SOME GENETIC AND ENVIRONMENTAL FACTORS INFLUENCING THE WEANING WEIGHTS OF SOUTHWESTERN RANGE CATTLE

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1958

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Date thesis is presented May 9, 1958

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ACKNOWLEDGEMENT

Sincere appreciation is expressed to those who contributed guidance and assistance in the preparation of this manuscript, to those who provided the essential facilities for the study upon which this report is based, and to those who assisted with the collection and consolidation of the data.

To Dr. Ralph Bogart, deep gratitude is expressed for his permission to pursue the study reported in this paper and for his generous advice and guidance in the preparation of the thesis. I also thank Dr. Hugo Krueger and Dr. James Oldfield for the many items of information that have contributed to the interpretation of the data.

To Dr. C. E. Shelby, Dr. Henry Tucker, and Dr. Lyle D. Calvin, appreciation is expressed for the valuable advice concerning statistical matters.

To the Arizona Agricultural Experiment Station, thanks are extended for permitting the use of the data involved in this study. I am particularly indebted to Professor E. B. Stanley and Dr. Carl B. Roubicek for their assistance in collecting and consolidating the initial information.

To the Empire and Arivaca ranches of Arizona, gratitude is expressed for the use of the livestock and facilities that made this study possible.

To my wife, Dee, I am grateful for her indulgence and encouragement while this study was in progress and for the transposition of the initial draft of the manuscript into a legible form.

To Verna Anglemier, I extend sincere thanks for typing this paper in the form in which it is presented.

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SOME GENETIC AND ENVIRONMENTAL FACTORS INFLUENCING THE WEANING WEIGHTS OF SOUTHWESTERN RANGE CATTLE

INTRODUCTION

More efficient beef production (in terms of the quantity of saleable market weight per dollar invested in breeding stock, land, labor, facilities, and miscellaneous operational costs) is one of the goals of progressive beef cattle breeders. No longer can the acquisition of cheap lands and increases in the number of breeding animals augment the income of American cattle producers or assure an ample meat supply for ever-increasing populations.

Production efficiency, as well as volume of production, must receive emphasis if the beef producer is to strengthen his position in the modern-day economy and continue to fulfill his obligation as a supplier of quality meat for the consuming public of the present and future. Strides have been made in this direction by improvements in nutritional regimes and other environmental factors which have enhanced the productivity of meat animals.

The beef-producing breeds, for which environmental adjustments have been formulated, were developed and improved largely within the limitations imposed by visual selection. While past procedures have wrought certain changes considered desirable by modern-day breeders, they have left a wide range of genetic variability in many economically important traits. This variability provides an opportunity for future genetic improvement if selection procedures, sufficiently accurate and feasible, are available for the evaluation of the traits involved. These contentions are supported by the literature cited in the review presented later in this paper.

The study reported herein was directed toward an evaluation of genetic and environmental factors contributing to the variability in weaning weights. That these weights are of economic importance to Southwestern cattlemen was pointed out by Stevens *et al*. (63, p.19-20) and Gray (18, p.23-27). The former authors determined that 35 to 45 per cent of the cattle operations in the Southwest Desert and Southern Plains regions are of the cow and calf type; the latter reported that calves accounted for 47 per cent of the weight of all beef cattle marketed by family-operated ranches in the Southwest from 1940 to 1954.

The first objective of the current study was an evaluation of major non-genetic factors contributing to the variability in weaning weights under operating conditions commonly encountered by cattlemen on Southwestern ranges. This objective was further extended to include the determination of correction factors that these operators might reasonably be expected to employ for the removal of nongenetic variation. The final objective involved an evaluation of that fraction of the remaining variance attributable to hereditary influences, thus providing an estimate of the increases in weaning weights obtainable through selection for genetic merit.

REVIEW OF LITERATURE

The Influence of Age at Weaning on Weaning Weights

Since it is a common practice to wean all calves in a given herd on the same day, even though the calving season may have ranged over a period of weeks or months, the resulting age discrepancy is recognized as one of the environmental factors contributing to the variation in weaning weights. Comparatively early studies of the growth pattern of calves, supported by more recent observations, have suggested methods by which this age discrepancy might be overcome.

