SELECTION FOR WEANING WEIGHT AND YEARLING WEIGHT IN HEREFORD CATTLE

By

TODD ALAN STANFORTH

Bachelor of Science

South Dakota State University

Brookings, South Dakota

1972

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1974

SELECTION FOR WEANING WEIGHT AND YEARLING

WEIGHT IN HEREFORD CATTLE

Thesis Approved:

Richard R Frahm
Thesis Adviser

Rodger K. Johnson

Robert P. Wettemann

D D Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. R. R. Frahm, Associate Professor of Animal Science, for his suggestions, guidance and counsel during the course of this study and throughout our aquaintance.

The author is grateful to Dr. Rodger Johnson and Dr. R. P. Wettemann for assisting in the proofing of this manuscript.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

II. REVIEW OF LITERATURE 4

Selection Theory. 4
Selection Studies With Related Species. 7
Selection Studies With Beef Cattle. 13
Summary of Literature Review. 28

III. MATERIALS AND METHODS. 30

Data. 30
Management and Data Collection. 34
Data Analyses 40
Measurement of Selection Applied 40
Estimation of Response to Selection. 44

IV. RESULTS AND DISCUSSION 47

Intensity of Selection. 47
Generation Intervals and Coefficients. 47
Intensity of Direct Selection. 50
Intensity of Correlated Selection. 54
Intensity of Male and Female Selection 57
Response to Selection 62
Phenotypic Trends. 62
Genetic Response 69
Conclusions 78

V. SUMMARY. 81

LITERATURE CITED. 86

APPENDIX. 90

LIST OF TABLES

Table		Page
I.	Heritability Estimates of Some Economically Important Traits	14
II.	Generation Intervals, Average Annual Selection Differentials and Estimated Genetic Responses Realized in Four Experiments	18
III.	Design of the Beef Cattle Selection Experiment	31
IV.	Numbers of Observations Per Year in Each Selection Line	34
V.	Composition of Bull Test Rations	36
VI.	Composition of Supplemental Pellets	37
VII.	Average Age of Parents and Generation Coefficients	49
VIII.	Total Individual Cumulative Selection Differentials (ICSD) for Weaning Weight and Yearling Weight by Line and Year	51
IX.	Total Individual Cumulative Selection Differentials (ICSD) for Birth Weight, Weaning Score, Average Daily Gain and Yearling Score by Line and Year	55
X.	Total Weaning Weight Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line	59
XI.	Total Yearling Weight Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line	60

Table		Page

XII. Coefficients of Regression of Mean Performance on Year. 63

XIII. Least Squares Means and Standard Errors for Foundation and Selected Sires. 71

XIV. Estimated Improvement in Breeding Value of the Selected Sires Over the Foundation Sires. 73

XV. Estimated Improvement in Breeding Value for Preweaning Traits From Within Year Comparisons of New Sire and Repeat Sire Means 76

XVI. Estimated Improvement in Breeding Value for Postweaning Traits From Within Year Comparisons of New Sire and Repeat Sire Means 77

XVII. Total Birth Weight Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line. 91

XVIII. Total Birth Weight Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line. 92

XVIX. Total Weaning Weight Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line. 93

XX. Total Weaning Score Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line 94

Table		Page

XXI. Total Weaning Score Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line. 95

XXII. Total Average Daily Gain Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line. 96

XXIII. Total Average Daily Gain Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line. 97

XXIV. Total Yearling Weight Male Cumulative Selection Differentials (FCSD), Female Cumulative Selection Differentials (FCSD) Selection Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line. 98

XXV. Total Yearling Score Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) Differentials (ICSD) for Sires, Dams and Midparents for the Weaning Weight Line 99

XXVI. Total Yearling Score Male Cumulative Selection Differentials (MCSD), Female Cumulative Selection Differentials (FCSD) and Individual Cumulative Selection Differentials (ICSD) for Sires, Dams and Midparents for the Yearling Weight Line 100

XXVII. Ten Year Means, Ranges and Standard Deviations for Birth and Weaning Traits. 101

XXVIII. Ten Year Means, Ranges and Standard Deviations for Postweaning Traits. 102

Table		Page
XXIX.	Annual Least Squares Means for Birth and Weaning Traits	103
XXX.	Annual Least Squares Means for Postweaning Traits	104

LIST OF FIGURES

Figure | Page

1. Least Squares Birth Weight Means Plotted on Year. 64

2. Least Squares Weaning Weight Means Plotted on Year. 65

3. Least Squares Average Daily Gain Means Plotted on Year. 66

4. Least Squares Yearling Weight Means Plotted on Year. 67

5. Least Squares Weaning Score and Yearling Score Means Plotted on Year 68

CHAPTER I

INTRODUCTION

The beef cattle industry is constantly striving to improve net productivity and efficiency in each phase of the industry. There are two basic reasons why there is a constant need to improve productivity and efficiency. Economics is one. The beef cattle industry is a major portion of the economy of Oklahoma and the nation, consequently improvement in productivity and efficiency benefits not only those directly involved in the industry but also benefits the consumer and the economy of the state and nation. Another reason for constantly striving to improve productivity and efficiency is that beef is a major source of the protein needed to meet the nutritional requirements of growing state, nation and world populations.

There currently are several problems facing the beef cattle industry which further emphasize the need to improve productivity and efficiency. Some of these problems include a rather severe cost-price squeeze, increased competition for feed grains for use in human diets and decreasing land area available for beef production. In addition, there has been increased pressure to alter some production practices that, in the eyes and minds of some, are not compatible with the need to keep the environment "clean."

As is the case with all biological populations, the factors which influence the expression of the economically important traits in beef cattle are either environmental or genetic in nature. Consequently, to make maximum improvement, attention must be given to improving the environment (management, nutrition, disease control, etc.) in which we produce beef cattle and to improving the genetic composition of our breeds and herds.

Improvement of the genetic composition of our breeds and herds can be achieved essentially only by selection of breeding animals that are genetically superior for the economically important traits. Most selection programs today place considerable emphasis on growth rate because of the desirable effect fast, early growth has on most segments of the industry. Rapid early growth provides a heavy weaning calf for the cow-calf man, fast and efficient gains for the feeder and lean, high yielding carcasses for the packer and consumer.

Relatively little research information is available to evaluate the effectiveness of selection for growth rate that can serve as a guide for breeders in designing effective breeding programs for improvement of beef cattle. Information is needed not only to evaluate how rapidly improvement can be attained in the trait(s) selected for but also to evaluate the changes that result in other traits since these correlated responses, that are due to genetic relationships between traits, affect net merit and, therefore, net improvement. Information is also needed to help breeders decide what selection methods and which selection tools will be most useful in a breeding program.

The research project which provided the data for this study was undertaken to provide some of this information. The objectives of this study were to quantify selection pressure and estimate response to selection in two lines of Hereford cattle selected for increased weaning weight and increased yearling weight, respectively.

CHAPTER II

REVIEW OF LITERATURE

Selection Theory

The first portion of this review is a brief summary of some of the theory upon which selection principles are based. The material in this discussion is based on information presented in books by Falconer (1960) and Pirchner (1969).

The theoretical aspects of selection have their foundation in quantitative genetic theory which began development around 1920 by R. A. Fisher, J. B. S. Haldane and S. Wright. The application of the early theoretical work to animal breeding and the development of most breeding principles is attributable mainly to the efforts of J. L. Lush and his coworkers. Many of the theoretical expectations developed by these early workers have been checked experimentally. This is especially true in laboratory species, although experimental investigations in livestock species are generally lacking.

Selection, with respect to our livestock species, merely means allowing some animals to become parents or have more offspring than others because of differences in their phenotypes. Selection can be of two types, natural and artificial. Natural selection, or survival of the fittest, is that done by natural forces which allow those animals best adapted to their environment to survive and produce the largest number of offspring. Artificial selection is that imposed by man where standards related to the animal's ability to serve human needs and desires become involved in deciding which animals will be allowed to reproduce.

The genetic effect of selection is to change gene frequency. Selection produces changes in gene frequency by separating the parent generation into two groups, those selected and those discarded, that differ in gene frequency. Changes in gene frequency at individual loci are not detectable when dealing with quantitative traits because the effects of individual genes are not observable. Therefore, means, variances and covariances are used to describe the effects of selection since these are observable properties of biological populations. Although these properties are used to describe the effects of selection, we must remember that they are the result of underlying changes in gene frequency.

Selection is based on differences in phenotype among individuals. Consequently, the effectiveness of selection in changing the mean of a population depends on the magnitude of the difference between the mean phenotypic value of the animals selected to be parents and the mean phenotypic value of the entire population and the extent to which differences in phenotype are inherited. The difference between the mean of the selected group and the mean of the entire parental generation is called the selection differential (SD). The extent to which differences in phenotype are inherited is measured by the heritability (h^2) of the trait under selection. Thus, the genetic progress (ΔG) expected in one generation of selection would be $\Delta G = h^2 \times SD$.

The size of the selection differential and, therefore, the effectiveness of selection, is affected by two factors; the proportion of the population selected to be parents and the phenotypic variability of the trait in question. The smaller the proportion of individuals kept for breeding the larger the selection differential. Since far fewer males than females are kept for breeding, the selection differential for males will almost always be larger than for females. Relatively more extreme phenotypes will occur when there is considerable variation in the trait selected for than when there is little variation. Thus, the selection differential would be expected to be larger when there is considerable variation since the mean of the selected group would be farther from the population mean than when there is little variation.

Heritability coefficients estimate the proportion of total phenotypic variation that is attributable to additive genetic effects and, thus, provide a measure of the extent to which phenotypic differences in the parents will be transmitted to the next generation. Heritability and, therefore, effectiveness of selection is influenced by the relative importance of the environment, non-additive genetic effects and additive genetic effects in controlling the trait in question. Traits that have a large amount of environmental and/or non-additive genetic variation relative to additive genetic variation are lowly heritable. Consequently, little response would be expected from selection for such traits. Traits that have a large amount of additive genetic variation relative to environmental and non-additive genetic variation are highly heritable and such traits would be expected to respond favorably to selection.

From a practical viewpoint, genetic change per unit of time is of more interest than genetic change per generation. In such cases the expected response is computed by dividing the response per generation by the generation interval. Generation interval is the interval of time between corresponding stages of the life cycle in successive generations. It is most commonly expressed as the average age of the parents when the offspring are born that are destined to become parents in the next generation. Expected genetic gain per unit of time should increase if the generation interval is shortened. In this respect it is often desirable to attempt to shorten generation intervals, however, in practical situations it is not always possible nor economically feasible to alter the generation intervals of our livestock species appreciably.

Selection Studies with Related Species

A review of selection results with other species is important to this discussion even though selection in beef cattle is of specific interest in this study. Because of the nature of the gene and the basic principles of heredity, the science of genetics transcends species barriers. Thus, information gathered from other species can assist in developing basic principles which, in combination with information gathered from beef cattle studies, can be useful in developing breeding programs for genetic improvement of beef cattle.

Numerous investigations with laboratory species concerning the effectiveness of selection for traits analogous to those that are of economic importance in beef cattle have been reported. The laboratory mouse has served as the experimental material in many of these investigations since it is closer biologically to livestock species than other common laboratory species, such as Drosophila and Tribolium. Chapman

(1951), in a review of the effectiveness of selection in laboratory species, concluded that no obvious inconsistencies between experimental results and existing genetic theory were evident in the work completed at that time. In a thorough review of the contributions of the laboratory mouse to animal breeding research, Roberts (1965) summarized the literature relative to selection for body weight and other measures of growth. The following are major points that have application to beef cattle populations:

1. The genetic control of body weight apparently is primarily additive in nature and largely uncomplicated by interactions either at the genetic level or with the environment.
2. Selection for body weight was usually effective in bringing about favorable changes in weight for 20 generations or more.
3. The genetic control of body weight appears to be such that individual phenotypic selection schemes, for instance those based on performance testing, may have greater efficiency than slower, more expensive schemes such as progeny testing.
4. Ample evidence was found indicating that selection for body weight may result in profound correlated changes in other traits. To the extent mouse traits have analogs in livestock, the direction of some correlated changes may not always be desirable.

Results similar to those from experiments with mice have been reported from selection studies with chickens and turkeys (Yamada, Bohren and Crittenden, 1958; Abplanalp, Ogasawara and Asmundson, 1963; Maloney, Gilbreath and Morrison, 1963; Festing and Nordskog, 1967). Therefore, it appears that different species may respond similarly to selection.

Fredeen (1958) summarized the literature dealing with selection in swine. Most of the work reported at that time dealt with studying the effectiveness of selection in development of inbred lines. Results of this early work were quite variable, depending on the traits studied, selection procedures used and mating systems utilized in the various studies. Although experimental populations were small and selection was of relatively short duration, the evidence indicated that selection for traits related to litter size and viability was least effective. Traits concerned with carcass conformation responded well to selection, while rate and efficiency of gain were intermediate in response to selection.

Krider et al. (1946) reported results of four generations of selection for rapid and slow growth (as measured by weight at various ages) in Hampshire pigs. The data indicated that selection for increased and decreased growth was effective in changing the mean level of performance, although responses were somewhat less than expected.

One of the more interesting studies reported in the literature dealt with selection for decreased body size in swine. Dettmers, Rempel and Comstock (1955) summarized the first 10 generations of this experiment which was designed to develop a strain of miniature pigs for use in medical research. Four wild strains of pigs were used as foundation stock and primary selection pressure was for decreased weight at 140 days of age. After the first 10 generations of selection

140 day weight had been reduced 29% relative to the mean of the foundation generation. Birth weight and 56-day weight were also reduced 14 and 23%, respectively, indicating fairly strong genetic relationships between these traits and 140-day weight. Litter size remained unchanged after 10 generations. The experimental population was subsequently split into two sublines and Dettmers, Rempel and Hacker (1971) summarized an additional seven generations of selection. Their data showed that after 17 total generations of selection, 140-day weight in the two sublines had been reduced 40 and 28% relative to the mean of the foundation generation. A reduction of one pig per litter had also been realized during the entire experiment. Interpretation of this correlated response is not clear cut since it may have been due to a true genetic relationship between litter size and 140-day weight or could have been due to an increased level of inbreeding.

Positive response to selection for growth rate in swine was reported by Rahnefield (1971), although response amounted to only 33% of expected. He summarized data collected during seven generations of selection for increased post-weaning average daily gain in a line of Lacombe swine. A closed, random-bred line of Yorkshire pigs was used as a control for estimating genetic response in the selected line. Litter size was positively genetically correlated with average daily gain.

Dickerson and Grimes (1947) concluded that selection based on rate of gain from weaning to market would be nearly as effective in improving feed efficiency as selection based directly on individual feed requirements. They reported data from two lines of Duroc swine selected five generations for high or low individual feed requirements per pound of gain.

Terrill (1951) reported data from 10 years of selection for net merit in inbred lines of range Rambouillet sheep. Wool and growth traits received selection emphasis. Overall merit of weanling lambs increased, although the rate of improvement was slightly less than expected from selection practiced. No attempt was made to partition genetic trends from environmental trends, consequently the improvement in performance could not be attributed solely to genetic gains. Terrill (1958) also reviewed the literature concerning selection with sheep and concluded that definite gains in the economically important traits had been made as the result of selection, however, much greater gains appeared possible. He noted that the show ring had played an important part in determining the emphasis of selection and that in some cases it had led to emphasis on economically unimportant traits. It was observed, in addition, that commercial producers of wool and lamb appeared to be more cognizant of the need to apply selection pressure on production traits than purebred breeders. These observations may help explain some of the problems the sheep industry faces today and provides "food for thought" for the beef cattle industry relative to the roles of the show ring and the purebred breeder in improvement programs.

Evaluation of direct and correlated response to selection for weaning weight was the objective of an experiment in Australia reported by Pattie (1965a,b). He studied data collected from 1951 through 1961 in three flocks of Merino sheep consisting of 100 ewes and 5 rams per flock. One flock was selected for increased weaning weight and one flock for decreased weaning weight. The third flock was a random bred flock that served as a control from which to estimate genetic trends. The analytical procedures, especially those concerning quantification of selection pressure, are of interest since they are similar to those utilized in the present study. A three part scheme was utilized to quantify cummulated selection pressure. Briefly, it consisted of calculating the following three components.

1. Individual selection differential, the difference between a lamb's weaning weight and the mean weaning weight of all lambs born in the same year.
2. Individual cumulated selection differential, the sum of a lamb's individual selection differential and the average of the individual cumulated selection differentials of its parents. Foundation animals were given individual cumulated selection differentials of zero.
3. Flock cumulated selection differential, the average of the individual cumulated selection differentials of all parents producing offspring in the flock in any particular year.

Since there is considerable overlapping of generations in sheep populations, this procedure provided a way of combining selection differentials realized in different years. Accumulation of flock cumulated selection differentials was generally linear in both selection flocks over the years studied. In the flock selected for increased weight, the flock cumulated selection differential after 10 years of selection was approximately 60% of control flock mean, indicating considerable selection had been practiced. Favorable responses to selection were realized in both selection flocks. The regression of cumulated response on cumulated selection differential yielded a realized heritability of 0.25. A realized genetic correlation of 0.72 between weaning weight and 17-month weight indicated that selection for weaning weight could be expected to increase mature weight, a change that may not always be desirable. No correlated response in reproductive traits were realized during the course of the experiment.

