.002 ± 0.002	-0.036 ± 0.018*	-0.001 ± 0.002
F	-0.084 ± 0.038	0.002 ± 0.002	-0.012 ± 0.021	-0.0004 ± 0.003

* $P<0.05$

** $P<0.01$

1 = males; 2 = females

units: Type score 1/3 of a U.S.D.A. grade; Inbreeding (1%)

Fc showed a significant ($P<0.01$) negative linear effect for weaning weight of both males and females, the effect being greater in the male calves. In table XXI are the values obtained with model two. The comparison between the values of the two tables reveal that the trend found in table XVII is only present in three of the six lines, A-3, A-4 and A-8. Angus line A-1 presented a positive linear regression coefficient for Fc in both bull calves and females. Comparing the values for Fd in both tables, it is possible to conclude that not all the Angus lines showed positive linear regression coefficients for males. Also females did not always have a greater negative regression coefficient than the males of the same lines.

Establishing the same comparisons between tables XVII and XXII for weaning weights of the Hereford breed, it is possible to reach the same conclusions about the different patterns of response of each line with regard to the values obtained for the whole breed. Females did not always have higher inbreeding depression than bull calves. Hereford lines H-3 and H-6 had positive regression coefficients for Fc in bull calves. The situation already discussed for the Angus and Hereford breeds is valid for weaning weight in Shorthorn (table XXIII). Only bull calves of lines S-1, S-4 and S-5 showed positive linear regression coefficients of weaning weight on Fc and the absolute values of these regressions are higher than those obtained with model one. Bull calves of lines S-2, S-7 and S-8 showed negative regression coefficients.

The effects of inbreeding of the calf and of the dam on the phenotypic regression of the annual weaning weight means (sex unweighted) on years may be seen by comparison of the solid and dotted lines of figures

2 through 20, for each line. The dotted lines represent the means adjusted for Fc and Fd effects. The adjustments were done using the proper Fc and Fd coefficient of each line when Fc and Fd showed a deleterious effect on weaning weight.

Phenotypic performance showed consistent progress after the adjustments were made in Angus lines A-1, A-3, Hereford lines H-4 and H-5, and in the four Shorthorn inbred lines. However, Hereford lines H-2 and H-3 still showed negative regression coefficients of weaning weight on years even after adjustment for Fc and Fd effects. The regression coefficient of sex unweighted weaning weight means on years adjusted for Fc and Fd effects were -2.956 and -0.383 for H-2 and H-3, respectively. In other lines the amount of change in the absolute value of the regression coefficients was small, as for instance, Angus lines A-2 and A-4. It is suggested that other genetic effects in addition to the inbreeding effect, might have influence upon the different responses obtained between lines. Therefore, to make inferences on the performance of each line from the results obtained with the first model of analysis will result in overestimation of inbreeding effects in some lines, and in the others these effects will be underestimated.

With reference to average daily gain, birth weight and type score, the same kind of discrepancies, already discussed for weaning weight, were found between the two models of analysis.

According to the number of observations reported in tables XXI, XXII and XXIII and with the size of the standard errors of the regression coefficients, some of the discrepancies might be attributed to an increase in sampling errors. However, several of these discrepancies cannot be explained as an effect of the sampling variances, and therefore a differential reaction to inbreeding rise is suggested as an explanation of the line performance.

As was discussed earlier dam and calf inbreeding coefficients increased together during the experiment and both are clearly confounded with years. The possibility that Fc and Fd coefficients were also themselves confounded was studied using a correlation analysis. Correlation coefficients for selection lines in the three breeds were low and not important. However, for the inbred lines the correlation coefficients between Fc and Fd ranged from 0.573 to 0.721; 0.387 to 0.704 and 0.138 to 0.850 for inbred lines of Angus, Hereford and Shorthorn, respectively. With the objective of obtaining a better estimation of the inbreeding effect under such circumstances, dams were divided into groups with a 6% range of inbreeding and new regressions of the values of the traits on Fc were estimated by fitting group-of-dam inbreeding in the model.

In the Angus and Shorthorn breeds the error mean squares of the analysis of variance of the regressions of the four traits on inbreeding were higher than those obtained when sires were fitted in the model. Sire effect was an important and significant source of variation in most of the regressions estimated with model number two. In the regressions where group-of-dam inbreeding was fitted, sire of calf was not included in the model because of the number of offspring per sire in each group was very small. For these reasons the results of the regressions where group-of-dam inbreeding was included as a main effect are not reported in this study.