Ragsdale, Elting and Brody (50, p.20) reported monthly weights of Holstein and Jersey calves over the age range that is of current interest at weaning time to breeders of beef cattle. The growth curves reported by these workers indicate that the growth of dairy calves was essentially linear from 4 months of age to the age of 5 to 7 months, after which a reduced growth rate was noted. Growth rate was also reasonably linear from the age at which this reduction occurred to the age of at least 11 months. Male calves of both breeds gained faster than females.

Lush *et al*. (45, p.8-17) found that the increase in weight of Hereford, Brahman and back-cross calves (born on Texas ranges in March and April) could be represented by a straight line until mid-July. Although the subsequent increase in weight was somewhat slower, the growth curve was linear from mid-July to weaning time in mid-October. The growth curves of steers and heifers tended to parallel, with the steers slightly heavier at all ages.

The growth of Hereford, Shorthorn and Aberdeen-Angus heifers was reported linear, by Guilbert and McDonald (21, p.247), from birth to at least 10 months of age.

Recently, Burns and Alexander (7, p.145) determined that Hereford calves, born during November in Australia, gained at a rate of approximately 1.5 pounds per day for about 6 months. A decline in rate thereafter was associated with pasture deterioration.

In research similar to that reported in this paper, although conducted under different environmental conditions, special attention was devoted to relatively short segments of the growth curve encompassing the mean weaning ages. Resulting proposals, for the adjustment of weaning weights to some constant age, were based upon the contention that growth was essentially a linear function of time throughout the segment or segments involved.

A positive correlation of 0.49 between weaning weight and weaning age was determined by Knapp _et_ _al_. (27, p.11) from their study of range Herefords in Montana.

Later, Koch (34, p.771) found that bull, steer, and heifer calves produced by a single Hereford line gained about 2.27 pounds per day between the ages of approximately 140 and 210 days in the same state. This high rate of gain was attributed to the fact that the line had been selected for weight and gaining ability.

Koger and Knox (40, p.17), calculating the average regression of weight on age, obtained a coefficient of 1.21 pounds per day. This coefficient was used to adjust the weaning weights of New Mexico steer and heifer calves, within a 100-day age range, to a constant age of 205 days. These same authors (39, p.285-289) subsequently determined that calves born late in the season gained faster than those born earlier and that the magnitude of subgroup coefficients was positively correlated with the mean weights of the subgroups on which calculated. A variable equation for the estimation of weaning weights at 205 days of age was therefore proposed.

The partial regression of weaning weights of New Mexico range Herefords on weaning age, by McCleery and Blackwell (47, p.224), suggested a correction of 1.17 pounds per day. This coefficient was smaller than the values calculated by Koger and Knox (39 and 40) and was believed due to the suppression of pre-weaning gains by drought conditions.

The average daily gain of Oregon steers and heifers between the ages of 175 and 245 days was reported to be almost constantly 1.28 pounds per day by Sawyer, Bogart, and Oloufa (57, p.515). Hitchcock _et al_. (23, p.8) later reported regression coefficients of 1.1 and 1.2 pounds per day for adjusting the weaning weights of heifer and steer calves respectively to a standard age of 225 days. The difference between these coefficients was insignificant.

Johnson and Dinkel (24, p.372-376) regressed the weights of South Dakota range Herefords on age from birth to 155 days and from 155 days to 225 days. These authors did not describe the sexes involved. Both regressions, 1.85 and 0.84 pounds per day for the first and second segments respectively, were linear. The two coefficients together were used to adjust weights, taken over a wide age range, to a standard age of 190 days. Similarly, Rollins, Guilbert, and Gregory (54, p.743) found that the growth of Hereford calves under California farm conditions was linear from birth to 4 months of age and from 4 to 8 months of age.

A regression of weaning weights of Oklahoma range Herefords (both steers and heifers) on ages ranging from 120 to 260 days resulted in a coefficient of 1.46 pounds per day according to Botkin and Whatley (2, p.553-554).

This value was somewhat smaller than the 1.67 pounds per day used by Burgess, Landblom, and Stonaker (6, p.846) to adjust the weights of Colorado range calves to about the same standard age. However, bulls, steers, and heifers were included in the latter study.