Selection Studies With Beef Cattle

Reproductive performance, mothering ability, rate of gain, efficiency of gain, longevity and carcass merit have long been recognized as the traits which have the greatest economic impact on the beef cattle industry. Consequently, the objective of beef improvement programs is to make continued improvement in these performance traits. As discussed previously, if selection is to be effective in changing the mean level of performance for a particular trait, the proportion of total variation in the trait that is due to additive gene effects must be relatively large, i.e., the trait must be moderately to highly heritable. Table I presents average heritability estimates of some of the economically important traits (Gregory, 1969). These estimates were based on reports from a number of different stations and give evidence for the generally accepted conclusion that reproductive traits are lowly heritable while traits associated with carcass merit are highly heritable with growth traits somewhat intermediate.

Since improvement in all or most of the performance traits is desired, a knowledge of the genetic relationships among these traits

TABLE I

HERITABILITY ESTIMATES OF SOME ECONOMICALLY IMPORTANT TRAITS

Trait	Heritability (%)
Calving interval (fertility)	10
Birth weight	40
Weaning weight	30
Feedlot gain	45
Pasture gain	30
Efficiency of gain	40
Final feedlot weight	60
Weaning conformation score	25
Slaughter conformation score	40
Carcass grade	40
Rib-eye area	70
Tenderness	60
Fat thickness	45

is needed. If favorable relationships exist, selection for one or a combination of traits should enhance the rate of improvement in total merit. Conversely, if a genetic antagonism exists among these traits, the rate of improvement in total merit is reduced. In general, available information indicates that few antagonistic genetic relationships exist among the economically important traits (Knapp and Clark, 1947; Koch and Clark, 1955; Carter and Kincaid, 1959; Shelby et al. 1963; Brinks et al. 1964; Dunn et al. 1970; Cundiff et al. 1971; Dinkel and Busch, 1973; Koch et al., 1973). Positive genetic correlations apparently exist between growth rate during various stages of life and between growth rate and feed efficiency. Relationships among growth and carcass traits are generally favorable in nature. Positive genetic relationships apparently exist between birth weight and growth rate and between growth rate and mature size. These relationships may not be favorable. Increased calving difficulty has been associated with heavy birth weights, thus, increasing birth weight may result in more calf losses at birth. Feed requirements generally increase as cow size increases, consequently, increased mature size may result in increased maintenance costs.

As a result of the moderate heritabilities and favorable genetic relationships described above, growth rate is currently receiving considerable emphasis in selection programs. In addition to these factors, growth rate is relatively easy to measure, consequently it lends itself to relatively efficient performance testing programs. Although considerable research effort has gone into estimating heritabilities and genetic correlations and developing breeding programs based on these estimates, relatively little definitive research information is available with which to evaluate the effectiveness of selection for measures of growth rate for improving the mean level of performance in beef cattle. In other words, the expectations (based on heritabilities and genetic correlations) have been developed but not tested.

There are a number of reasons why selection studies with beef cattle are not numerous. Generation intervals are long in beef cattle, consequently selection studies by necessity are long term undertakings. Fairly large sample sizes are needed to reduce sampling errors and chance deviations in gene frequency. It is difficult to estimate genetic change in beef cattle populations because of the difficulty in estimating genetic changes independent of environmental fluctuations. Also, efforts must be made to control inbreeding such that inbreeding effects are not confounded with changes that result from selection. The studies reported to date in the literature, although not all designed to specifically evaluate selection, do supply valuable information and more definitive information is beginning to accumulate.

An analytical procedure developed initially by Flower et al. (1964) has been utilized to study the effectiveness of multiple trait selection in inbred lines (Brinks, Clark and Kieffer, 1965; Armstrong et al., 1965; Hornbeck and Bogart, 1966) and non-inbred lines (Chapman, 1968) of beef cattle. Selection intensity was measured by average annual selection differentials calculated using the following formulae:

$$\text{Sire selection differential} = \Delta S = \frac{n_1^s s_1 + n_2^s s_2 + \ldots + n_i^s s_i}{N\bar{A}}$$

$$\text{Dam selection differential} = \Delta D = \frac{n_1^d d_1 + n_2^d d_2 + \ldots + n_i^d d_i}{N\bar{A}}$$

$$\text{Average annual selection differential} = \Delta P = \frac{\Delta S + \Delta D}{2}$$

where,

n_i^s, n_i^d = Number of progeny per sire or dam, respectively, in a given year.

s_i, d_i = Superiority or inferiority of a particular sire or dam, measured as the deviation between the sire or dam's individual record and the mean of the unselected group he or she was born in.

N = Total number of progeny in a given year.

$\bar{A}$ = Generation interval, average age of the parents when the offspring were born.

Phenotypic time trends for a trait were established by the regression of mean performance on years. The phenotypic trend was assumed to be made up of two components, a genetic component and an environmental component. The environmental component was estimated by use of records from repeat matings made in consecutive years. The environmental difference between any two years was taken as the difference between the records of calves produced by consecutive repeat matings. Records were adjusted for known sources of non-genetic variation when possible. The means of several differences between records from consecutive years were regressed on years to estimate the environmental trend. The genetic component was then calculated as the difference between the phenotypic and environmental regressions. Trends calculated in this manner are subject to bias if interactions involving sire, dam, sex of calf, month of birth and age of dam exist. In addition, sampling errors are probably large with this procedure because of the random nature of gametogenesis and small sample sizes. Consequently, genetic trends established in this manner must be interpreted with these things in mind.

Table II summarizes pertinent data from some of these studies. Selection procedures varied somewhat from study to study but the basic approach in each was to base selection on overall performance. Selection pressure was primarily for weaning weight and postweaning growth rate. In some instances consideration was given to conformation score, both at weaning and yearling ages. Birth weight was not given any consideration in any selection scheme. Specific selection indices were not used. A review of Table II and other data in these reports leads to the following generalizations:

TABLE II

GENERATION INTERVALS, AVERAGE ANNUAL SELECTION DIFFERENTIALS AND ESTIMATED GENETIC RESPONSES REALIZED IN FOUR EXPERIMENTS

Experiment	Total Records	Years In Study	Generation Interval Years	Birth Weight S.D. Lbs.	Birth Weight Response Lbs./Yr.	Weaning Weight S.D. Lbs.	Weaning Weight Response Lbs./Yr.	Feed Test ADG S.D. Lbs./Da.	Feed Test ADG Response (Lbs./Da.)/Yr.
Flower *et al.* (1964)	550	8	4.03	0.75	0.64	6.3	4.9	0.03	--
Brinks *et al.* (1965)	2,027	26	4.93	0.62	0.38	5.5	2.4	0.02	--
Chapman (1968)									
Brahman	390	17	5.53	0.71	0.62	2.6	-0.02	0.04	0.04
Hereford	1,450	17	5.06	0.74	-0.22	4.0	1.80	0.03	0.02

1. Generation intervals were typical of those expected in beef cattle herds, ranging from 4 to 5.5 years.
2. Positive selection pressure was exerted on the traits studied. Selection differentials were not great for a particular trait, a result of multiple trait selection, however, appreciable pressure was exerted on total growth performance.
3. Selection was much more intense on the sire side. Annual sire selection differentials were from 2.5 to 10 times as large as annual dam selection differentials.
4. Positive genetic response was generally achieved in the traits studied. Response was generally greatest in those traits for which selection was most intense.
5. Although not directly selected for, positive selection pressure and positive genetic change were realized for birth weight. Also, Brinks et al. (1965) observed positive selection pressure and positive genetic change in mature weight. Correlated responses in birth weight and mature weight may not be desirable because of the association between large birth weights and calving difficulty and the increased cost of maintaining larger cows. Changes in calving difficulty and maintenance costs were not monitered in the study, however.

In addition to the procedures and results discussed above, Brinks *et al*. (1965) and Chapman (1968) compared expected genetic responses with estimated genetic responses achieved. They calculated expected responses by methods described by Dickerson *et al*. (1954) which basically involved use of selection indices calculated in retrospect. Results from these studies indicated appreciable positive genetic response was expected in all traits studied. Brinks *et al*. (1965) found that estimated genetic response achieved exceeded expected response in all traits except final weight off feed test. Chapman (1968) found that estimated genetic response achieved was somewhat less than expected for birth weight and weaning weight, although the comparisons were in good agreement except for Hereford birth weight and Brahman weaning weight, where negative genetic responses were estimated. Estimated response exceeded expected for post-weaning traits in his study. The selection differentials used in these two studies may have been biased downward slightly, especially for postweaning traits, as the result of culling of some calves prior to and at weaning. If selection differentials were underestimated, expected genetic responses calculated from them would also be underestimated. Regardless of these qualifications, in general positive genetic response comparable to that expected was achieved in these studies. Contrary to the results just discussed, Armstrong *et al*. (1965) estimated negative genetic changes in weaning weight, weaning score, postweaning gain and feed efficiency when multiple trait selection was practiced. This was a surprising result in view of positive selection differentials and appreciable positive response expected. Small sample size and inbreeding, in excess of 30%, may provide partial explanation for the negative results observed.

Nelms and Stratton (1967) reported selection intensities and phenotypic responses achieved over a 12 year period in a closed line of Hereford cattle. Selection was solely for unadjusted weight at the end of a 168-day postweaning feed test. Generation interval in their data was 4.29 years. They reported an annual selection differential of 13 pounds for final off test with a corresponding 6 pound phenotypic change. Secondary selection differentials and actual change per year for birth weight, 180-day weight and daily gain were 0.42 pounds and 0.66 pounds, 3.3 pounds and 1.5 pounds and 0.03 pounds per day and 0.02 pounds per day, respectively. They concluded selection could be effective in making phenotypic improvement in small populations.

Chapman, Clyburn and McCormick (1969, 1972) reported results from a two phase experiment designed to compare criteria for selecting bulls from purebred herds for use in commercial herds. The first phase of the study (Chapman et al., 1969) dealt with evaluating response in performance when test lines of grade Polled Hereford cows were mated to bulls selected, from a single purebred herd, on the basis of different criteria. Sires selected on the basis of high weaning weight were used in one line, on the basis of rapid postweaning daily gain in a second line and on the basis of yearling type score in a third line. Sires as nearly average as possible in weaning weight, daily gain and type were used in a fourth line. No selection was practiced in females. Bulls were used in batteries of two per herd per year, except the first year when one bull was used per herd. Individual bulls were used two years and culled, thus of the two bulls used in any given year one bull was in service for the second time, the other bull for the first time. A total of 7 bulls were represented in the 7 years of data reported. The second phase of the experiment (Chapman et al., 1972) dealt with evaluating response in performance when heifers born in these lines described above were mated to bulls selected from the purebred herd on the same bases. In other words, heifers sired by bulls selected for weaning weight were bred to bulls selected on the same basis. The breeding procedure was the same as in the first phase. Effectively this design monitered the amount of change made in a line where the only selection applied was through bulls selected from a purebred herd (phase 1) and in a line where heifer replacements were selected from within the line on the same basis as the bulls were selected (phase 2). Genetic progress made in these lines would be the result of genetic change made in the purebred herd from which bulls were selected. Therefore, this study provided information relative to whether or not genetic progress was being made in the purebred herd that served as the source of breeding bulls for the four grade lines. Also, comparison of the performance of the different lines provided information relative to the criteria on which to base bull selection. Data from both phases of the study indicated that differences in performance between lines were not great; however, the lines in which the bulls used were selected for weaning weight and daily gain rather consistently outperformed the herds in which bulls selected on type were used. Comparisons with the average line indicated that genetic progress had been made in all the lines, consequently positive genetic progress was being made in the purebred herd. A rather disconcerting result was observed when comparisons were made between phases. In phase 1 positive response was observed for weaning weight in the line which used bulls selected for postweaning daily gain. In the second phase, however, weaning weights decreased somewhat in the daily gain line, even though daily gain improved. Negative selection differentials were observed, also, for weaning weight in this herd. This suggests, since there is a large maternal component for weaning weight, that the heifers out of bulls selected for rapid postweaning gain did not provide a superior preweaning environment for their calves.

Direct and correlated responses to selection for postweaning gain, feed efficiency and yearling conformation score were evaluated by Bailey et al. (1971). They analyzed data on 1488 progeny born from 1956 through 1968 in five lines of Hereford cattle. Selection was practiced for increased postweaning gain (two lines), feed efficiency (two lines) and yearling conformation score (one line). Selection intensity was measured by average annual selection differentials calculated in the same manner as Flower et al. (1964) and described previously in this review. Genetic trends were estimated from least squares and maximum likelihood analyses of differences between dam birth year groups. The following summarize findings of their study:

1. Generation intervals ranged from 4.57 to 4.92 years in the five lines.
2. Positive selection pressure was achieved for all traits selected for. Selection was much more intense in bulls than in cows.
3. Genetic trends indicated that positive changes had occurred in gain and efficiency in all lines, although the trends were significantly different from zero in only one line.
4. Genetic changes in conformation score, with effects of body weight removed, were minimal.

5. Regressions of efficiency on dam birth year in the gain lines were of the same order of magnitude, or somewhat higher, as compared to values for lines in which efficiency was directly selected for. This suggests that selection for rapid postweaning gain was as effective in improving efficiency as direct selection for efficiency.

Newman, Rahnefeld and Fredeen (1973) based selection solely on yearling weight in two replicate herds of Shorthorn cattle for 10 years. They quantified selection pressure in the same manner as Pattie (1965) did with sheep. An unselected control line provided the basis for estimating environmental and genetic trends. The accumulation of selection differentials was irregular, as expected, during the early, formative years of the project. During the latter six years of the study the accumulation of selection differentials advanced regularly at rates of 26.6±1.54 and 24.6±1.98 pounds per year for males and 20.0±0.66 and 16.7±0.88 pounds per year for females. The difference between the rate of accumulation in males and females was statistically significant in both herds, a somewhat surprising result to the authors. The accumulated selection differential of male parents is generally much larger in magnitude than that of female parents, however selection differential is transmitted equally to male and female progeny. Therefore, the rate of accumulation would be expected to be the same in both male and female parents. The deviation of each selected individual's record from the population mean was included in the cumulated selection differential. This could possibly explain why selection pressure accumulated more rapidly in the sires since the average deviation for sires was much larger than the average deviation for dams. Selection was effective in improving yearling weight in the two herds studied. Genetic increases of 10.6±6.8 and 9.0±6.6 pounds per year in males and 7.3±5.9 and 5.1±3.3 pounds per year in females were estimated. These estimates were the differences between regressions of yearling weight on year for the control line and selected lines. Although these responses were appreciable, they accounted for only 40-45% of the total phenotypic increase in yearling weight achieved over the course of the study. In other words, improvement in the environment resulted in 60-65% of the total improvement attained.

Koch, Gregory and Cundiff (1974a,b) summarized the first 10 years of data collected in three lines of Hereford cattle (150 cows and 6 sires per line) selected for weaning weight (WWL), yearling weight (YWL) or an index of yearling weight and muscling score (IXL). Bulls were used first as 2-year-olds and remained in service for three years. Once line numbers stabilized at 150 cows per line, 25 bred heifers, selected on the criteria of the line they were born in, were retained each year with subsequent culling of 25 cows. Complete performance records, including birth weights, preweaning daily gains, weaning weights, postweaning daily gains, yearling weights and muscling scores, were available on 2,956 calves. Selection intensity was quantified in two ways, (1) as average annual selection differentials and (2) accumulated selection differentials. Procedures used are the same as those previously outlined in this review (Flower et al., 1964 and Pattie, 1965). A formula for calculating generations of selection was presented as $GC = (GC_s + GC_d)/2 + 1$, where GC, GC_s and GC_d are generation coefficients of the individual, its sire and its dam, respectively.

Foundation animals were given generation coefficients of zero. Coefficients calculated in this manner measure the average number of segregations in an individual's pedigree back to foundation parents. Generations of selection were calculated by subtracting 1.0 from the generation coefficient. Response was estimated by five different methods. Each involved some sort of regression of offspring performance on selection in the parents. The various regressions used made use of statistics and quantitative genetic theory at such a level that an evaluation of these methods will not be attempted here. The following are an attempt to summarize the major findings of this comprehensive study:

1. Generation intervals in the WWL, YWL and IXL were, respectively, 4.19, 4.19 and 4.17 years. By the last year of the study 2.0, 1.8 and 1.9 generations of selection had been practiced in the WWL, YWL and IXL, respectively.
2. Average annual selection differentials averaged 9 pounds for weaning weight in the WWL, 16 pounds for yearling weight in the YWL and 12.5 pounds for yearling weight and 0.5 units for muscling score in the IXL. Positive secondary selection differentials were realized for birth weight and pre- and postweaning daily gain in all lines.
3. Cumulative selection differentials followed the same pattern as annual selection differentials. That is, in the last calf crop accumulated selection pressure was greatest in each line for the trait being selected for. The rate of

accumulation of selection pressure in the YWL was about 15 pounds per year, somewhat less than that realized by Newman et al. (1973).