Estimated Genetic Progress

The estimated genetic progress was calculated for each line separately by subtracting the environmental regressions from the phenotypic regressions. In tables XXXIII and XXXV are presented the corresponding values for weaning weight and type score estimated in the inbred lines.

Positive and consistent genetic progress for weaning weight was found in the four Shorthorn inbred lines, in three Angus inbred lines, but in only two of the four Hereford inbred lines. Among selection lines (table XXXV) the only line that did not show genetic progress was Hereford type selection line H-7. In general Shorthorn inbred lines showed higher values of genetic progress than Angus and Hereford. The range of change on weaning weight (pounds per year) was: Angus inbred lines, -0.52 to 1.75; Hereford inbred lines, -6.25 to 0.47; and Shorthorn inbred lines, 1.20 to 3.76.

In the second column of table XXXIII are presented the values for estimated genetic progress of weaning weight after adjustments were made for effects of inbreeding of calf and dam. The increase in the estimated genetic progress in Angus inbred lines after adjustment for Fc and Fd deleterious effects were: 2.157, 3.371, 3.602 and 3.725 pounds of weaning weight per year for the inbred lines A-1, A-2, A-3 and A-4, respectively. In Hereford inbred lines the same adjustment increased the estimated genetic progress to 3.90, 0.93, 1.98 and 0.14 pounds of weaning weight per year for lines H-2, H-3, H-4 and H-5, respectively. After adjustment, Hereford inbred line H-2 still showed negative genetic progress. In Shorthorn inbred lines, adjusted weaning weight genetic progress was 3.14, 2.51, 1.14 and 6.20 pounds of weaning weight per year

TABLE XXXIII. ESTIMATED GENETIC PROGRESS FOR WEANING WEIGHT[1] IN ABERDEEN ANGUS, HEREFORD AND SHORTHORN INBRED LINES

	Unadjusted estimates	Estimates adjusted for calf and dam inbreeding effects
A-1	0.743	2.900
A-2	-0.520	2.851
A-3	1.751	5.353
A-4	0.518	4.243
H-2	-6.255	-2.355
H-3	-0.722	0.209
H-4	0.472	2.450
H-5	0.172	0.315
S-1	3.756	6.891
S-2	1.203	3.714
S-4	3.311	4.456
S-5	2.495	8.700

[1] Unit: Pounds per year.

TABLE XXXIV. ESTIMATED GENETIC PROGRESS FOR TYPE SCORE AT WEANING[1] IN ABERDEEN ANGUS, HEREFORD AND SHORTHORN INBRED LINES

	Unadjusted estimates	Estimates adjusted for calf and dam inbreeding effects
A-1	-0.009	0.030
A-2	-0.018	0.048
A-3	-0.348	0.084
A-4	0.005	0.074
H-2	-0.134	-0.058
H-3	-0.038	0.013
H-4	-0.036	-0.001
H-5	-0.059	-0.003
S-1	0.001	0.044
S-2	-0.034	0.048
S-4	-0.071	0.041
S-5	-0.006	0.031

[1] Unit: 1/3 of U.S.D.A. grade per year.

TABLE XXXV. ESTIMATED GENETIC PROGRESS FOR WEANING WEIGHT AND TYPE SCORE AT WEANING IN ABERDEEN ANGUS, HEREFORD AND SHORTHORN SELECTION LINES

	Weaning weight[1]	Type score[2]
A-7	2.892	0.073
A-8	3.566	0.019
H-6	3.291	-0.142
H-7	-2.648	-0.430
H-8	4.994	0.004
S-7	4.524	0.069
S-8	4.305	-0.008

[1] Unit: Pound per year.

[2] Unit: 1/3 of U.S.D.A. grade per year.

higher than nonadjusted genetic progress for inbred lines S-1, S-2, S-4 and S-5, respectively. The size of the increase in Shorthorn line S-5 is explained because the large negative regressions of weaning weight on Fc and Fd.