Few workers have offered indications that the sexes differed sufficiently in growth rate to require separate weight-for-age adjustments. Knapp and Black (28, p.250-253) did report that sex had a significant influence on the pre-weaning gains of beef Shorthorn calves and on range Hereford calves weaned at 140 and 180 days of age respectively. These authors, however, did not indicate the influence of sex on gains within the segment of the growth curve that normally would be considered in adjusting weaning weights for age differences. On the other hand, Rice (51, p.20) reported the regression of weaning weight on age to be about 0.16 pounds per day greater for bull calves than for heifers. Although a test of significance was not reported, this author used different factors to adjust the weaning weights of bull and heifer calves to 205 days of age under Arizona range conditions.

Contrary to the aforementioned reports, Gregory, Blunn, and Baker (19, p.341-342) found that sex had no significant influence on the gains of Hereford calves from birth to weaning ages of 150 to 200 days. Similarly, Hitchcock (23, p.8) determined that steer and heifer calves gained at comparable rates about a standard age of 225 days.

The Influence of Age of Dam on Weaning Weights

A curvilinear influence of age of dam on the weaning weights of beef calves has been reported by various authors. Furthermore, the influence of the age of dairy cows on milk production has resulted in a curvilinear relationship suggesting that the availability of milk is largely responsible for the age-of-dam influence on weaning weights.

Gowen (16, p.54) observed that the 365-day milk yield of Holstein cows increased as the age of the cows advanced from 2 to 8 years and then declined at about the same rate as age progressed to 14 years. Production at 3 years of age and at 14 or 15 years of age was comparable. Similar studies by Lush and Shrode (46, p.342-345) provided results that were in reasonable agreement with those reported by Gowen (16).

Brody (3, p.15) produced evidence that milk production may be more closely associated with body weight than with skeletal size. This was suggested by the fact that Jersey cows reached mature weight at about 8 years of age while mature skeletal size was attained at an age of approximately 55 months. Later, Brody and Proctor (4, p.17) reported that the annual quantity of fat-constant milk increased as the age of dairy cows advanced from 2 to about 8 years. Milk production was, however, positively correlated with body weight within the age groups observed.

That milk production was an important factor influencing the suckling gains of Shorthorn calves was pointed out by Knapp and Black (28, p.250-251). Knapp _et_ _al_. (27, p.9-10) then recognized the similarity between the milk production curve reported by Gowen (16) and the curve portraying the age-of-dam influence on the preweaning gains of beef calves. The repeatability of weaning weights of beef calves was later associated with the repeatability of milk production by Gregory, Blunn, and Baker (19, p.344). Gifford (15, p.10-11) subsequently determined that Hereford cows reached the peak in milk production at about 8 years of age. It should, however, be pointed out that Gifford (14, p.606 and 15, p.24) cautioned against an overestimation of the importance of milk production. This author found that the correlation of milk production of Hereford cows with the suckling gains of their calves was insignificant after the calves reached 4 months of age.

Factors for adjusting weaning weights of beef calves to overcome the inequalities due to age-of-dam influences have been reported by a number of experiment stations. With respect to the curvilinear nature of such influences, these reports are in general agreement; on the other hand, the shape of the reported curves is somewhat variable. It should be recognized, however, that the environmental conditions differed among stations.

According to Knapp _et_ _al_. (27, p.9-10), the weaning weights of Montana range Herefords became heavier as the age of dam increased from 2 to 6 years and then declined at a similar rate until the cows reached 10 years of age. Koch and Clark (35, p.394) reported revised estimates of age-of-dam influences in the same locality. These authors, in agreement with Knapp _et_ _al_. (27), found that Hereford cows produced their heaviest calves at 6 years of age. It was noted, however, that cows from 5 to 8 years of age weaned calves within a 6-pound weight range. At the ages of 3, 4, and 9 years, the weights were lighter by about 41, 12, and 18 pounds respectively.

Botkin and Whatley (2, p.554) added 35 pounds to the weights of Oklahoma range calves weaned by 3-year-old cows and 15 pound to the weights of those produced by cows that were 1 year older. These adjustments were required to place the weights on a basis comparable to those of calves weaned by cows from 5 to 9 years of age.

Such adjustments were also recommended by Chambers, Botkin, and Whatley (8, p.14).

Under Florida conditions, Clum, Kidder, and Koger (9, p.1209) learned that the heaviest calves were weaned by cows ranging from 5 to 10 years of age. Those produced by 3-year-old cows were only 12 pounds lighter and calves weaned by 4-year-old females were 5 pounds lighter.