4. Response per generation was estimated to be 10.5 pounds for weaning weight in the WWL, 31 pounds for yearling weight in the YWL and 24 pounds and 0.6 units for yearling weight and muscling score in the IXL.

5. Appreciable positive correlated responses were achieved in all traits in all lines except muscling score in the WWL where a slight negative response was estimated. These researchers postulated that selection for postweaning gain or yearling weight should result in as much or more response in preweaning gain and weaning weight as direct selection for these traits. They based this postulation on the low heritability of preweaning growth, the relatively higher heritability of postweaning growth and the strong genetic relationship that appeared to exist between pre- and postweaning growth. This expectation was not realized, however, since the average responses in preweaning gain and weaning weight were greater in the WWL than in the YWL.

The general conclusion made based on these results was that, the similarity of response in birth weight, weaning weight and yearling weight in the three lines which differed markedly in the relative selection applied is evidence of strong genetic correlations between the traits under selection. This situation is fortunate in that improvement programs can utilize a wide variety of performance evaluation patterns as dictated by various management considerations to attain improved growth performance.

Summary of Literature Review

Evidence accumulated to date in laboratory species and livestock species indicates that differences among animals in most economically important traits are, to a considerable extent, heritable differences. Available information indicates that generally favorable genetic relationships exist among these traits. Consequently, selection for these traits would be expected to be effective in improving net merit in beef cattle populations.

Studies designed to test the effectiveness of selection for economically important traits in beef cattle are relatively scarce. Experiments reported in the literature have varied considerably in the traits studied, selection procedures used, mating systems followed and analytical procedures utilized. Most of these studies, however, have dealt with the effectiveness of selection for growth and provide valuable information. In general these studies have shown that,

1. Appreciable selection pressure can be realized for measures of pre- and postweaning growth.
2. Genetic responses per unit of time are not large. However, positive genetic responses can be realized and, because of the cumulative

nature of selection, appreciable, permanent genetic changes can be made over a period of time.

3. Correlated responses can be realized. In general these correlated changes have been favorable in nature and indicate that various selection schemes can be effective in improving net performance. However, some correlated changes, such as those observed in birth weight and mature weight, may not be desirable.

The evidence indicates that selection can be an effective tool in improving performance in beef cattle populations. However, additional information is needed to construct breeding programs that will make maximum improvement. The present study is part of an overall effort designed to provide additional information relative to the effectiveness of selection for economically important characters in beef cattle.

CHAPTER III

MATERIALS AND METHODS

Data

The primary data used in this study were the performance records of 827 registered Hereford calves raised from 1964 through 1973 as part of the beef cattle selection project being conducted by the Oklahoma Agricultural Experiment Station. The overall objectives of the project are to (1) measure direct and correlated response to selection for increased weight at 205 and 365 days of age, (2) measure the genetic relationship between body weight at 205 and 365 days of age and (3) compare realized genetic response from selection based on individual performance with selection based on a combination of individual and progeny test performance for increased body weight at 205 days of age. Table III summarizes the design of the selection experiment.

Foundation animals used to initiate the project were assembled at the Fort Reno Livestock Research Station, El Reno, Oklahoma starting in 1960. Foundation females were randomly allocated to lines for the 1963 breeding season to initiate the project. Foundation females came from several herds in the midwest and southwest. Foundation Angus females were the progeny of 30 sires while 16 sires were represented by daughters in the Hereford lines. Foundation sires of each breed came from several sources with 10 foundation Hereford sires and 25 foundation

Angus sires being used. Foundation sires were used in the 1963, 1964, 1965 and 1966 breeding seasons in the two Hereford lines. Foundation Angus sires were used through the 1967 breeding season. Subsequent to 1966 and 1967 the Hereford and Angus lines, respectively, were closed and all replacement breeding stock selected from within each line. In the years used, foundation sires were bred to cows from all selection lines (within breed). The wide sampling of breeds and the procedures used in formation of the project should make the results as applicable as is experimentally possible.

TABLE III

DESIGN OF THE BEEF CATTLE SELECTION EXPERIMENT

	Line Number					
	5	6	7	8	9	10
Breed[a]	H	H	A	A	A	A
Number of cows per line	50	50	50	50	50	50
Trait Selected:						
Wt. at specified age	205	365	205	365	R[b]	205
Selection Criteria[c]	I	I	I	I	M C	I/P
Number of males selected per year	2	2	2	2	2	5/2[d]
Number of years selected males used	2	2	2	2	2	2
Number of females selected per year	10	10	10	10	10	10

[a]H=Hereford, A=Angus.

[b]Random mating control line. Replacement breeding stock are as near herd average in 205 day weight and 365 day weight as possible.

[c]I=Individual, P=Progeny.

[d]Five sires initially selected for progeny testing on the basis of their 205 day weight. The top 2 bulls are selected for use in the line based on progeny 205 day weight.

Only data from the two Hereford lines were used in the present study, therefore, the rest of this report will deal specifically with these lines. However, the general procedures were the same for all lines, regardless of breed.

Replacement breeding animals were selected on the basis of heaviest 205-day weight (weaning weight) in one line (WWL) and heaviest yearling weight (365 days for bulls and 425 days for heifers) in the other line (YWL). Each year two bulls were selected from each line based on the respective selection criteria and were used for two years and discarded. Thus, four bulls were used per line per year, two were being used the first time and the other two were being used for their second year. Bulls were used first as two year olds through the 1970 breeding season, subsequently bulls were first used as yearlings. The third ranking bull in each line was kept as an alternate for use in the event something happened to one of the selected bulls. During the course of this study it was necessary to use only one alternate bull and that was to replace a selected bull by an alternate bull for the second year of service.

The thirteen top heifers based on the respective selection criteria were kept from each line each year and bred as yearlings. All of the heifers were pregnancy checked after the breeding season and the 10 highest ranking pregnant heifers were selected to remain in the line. Fifty breeding age females were maintained per line, thus, since 10 heifers were selected each year, 10 cows were culled yearly. The following criteria were used to cull cows: (1) serious unsoundness, (2) not pregnant based on fall pregnancy check and (3) oldest age.

The first selections were made from the 1964 calf crop. The first calves produced by selected heifers were born in 1966 and selected bulls first sired calves in the 1967 calf crop.

From the design and procedures described above it would be possible to estimate genetic change in two ways. One would be by use of the control line. Another would be from within year comparisons of progeny produced by the bulls being used for the first time with progeny from the bulls being used the second time. The new and repeat sires would differ in age by one year; therefore, twice the difference between the performance of their progeny would estimate the genetic change (improvement in breeding value) made from one year of selection. An additional procedure was implemented in the project to provide another estimate of genetic change. Semen was collected from foundation sires and stored. Use of this semen after a number of years of selection would provide a means for comparing performance of progeny from foundation sires and selected sires. Such a comparison, made within year, would provide an estimate of genetic progress.

The primary data used in this study were collected from 1964 through 1973 on 827 calves born in the two selection lines. Table IV presents the number of calves included each year. A secondary set of data was also utilized. Semen from two foundation sires and four bulls selected in 1970 from the two Hereford lines was used to produce progeny in 1972. The progeny were produced by Angus cows maintained in the herd used to progeny test bulls from the Angus progeny test line, thus the calves involved in this set of data were crossbreds. A total of 103 calves, 61 steers and 42 heifers, were represented in the data. Data from the control line were not used. Originally this line was to be a progeny test selection line for yearling weight. The line was changed to a control in 1969 when it was decided the utility of a control outweighed the need for another selection line. Since the control was not formed until 1969, data from the line was not sufficient for use in this study.

TABLE IV

NUMBERS OF OBSERVATIONS PER YEAR IN EACH SELECTION LINE

	Weaning Weight Line		Yearling Weight Line	
Year	Males	Females	Males	Females
1964	11	13	16	10
1965	25	24	22	25
1966	28	16	25	20
1967	20	22	25	20
1968	22	23	27	19
1969	24	19	23	21
1970	23	26	23	24
1971	16	27	22	25
1972	24	20	23	20
1973	18	20	16	20
Total	211	210	222	204

Management and Data Collection

The selection lines were maintained at the Fort Reno Livestock Research Station. They were managed as a single herd except during the breeding season and when circumstances such as pasture size and forage availability dictated otherwise. Special effort was made to provide as uniform an environment as possible for all cattle. During the spring and summer the herd was maintained on native range typical of central

Oklahoma. During the winter the cow herd was run on native winter range and wheat pasture, when available, and supplemented with prairie hay, alfalfa and cottonseed cake as necessary.

Breeding females were alloted to sires within line by stratified randomization to obtain equal distribution of cow age groups within sires. Matings between half-sibs or more closely related animals were avoided to minimize inbreeding. Bulls were placed with the cows in single sire breeding pastures on May 1 of each year. The breeding season initially ran for 90 days but was later reduced to 60 days. Reduction in the length of the breeding season was made with the 1968 and 1969 breeding seasons. Calves were born in the spring starting about February 1. Most calves were born in February and March. All calves were tatooed, ear tagged and weighed within 24 hours of birth. Calves ran with their dams without creep feed and were weaned when the average age of all calves was 205 days. At weaning all calves were weighed following a 12 hour shrink off water and separated from their dams. All calves were scored by a committee of at least three persons for conformation and condition.

After weaning bull calves were given a two-week warm up period before being placed on a feedlot performance test. From 1964 through 1971 these tests were 160 days in duration and were reduced to 140 day tests in 1972 and 1973. Bulls were weighed at the end of the tests following a 12 hour shrink off feed and water and scored for conformation and condition. The rations fed during the tests underwent two basic changes over the time period involved in the present study. Table V summarizes the composition of the rations. The initial ration, used in 1964 and 1965, included ground whole ear corn and the first change involved substitution of ground shell corn for the ground ear corn. The second change, which took place with the 1970 test, involved addition of a preformulated supplemental pellet containing mainly dehydrated alfalfa, soybean oil meal and wheat middlings. Alfalfa hay, oats and wheat bran were dropped from the ration at this time. Table VI presents the composition of the supplemental pellets. Rations were fed ad libitum from self feeders.

TABLE V

COMPOSITION OF BULL TEST RATIONS

	Rations (Years Used)		
Ingredient	1964-1965	1966-1969	1970-1973
	%	%	%
Ground Whole Ear Corn	35	--	--
Ground Shell Corn	--	30	57
Cottonseed Hulls	20	15	23
Ground Alfalfa Hay	10	10	--
Whole Oats	10	20	--
Wheat Bran	10	10	--
Protein Supplement[a]	10	10	--
Molasses	5	5	5
Supplemental Pellets	--	--	15

[a]Cottonseed meal and soybean oil meal were used interchangeably depending on relative prices.

Heifers calves were placed on wheat pasture after weaning and supplemented with prairie hay, alfalfa, cottonseed meal and grain so as to gain from 0.75 to 1.00 pound per day from weaning to 425 days of age.

The longer postweaning period was used for the heifers in order to permit a greater opportunity for genetic differences in postweaning gain to be expressed under the lower nutritional level. Weights and scores were taken at an average age of 425 days to terminate the postweaning evaluation of the heifers. This age was just prior to when the selected heifers were placed in the breeding pastures.

TABLE VI

COMPOSITION OF SUPPLEMENTAL PELLETS

Ingredient	%
Dehydrated Alfalfa	33
Soybean Oil Meal	40
Wheat Middlings	16
Urea	3
Salt	3
Dicalcium Phosphate	2
Calcium Carbonate	2
Aurofac-10 (Cyanamid Auromycin)	0.3
Trace Mineral	0.1
Vitamin A (10,000 I.U./gram)	0.2

The herd used to compare foundation and selected sires in this study was maintained at the Lake Carl Blackwell Research Range west of Stillwater. General management of the cow herd was similar to that described previously for the selection line cows. Bull calves were castrated at about 3 months of age. After weaning at an average of 205 days, 61 steers and 42 heifers were trucked to the Fort Reno Livestock Research Station and placed on postweaning feedlot tests.

As alluded to above, complete performance records were collected on each calf through a year of age for bulls and through 425 days of age for heifers. The records used in this study are as follows:

1. Birth weight: All calves were weighed within 24 hours of birth. Birth weights of all calves weaned were utilized in this study.

2. Weaning weight: Calves were weaned and weighed at an average age of 205-days. Weaning weights were adjusted to a 205-day basis by multiplying average daily gain from birth to weaning by 205 and adding birth weight. Weaning weights were adjusted for age of dam effects in the selection lines using additive correction factors developed by Cardellino and Frahm (1971). Weights were adjusted to a mature dam basis by adding 84 pounds, 37 pounds and 5 pounds to the 205-day weights of calves from 2-year old, 3-year old and 4-year old dams, respectively. No adjustment was made for calves from dams 5 years old and older. The weights of the crossbred calves produced in the progeny test herd were adjusted for age of dam effects using industry recommended multiplicative correction factors. Weights of calves out of 2, 3 and 4-year old dams were multiplied by 1.15, 1.10 and 1.05, respectively. Age of dam adjusted 205-day weaning weight was the primary selection trait in the WWL.

3. Weaning conformation score: A committee of at least three persons independently scored each calf for conformation at weaning. The three scores were averaged for each calf and recorded. A 17 point scoring system was used in which feeder calf grades were broken into thirds with a score of 13 representing average choice, 14 high choice and so on. These scores were given to reflect differences in muscling independent of fatness and size.
4. Postweaning average daily gain: Postweaning average daily gains were calculated for bulls by dividing the difference between on test weight and off test weight by the number of days on test, 160 days for calves tested from 1964 through 1971 and 140 days subsequently. Postweaning daily gains for heifers were calculated by dividing the difference between unadjusted weaning weight and unadjusted 425 day weight by the number of days between weaning date and the date 425 day weights were taken.
5. Yearling weight: Adjusted 365-day weights were obtained for bulls by multiplying 160 times average daily gain and adding the 205-day adjusted weight. Adjusted 425-day weights for heifers were obtained by multiplying 220 times average daily gain and adding weaning weight. These weights were the primary selection trait in the YWL.

6. Yearling conformation score: Bulls and heifers were scored for conformation at the end of their respective postweaning tests. The procedures and scoring system were the same as those described previously for scoring at weaning.

Data Analyses

Measurement of Selection Applied

The long term nature of the selection project and the extensive overlapping of generations inherent in beef cattle populations necessitated the use of an analytical procedure for combining selection differentials realized in different years. The procedure used to measure selection intensity involved quantification of cumulative selection associated with the parents of each calf crop. An individual cumulative selection differential (ICSD) was calculated for each animal which was the parent of at least one offspring in the study. Each ICSD was the sum of two components, a male cumulative selection differential (MCSD) and a female cumulative selection differential (FCSD). The MCSD for a selected bull was calculated by adding the deviation between the bull's individual record and the mean of all bulls born in the same year to the average of the MCSD's of his sire and dam. The MCSD for selected heifers was simply the average of the MCSD's of the parents. The FCSD for selected bulls was the average of the FCSD's of the parents. The FCSD for selected heifers was obtained by averaging the FCSD's of the parents and adding the deviation between the heifer's record and the mean of all heifers born in the same year. ICSD's, MCSD's and FCSD's were zero for all foundation animals and calculations were carried forward for each selected animal which became a parent. This system is an expansion of similar systems utilized by Pattie (1965), Newman et al. (1973) and Koch et al. (1974). Their systems involved calculating ICSD as the average of ICSD's of the parents plus the deviation between the individual's record and the mean of the year-sex group born in. The system used in this study did essentially the same thing. However, calculating MCSD and FCSD for each individual allowed the selection pressure realized from sire selection and dam selection back through an individual's pedigree to be quantified. The mathematical development of the system was as follows:

$$\begin{aligned} ICSD &= \tfrac{1}{2}[ICSD_s + ICSD_d] + ID \\ &= \tfrac{1}{2}[(MCSD_s + FCSD_s) + (MCSD_d + Fcsd_d)] + ID \\ &= \tfrac{1}{2}(MCSD_s + MCSD_d + FCSD_s + FCSD_d) + ID \\ &= \tfrac{1}{2}(MCSD_s + MCSD_d) + \tfrac{1}{2}(FCSD_s + FCSD_d) + ID \end{aligned}$$

The individual deviation (ID) was added to the MCSD in the case of bulls and to the FCSD in the case of heifers. Thus, for males:

$$\begin{aligned} ICSD &= [\tfrac{1}{2}(MCSD_s + MCSD_d) + ID] + \tfrac{1}{2}(FCSD_s + FCSD_d) \\ &= MCSD + FCSD \end{aligned}$$

and for females:

$$\begin{aligned} ICSD &= \tfrac{1}{2}(MCSD_s + MCSD_d) + [\tfrac{1}{2}(FCSD_s + FCSD_d) + ID] \\ &= MCSD + FCSD \end{aligned}$$

where,

ID = Deviation between individual's record and its sex-year group mean.

ICSD = Individual cumulative selection differential for all selected individuals. ICSD = MCSD + FCSD.