The order of rank in weaning weight on both nonadjusted and adjusted estimated progress of the inbred lines showed relatively close agreement in the Hereford and Angus breeds. In Shorthorn, inbred line S-5 ranked second before adjustment and moved to first place after adjustment, but the other 3 inbred lines remained in their same relative positions. This discrepancy suggests that inbreeding effects for Shorthorn inbred line S-5 might be overestimated.

A complete evaluation of the effectiveness of the selection applied to each line is not possible at this time because in the present study the selection differentials and the expected genetic progress were not estimated. Despite this fact, with the results presented in table XXXIII, it is evident that the selection practiced in Hereford line H-5 and in Shorthorns S-1 and S-4 was effective, and overcompensated the depressing effects of Fc and Fd. The effectiveness was partial in the other lines considered and in Hereford H-2 the selection applied was not effective in overcoming the depressing inbreeding effects.

The estimated weaning weight genetic progress in the growth and type selection lines of the three breeds are shown in table XXXV. With the exception of Hereford type line H-7, the other selection lines, both growth and type, showed a consistent and positive estimated genetic progress for weaning weight. It is remarkable that the type selection lines of the Angus and Shorthorn breeds, with no selection for growth, showed a consistent and positive estimated genetic progress for weaning weight, 2.89 and 4.52 pounds per year for A-7 and S-7, respectively. Shorthorn type line S-7 showed an estimated genetic progress of 0.219 higher than Shorthorn growth line S-8 that was selected specifically for growth. These results may be due to positive genetic correlation between the two traits, or the system of classification, or other factors. Koch and Clark, 1955; Carter and Kincaid, 1959; Lehman _et al_., 1961, Brinks _et al_., 1962; Shelby _et al_., 1963 and Petty, 1966 reported genetic correlation coefficients for weaning weight and weaning score of 0.64, 0.49, 0.39, 0.72, 0.51 and 0.43, respectively. The results of the comparison of the estimated genetic progress of Shorthorn lines S-7 and S-8 is not surprising, because line S-7 showed very good growth ability during the experiment and two of the fastest growing bulls selected for use in Shorthorn line S-8 were bull calves born in line S-7.

In the inbred lines of the three breeds, and in Shorthorn selection lines, a definite trend was found toward higher estimated genetic progress among those lines with lower average weaning weights at the time the experiment started. This trend is not present in Angus and Hereford selection lines.

The average of calf inbreeding coefficients for Angus inbred lines were: A-3 = 14.5%; A-4 = 17%; A-1 = 21%; and A-2 = 25%. By comparing these values with the estimated genetic progress presented in table XXXIV, it is evident that the line with smallest average inbreeding coefficient, A-3, had the greatest estimated genetic progress. The reverse situation is also true and the line with the highest average inbreeding coefficient, A-2, showed the least estimated genetic progress. Lines A-4 and A-1 had intermediate estimated genetic progress which also corresponded to their average inbreeding coefficients.

In Hereford inbred lines, the range of the averages of calf inbreeding coefficients is smaller than Angus and Shorthorn. The average of calf inbreeding coefficients were 12.5%, 13.0%, 13.5% and 14.5% for lines H-4, H-2, H-3 and H-5, respectively. The inbred line with the smallest average, H-4, showed the highest estimated genetic progress. However, in this breed, line H-5, with the highest average inbreeding coefficient, showed an estimate genetic progress superior to lines H-2 and H-3, which had smaller average calf inbreeding coefficients.

Shorthorn inbred lines showed the following average calf inbreeding coefficients: S-5 = 24.0%; S-4 = 29.5%; S-2 = 31.5%; and S-1 = 34.0%. Comparing these averages of coefficients with the estimated genetic progress, revealed that line S-1, with the highest inbreeding coefficient, also showed the highest estimated genetic progress. Inbred line S-2, with the second highest inbreeding coefficient, was the line that accounted for the least estimated genetic progress and lines S-4 and S-5 showed estimated genetic progress corresponding to their relative average inbreeding coefficients.

These comparisons support the suggestion discussed earlier with regard to the difference in performance of the lines during the inbreeding process. Among line differences in the original genetic complex, differences in the amount of selection applied to each line or differences in the frequency of genetic abnormalities might be factors that influence the different response to inbreeding and selection.