That the heaviest range calves were produced by 7-year-old cows on New Mexico ranges was reported by Knox _et al_. (33, p.31). There were, nevertheless, only small differences among the weights of calves weaned by cows within an age range of 6 to 8 years. This is in agreement with the findings of Burgess, Landblom, and Stonaker (6, p.846) in Colorado.

Rice (51, p.57) determined that the weaning weights of Hereford calves in an Arizona range herd increased progressively as the age of dam increased from 3 to 9 years. A decline then followed.

According to Rollins and Guilbert (53, p.521-524), additions of 21 and 13 pounds were required to adjust the weaning weights of calves produced by females that were 3 and 4 years of age to the 7- to 10-year age basis. These calves, weaned at an average age of 240 days, were somewhat older than those involved in the previous reports cited. The magnitude of the corrections was greater for male calves than for females through the 10-year-old group; beyond this age, the reverse was true. The differences in these corrections were, however, believed to be insignificant. These calves were produced under irrigated farm conditions.

Sawyer, Bogart, and Oloufa (57, p.515) found that Oregon calves from 2-year-old cows were 75 pounds lighter at weaning time than were those from mature cows. Weaning weights increased with age of dam through the age of 8 years and then declined. In a subsequent study, Nelms and Bogart (48, p.663-664) found that the age-of-dam influence on suckling gains was insignificant. Calves from 2-year-old cows appeared to gain faster than expected. This may have been due, in part, to the fact that the 2-year-old females were selected for gaining ability while the older cows were not.

The Influence of Sex on Weaning Weights

The weaning weights of the calves involved in this experiment clearly indicate a difference between sexes. This has been reported previously in published data, although many prior studies involved castrated males. The magnitude of reported differences in the weaning weights of male and female calves has been quite variable. Only one report of the sex influence on weaning weights at the advanced age of 270 days has been found in the literature.

Lush et al. (45, p.8-10), studying Texas range cattle, found that males were heavier than females at birth and that steer calves maintained a weight advantage during and following the suckling period. Similarly, Gramlich and Thalman (17, p.51-53) reported that the daily gains of steer calves exceeded those of heifers during the feeding period after weaning. Sex groups of about the same starting weights were compared. The average beginning weights of these groups were between 337 and 349 pounds.

Knapp and Black (28, p.251-253) observed that sex had a highly significant influence on the pre-weaning gains of Shorthorn calves at Beltsville, Maryland. Similar results were obtained from a study of Montana Herefords. The Shorthorn calves were weaned at an age of 140 days, while the Hereford calves averaged 40 days older. Later, Knapp et al. (27, p.9) reported that the weaning weights of range-raised Hereford males in Montana were 22 pounds heavier than those of heifers. Sex influences accounted for 7 per cent of the variation in weaning weights adjusted to a constant age, presumed to be about 180 days.

Subsequent to the reports of Knapp and Black (28) and Knapp et al. (27), Koch (34, p.771) determined that the weights of Montana range bulls, weaned at about 180 days of age, were 44 pounds heavier than those of heifers weaned at the same age. The bull calves were 31 pounds heavier than steer calves. These studies were confined to the Line 1 Herefords developed at the U.S. Range Livestock Experiment Station at Miles City, Montana. Later, Koch and Clark (35, p.387-388) found a difference of 26 pounds in favor of male calves after the weaning weights were adjusted to a constant age of 182 days. The latter study was not confined to Line 1 animals, and the males included both steers and bulls. Age of dam had no apparent influence on the sex differences.

Grade Hereford steers were 32 pounds heavier than heifers at a weaning age of 205 days in New Mexico, according to Koger and Knox (40, p.17). This was reiterated by these authors (41, p.461-462) when a sex adjustment of 30 pounds was applied to weaning weights. McCleery and Blackwell (47, p.224) found that the weaning weights of New Mexico Herefords indicated a sex difference of only 25 pounds. The latter authors believed that drought conditions may have accounted for a difference somewhat smaller than that reported by Koger and Knox (40). It was also suspected that the difference in the weights of steer and heifer calves may be a function of the size attained by weaning time. The latter supposition was supported by Clum, Kidder, and Koger (9, p.1209). These workers found that the sex influence on the weights of Florida calves increased with the mean weights.