$ICSD_s$, $ICSD_d$ = Individual cumulative selection differential of the sire and dam, respectively.

$$ICSD_s = MCSD_s + FCSD_s;$$

$$ICSD_d = MCSD_d + FCSD_d.$$

$MCSD_s$, $MCSD_d$ = Male cumulative selection differential of the sire and dam, respectively.

$FCSD_s$, $FCSD_d$ = Female cumulative selection differential of the sire and dam, respectively.

MCSD = Male cumulative selection differential of individual in question.

FCSD = Female cumulative selection differential of individual in question.

To measure cumulative selection pressure on a calf crop basis, weighted average MCSD's, FCSD's and ICSD's were calculated for the parents of each calf crop for each line. The weights were the number of offspring each parent contributed to the calf crop. The mean ICSD for a calf crop measured the cumulative selection intensity realized from selection to that point in time. Calculation of mean MCSD's and FCSD's partitioned mean ICSD's into the components related to sire and dam selection, respectively. Thus, the relative intensity of cumulative sire and dam selection was evaluated independently. To measure the rate of accumulation of selection pressure, calf crop ICSD's were regressed on years using simple linear regression techniques (Snedecor and Cochran, 1967). The 1964 and 1965 calf crops were considered together in the regression since only foundation matings were involved and, hence, there was no opportunity for accumulation of selection pressure in these two calf crops.

In beef cattle populations there is considerable overlap in generations producing calves in any year. Generations of selection were measured in this study by calculating a generation coefficient for each calf produced. The procedure used is similar to the formula suggested by Brinks, Clark and Rice (1961). Their formula was as follows:

$$GC = \frac{(GC_s + GC_d)}{2} + 1$$

where, GC = Generation coefficient of the individual

GC_s, GC_d = Generation coefficient of sire and dam, respectively.

This formula indicates that generation coefficients advance one generation beyond the average of the parents. This is not the case, however, when foundation animals are involved since progeny of foundation animals do not represent one generation of selection, as this formula would indicate. Thus, as pointed out by Koch et al. (1974) this formula measures the average number of segregations in an animal's pedigree back to foundation animals and to get generations of selection 1.0 must be subtracted from the average calf crop GC. Generations of selection were calculated directly in this study by slight modification of this basic formula.

The formula used was $GC = \frac{GC_s + GC_d}{2} + \frac{1}{2}(s) + \frac{1}{2}(d)$, where s and d had the value of 1.0 if they were a selected sire or dam, respectively; s and d were zero in the case of foundation animals. Use of this formula adequately accounts for the matings involving foundation animals and directly measures generations of selection actually practiced at any stage of the study. Once all foundation animals have been removed from the line the two formulas are synonomous.

Generation intervals were estimated by calculating the average age of the parents at the time of birth for each calf crop.

Estimation of Response to Selection

General least squares procedures (Harvey, 1960) were used to obtain line-year means for evaluation of phenotypic time trends. The linear model used included the effects of selection line, sires nested within selection line, sex of calf, line by sex of calf interaction and random error. All effects were considered fixed. Sire by sex interaction was not included since previous analyses indicated the interaction was not important in these herds (Tanner et al., 1970). Analyses were done on a within year basis. The least squares line-year means were regressed on years using simple linear regression techniques (Snedecor and Cochran, 1967). The regression of mean performance on year estimated the average phenotypic change per year realized in each line over the time period involved. As such, the regressions do not estimate genetic change since environmental changes were included. However, they are of practical importance since they estimated the overall change in performance that was realized over the course of the study.

Genetic change was estimated by comparison of progeny produced by foundation sires with progeny produced by selected sires. Semen from two foundation sires and the four selected sires from the 1970 calf crop was used to produce progeny in the progeny test herd in 1972, as described previously. General least squares procedures (Harvey, 1960) were used to obtain foundation sire group means and selected sire group means. The linear model used included the fixed effects of selection group, sires within selection group, sex of calf and random error. Selected sires were considered as one selection group in the analysis, i.e., no differentiation was made between progeny from WWL bulls and progeny from YWL bulls. The lines were considered together because the within year analyses of the selection line data indicated that the two lines were very similar in performance at that particular state of the study. That is, over the time period considered selection had not caused a detectable divergence between the two lines. Thus, the objective of the analysis was to compare foundation sires with selected sires, ignoring selection lines. Twice the difference between the selected sire group mean and the foundation sire group mean estimated the genetic change (improvement in breeding value) realized from seven years of selection (1964 through 1971). The difference between means was doubled since only the sires contribution was measured by this comparison. The estimated genetic change per year was obtained by dividing by seven, the number of years selection had been conducted. The standard error of the estimated genetic change per year was obtained as follows (Dickerson, 1960):

$$S.E. = \frac{2}{7}\sqrt{EMS\left(\frac{1}{n_s} + \frac{1}{n_f}\right)}$$

where,

EMS = Error mean square from least squares analysis of variance.

n_s, n_f = Number of progeny in selected sire group and foundation sire group, respectively.

The general response formula, response = h^2 x average selection differential of parents, was used as a basis for estimating realized heritability from the progeny test herd data. Development of the equation used was as follows:

$$\text{Response} = \tfrac{1}{2}\,(ICSD_{sires} + ICSD_{dams})\,h^2$$

$$h^2 = \frac{2(\text{Response})}{ICSD_{sires} + ICSD_{dams}}$$

Since the dams were unselected, $ICSD_{dams} = 0$ and

$$h^2 = \frac{2(\text{Response})}{ICSD_{sires}}$$

Since foundation sires were unselected, response used in the calculations was the difference between selected sire means and foundation sire means.

As described previously, four bulls were used per line per year. In any year, two of the bulls were being used for the first time, the other two being in their second year of service. The two bull pairs differed in age and selection by one year, therefore, another estimate of genetic change per year was obtained by doubling the difference between the means of the sire pairs. The difference was doubled because only the sires contribution was measured in these comparisons. Genetic differences among cows should not have become involved in these comparisons since cows were alloted to sires at random. Progeny means for sire pairs were obtained by averaging the least squares sire within line means obtained from the within year analyses described previously.

CHAPTER IV

RESULTS AND DISCUSSION

Intensity of Selection

Generation Intervals and Coefficients

The average age of the parents when the offspring are born has often been used as a measure of generation interval in beef cattle populations. Table VII presents the average age of the parents and the average generation coefficients for each calf crop. Average age of the parents was similar in the two lines, averaging 4.09 years and 4.06 years in the WWL and YWL, respectively. Sires averaged 3.38 years of age in both lines while WWL dams averaged 4.8 years and YWL dams 4.75 years. Average age of the parents increased until 1967 in the YWL and until 1968 in the WWL. These increases in average age were due to increased age of the cows in both lines. Foundation cows averaged only 4.08 and 4.05 years in the WWL and YWL, respectively. Subsequent to 1967 and 1968 average age of the parents decreased to 3.39 years in 1973 in the WWL and 3.54 years in the YWL. This was due largely to decreasing sire age in 1972 and 1973 when replacement bulls were first used as yearlings rather than two-year olds.

The average ages of parents summarized in Table VII indicate that generation intervals in these lines were somewhat shorter than generally observed in beef cattle populations. Brinks *et al*. (1965) reported an average generation interval of 4.93 years in 26 years of data from a line of Hereford cattle. Generation intervals averaged 5.11 years and 4.80 years, respectively, in Brahman and Hereford herds studied by Chapman (1968). Koch et al. (1974) worked with data from three Hereford lines and reported an average generation interval of 4.6 years. Nelms and Stratton (1967) reported generation intervals averaged 4.29 years in a small Hereford herd during a 12 year period. Generation intervals similar to those found in the present study have been reported by Flower et al. (1964) who found generation intervals averaged 4.03 years in four lines of Hereford cattle. The shorter generation intervals of the present study were due primarily to a higher annual replacement rate in the cow herd and, in the last two years, the practice of using bulls first as yearlings. Generation coefficients reported in Table VII measure the average number of generations of selection in the pedigrees of calves born in a given line and year. By 1973 an average of 1.98 and 2.12 generations of selection had been practiced in the WWL and YWL, respectively. Koch et al. (1974) reported that after the first ten years 2.02, 1.8 and 1.9 generations of selection had been practiced in lines of Hereford cattle selected for weaning weight, yearling weight and an index, respectively.

Comparisons between lines concerning generation intervals and generation coefficients indicate that generation turnover was similar in the two lines. This is of importance since comparison between lines on the basis of selection intensity and selection response are easier to interpret if both lines are at the same state of selection.

TABLE VII

AVERAGE AGE OF PARENTS AND GENERATION COEFFICIENTS

	WWL[a]				YWL[a]			
		Average Age				Average Age		
Year	GC	Sires	Dams	Midparents	GC	Sires	Dams	Midparents
1964	0	3.72	4.08	3.90	0	3.59	4.05	3.82
1965	0	3.49	4.41	3.95	0	3.49	4.68	4.09
1966	0.06	3.54	4.95	4.25	0.07	3.43	5.31	4.37
1967	0.38	3.50	5.47	4.49	0.39	3.54	5.34	4.44
1968	0.68	3.53	5.93	4.73	0.71	3.52	5.32	4.42
1969	0.80	3.49	5.47	5.47	0.83	3.43	4.95	4.19
1970	1.00	3.49	4.48	3.98	1.18	3.55	4.29	3.92
1971	1.32	3.49	4.39	3.94	1.50	3.55	4.59	4.07
1972	1.74	3.04	4.55	3.79	1.76	3.16	4.41	3.79
1973	1.98	2.54	4.25	3.39	2.12	2.57	4.51	3.54
MEAN	-	3.38	4.80	4.09	-	3.38	4.75	4.06

[a]WWL = Weaning weight line; YWL = Yearling weight line.

Intensity of Direct Selection

Weight at weaning (205-days) and yearling (365- and 425-days) were the traits selected for in the two lines, respectively. Consequently, intensity of selection for these traits is of primary interest. Table VIII summarizes cumulative selection pressure realized for weaning weight and yearling weight in both lines. As described previously the total ICSD reflects the cumulative selection intensity associated with the parents of each calf crop. Examination of weaning weight ICSD's with WWL and yearling weight in the YWL indicates that selecting was fairly intense for the primary selection traits. Accumulation of selection pressure was quite regular in nature even though numerous foundation animals were involved in the initial years. In 1973, total ICSD for weaning weight in the WWL was 98.2 pounds and for yearling weight in the YWL was 196.4 pounds. These selection differentials in standard measure were 2.07 and 2.48 phenotypic standard deviations, respectively.

Koch et al. (1974) reported a total cumulative selection differential of 95.2 pounds for weaning weight in a line selected for weaning weight for nine years. This represented an average increase in total cumulative selection differential of 10.6 pounds per year. In the present study, the total ICSD for weaning weight was 98.2 pounds in the WWL. This represented an annual increase of 11.96 pounds in total ICSD. Thus, selection was slightly more intense in the present study.

Newman et al. (1973) selected for yearling weight in two replicate herds of Shorthorn cattle. Total cumulative differentials in the two herds were 199.1 and 180.5 pounds at the end of the first ten years of the experiment. Regression of total cumulative selection differen-

TABLE VIII

TOTAL INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR WEANING WEIGHT AND YEARLING WEIGHT BY LINE AND YEAR

	Weaning Weight (Lbs.)		Yearling Weight (Lbs.)	
Year	WWL[a]	YWL[a]	WWL[a]	YWL[a]
1964-1965	0	0	0	0
1966	1.35	2.15	-0.26	0.31
1967	11.87	20.61	9.73	40.47
1968	26.74	29.63	21.97	67.34
1969	37.25	29.29	46.97	65.17
1970	39.10	44.33	58.39	104.91
1971	56.19	54.25	82.75	143.94
1972	75.85	68.39	96.89	161.01
1973	98.19	94.02	129.98	196.35
Standard Measure (1973)	2.07	1.99	1.62	2.48
Regression on Years	11.96±0.986	10.95±0.918	16.56±1.307	25.20±1.547

[a]WWL = Weaning weight line; YWL = Yearling weight line.

tial on year indicated that selection pressure accumulated at rates of 23.3 and 20.7 pounds per year in the two herds. Koch et al. (1974) reported a total cumulative selection differential of 143.7 pounds for yearling weight in a line selected for yearling weight. On a per year basis this amounted to an average increase of 16 pounds per year. In the present study, total ICSD for yearling weight in the YWL in 1973 was 196.4 pounds and increased at an average rate of 25.2 pounds per year. Thus, selection in the present study was slightly more intense than that achieved by Newman et al. (1973) and considerably more intense than that achieved by Koch et al. (1974). Between line comparisons of selection intensities for weaning weight and yearling weight provides information relative to selection intensity for correlated traits. Of primary interest is evaluation of ICSD's for yearling weight in the WWL. If appreciable selection can be applied for yearling weight by selection for weaning weight, considerable savings in time and money could be realized by being able to cull at weaning rather than waiting until animals reach a year of age. The total ICSD in 1973 for yearling weight in the WWL was 130.0 pounds and 196.4 pounds in the YWL. Regressions of yearling weight ICSD on year in the WWL and YWL were 16.6 and 25.2 pounds, respectively. This suggests that animals selected for heavy weaning weights were also phenotypically above average for yearling weight. The annual correlated selection differentials achieved for yearling weight in the WWL were 66% as large as selecting directly for yearling weight. Koch et al. (1974) found a total cumulative selection differential for yearling weight of 137.2 and 143.7 pounds in weaning weight and yearling weight lines, respectively. Only 1.8 generations of selection had been practiced in the yearling weight line while 2.02 generations of selection had been practiced in the weaning weight line. Thus, selection directly for yearling weight was more intense, although the difference in intensity between lines was not as great as in the present study.

It has been postulated that selection for yearling weight might be expected to improve weaning weight as much or more as direct selection for weaning weight (Koch et al., 1974). This hypothesis was based on the higher heritability of yearling weight relative to heritability of weaning weight and the high, positive genetic correlation that apparently exists between weaning weight and yearling weight. The total ICSD for weaning weight in the YWL was 94.0 pounds and the regression of ICSD on year was 10.9 pounds. Comparable figures in the WWL were 98.2 pounds and 12.0 pounds, respectively. The difference between regressions was not significant ($P>.4$). Thus, in these data, the correlated selection differential for weaning weight that occurred in the YWL was 92% as large as the cumulated selection differential achieved from directly selecting on the basis of weaning weight. Contrary to their postulation, and the data from the present study, Koch et al. (1974) obtained correlated cumulative selection differentials for weaning weight in their yearling weight line that were only 58% as large as cumulative selection differentials realized from direct selection for weaning weight.

Weaning weight and yearling weight are both traits of which the expression is influenced by numerous components. Weaning weight reflects the combined effect of mothering and milking ability of the dam in addition to the birth weight and inherent growth potential of the calf. Yearling weight reflects the effect of weaning weight and its components plus the effects of growth potential, appetite and efficiency of feed use postweaning. It is important to evaluate correlated selection pressure that is realized for these correlated traits when selection is for weaning weight or yearling weight since overall improvement in net productivity is influenced by changes made in these correlated traits.

Intensity of Correlated Selection

Table IX summarizes total ICSD's realized for birth weight, ADG, and weaning and yearling score in the two selection lines.

Correlated selection intensity and response for birth weight is of specific concern since heavy birth weights have been associated with increased calving difficulty and the resulting increase in calf losses at birth. Thus, a correlated response in birth weight may not be favorable to improving net productivity. Total birth weight ICSD's in 1973 were 9.9 and 11.2 pounds in the WWL and YWL, respectively. Regression of ICSD on year was 0.97 pounds in the WWL and 1.27 pounds in the YWL. The difference between the regression coefficients was not significant (P>.2). Results reported by Koch et al. (1974) were similar to those found in this study. Selection for yearling weight resulted in more intense correlated selection for birth weight than did selection for weaning weight, although the difference was not large. Other studies have shown positive secondary selection intensities for birth weight when multiple trait selection schemes were used (Flower et al., 1964; Brinks et al., 1965; Nelms and Stratton, 1967; Chapman, 1968). Average annual selection differentials for birth weight ranged from 0.4 pounds to 1.08 pounds in these studies.