Wright and Eaton (1929) concluded that the families of guinea pigs became markedly differentiated from one to another. A certain growth tendency was completely fixed in each family and they found almost perfect parallelism in the response of the lines to the varying environmental conditions from year to year. They concluded further after the analysis of the pedigrees of the lines that segregation and mutation can account only to a slight extent for the observed differential trends.

Hoornbeek and Bogart (1965) reported negative regression coefficients of suckling gain on years in three Hereford lines. However, the Angus inbred line showed a positive regression coefficient. They explained these results as a consequence of the basis on which the lines were established, the number of males and females used in each line, and the genetic merit of the foundation material.

Flower et al. (1964) reported estimations of weaning weight genetic progress from three closed lines of Hereford cattle and crosses of these lines with a tester line. Estimated genetic progress was positive and ranged from 2.16 to 6.51 lb. per year between lines.

Brinks et al. (1965) found in Hereford Montana line H-1 an estimated genetic progress of 1.234 pounds per year and 0.313 percent for weaning weight and weaning score, respectively. Dickerson et al. (1954) published the evaluation of selection in developing inbred lines of swine from the Regional Swine Breeding Laboratory and they found that selection in mildly inbred lines of swine failed to improve the genetic merit for traits associated with growth and litter size even after adjusting for the effect of inbreeding.

The estimated genetic progress for type score at weaning was negative in Hereford selection lines H-6 and H-7 and in Shorthorn selection line S-8. In general, the amount of progress accounted for in the type selection lines in the Angus and Shorthorn breeds was around 0.07 for each one-third of U.S.D.A. grade per year. Angus and Hereford growth selection lines A-8 and H-8 showed an estimated genetic progress of 0.019 and 0.004 for each one-third of U.S.D.A. grade per year, respectively. However, Shorthorn growth selection line S-8 showed a negative estimated genetic progress of -0.008. These results suggest that growth selection criteria applied alone in these lines did not modify to a great extent the type score at weaning of the calves.

Considering the values of estimated genetic progress in the inbred lines presented in table XXXIV it is possible to see that with the exception of Angus line A-4 and Shorthorn S-1 the other lines showed negative values for estimates of type score. After adjustment for calf and dam inbreeding effects three of the four Hereford inbred lines still presented negative estimated genetic progress for type score. Adjusted estimates in Angus and Shorthorn were positive and the range of estimated genetic progress for type score at weaning was 0.030 to 0.084 and 0.031 to 0.048 in each breed, respectively.

SUMMARY

An investigation was conducted to determine the effects of inbreeding on birth weight, weaning weight, daily gain from birth to weaning, type score at weaning and to estimate the genetic progress obtained in each line of each breed with the selection practiced. The data for this study were collected at the Beef Cattle Research Station, Front Royal, Virginia, from 1951 through 1969, excluding year 1960. For the analysis, data were available on 1,571 Angus, 1,737 Hereford and 1,313 Shorthorn cattle. Inbreeding effects were studied in each sex separately, with data adjusted for age of dam differences and for environmental year variations, by using linear and quadratic regressions of the four traits mentioned above on inbreeding of the calf and of the dam.

When inbreeding effects were estimated from the model including all the lines available for each breed, the regression coefficients for weaning weights on inbreeding of the calf were negative and significant at $P<0.01$ with the exception of the regressions corresponding to Shorthorn bull calves. The regressions ranged from -0.07 to -1.33 lb. per 1% inbreeding. In the Hereford and Shorthorn breeds, inbreeding of the calf had a greater effect on the weaning weight of heifer calves than on bull calves. In the Angus, breed, the reverse situation was true. The regression coefficients of weaning weight on inbreeding of the dam were all negative with the exception of Angus bull calves. However, the only two coefficients that were found to be significant at $P<0.01$ and $P<0.05$ were those corresponding to Shorthorn and Angus bull calves. The effects of inbreeding of the dam were higher in Shorthorn and Hereford bull calves than in heifers, and the reverse situation is true for the Angus breed.

The only quadratic effect found to be significant with respect to weaning weight was the regression on inbreeding of calf with Hereford bull calves.

The regression coefficients of average daily gain from birth to weaning on inbreeding of the calf and of the dam followed the same trend as those reported for weaning weight. However, the corresponding coefficients of Hereford and Shorthorn females were not significant.