Gerlaugh, Kunkle, and Rife (13, p.11) reported the age-adjusted weaning weights of steers and heifers from Angus, Hereford, Hereford X Angus, and Angus X Hereford matings. The steers were consistently heavier, but the sex difference varied among the breeds and breed crosses. Their data suggests that sex differences increase with the increase in mean weaning weights, thus lending support to the observations of McCleery and Blackwell (47) and Clum, Kidder, and Koger (9).

The difference in the weights of Hereford bull and heifer calves at various ages was reported by Guilbert and Gregory (20, p.11). Heifer weights expressed as a percentage of bull weights at these different ages were as follows: 1 month - 97%, 4 months - 89%, 8 months - 87%, and 12 months - 77%. Rollins and Guilbert (53, p. 521-522) later reported that bull calves gained 0.13 pounds per day more than heifers from birth to 4 months of age and that the bull calves were 68 pounds heavier when weaned at 240 days of age. These calves were raised under irrigated farm conditions.

Botkin and Whatley (2, p.554) reported that the mean difference between the weaning weights of steer and heifer calves of Hereford breeding on Oklahoma ranges was 25 pounds at 210 days of age.

The weaning weights of Hereford range bulls in Colorado, at an average age of 211 days, were 22 pounds heavier than those of the heifers observed by Burgess, Landblom, and Stonaker (6, p.846). The weights of steer calves exceeded those of the heifers by only 2 pounds.

Burns and Alexander (7, p.145) reported that Hereford steers, in Australia, were about 28 pounds heavier than heifers at weaning time. Since these calves were weaned at approximately 9 months of age, the age was comparable to that of the Arizona calves involved in the present study.

Hereford range bulls, raised under Arizona conditions, were 28.8 pounds heavier than heifers at 205 days of age according to Rice, Kelly, and Lasley (52, p.962). Rice (51, p.42) later reported a sex difference of 21.5 pounds in the same herd.

A few reports have indicated no weight advantage in favor of males at weaning age. Studies by Knapp and Phillips (31, p.347) produced no evidence of significant differences in the weaning weights of Montana Hereford steers and heifers, but a sex X sire interaction was noted. Sawyer, Bogart, and Oloufa (57, p.515) determined that Oregon heifer calves were heavier than steers at 30 weeks of age, although the difference was insignificant. Insignificant sex influences on gains from birth to weaning and on weaning weight were also encountered by Gregory, Blunn, and Baker (19, p.341). These authors reported on Nebraska Herefords.

The Heritability of Weaning Weights

Heritability was defined by Lush (44, p.293-301) as that fraction of the observed variance that is caused by differences in heredity. It was pointed out that heritability, as estimated by the likeness of relatives, includes all of the additive genetic variance, usually less than half of the variance due to epistatic interactions, and generally none of the variance produced by dominance deviations. The merits and weaknesses of the common methods of estimating heritabilities of beef cattle traits have been adequately discussed by this author and by Koch and Clark (36, p.777-782 and 37, p.790-791).

That weaning weight is apparently influenced by inheritance was pointed out by Knapp *et al*. (26, p.10 and 27, p.10). These workers observed significant differences when comparing the progeny of Hereford sires. This, however, has not been consistently true, according to the work of Knapp and Phillips (31, p.347). Significant weight differences between the progeny of several sire groups were obtained in only one of four years in which comparisons were made. Knapp and Black (28, p.251-253) failed to find significant sire influences on the preweaning gains of Shorthorn and Hereford calves.

Subsequent to the reports cited, various workers have calculated estimates of the heritability of weaning weight by several alternative methods. Paternal half-sib correlations and parent-offspring regressions were the methods commonly employed.

Knapp and Nordskog (30, p.66) first presented heritability estimates derived from Hereford data accumulated at the U.S. Range Livestock Experiment Station at Miles City, Montana. The heritability of weaning weight estimated by paternal-half-sib correlation was 12 per cent; that resulting from two studies by sire-offspring regressions was zero and 30 per cent. Knapp and Clark (29, p.584) later reported a revised estimate of 28 per cent, calculated by paternal half-sib correlation. Knapp and Woodward (32, p.1026) still considered the latter estimate acceptable.

Estimates of 26 and 52 per cent were derived from the Hereford herds in Nebraska by Gregory, Blunn, and Baker (19, p.341). They also used the paternal half-sib correlation.