TABLE IX

TOTAL INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR BIRTH WEIGHT, WEANING SCORE, AVERAGE DAILY GAIN AND YEARLING SCORE BY LINE AND YEAR

	Birth Weight (lbs.)		Weaning Score[b]		Daily Gain (lbs./day)		Yearling Score[b]	
Year	WWL[a]	YWL[a]	WWL[a]	YWL[a]	WWL[a]	YWL[a]	WWL[a]	YWL[a]
1964-1965	0	0	0	0	0	0	0	0
1966	0.40	0.62	0.01	0.06	0	0	0.01	0.01
1967	2.67	4.12	0.38	0.34	0	0.12	0.21	0.40
1968	4.65	6.05	0.76	0.41	-0.01	0.23	0.34	0.62
1969	3.41	6.61	0.50	0.13	0.05	0.23	0.32	0.63
1970	4.76	8.72	0.48	0.37	0.13	0.37	0.51	0.86
1971	4.38	7.02	0.87	0.64	0.19	0.55	0.64	0.98
1972	5.42	8.37	1.05	0.64	0.16	0.58	0.89	0.75
1973	9.87	11.17	1.25	0.69	0.24	0.63	1.04	0.84
Regression on year	0.97±0.172	1.27±0.170	0.15±0.022	0.08±0.017	0.03±0.005	0.08±0.017	0.13±0.010	0.12±0.023

[a]WWL = Weaning weight line; YWL = Yearling weight line

[b]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

Secondary selection for postweaning average daily gain was more intense in the YWL than in the WWL. In 1973 the total ICSD's for average daily gain were 0.63 pounds per day and 0.24 pounds per day in the YWL and WWL, respectively. Total ICSD accumulated significantly ($P<.001$) faster in the YWL, 0.08 pounds per day per year as compared to 0.03 pounds per day per year in the WWL. Accumulation of ICSD was also more irregular in the WWL as essentially no selection was realized in the first five calf crops. Koch _et al_. (1974) found that average daily gain cumulative selection differentials averaged 0.311 pounds per day when selection was for yearling weight for 1.8 generations. Cumulative selection differentials for average daily gain in their weaning weight line averaged 0.159 pounds per day after 2.02 generations of selection. Nelms and Stratton (1967) found that during a 12 year study selection differentials for daily gain averaged 0.03 pounds per day per year when selection was for unadjusted weight at the end of a 168 day postweaning feed test.

Concern has been expressed by some people in the beef cattle industry, especially those oriented to the show ring, that intense selection for performance will result in deterioration of conformation, unless conformation is given attention in selection programs. Thus, it is of interest to evaluate correlated selection intensities for weaning score and yearling score in these data. As summarized in Table IX, secondary selection for weaning or yearling conformation was not intense in either selection line. Accumulation of ICSD for weaning or yearling score was somewhat more irregular than for other traits. This is not a surprising result since scores were subjectively made and numerous different people were involved in scoring over the years of the study. Although not intense, positive secondary selection pressure was realized for conformation in these lines. Thus, conformation would not be expected to deteriorate as a result of selection in these lines but would rather be expected to exhibit some improvement.

Intensity of Male and Female Selection

In a population under long term selection, cumulative selection differentials of parents are the combined result of male and female selection. Reports in the literature have shown that selection differentials of sires are generally much larger than selection differentials of dams. This would be expected since there is considerably more opportunity for selection among males than among females because of the large proportion of females that must be saved for replacements each year. These reports, however, have not independently quantified selection pressure realized through male and female selection since selection differentials of sires and dams both are the combined result of male and female selection. Evaluation of cumulative selection pressure realized from male and female selection, respectively, requires that selection differentials of the sires and dams be partitioned into components that quantify male and female selection. The male components for sires and dams are then combined to quantify selection intensity realized through male selection. In like manner combining the female components from the sires and dams would quantify intensity of female selection. Male cumulative selection differentials (MCSD's) and female cumulative selection differentials (FCSD's) calculated in the manner described previously partitioned cumulative parental selection differentials into components related to male and female selection. Table X and Table XI present total MCSD's, FCSD's and ICSD's for sires, dams and midparents (average of sire and dam components) for weaning weight in the WWL and for yearling weight in the YWL, respectively. Discussion will essentially involve only these two tables since they summarize data for the traits directly selected for. Similar data for correlated traits are presented in Tables XVII through XXVI in the Appendix.

Total midparent MCSD's and FCSD's quantify the intensity of selection realized from male and female selection, respectively, in the pedigrees of the parents of each calf crop. In 1973, total weaning weight MCSD's and FCSD's were 78.5 and 19.7 pounds, respectively, in the WWL (Table X). Thus, of the total midparent ICSD of 98.2 pounds, 80% was due to cumulative male selection. In the YWL in 1973, total yearling weight MCSD's and FCSD's were 162.2 and 34.1 pounds, respectively (Table XI). Thus, of the total midparent ICSD of 196.3 pounds, 83% was due to male selection. These data indicate that cumulative male selection is much more intense than female selection and provide evidence to support the statement "that from 80 to 90% of the genetic improvement made in beef cattle herds is the result of selection of males." Replacement of females in the lines was somewhat faster than replacement rates in most commercial herds. Thus, in most practical situations male selection would be even more intense than that realized in this study.

Midparent MCSD's and FCSD's discussed above were the combined result of male and female selection, respectively, in the pedigrees of both sires and dams. Sire MCSD's and dam MCSD's were calculated to quantify the intensity of male selection in the ancestry of sires independent of male selection in the ancestry of dams, respectively. In

TABLE X

TOTAL WEANING WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	2.7	2.7	0	1.35	1.35
1967	14.79	0	14.79	0	8.95	8.95	7.40	4.47	11.87
1968	48.40	0	48.40	0	5.09	5.09	24.20	2.54	26.74
1969	60.77	0	60.77	0.97	12.77	13.74	30.87	6.38	37.25
1970	55.14	0	55.14	6.13	16.93	23.06	30.63	8.47	39.10
1971	77.89	-1.28	76.61	12.43	23.34	35.77	45.16	11.03	56.19
1972	109.19	0.17	109.36	15.87	26.48	42.35	62.53	13.32	75.85
1973	129.16	6.55	135.71	27.90	32.77	60.67	78.53	19.66	98.19

TABLE XI

TOTAL YEARLING WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	4.29	4.29	0	2.15	2.15
1967	74.25	0	74.25	0	6.68	6.68	37.13	3.34	40.47
1968	127.02	0	127.02	0	7.65	7.65	63.51	3.83	67.34
1969	111.84	0	111.84	2.77	15.74	18.51	57.30	7.87	65.17
1970	162.14	1.43	163.57	21.24	25.01	46.25	91.69	13.22	104.91
1971	229.35	5.81	235.16	29.23	23.49	52.72	129.29	14.65	143.94
1972	234.48	13.43	247.91	42.09	32.02	74.11	138.28	22.73	161.01
1973	261.20	18.29	279.49	63.24	49.97	113.21	162.22	34.13	196.35

like manner, sire FCSD's and dam FCSD's were calculated to independently quantify the intensity of female selection in the pedigrees of sires and dams, respectively. In 1973 sire and dam MCSD's for weaning weight in the WWL were 129.2 and 27.9 pounds, respectively. The average of these components or the midparent MCSD, was 78.5 pounds. Therefore, of the total selection pressure realized from male selection for weaning weight, 83% was due to male selection in the ancestry of the sires used in 1973. In the YWL, in 1973, the midparent MCSD for yearling weight was 162.2 pounds, the average of the sire MCSD of 261.2 pounds and the dam MCSD of 63.2 pounds. Of the total selection pressure realized from male selection for yearling weight, 81% was the result of male selection in the pedigrees of the sires. These data further emphasize the intensity of male selection and show that it was largely the result of male selection in the ancestry of sires.

It is interesting to compare the intensity of male and female selection in sires with the intensity of male and female selection in dams. In the WWL in 1973 the sire ICSD for weaning weight was 135.7 pounds and was made up of a sire MCSD and a sire FCSD of 129.2 and 6.55 pounds, respectively. In the YWL in 1973 the sire MCSD for yearling weight was 261.2 pounds and the sire FCSD was 18.3 pounds for a sire ICSD of 279.5 pounds. Thus, male selection accounted for 95% and 93% of the total selection pressure that had accumulated in the sires used in 1973 in the WWL and YWL, respectively. Total dam ICSD for weaning weight in the WWL in 1973 was 60.7 pounds and was the sum of a dam MCSD of 27.9 pounds and a dam FCSD of 32.8 pounds. In the YWL in 1973, total dam ICSD for yearling weight was 113.2 pounds and was made up of a dam MCSD and a dam FCSD of 63.2 and 50.0 pounds, respectively. Therefore, male selection accounted for 46% and 56% of the total selection pressure that had accumulated in the dams used in 1973 in the WWL and YWL, respectively. Thus, these data show that in the sires the majority of the cumulative selection pressure was the result of male selection. In the dams, however, male and female selection shared more equally in total selection pressure. Male selection in the dams was not as intense as in sires probably because in the early years (1964 through 1968) replacement heifers came largely from matings between foundation bulls and selected cows while replacement bulls came mainly from matings between selected sires and foundation cows. As foundation sires were eliminated, male selection in dams began to accumulate and over time would be expected to be more intense than female selection in the ancestry of dams.

Response to Selection

Phenotypic Trends

To help characterize the lines, Table XXVII and Table XXVIII in the appendix summarize data relative to level of performance and variation observed during the study. Ten year means and standard deviations are presented along with the range in annual means. As described previously, least squares annual means were regressed on year to quantify phenotypic time trends. Table XII summarizes the coefficients obtained. The least squares means used in the calculations are presented in Table XXIX and Table XXX in the appendix. To help clarify time trends for the primary selection traits, least squares means for birth weight, weaning weight, daily gain postweaning, yearling weight and weaning and yearling score are plotted on year in Figures 1, 2, 3, 4 and 5, respectively.

TABLE XII

COEFFICIENTS OF REGRESSION OF MEAN PERFORMANCE ON YEAR

Trait	WWL	YWL
Birth weight (lbs.)	-0.03±0.264	-0.00±0.436
Weaning weight (lbs.)	2.19±2.011	1.59±2.524
Weaning score[a]	0.10±0.035	0.09±0.042
Average daily gain (lbs./day)	0.00±0.028	0.00±0.026
Yearling weight (lbs.)	3.91±5.221	2.21±4.653
Yearling score[a]	0.12±0.045	0.11±0.046

[a]A 17 point scoring system was used where 13=average choice, 14=high choice, etc.

Inspection of the regression coefficients in Table XII for weaning weight and yearling weight indicate that change per year was not large in either line. The standard errors of the regression coefficients and the plots (Figures 1 and 2) indicate that there was considerable year to year variation in mean weights. In general, weights decreased, on the average, until 1969 or 1970, increased rather dramatically and then tailed off somewhat again in the last year or two. Mean birth weights in the two lines did not show a large amount of year to year variation and remained essentially unchanged over the study. Average daily gain fluctuations were similar to weaning and yearling weight changes. On

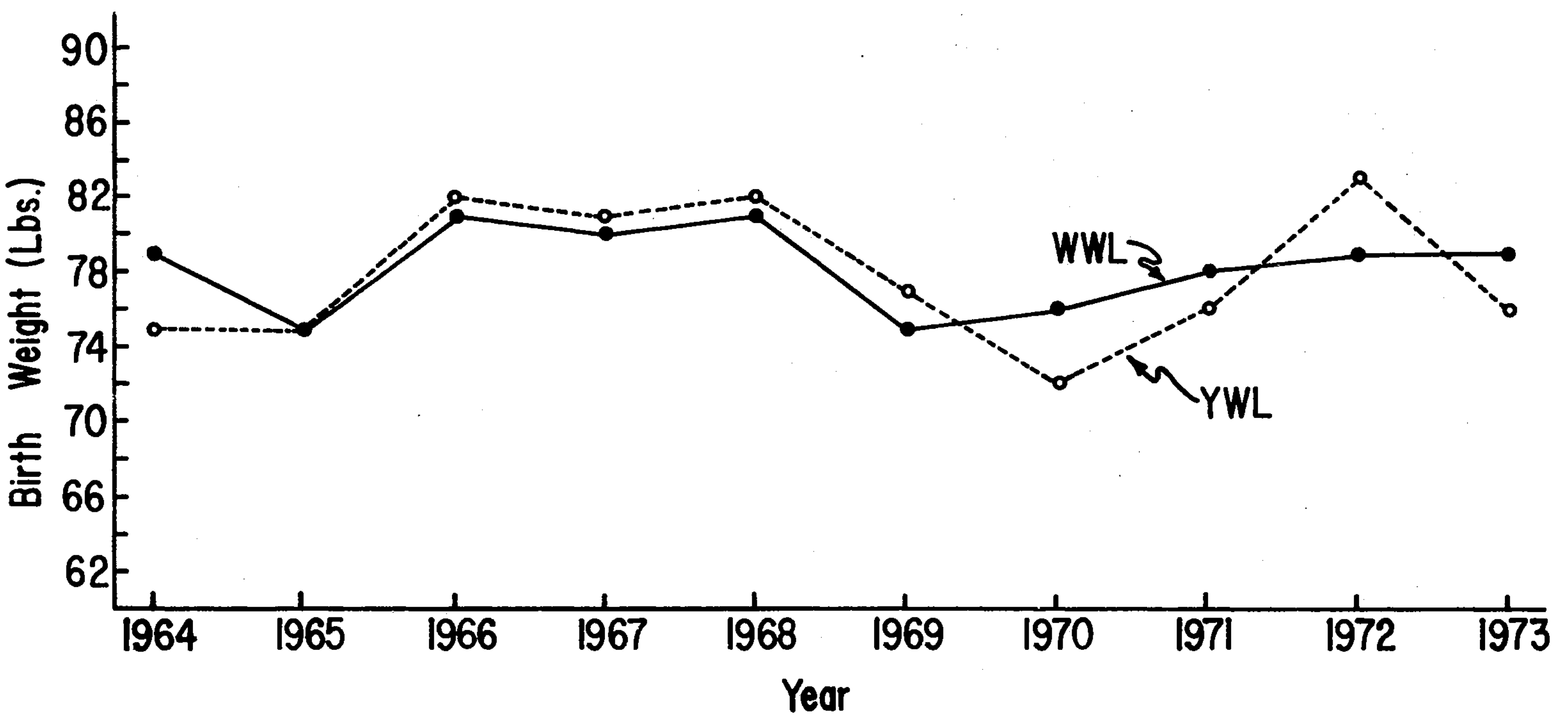

Figure 1. Least Squares Birth Weight Means Plotted on Year.

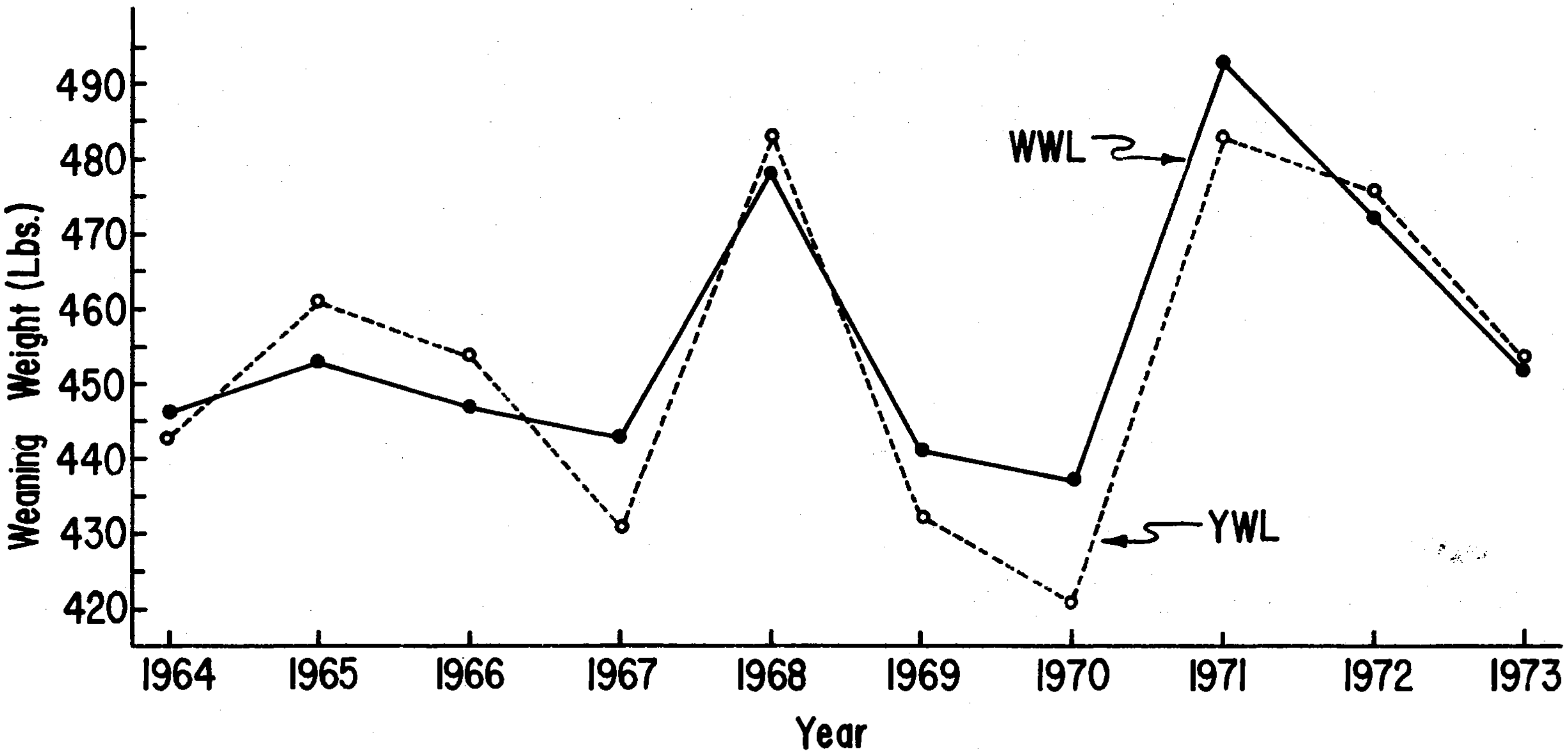

Figure 2. Least Squares Weaning Weight Means Plotted on Year.