Inbreeding of the calf affected significantly ($P<0.01$) the birth weight of Hereford and Shorthorn bull calves and Hereford heifers. The coefficient of regression for Angus bull calves was negative and nonsignificant and the regressions corresponding to Angus and Shorthorn heifers were positive. With the exception of Angus, the other coefficients of regression were negative and nonsignificant.

Inbreeding of the calf affected type score at weaning of Angus bull calves and Hereford heifers. This effect on Shorthorn calves was negligible. However, inbreeding of the dam on type score affected significantly ($P<0.01$) Angus heifers and both bull and heifer calves in the Shorthorn breed.

When inbreeding effects were estimated in each line separately no definite trend of inbreeding effects on both sexes was found and the values of the regression coefficients were largely spread over a wide range. The range of the regression coefficients of weaning weight on inbreeding of the calf for the Angus breed was 0.05 to -2.81 and 0.20 to -1.58 (lb.) for bull and heifer calves, respectively. In the Hereford breed the regression coefficients ranged from 1.47 to -2.67 and 0.12 to -2.34 for bull and heifer calves, respectively.

The average phenotypic change during the eighteen years, calculated as the regression of the annual sex unweighted means of weaning weight on years indicate sizeable differences between the lines. Excepting Hereford type selection line H-7, the selection lines of all the breeds showed a consistent and positive change. The range of values for the selection lines of each breed was 1.68 to 2.36; -2.05 to 5.60 and 3.92 to 3.70 pounds of weaning weight per year in Angus, Hereford and Shorthorn, respectively. The phenotypic change estimated in the inbred lines ranged from -1.73 to 0.54; -6.86 to 1.07 and 0.60 to 3.15 pounds of weaning weight per year for inbred lines, Angus, Hereford and Shorthorn, respectively.

The estimated average phenotypic change for type score at weaning also showed sizeable variation between lines. The ranges of estimated change for the selection lines were 0.03 to 0.06, -0.38 to 0.05 and 0.06 to 0.14 in Angus, Hereford and Shorthorn breeds, respectively. The range of the estimated change for the inbred lines was: -0.34 to 0.01, -0.08 to 0.01 and zero to 0.07 for inbred lines Angus, Hereford and Shorthorn, respectively.

When estimated phenotypic change for both weaning weight and type score at weaning were adjusted for the effects of inbreeding of the calf and of the dam, all the values were positive with the exception of Hereford inbred lines H-2 and H-3 for weaning weight and Hereford H-2 for type score at weaning.

Estimates of environmental changes calculated for weaning weight and type score at weaning from repeat mating information indicated a positive trend for type score at weaning in the three breeds and for weaning weight in Herefords. Weaning weight environmental changes for Angus and Shorthorn were negative.

Estimates of genetic progress, calculated by subtracting the environmental trend from the phenotypic trend indicate important genetic progress for weaning weight in most of the lines. The range of estimates in the selection lines were from 2.89 to 3.57; -2.65 to 4.99 and 4.30 to 4.52 pounds of weaning weight per year for Angus, Hereford and Shorthorn, respectively. The range of estimates for the inbred lines were -0.52 to 1.75; -6.26 to 0.47 and 1.20 to 3.76 pounds of weaning weight per year for Angus, Hereford and Shorthorn, respectively. Estimates of genetic progress adjusted for inbreeding of the calf and of the dam were positive in all the lines with the exception of Hereford inbred line H-2.

Estimates of genetic progress for type score at weaning were negative for most of the lines. The range of the estimates in the selection lines was 0.02 to 0.07; -0.43 to 0.004 and -0.008 to 0.07 for each one-third of U.S.D.A. grade per year for Angus, Hereford and Shorthorn breeds, respectively. The range of the estimates in the inbred lines were -0.348 to 0.005; -0.134 to -0.036 and -0.034 to 0.001 for each one-third of U.S.D.A. grade per year in Angus, Hereford and Shorthorn breeds, respectively. Adjusted estimates for the effects of inbreeding of calf and dam were still negative in Hereford inbred lines H-2, H-4 and H-5.

The results of this study suggest that when inbreeding effects are evaluated from data representing several different populations (lines), this does not provide an accurate estimate of the calf and of the dam inbreeding effects for each particular population (lines). Selection applied to the inbred lines should be effective in diminishing the deleterious inbreeding effects. The combination of inbreeding with selection should yield beneficial effects in the improvement of the growth traits. The effects of inbreeding and estimated genetic progress varied widely between the breeds and between the lines in each breed.