Louisiana studies by Dawson _et_ _al_. (10, p.558-559) resulted in heritability estimates of 5, 15, and 19 per cent respectively by intra-sire regression of offspring on dam, regression of offspring on dam within sire of the dam, and paternal half-sib correlation.

Shelby _et_ _al_. (58, p.962 and 59, p.376), using the paternal half-sib correlation, calculated a heritability estimate of about 23 per cent. This is somewhat lower than the revised estimate of Knapp and Clark (29), but it appears that not all of the cattle involved in the two studies were from the same source.

Koch and Clark (36, p.779; 37, p.788-791; 38, p.995) estimated the heritability of weaning weight in the Hereford herd at the United States Range Livestock Experiment Station at Miles City, Montana. A paternal half-sib correlation produced an estimate of 24 per cent; regression of offspring on sire resulted in a value of 25 per cent; the estimate by regression of offspring on dam was only 11 per cent. It was anticipated that the latter value would exceed that resulting from the paternal half-sib correlation. The discrepancy was presumed due to sampling error, inadequate discounting of the environmental correlation among paternal half sibs, or a negative correlation between genes affecting maternal environment and those directly affecting growth response. An additional approach was designed to evaluate the maternal environment as well as the direct genetic influence on weaning weight. This produced a heritability estimate of 19 per cent.

Dinkel and Musson (12, p.9), working with South Dakota Hereford calves, reported about 36 per cent of the differences in weaning weights to be inherited.

Rollins and Wagnon (55, p.130-132) reported a heritability estimate of 30 per cent and concluded that differences in nutritional levels did not influence the heritability of weaning weight.

Buiatti (5, p.207) reported the heritability of 6-month weights of Chiana heifers to be about 64 per cent.

The heritability of gains from birth to weaning was found to be 100 per cent by Kidwell (25, p.57), but the estimate was based on stock purchased from 4 different ranches. Prepurchase environment and sampling error were presumed to account for the high estimate. Gregory, Blunn, and Baker (19, p.341) reported heritability estimates of zero and 45 per cent for this trait, while Koch and Clark (36, p.779; 37, p.788-790; 38, p.995) obtained values ranging from 7 to 21 per cent by different methods of estimation.

Dawson, Yao, and Cook (11, p.210) found that 45 per cent of the variation in the length of time required for calves to reach a weaning weight of 500 pounds was attributable to inheritance.

MATERIALS AND METHODS

The purebred Hereford cattle, upon which the current study was based, were unregistered animals made available for research under a cooperative agreement with private breeders[1] at Sonoita and Arivaca, Arizona. The ranch at Sonoita was designated ranch I. Ranch II became the designation of the facilities at Arivaca. Over a period of 6 years (1949-1954), weaning data were collected on 329 bull calves and 332 heifer calves produced on the desert grassland ranges of the 2 ranches. These calves were the progeny of 11 Hereford sires, some of which were used more than 1 year. A minimum of 4 sire groups was involved each year.

From 1949 through 1951, the entire cow herd was maintained on ranch I. At the conclusion of this 3-year period, the herd was divided between the 2 ranches on the basis of ancestry and existing production records. Desert grassland ranges, as described by Nichol (49, p. 206-209), were common to both ranches. The chemical composition of major forage species in the Sonoita area was reported by Stanley (61, p.140-143) and by Stanley and Hodgson (62, p.455-459). The general management

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[1] Initially the Chiricahua Ranches Company of Sonoita, Arizona; later, Frank S. Boice of Sonoita and Henry G. Boice of Arivaca, Arizona.

procedures described in the following section apply to each ranch.

General Management

Breeding and Selection Procedures

Sires were assigned to their respective breeding pastures between April 5 and April 15 of each year. All cows bore horn brands indicating the year of birth. These brands also contained numerals for the identification of individual animals. Ear tattoos identified the sires of most of the cows that were in the herd when the experimental program was initiated. The sires of the replacement heifers added thereafter were also known.

The breeding females available for experimental use at the outset were divided into sire groups on the basis of limited knowledge of the male ancestry. Female ancestry was, for the most part, unknown. It was the desire of the cooperators to assign sires in a manner that would hold the degree of inbreeding at a minimum. This policy was maintained throughout the study by assigning heifer replacements to groups other than those in which they were produced and by assigning sire replacements to the groups into which they were born.