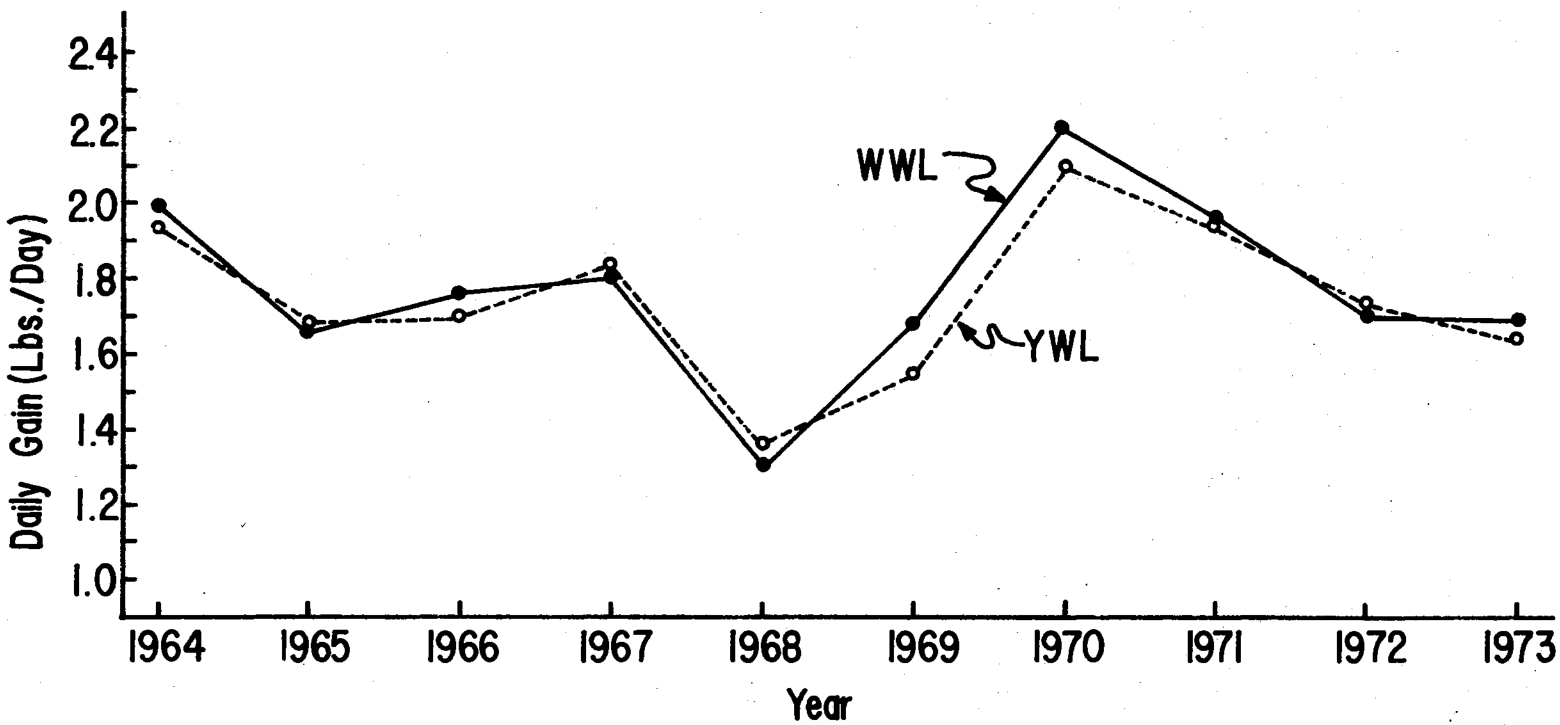

Figure 3. Least Squares Average Daily Gain Means Plotted on Year.

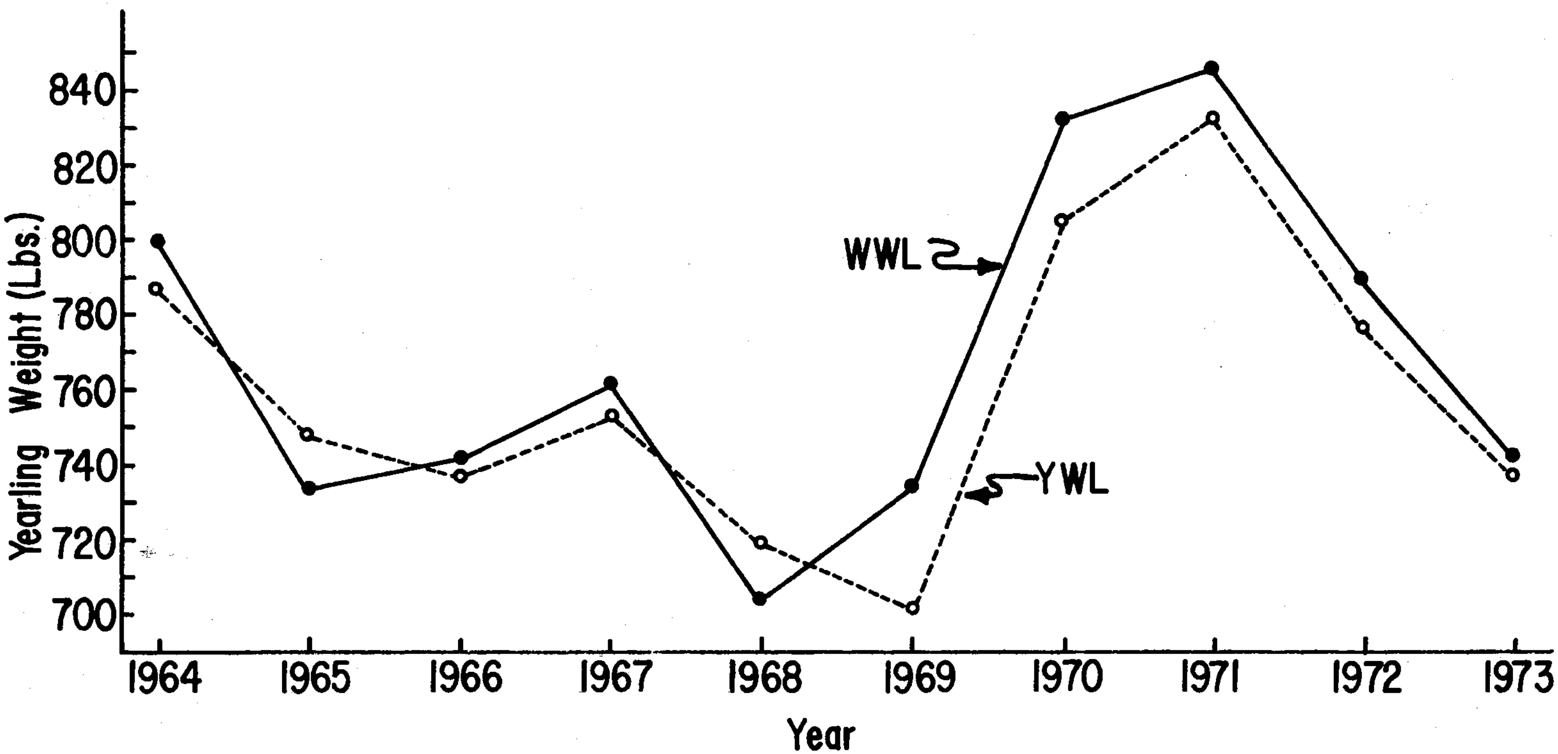

Figure 4. Least Squares Yearling Weight Means Plotted on Year.

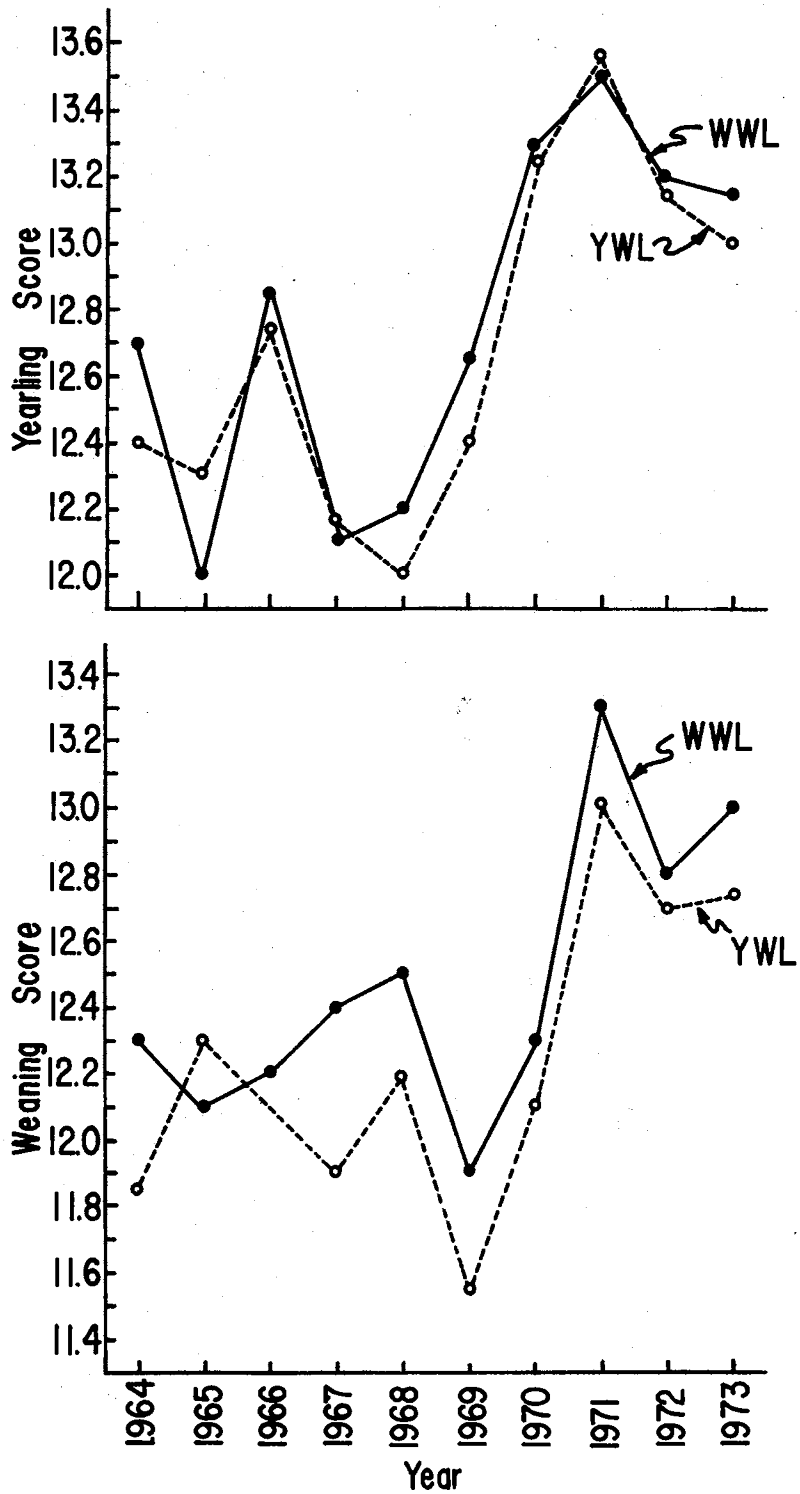

Figure 5. Least Squares Weaning Score and Yearling Score Means Plotted on Year.

the average, daily gain did not show any change. Weaning and yearling score were the only traits that consistently improved. Regression coefficients for weaning and yearling score were significantly different from zero ($P<.025$ except for weaning score in the yearling weight line where $P<.10$) indicating that appreciable per year change was realized.

Line comparisons indicate that performance in the two selection lines was similar over the time period involved. Regression coefficients were not significantly different in any case. In addition, F tests for line differences from the within year least squares analyses of variance were nonsignificant for all traits in all years.

The changes and trends indicated by the data and discussed briefly above are the combined result of genetic and environmental effects. Direct estimation of environmental trends was not possible, consequently, interpretation of this portion of the data relative to genetic change is not possible. However, for the primary selection traits positive net improvement apparently was made, although small in magnitude. Assuming the environmental trends were the same for both lines, the close similarity between the two lines for phenotypic means would suggest the genetic responses in weaning weight and yearling weight has been quite similar for both lines.

Genetic Response

In most studies genetic response to selection has been estimated in terms of average change of the population mean per year and/or per generation. Procedures used to estimate genetic change in this manner involve partitioning total phenotypic change into genetic and environmental components by use of control lines or other schemes by which environmental trends can be quantified. In the present study it was not possible to estimate genetic response in terms of annual change of the line means since it was not possible to quantify genetic response independent of environmental effects. However, another estimate of genetic change was available. As described in the Materials and Methods, semen from two foundation sires and the four selected bulls from the 1970 calf crop was used to produce calves in the progeny test herd in 1972. Progeny produced by the two sire groups provided data for quantifying the difference in genetic worth of foundation sires and selected bulls produced in the lines after seven years of selection. Genetic change was estimated by doubling the difference between the means for progeny produced by selected sires and progeny produced by foundation sires. This quantity estimated the difference in breeding value between the two sire groups. Therefore, using the foundation sires as the base, this difference in breeding value measured the amount of genetic improvement realized from seven years of selection in the pedigrees of the selected bulls. Genetic change (difference in breeding value) was divided by seven to put genetic improvement on a per year basis. Although this type of comparison does not quantify genetic response in relation to the population mean it does provide information which can be used to evaluate the relative effectiveness of selection.

Least squares means and standard errors for progeny from foundation and selected sires are presented in Table XIII. Progeny produced by selected sires outperformed foundation sires' progeny in all traits. For the primary selection traits, selected sires' progeny weighed 29 pounds more at weaning ($P<.01$) and were 54 pounds heavier at yearling

TABLE XIII

LEAST SQUARES MEANS AND STANDARD ERRORS
FOR FOUNDATION AND SELECTED SIRES

Trait	Foundation Sires	Selected Sires	Difference	
Number of progeny	56	47		
Birth weight (lbs.)	66.60± 1.112	70.30± 1.780	3.7	($P<.10$)
Weaning weight (lbs.)	490.00± 5.183	519.00± 8.300	29	($P<.01$)
Weaning score[a]	13.44± 0.085	13.52± 0.136	0.08	(NS)
Average daily gain (lbs./day)	1.84± 0.051	2.01± 0.082	0.17	($P<.10$)
Yearling weight (lbs.)	778.00±18.427	832.00±29.503	54	($P\doteq.25$)

[a]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

age (P<0.25). There was evidence to indicate that selected sires' progeny had heavier weaning weights (P<.01) and gained faster postweaning (P<.10). Since these were the components used to compute yearling weight, it is likely that the difference between yearling weight means reflects real biological differences. Appreciable differences were found for correlated traits, also. Selected sire's progeny averaged 3.7 pounds heavier at birth (P<.10) and gained 0.17 pounds more per day postweaning (P<.10) than progeny produced by foundation sires. Differences in weaning score were not significant. Yearling conformation socres were not obtained in this set of cattle.

To put these comparisons on a genetic basis, the difference between means were doubled, as described previously, to quantify the difference in breeding values of the two sire groups. The resultant estimates of genetic change and genetic change per year are summarized in Table XIV. The average breeding value of the selected sires was 58 pounds better than the average breeding value of the foundation sires for weaning weight. On a per year basis this represented an annual improvement in breeding value of 8.28 pounds. Breeding value of the selected sires for yearling weight averaged 108 pounds better than foundation sires' breeding value. This represented an annual improvement in breeding value of 15.43 pounds. Selected sires' breeding value for birth weight and average daily gain were 7.4 pounds and 0.34 pounds per day, respectively, better than foundation sires' breeding value for these traits. These estimates of genetic change cannot be related directly to effectiveness of selection for improving mean population performance since the selected bulls were not "average" and genetic improvement of the cow herd was not quantified. However, the data

TABLE XIV

ESTIMATED IMPROVEMENT IN BREEDING VALUE OF THE SELECTED SIRES OVER THE FOUNDATION SIRES

Trait	Estimated Improvement	
	Total Change±S.E.	Change/Year±S.E.
Birth weight (lbs.)	7.4 ± 3.120	1.06 ± 0.446
Weaning weight (lbs.)	58.00±14.548	8.28 ± 2.078
Weaning score[a]	0.16± 0.239	0.02 ± 0.034
Average daily gain (lbs./day)	0.34± 0.144	0.50 ± 0.021
Yearling weight (lbs.)	108.00±51.718	15.43 ± 7.388

[a]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

indicates that selection for weaning weight and yearling weight was effective since selected animals produced in the lines after seven years of selection had breeding values much superior to breeding values of foundation animals.