BIBLIOGRAPHY

Alexander, G. I. and Ralph Bogart. 1961. Effect of inbreeding and selection on performance characteristics of beef cattle. J. Anim. Sci. 20:702.

Bell, A. E., C. H. Moore and D. C. Warren. 1955. The evaluation of new methods for the improvement of quantitative characteristics. Cold Spring Harbor Symposia on Quant. Biol. 20:197.

Bereskin, B., C. E. Shelby, K. E. Rowe, W. E. Rempel, A. E. Dettmers and H. W. Norton. 1970. Inbreeding and swine productivity in Minnesota experimental herds. J. Anim. Sci. 31:278.

Bovard, K. P. and B. M. Priode. 1963. Beef cattle research at the Front Royal Station, 1950-1961. Va. Agr. Exp. Sta. Bul. 547.

Brinks, J. S., R. T. Clark, N. M. Kieffer and J. R. Quesenberry. 1962. Genetic and environmental factors affecting performance traits of Hereford bulls. J. Anim. Sci. 21:777.

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

Brown, C. J. 1960. Influence of year and season of birth, sex, sire and age of dam on weight of beef calves at 60, 120, 180 and 240 days of age. J. Anim. Sci. 19:1062.

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

Cardellino, R. 1970. A comparison of different age of dam correction factors for weaning weight in beef cattle. M.S. Thesis. Oklahoma State University, Stillwater, Oklahoma.

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

Carter, R. C. and C. M. Kincaid. 1959b. Estimates of genetic and phenotypic parameters in beef cattle. III. Genetic and phenotypic correlations among economic characters. J. Anim. Sci. 18:331.

Cundiff, L. V., R. L. Willham and Charles A. Pratt. 1966. Additive *versus* multiplicative correction factors for weaning weight in beef cattle. J. Anim. Sci. 25:983.

Dickerson, G. E., C. T. Blunn, A. B. Chapman, R. M. Kottman, J. L. Krider, E. J. Warwick, J. A. Whatley, Jr., in collaboration with M. L. Baker, J. L. Lush and L. M. Winters. 1954. Evaluation of selection in developing inbred lines of swine. Missouri Agr. Exp. Sta. Res. Bul. 551.

Dickerson, G. E. 1960. In techniques and procedures in animal production research. American Society of Anim. Prod., Beltsville, Maryland.

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

Flower, A. E., J. S. Brinks, J. J. Urick and F. S. Willson. 1964. Selection intensities and time trends for performance traits in range Hereford cattle under mass and recurrent selection. J. Anim. Sci.

Goodwin, K., G. E. Dickerson and W. F. Lamoureux. 1960. An experimental design for separating genetic and environmental changes in animal populations under selection. Biometrical Genetics. Edited by O. Kemphorne, Pergamon Press, London, 1960.

Harvey, W. R. 1968. Least-squares and Maximum Likelihood General Purpose Program. Ohio State University, Columbus, Ohio.

Hoornbeek, F. K. and R. Bogart. 1966. Amount of selection applied and response of traits in four inbred lines of beef cattle. Oregon Agr. Exp. Sta. Tech. Bul. 96.

King, H. D. 1918. Studies on inbreeding. I. The effect of inbreeding on the growth and variability in body weight of the albino rat. J. Exp. Zoology 29:71.

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

Koch, R. M. and R. T. Clark. 1955. Genetic and environmental relationships among economic characters in beef cattle. I. Correlation among paternal and maternal half-sibs. J. Anim. Sci. 14:775.

Lehman, R. P., S. A. Gaines, R. C. Carter, K. P. Bovard and C. M. Kincaid. 1961. Selection indexes for weanling traits in beef calves. J. Anim. Sci. 20:53.

Lush, J. L., C. C. Culbertson, W. A. Craft, P. S. Shearer and L. N. Hazel. 1948. History of swine breeding research at the Iowa Station. Ann'l. Rpt., Iowa Agr. Exp. Sta.

Petty, R. R. and T. C. Cartwright. 1966. A summary of genetic and environmental statistics for growth and conformation traits of young beef cattle. Dept. Anim. Sci., Texas A&M Univ. Tech. Rpt. No. 5.