During the breeding seasons in which the 1949-51 calves were conceived, the sires remained in their assigned breeding pastures until the December weaning date. After August 1 of these particular seasons, cows with bull calves showing marked sexual development were isolated. During the years in which the 1952-54 calves were conceived, the sires were removed from their respective breeding pastures about August 1. The cows were then redivided into two general groups with the current calves segregated by sexes. One sire was returned to each of these pastures after September 1 to breed the few cows that had not conceived earlier.

Although the cow herds were subject to continuous culling as the necessity arose, most of the culling was done at the beginning of the breeding seasons. Cows reaching 10 years of age were automatically removed, as the cooperators found that cows beyond this age seldom performed to their satisfaction. Unthriftiness at any age, disease or injury, and failure to produce thrifty calves of desired type were additional criteria for removal. A few inconsistent breeders were culled, as were cows that did not meet the type standards of the cooperators at maturity. When production records became available, a preliminary weaning index of the calf was used as an additional means of evaluating its dam. This index placed equal emphasis on the conformation score of the calf at weaning time and on the weaning weight adjusted for age of calf, sex of calf, and age of dam. The adjustment factors were recalculated each year.

Until weaning and fall-yearling data became available for the selection of 2-year-old replacement heifers, these females were selected in conformity with the visual standards of the cooperators. After 1950, gains from weaning time to the following September were combined with corresponding conformation scores to provide a post-weaning index. This index, combined with the weaning index previously described, formed an additional basis for the selection of replacement heifers. All factors in the selection index received equal emphasis.

Of the 11 sires involved in this study, 5 were selected by visual appraisal from a New Mexico purebred herd; 3 were selected by similar means from prospects raised by the cooperators; the remaining 3 were selected from the experimental herd on the basis of pre-weaning and post-weaning performance records. The selection index used in the latter case was a modified form of that used for the selection of heifer replacements. Since the bull prospects were subjected to feedlot performance tests, the post-weaning data included efficiency of feed utilization.

Calving Procedures

The calving season began in early January of each year. Because of the sire management, births through the month of August were within the realm of probability, although few calves were actually conceived after September 1. In general, at least two thirds of the calves were dropped within 45 days on either side of the mean birth date.

During the calving season, the cows were under daily observation. The birth date and sex of each calf was noted on the cow roster carried by the observer. Cow or calf losses, with the apparent reasons, were also noted. Furthermore, a record was made of sickness, injuries, and other factors that might conceivably influence the performance record of any calf, dam, or sire.

Near the conclusion of each calving season, the calves were marked with the registered brand of the cooperators and a number brand indicating the year of birth. Ear tattoos were applied to provide a permanent identification of the sires.

Weaning Procedures

Weaning operations required a period of two days each year. From 1949 through 1952, these were consecutive days between November 29 and December 4. Since the mean weaning ages increased progressively over this period, the weaning dates for the next three years were changed to the period between November 14 and November 21. At weaning time, the calves were hide branded with numerals for individual identification. Weaning weights and conformation scores were recorded. After the identifying numbers of the calves and their dams were properly associated, the calves were weaned.

Range Nutrition

Until the summer of 1951, the various sire groups remained in their respective pastures throughout the year. As mentioned previously, however, the cows with the older bull calves were isolated after August 1 and remained so until weaning time. A system of pasture rotations from year to year was introduced to minimize the intangible influence of pasture differences during this time. In the summer of 1951 and thereafter, the cows were segregated by sex of calf about August 1 and remained so segregated until weaning time. After weaning, the cows were maintained as a single herd until the following breeding season.

Pasture supplementation was first introduced into the herd in December of 1948. Soon after December 1, the cows and yearlings received a free-choice supplement of cottonseed meal containing one third salt by weight. The weanling calves were given a supplement of 75 per cent cottonseed meal and 25 per cent salt. These supplements were offered until consumption dropped with the appearance of green summer forage. After the weaning date in 1950 and in all succeeding years, a commercial supplement containing dehydrated alfalfa, cottonseed meal and trace minerals was used. The proportions of salt, used to limit consumption to about 1 or 2 pounds per day, were as previously indicated. Block salt was available free-choice throughout the year.