Realized heritability estimates can provide information relative to the effectiveness of selection since they quantify the extent to which phenotypic differences in the parents (selection differentials) were actually transmitted to the offspring. Realized heritabilities were calculated in the present study as twice the difference between selected sire and foundation sire means divided by the average cumulative selection differentials of the selected sires. Estimates of realized heritability for weaning weight and yearling weight were 0.43 and 0.53, respectively. These estimates indicate that selection was effective since 43% and 53% of the phenotypic differences in the parents for weaning weight and yearling weight, respectively, were transmitted to the offspring. Koch et al. (1974) obtained a realized heritability estimate of 0.27 for weaning weight which is somewhat less than the 0.43 estimate in this study. Newman et al. (1974) obtained a pooled estimate of realized heritability for yearling weight of 0.45 from two selection lines and Koch et al. (1974) estimated realized heritability to be 0.45 for yearling weight in their data. These compare favorably with the estimate of 0.53 from this study.

An additional estimate of genetic change was obtained from the selection line data. As discussed previously, of the four bulls used in any one year two were new (first service) bulls and two were repeat (second service) bulls. The new and repeat sire pairs differed in age and selection by one year. Thus, differences in progeny provided an estimate of the change in genetic merit realized from selection of the sires. Differences between means for progeny produced by new sires and repeat sires were doubled to estimate differences in breeding value. Differences in genetic merit of the sire pairs used in each line from 1967 through 1973 are summarized in Table XV and Table XVI. The estimates of genetic change in the weaning weight line are puzzling. The average difference between new and repeat sire's breeding values for weaning weight was negative 15 pounds and the average difference in breeding values for yearling weight was negative 30 pounds. Negative differences in breeding value were obtained for birth weight (-0.8 pounds), daily gain (-0.03 pounds per day), weaning score (-0.17) and yearling score (-0.36), also. Thus, on the average, breeding values of new sires were inferior to breeding values of repeat sires, suggesting that improvement of genetic merit was not realized in this line.

In the yearling weight line, estimates of genetic change were generally positive. For yearling weight, breeding values of new sires averaged 26 pounds more than breeding values of repeat sires. For weaning weight breeding values of new sires averaged 4 pounds more than breeding values of repeat sires. Positive differences in breeding value were obtained for weaning socre (0.06), yearling score (0.24) and daily gain (0.14 pounds per day). Breeding values for birth weight averaged 2 pounds less for new sires than repeat sires. Thus, on the average, breeding values of new sires were superior to breeding values of repeat sires, suggesting that improvement in genetic merit was realized from selection in this line. All other results indicate that progress has been made in the WWL. The negative breeding values generally obtained from the new versus repeat sire comparisons in the WWL

TABLE XV

ESTIMATED IMPROVEMENT IN BREEDING VALUE FOR PREWEANING TRAITS FROM WITHIN YEAR COMPARISONS OF NEW SIRE AND REPEAT SIRE MEANS

	Birth Weight (Lbs.)		Weaning Weight (Lbs.)		Weaning Score[a]	
Year	WWL[b]	YWL[b]	WWL[b]	YWL[b]	WWL[b]	YWL[b]
1967	-4.8	4.9	- 9	10	0.45	0.67
1968	-1.2	-17.1	1	-33	-0.14	-0.77
1969	-0.6	6.2	-46	26	-0.98	-0.55
1970	0.6	- 7.7	-40	8	-0.56	0.87
1971	-1.0	8.0	-19	21	-0.05	0.49
1972	5.5	- 0.6	7	- 1	-0.20	-0.03
1973	-4.2	- 7.7	1	- 2	0.27	-0.28
Mean	-0.8	- 2.0	-15	4	-0.17	0.06

[a]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

[b]WWL = Weaning weight line; YWL = Yearling weight line.

TABLE XVI

ESTIMATED IMPROVEMENT IN BREEDING VALUE FOR POSTWEANING TRAITS FROM WITHIN YEAR COMPARISONS OF NEW SIRE AND REPEAT SIRE MEANS

	Average Daily Gain		Yearling Weight		Yearling Score[a]	
Year	WWL[b]	YWL[b]	WWL[b]	YWL[b]	WWL[b]	YWL[b]
1967	-0.29	0.23	-61	50	-0.43	1.09
1968	0.16	-0.15	20	-62	-0.11	-0.42
1969	-0.02	0.08	-54	30	-0.93	-0.44
1970	0.15	0.33	- 3	67	0.68	0.53
1971	-0.22	0.16	-63	51	-0.36	1.01
1972	0.02	0.10	-36	15	-0.67	0.62
1973	-0.04	0.23	-15	34	-0.74	-0.73
Mean	-0.03	0.14	-30	26	-0.36	0.24

[a]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

[b]WWL = Weaning weight line; YWL = Yearling weight line.

are unexplainable at this time. It does cast some doubt on the precision of this technique for estimating selection progress.

Conclusions

Although this experiment differed in some ways from most purebred and commercial beef cattle breeding programs, the data presented have practical applicability. Quantification of selection intensity shows how selection differentials can be expected to accumulate in systematic breeding programs. In both selection lines accumulation of selection differentials was quite regular even though numerous foundation animals were included in the early years of the study. Generation intervals were shorter than in most commercial herds, therefore selection would not be expected to be as intense in most commercial situations as it was in these lines. However, it is reasonable to conclude that intense selection can be realized from selection for weaning weight and yearling weight. Thus, in light of the moderate heritability of weaning weight and the somewhat higher heritability of yearling weight, it is reasonable to expect appreciable positive genetic responses to selection for these characters.

Evaluation of correlated selection differentials indicated that correlated selection differentials for yearling weight in the WWL were 66% as large as selection differentials realized from direct selection for yearling weight. In like manner, correlated selection differentials for weaning weight in the YWL were 92% as large as selection differentials realized from direct selection for weaning weight. Positive correlated selection was also realized for birth weight, postweaning average daily gain and weaning and yearling scores. In the YWL correlated selection for birth weight was slightly more intense than in the WWL and substantially more intense for daily gain. These data indicate then that improvement in total growth performance from birth to yearling age can be expected from selection for either weaning weight or yearling weight. The intensity of correlated selection for weaning weight and daily gain in the YWL, however, indicates that yearling weight is a better measure of total growth potential. Thus, it is conceivable that more improvement in total growth performance from birth to yearling age could be attained from selection based on heavy yearling weight.

Quantification of the intensity of male and female selection indicated that 80% and 83% of the total cumulative selection differentials for weaning weight in the WWL and yearling weight in the YWL, respectively, were the result of male selection. In most commercial situations male selection would be expected to be even more intense in this study since female replacement rates were somewhat faster than in most commercial herds. Thus, sire evaluation and selection should be of utmost importance in any breeding program.

In light of the substantial selection applied in both lines, positive genetic response was expected. Estimates of genetic change in terms of improvement in breeding values, indicate that positive genetic change was made over the course of the study. It was not possible to interpret genetic change in terms of improvement of population means, however, the data does indicate that appreciable improvement in genetic worth of both lines has been realized as a result of selection. Precise between line comparisons were not available, however, the similarity of phenotypic means and time trends indicate that genetic response was similar in the two lines. Only two generations of selection had been practiced, consequently more time will be needed before reliable comparisons of weaning weight and yearling weight as selection criteria can be made. However, the similarity of response in the two lines to date may indicate a fortunate situation in that if response in total growth performance is similar, regardless of whether selection is based on weaning weight or yearling weight, a wide variety of performance testing programs could be used to attain improved growth performance. It would allow producers considerable flexibility in developing workable performance testing programs to fit specific production and management situations.

CHAPTER V

SUMMARY

The objectives of this study were to quantify selection pressure and estimate response to selection in two lines of Hereford cattle selected for weaning weight and yearling weight, respectively.

The primary data were collected on 827 purebred Hereford calves raised from 1964 through 1973 as part of the Oklahoma beef cattle selection project. Replacement breeding animals were selected on the basis of heaviest weaning weight (205-day weight) in one line (WWL) and heaviest yearling weight (365-day weight for bulls and 425-day weight for heifers) in the other line (YWL). Each year two bulls were selected from each line based on the respective selection criteria and were used for two years and discarded. Four bulls were used per year in each line, two of which were in their first year of service and two which were in their second year os service. The 13 top heifers based on the respective selection criteria were kept from each line each year and bred as yearlings. The 10 highest ranking pregnant heifers were selected to remain in the line with subsequent culling of 10 cows. Fifty breeding age females were maintained in each line.

Complete performance records were collected on each calf through a year of age for bulls and through 425 days of age for heifers. The records used in this study were birth weight, weaning weight, postweaning average daily gain, yearling weight and weaning and yearling conformation scores. Weaning weights were 205-day weights adjusted for age of dam effects using additive correction factors. Average daily gains were based on postweaning feedlot tests for bulls and pasture gains for heifers. Yearling weights were 365-day weights for bulls and 425-day weights for heifers. Conformation scores were the average of scores given each animal by a committee of at least three persons. A 17 point system was used where 13 represented average choice.

The procedure used to measure selection intensity quantified cumulative selection pressure associated with the parents of each calf crop. An individual cumulative selection differential (ICSD) was calculated for each selected parent. ICSD's were the sum of a male cumulative selection differential (MCSD) and a female cumulative selection differential (FCSD). MCSD's and FCSD's were components that quantified the intensity of cumulative male and female selection, respectively. Weighted average MCSD's, FCSD's and ICSD's were calculated for the parents of each calf crop to put selection pressure on a calf crop basis. The weights were the number of offspring each parent contributed to the calf crop.

Generation coefficients were calculated for all calves using the formula $GC = GC_s + GC_d/2 + \frac{1}{2}(s) + \frac{1}{2}(d)$, where GC_s and GC_d were the generation coefficients of the sire and dam, respectively, and s and d had the value 1.0 if they were a selected sire or dam, respectively, and where zero in the case of foundation animals. This formula measured generations of selection actually practiced at any state of the study and adequately accounted for matings involving foundation animals. Generation intervals were estimated by calculating the average age of the parents at the time of birth for each calf crop.

Annual least squares means were regressed on years to establish overall phenotypic trends. Genetic change was estimated by comparison of progeny produced by foundation sires with progeny produced by selected sires. Semen from two foundation sires and the four selected sires from the 1970 calf crop was used to produce 103 crossbred progeny in the Angus progeny test herd in 1972. Twice the difference between the selected sire group mean and the foundation sire group mean estimated the total improvement in breeding value realized from seven years of selection. Estimated genetic change per year was obtained by dividing total change by seven. Realized heritabilities were estimated as twice the difference between the selected sire group means and the foundation sire group means divided by the average cumulative selection differentials of the selected sires. Secondary estimates of genetic change were obtained from within line comparisons of new and repeat sires. Twice the difference between new sire means and repeat sire means estimated the improvement in breeding value realized from one year of selection.

Generation intervals averaged 4.09 and 4.06 years in the WWL and YWL, respectively. Sires averaged 3.4 years of age in both lines while WWL dams averaged 4.8 years and YWL dams 4.7 years of age. By 1973 an average of 1.98 and 2.12 generations of selection had been practiced in the WWL and YWL, respectively. In 1973, cumulative selection differentials (ICSD) were 98.2 pounds for weaning weight in the WWL and 196.4 pounds for yearling weight in the YWL. Accumulation of selection differential for the primary selection traits advanced regularly at rates of 12.0 and 25.2 pounds per year for weaning weight and yearling weight, respectively. These results indicate that appreciable selection can be realized from selection for weaning weight or yearling weight and, therefore, indicate that positive genetic response should be realized from selection for these characters.

Annual correlated selection differentials for yearling weight in the WWL were 66% as large as selecting directly for yearling weight. In the YWL, correlated selection for weaning weight was 92% as intense as direct selection for weaning weight. Positive correlated selection differentials were realized for birth weight, postweaning daily gain and weaning and yearling conformation scores. Correlated selection for birth weight and daily gain was more intense in the YWL. These data indicate that improvement in total growth performance from birth to yearling age can be expected from selection for either weaning weight or yearling weight. Intensity of correlated selection indicates, however, that selection for yearling weight should result in more improvement in total growth performance than selection for weaning weight.

In 1973 in the WWL, the male cumulative selection differential (MCSD) for weaning weight was 78.5 pounds which accounted for 80% of the total midparent cumulative selection differential of 98.2 pounds. Likewise in the YWL, the MCSD for yearling weight was 162.2 pounds and accounted for 83% of the total midparent cumulative selection differential of 196.3 pounds. These data indicate that male selection is much more intense than female selection and emphasize the importance of sire evaluation and selection.

Evaluation of phenotypic time trends indicated positive phenotypic response had been realized although the phenotypic regressions were not large and there was considerable year to year variation in mean performance. Annual means and overall trends were very similar in both selection lines, indicating that response to selection was similar in the two lines over the time period studied. Progeny test data indicated that the sires selected from the 1970 calf crop had breeding values for weaning weight and yearling weight which were, respectively, 58 and 108 pounds superior to breeding values of foundation sires. On a per year basis this represented 8.3 and 15.4 pounds annual improvement in breeding value for weaning weight and yearling weight, respectively. Selected sires also excelled foundation sires in breeding value for birth weight (7.4 pounds), daily gain (0.34 pounds per day) and weaning score (0.16 units). These data indicate that selection for weaning weight and yearling weight was effective in improving the genetic merit of the lines. Realized heritability estimates of 0.43 for weaning weight and 0.53 for yearling weight support this conclusion.

Estimates of breeding value differences from the selection line data were puzzling. In the YWL breeding values of new sires were superior to breeding values of repeat sires for all traits except birth weight while in the WWL breeding values of new sires were generally inferior to breeding values of repeat sires. In light of all other results which indicate that progress was made in the WWL, the negative results cast some doubt on the precision of this technique for estimating selection response.

LITERATURE CITED

Abplanalp, H., F. X. Ogasawara and V. S. Asmundson. 1963. Influence of selection for body weight at different ages on growth of turkeys. Brit. Poul. Sci. 4:71.

Armstrong, J. B., H. H. Stonaker, T. M. Sutherland and K. R. Riddle. 1965. Selection and genetic change in inbred Herefords. J. Anim. Sci. 24:845. (Abstr.)

Bailey, C. M., W. R. Harvey, J. E. Hunter and C. R. Torell. 1971. Estimated direct and correlated response to selection in closed Hereford lines under different types of environment. J. Anim. Sci. 33:541.

Brinks, J. S., R. T. Clark and F. J. Rice. 1961. Estimation of genetic trends in beef cattle. J. Anim. Sci. 20:903 (Abstract)

Brinks, J. S., R. T. Clark, N. M. Kieffer and J. J. Urick. 1964. Estimates of genetic, environmental and phenotypic parameters in range Hereford females. J. Anim. Sci. 23:711.

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. Tech. Bull. 1323, Agr. Res. Service, U.S. Dept. of Agr., Washington, D.C.

Cardellino, Ricardo and R. R. Frahm. 1971. Evaluation of two types of age of dam correction factors for weaning weight in beef cattle. J. Anim. Sci. 32:1078.

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

Chapman, Arthur B. 1951. Effectiveness of selection in laboratory animals. J. Anim. 10:3.

Chapman, Hollis D. 1968. Response from selection in a herd of Braham and Hereford cattle. Ph.D. Dissertation, Texas A&M Univ., College Station, Texas.

Chapman, Hollis D., T. M. Clyburn and W. C. McCormick. 1969. Selection of beef cattle for single traits. J. Anim. Sci. 29:225.

Chapman, Hollis D., T. M. Clyburn and W. C. McCormick. 1972. Comparison of criteria for selecting introduced beef sires. J. Anim. Sci. 35:321.

Cundiff, L. V., K. E. Gregory, R. M. Koch and G. E. Dickerson. 1971. Genetic relationships among growth and carcass traits of beef cattle. J. Anim. Sci. 33:550.

Dettmers, Almut E., W. E. Rempel and R. E. Comstock. 1955. Selection for small size in swine. J. Anim. Sci. 24:216.

Dettmers, Almut E., W. E. Rempel and Dennis E. Hacker. 1971. Response to recurrent mass selection for small size in swine. J. Anim. Sci. 33:1212.

Dickerson, G. E. and J. C. Grimes. 1947. Effectiveness of selection for efficiency of gain in Duroc swine. J. Anim. Sci. 6:265.

Dickerson, G. E. 1960. Experimental estimation of selection response in beef cattle. Proc. 1960 Tech. Comm. Meet NC-1, Okla. State Univ., pp. 67-75.

Dinkel, C. A. and D. A. Busch. 1973. Genetic parameters among production, carcass composition and carcass quality traits of beef cattle. J. Anim. Sci. 36:832.

Dunn, R. J., W. T. Magee, K. E. Gregory, L. V. Cundiff and R. M. Koch. 1970. Genetic parameters in straightbred and crossbred beef cattle. J. Anim. Sci. 31:656.

Falconer, D. S. 1953. Introduction to Quantitative Genetics. Ronald Press Co., New York.

Festing, Michael F. and A. W. Nordskog. 1967. Response to selection for body weight and egg weight in chickens. Genetics 55:219.

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. 23:189.