Shelby, C. E., W. R. Harvey, R. T. Clark, J. R. Quesenberry and R. R. Woodward. 1963. Estimates of phenotypic and genetic parameters in ten years of Miles City R.O.P. steer data. J. Anim. Sci. 22:346.

Smith, C. 1962. Estimation of genetic change in farm livestock using field records. Anim. Prod. 4:239.

Stonaker, H. H. 1954. Observations on reproduction, growth, feed utilization and grades of inbred and outbred Hereford cattle. J. Anim. Sci. 13:963.

Stonaker, H. H. 1963. A genetic hypothesis for sex-mating system interactions in growth of cattle and poultry. J. Anim. Sci. 22:320.

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

Tyler, W. J., A. B. Chapman and G. E. Dickerson. 1949. Growth and production of inbred and outbred Holstein-Fresian cattle. J. Dairy Sci. 32:247.

Von Krosigk, C. M. and J. L. Lush. 1958. Effect of inbreeding on production in Holsteins. J. Dairy Sci. 58:105.

Wright, S. 1920. Principles of livestock breeding. U. S. Dept. Agr. Bul. 905.

Wright. S. and O. N. Eaton. 1929. The persistence of differentiation among inbred families of guinea pigs. U. S. Dept. Agr. Tech. Bul. 103.

EFFECTS OF INBREEDING AND ESTIMATION OF GENETIC PROGRESS UPON PREWEANING TRAITS IN BEEF CATTLE

by

Juan C. Scarsi

Abstract

Data on 1571 Angus, 1737 Herefords and 1313 Shorthorns from the BCRS, Front Royal, Va. from 1951 through 1969 (excluding 1960) were used to study the effect of inbreeding on birth and weaning weights, ADG birth to weaning and type score at weaning, and estimate genetic progress from selection in each line of each breed. Inbreeding effects were linear and quadratic regressions of the traits mentioned on inbreeding of the calf and of the dam, each sex separately, after adjustment for years (using repeat matings) and age of dam (using type and selection lines of all breeds). Breed weaning weight regression coefficients ranged from -0.073 to -1.333 lbs. per 1% increase in inbreeding of the calf, significant ($P<.01$) for Angus and Hereford bulls and heifers, and the Shorthorn heifers; the effect was stronger in heifers than in bulls. For inbreeding of the dam, Hereford and Shorthorn bulls were depressed more than heifers, and *vice versa* in Angus. Most regressions of birth weight on inbreeding of calf were negative (significant [$P<.01$] for Hereford bulls and heifers and Shorthorn bulls). Type score regressions on inbreeding of calf were negligible in Shorthorns, but significant in Angus bulls ($P<.05$) and Hereford heifers ($P<.01$); those on inbreeding of dam were significant ($P<.01$) for Shorthorn bulls and heifers and Angus heifers. These effects calculated within line showed great dispersion, and the breed trends

disappeared. Phenotypic change, calculated as regression of annual means of each trait (sex unweighted) on years, showed sizeable differences between the lines. For example, the range of weaning weight estimates was 1.68 to 2.36; -2.05 to 5.60 and 3.92 to 3.70 pounds per year in Angus, Hereford and Shorthorn. Excepting one Hereford line, the selection lines showed a consistent and positive annual change; the inbred lines showed smaller changes that were negative in three out of four Angus and Hereford lines and positive in all Shorthorn lines. Environmental weaning weight regressions on years (using repeat matings) were negative for Angus and Shorthorns and positive for Herefords; the type score regressions were positive for all three breeds. Estimates of genetic progress, i.e., subtract the environmental change from the phenotypic change, indicate wide variation and definite genetic improvement in most of the lines. Weaning weight ranges in the selection lines for Angus, Hereford and Shorthorn, respectively, were 2.89 to 3.57, -2.65 to 4.99 and 4.30 to 4.52 pounds; ranges in inbred lines were -0.52 to 1.75, -6.26 to 0.47 and 1.20 to 3.76 pounds. When estimates of genetic progress were adjusted for inbreeding of the calf and of the dam, they were positive in all lines except H-2. Results suggest that effects of inbreeding calculated from several divergent genetic populations (lines) do not accurately estimate the effects for individual lines. The combination of inbreeding with selection can yield positive improvement of growth.