Fredeen, H. T. 1958. Selection and swine improvement. Anim. Breed. Sbstr. 26:229.

Gregory, K. E. 1969. Beef Cattle Breeding. U.S.D.A. Agr. Inf. Bull. No. 286. (Rev.)

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

Hornbeck, Frank and Ralph Bogart. 1966. Amount of selection applied and response of traits in four inbred lines of beef cattle. Oregon Agr. Exp. Sta. Tech. Bull. 96.

Knapp, Bradford, Jr. and R. T. Clark. 1947. Genetic and environmental correlations between growth rates of beef cattle at different ages. J. Anim. Sci. 6:174.

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.

Koch, R. M., J. V. Cundiff, K. E. Gregory and G. E. Dickerson. 1973. Genetic and phenotypic relations associated with preweaning and postweaning growth of Hereford bulls and heifers. J. Anim. Sci. 36:235.

Koch, Robert M., Keith E. Gregory and Larry V. Cundiff. 1974a. Selection in beef cattle. I. Selection applied and generation interval, J. Anim. Sci. 39:449.

Koch, Robert M., Keith E. Gregory and Larry V. Cundiff. 1974b. Selection in beef cattle. II. Selection response. J. Anim. Sci. 39:459.

Krider, J. L., B. W. Fairbanks, W. E. Carroll and E. R. Roberts. 1946. Effectiveness of selecting for rapid or slow growth rate in Hampshire swine. J. Anim. Sci. 5:3.

Maloney, M. A., J. C. Gilbreath and R. D. Morrison. 1963. Two-way selection for body weight in chickens. Okla. Agr. Exp. Sta. Tech. Bull., T-99.

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

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

Nwakalor, L. N. and J. S. Brinks. 1974. Response to selection for weaning weight in beef cattle. 25th Annual Beef Cattle Improvement Report, Colo. Agr. Exp. Sta. Gen. Ser. 940:4.

Pattie, W. A. 1965a. Selection for weaning weight in Merino sheep. I. Direct response to selection. Aust. J. Exp. Ag. and Anim. Hub. 5:353.

Pattie, W. A. 1965b. Selection for weaning weight in Merino sheep. II. Correlated responses in other production characters. Aust. J. Exp. Ag. and Anim. Hub. 5:353.

Pirchner, Franz. 1969. Population Genetics in Animal Breeding. W. H. Freeman and Co., San Francisco.

Rahnefield, G. W. 1971. Mass selection for postweaning growth in swine. II. Response to selection. Can. J. Anim. Sci. 51:497.

Roberts, R. C. 1965. Some contributions of the laboratory mouse to animal breeding research. Anim. Breed. Abstr. 33:339.

Snedecor, George W. and W. G. Cochran. 1967. Statistical Methods. (6th Ed.). Iowa State University Press, Ames, Iowa.

Shelby, C. E., 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.

Tanner, J. E., R. R. Frahm, R. L. Wilham and J. V. Whiteman. 1970. Sire x sex interactions and sex differences in growth and carcass traits of Angus bulls, steers and heifers. J. Anim. Sci. 31:1058.

Terrill, Clair E. 1951. Effectiveness of selection for economically important traits of sheep. J. Anim. Sci. 10:17.

Terrill, Clair E. 1958. Fifty years of progress in sheep breeding. J. Anim. Sci. 17:944.

Yamada, Yukio, B. B. Bohren and L. B. Crittenden. 1958. Genetic analysis of a White Leghorn closed flock apparently plateaued for egg production. Poul. Sci. 37:565.

A P P E N D I X

TABLE XVII

TOTAL BIRTH WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIAL (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS, AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0.79	0.79	0	0.40	0.40
1967	3.71	0	3.71	0	1.62	1.62	1.85	0.81	2.66
1968	7.50	0	7.50	0	1.80	1.80	3.75	0.90	4.65
1969	4.37	0	4.37	0.26	2.19	2.44	2.31	1.09	3.40
1970	4.02	0	4.02	1.10	4.40	5.50	2.56	2.20	4.76
1971	4.63	-1.66	2.97	1.50	4.30	5.80	3.06	1.32	4.38
1972	3.81	1.36	5.17	2.16	3.52	5.68	2.98	2.44	5.42
1973	7.74	6.13	13.87	2.29	3.59	5.88	5.01	4.86	9.87

TABLE XVIII

TOTAL BIRTH WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIAL (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	1.24	1.24	0	0.62	0.62
1967	7.58	0	7.58	0	0.67	0.67	3.79	0.33	4.12
1968	10.98	0	10.98	0	1.12	1.12	5.49	0.56	6.05
1969	10.89	0	10.89	0.48	1.85	2.33	5.68	0.93	6.61
1970	12.56	1.06	13.62	1.78	2.03	3.81	7.17	1.55	8.72
1971	8.41	1.66	10.07	2.47	1.50	3.97	5.44	1.58	7.02
1972	10.20	0.37	10.57	4.13	2.04	6.17	7.16	1.21	8.37
1973	13.90	0.77	14.67	4.13	1.53	7.66	9.01	2.15	11.16

TABLE XVIX

TOTAL WEANING WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	4.29	4.29	0	2.14	2.14
1967	33.98	0	33.98	0	7.24	7.24	16.99	3.62	20.61
1968	52.57	0	52.57	0	6.70	6.70	26.28	3.35	29.63
1969	46.30	0	46.30	1.02	11.27	12.29	23.66	5.64	29.30
1970	59.82	3.72	63.54	9.17	15.96	25.13	34.49	9.84	44.33
1971	74.89	7.33	82.22	13.19	13.07	26.26	44.04	10.20	54.24
1972	90.01	7.28	97.29	19.33	20.17	39.50	54.67	13.73	68.40
1973	125.53	2.91	128.44	24.11	35.49	59.60	74.82	19.20	94.02

TABLE XX

TOTAL WEANING SCORE MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0.02	0.02	0	0.01	0.01
1967	0.71	0	0.71	0	0.06	0.06	0.35	0.03	0.38
1968	1.46	0	1.46	0	0.05	0.05	0.73	0.03	0.76
1969	0.87	0	0.87	0.05	0.08	0.13	0.46	0.04	0.50
1970	0.53	0	0.53	0.21	0.22	0.43	0.37	0.11	0.48
1971	1.07	-0.03	1.04	0.33	0.37	0.70	0.70	0.17	0.87
1972	1.34	0.03	1.38	0.38	0.34	0.72	0.86	0.18	1.04
1973	1.46	0.16	1.62	0.51	0.39	0.90	0.98	0.27	1.25

TABLE XXI

TOTAL WEANING SCORE MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0.12	0.12	0	0.06	0.06
1967	0.54	0	0.54	0	0.14	0.14	0.27	0.07	0.34
1968	0.74	0	0.74	0	0.09	0.09	0.37	0.04	0.41
1969	0.11	0	0.11	0	0.14	0.14	0.06	0.07	0.13
1970	0.36	0.01	0.37	0.16	0.19	0.35	0.26	0.10	0.36
1971	0.93	0.03	0.96	0.16	0.15	0.31	0.55	0.09	0.64
1972	0.78	0.16	0.94	0.17	0.16	0.33	0.47	0.16	0.63
1973	0.85	0.17	1.02	0.16	0.21	0.37	0.50	0.19	0.69

TABLE XXII

TOTAL AVERAGE DAILY GAIN MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD) FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD), AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS FOR SIRES, DAMS AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0
1967	-0.01	0	-0.01	0	0.01	0.01	-0.005	0.005	0
1968	-0.03	0	-0.03	0	0.01	0.01	-0.01	0.005	-0.005
1969	0.08	0	0.08	0	0.02	0.02	0.04	0.01	0.05
1970	0.25	0	0.25	0	0.02	0.02	0.12	0.01	0.13
1971	0.40	-0.01	0.39	-0.01	0.01	0.00	0.20	0.00	0.20
1972	0.23	0.01	0.24	0.06	0.01	0.07	0.14	0.01	0.15
1973	0.35	0.05	0.40	0.10	-0.02	0.08	0.23	0.01	0.24

TABLE XXIII

TOTAL AVERAGE DAILY GAIN MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day	Lbs/day
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0
1967	0.25	0	0.25	0	0	0	0.12	0	0.12
1968	0.47	0	0.47	0	0	0	0.23	0	0.23
1969	9.41	0	0.41	0.01	0.03	0.04	0.21	0.02	0.23
1970	0.64	-0.01	0.63	0.07	0.04	0.11	0.35	0.01	0.36
1971	0.96	-0.01	0.95	0.10	0.05	0.15	0.53	0.02	0.55
1972	0.93	0.03	0.96	0.15	0.05	0.20	0.54	0.04	0.58
1973	0.88	0.07	0.95	0.25	0.05	0.30	0.57	0.06	0.63

TABLE XXIV

TOTAL YEARLING WEIGHT MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	-0.52	-0.52	0	-0.26	-0.26
1967	7.15	0	7.15	0	12.31	12.31	3.58	6.15	9.73
1968	35.89	0	35.89	0	8.05	8.05	17.95	4.02	21.97
1969	75.14	0	75.14	0.51	18.28	18.79	37.83	9.14	46.97
1970	93.53	0	93.53	4.35	18.90	23.25	48.94	9.45	58.39
1971	134.56	-3.35	131.21	10.48	23.82	34.30	72.52	10.23	82.75
1972	135.26	3.00	138.26	24.93	30.59	55.52	80.09	16.80	96.89
1973	178.63	16.18	194.82	42.51	22.63	65.14	110.57	19.40	129.97

TOTAL XXV

TOTAL YEARLING SCORE MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE WEANING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0.02	0.02	0	0.01	0.01
1967	0.36	0	0.36	0	0.05	0.05	0.18	0.02	0.20
1968	0.64	0	0.64	0	0.05	0.05	0.32	0.02	0.34
1969	0.66	0	0.66	0.02	-0.04	-0.02	0.34	-0.02	0.32
1970	0.70	0	0.70	0.11	0.20	0.31	0.41	0.10	0.51
1971	0.98	-0.05	0.93	0.14	0.21	0.35	0.56	0.08	0.64
1972	0.93	0.19	1.12	0.31	0.33	0.64	0.62	0.26	0.88
1973	1.07	0.43	1.50	0.39	0.19	0.58	0.73	0.31	1.04

TABLE XXVI

TOTAL YEARLING SCORE MALE CUMULATIVE SELECTION DIFFERENTIALS (MCSD), FEMALE CUMULATIVE SELECTION DIFFERENTIALS (FCSD) AND INDIVIDUAL CUMULATIVE SELECTION DIFFERENTIALS (ICSD) FOR SIRES, DAMS AND MIDPARENTS FOR THE YEARLING WEIGHT LINE

	Sires			Dams			Midparents		
Year	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD	MCSD	FCSD	ICSD
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1964-1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0.02	0.02	0	0.01	0.01
1967	0.7	0	0.7	0	0.10	0.10	0.35	0.05	0.40
1968	1.26	0	1.26	0	-0.01	-0.01	0.63	-0.005	0.625
1969	1.13	0	1.13	0.03	0.09	0.12	0.58	0.04	0.62
1970	1.35	-0.03	1.32	0.21	0.19	0.40	0.78	0.08	0.86
1971	1.38	0.05	1.43	0.29	0.24	0.53	0.83	0.15	0.98
1972	0.82	0.12	0.94	0.41	0.14	0.55	0.62	0.13	0.75
1973	0.87	-0.03	0.84	0.50	0.33	0.83	0.69	0.15	0.84

TABLE XXVII

TEN YEAR MEANS, RANGES AND STANDARD DEVIATIONS FOR BIRTH AND WEANING TRAITS

Item	Bulls		Heifers	
	Mean	Range[a]	Mean	Range[a]
Number of progeny				
WWL[b]	21.1	11-28	21.0	13-27
YWL[b]	22.2	16-27	20.4	10-25
Birth Weight (lbs.)				
WWL[b]	80.	76-84	76	69-79
YWL[b]	81	75-86	75	69-80
SD[c]	9.612		8.624	
Weaning Weight (lbs.)				
WWL[b]	469	441-514	442	422-470
YWL[b]	473	437-516	435	402-465
SD[c]	49.284		40.658	
Weaning Score[d]				
WWL[b]	12.4	12.1-13.2	12.5	11.8-13.3
YWL[b]	12.3	11.7-13.0	12.1	11.4-13.1
SD[c]	0.918		0.751	

[a]Range of annual means.

[b]WWL, YWL = Weaning weight line and yearling weight line, respectively.

[c]SD = Intra- year - line - sex standard deviation obtained by pooling sums of squares.

[d]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

TABLE XXVIII

TEN YEAR MEANS, RANGES AND STANDARD DEVIATIONS FOR POSTWEANING TRAITS

Item	Bulls Mean	Bulls Range[a]	Heifers Mean	Heifers Range[a]
Number of progeny				
WWL[b]	18.0	10-25	20.2	11-26
YWL[b]	20.3	15-25	19.2	10-25
Average Daily Gain				
WWL[b]	2.73	2.00-3.09	0.84	0.45-1.31
YWL[b]	2.62	2.10-3.00	0.86	0.43-1.41
SD[c]	0.370		0.170	
Yearling Weight				
WWL[b]	919	885-958	627	527-728
YWL[b]	895	819-959	625	539-730
SD[c]	85.781		57.831	
Yearling Score[d]				
WWL[b]	12.8	12.0-13.8	12.6	11.8-13.3
WYL[b]	12.8	12.1-13.8	12.6	11.9-13.3
SD[c]	0.892		0.725	

[a]Range of annual means

[b]WWL, YWL = Weaning weight line and yearling weight line, respectively.

[c]SD = Intra - year - line - sex standard deviation obtained by pooling sums of squares.

[d]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

TABLE XXVIX

ANNUAL LEAST SQUARES MEANS FOR
BIRTH AND WEANING TRAITS[a]

		WWL[b]				YWL[b]		
Year	N	Birth Weight (Lbs.)	Weaning Weight (Lbs.)	Weaning Score[c]	N	Birth Weight (Lbs.)	Weaning Weight (Lbs.)	Weaning Score[c]
1964	24	78.6	446	12.3	26	75.5	443	11.9
1965	49	75.4	453	12.1	47	75.1	461	12.3
1966	44	81.3	447	12.2	45	81.5	454	12.2
1967	42	79.6	443	12.4	45	81.2	431	11.9
1968	45	81.4	478	12.5	46	82.1	483	12.2
1969	43	75.1	441	11.9	44	77.0	432	11.5
1970	49	75.9	437	12.3	47	71.6	421	12.1
1971	43	77.9	493	13.2	47	76.1	483	13.0
1972	44	79.0	472	12.8	43	82.8	476	12.7
1973	38	79.1	452	13.0	36	76.2	453	12.7

[a]Approximate standard errors for annual means were: Birth weight, ± 1.49 lbs; weaning weight, ± 7.41 lbs.; weaning score ± 0.14.

[b]WWL = Weaning weight line; YWL = Yearling weight line.

[c]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

TABLE XXX

ANNUAL LEAST SQUARES MEANS FOR POSTWEANING TRAITS[a]

Year	N	WWL[b] Daily Gain (Lbs./Day)	WWL[b] Yearling Weight (LBS.)	WWL[b] Yearling Score[c]	N	YWL[b] Daily Gain (LBS./Day)	YWL[b] Yearling Weight (LBS.)	YWL[b] Yearling Score[c]
1964	23	1.96	799	12.7	26	1.94	787	12.4
1965	49	1.66	734	12.0	45	1.68	748	12.3
1966	29	1.76	742	12.9	31	1.70	737	12.8
1967	39	1.81	762	12.1	44	1.84	753	12.1
1968	44	1.30	704	12.2	43	1.34	719	12.0
1969	36	1.68	735	12.7	43	1.55	701	12.4
1970	47	2.20	833	13.3	44	2.11	806	13.3
1971	41	1.97	845	13.5	47	1.95	832	13.6
1972	40	1.70	790	13.2	37	1.73	777	13.1
1973	34	1.69	743	13.1	35	1.64	737	13.0

[a]Approximate standard errors for annual means were: Average daily gain, ± 0.05 lbs./day; yearling weight, ± 12.25 lbs.; yearling score, ± 0.14.

[b]WWL = Weaning weight line; YWL = Yearling weight line.

[c]A 17 point scoring system was used where 13 = average choice, 14 = high choice, etc.

VITA

Todd Alan Stanforth

Candidate for the Degree of

Master of Science

Thesis: SELECTION FOR WEANING WEIGHT AND YEARLING WEIGHT IN HEREFORD CATTLE

Major Field: Animal Science

Biographical:

Personal Data: Born in La Harpe, Illinois, February 17, 1951, the son of Mr. and Mrs. W. T. Stanforth.

Education: Graduated from Platte High School, Platte, South Dakota, June, 1969. Received a Bachelor of Science degree from South Dakota State University, Brookings, South Dakota, in December, 1972, with a major in Animal Science.

Experience: Graduate Assistant at Oklahoma State University 1973-1974.

Member: Phi Kappa Phi, American Society of Animal Science.

Date of Degree: December, 1974.