Collection of Weaning Data

Individual weaning weights, to the nearest 5 pounds, were taken on the weaning dates previously discussed. Conformation scores were assigned by a committee of 3 men at this time. While the cattle were consolidated at Sonoita (1949-51), these operations required a period of 2 days. After the herd was divided, 1 day was required at each location. The cattle were driven from the range areas to the corrals, a distance of about 1 mile, immediately prior to weighing.

Statistical Procedures

The weaning data, collected over a period of 6 years, were coded and recorded in punched cards to permit computations on international business machines. The card for each individual animal bore its identity, immediate ancestry, age, weaning weight, and miscellaneous remarks deemed worthy of note. Statistical procedures used in the evaluation of the weaning weights are described in the succeeding subsections.

The Influence of Age at Weaning on Weaning Weights

To evaluate the influence of age at weaning on weaning weight, the unadjusted data were first classified by year and ranch within sex. Within each subclass, the data were assembled in 20-day age arrays. The mean weights of these arrays were then plotted against the appropriate mean ages to determine whether linear relationships existed. Because the plotted data revealed distinct linear relationships, evaluations of the deviations from linearity were deemed unnecessary. The 20-day age arrays were, therefore, discarded. In the regression analyses that followed, the observations at each day of age (throughout the age range involved) became the arrays.

After determining the existence of linear weight-age relationships by the method previously described, an average regression coefficient was calculated for each sex. The method of covariance analysis outlined by Snedecor (60, p.318-328) was employed for this purpose.

The Influence of Age-of-Dam on Weaning Weights

Following the regression of weaning weight on weaning age as previously described, the actual weights were adjusted to a standard age of 270 days by using the coefficients thus obtained. Within each sex, the weights were adjusted by the coefficient applicable to that sex. The influence of age of dam on weaning weight was then evaluated in the manner subsequently presented.

The age-adjusted weaning weights were first classified by year and ranch within each sex. Within these subclasses, the mean weights were computed for each age of dam. The cows ranged from 3 to 9 years of age.

When the mean weights of the age-of-dam subclasses were plotted against age of dam, a curvilinear relationship was apparent. Bull calves produced by cows ranging from 5 to 8 years of age were the heaviest, and these age groups all produced calves of similar weights. Male calves produced by 3-year-old cows weighed the least, while cows at 4 and 9 years of age weaned calves of intermediate and comparable weights. An examination of the heifer data revealed a similar but more variable trend.

Upon completion of the comparisons described, the age-of-dam classes were grouped as follows: 3; 4 and 9; 5, 6, 7 and 8. The means of these groups indicated that the age-of-dam influence could be represented by a straight line. These groups, which became the independent variables in the subsequent regression of weaning weights on age of dam, were assigned values of -1, zero and +1. Covariance analysis, as outlined by Snedecor (60, p.318-328), resulted in an average regression coefficient representing the age-of-dam influence on the weights of each sex.

In the process of computing the average regression coefficients, separate estimates were determined for each ranch-within-year subclass. These coefficients were then regressed on the mean weights of the subclasses from which derived. This was done to determine the possibility of using mean weaning weights as a criterion upon which to base variable age-of-dam adjustments.

Although the preliminary examination of the data revealed that the trend in age-of-dam influence was similar for both sexes, the 8-year-old cows did wean relatively light heifer calves. It was, therefore, considered advisable to repeat the initial regression analyses after segregating the weights into the following age-of-dam subclasses: 3; 4, 8 and 9; 5, 6 and 7. The analysis was repeated for each sex, and the errors of estimate were compared with those obtained in the earlier calculations.

The Influence of Sex on Weaning Weights

An evaluation of the influence of sex on weaning weights was conducted after the weights were adjusted to 270 days of age and to a common age-of-dam basis (5 to 8 years). All of the data involved in the studies previously described in this paper were used. Adaptations of the variance analyses for multiple classifications with disproportionate subclass numbers (Snedecor, 60, p.286-292) were employed.

Since Koger and Knox (40, p.16) cited reports suggesting that sex differences were inconsistent among the progeny of different males and yet found that this was not substantiated by their data, the sex X sire interaction within ranch and year was tested for significance. The error variance within sire, sex, ranch, and year was used for this test.

Because data were accumulated on ranch I over a period of 6 consecutive years (1949 to 1954) this block of data was first used to test the significance of sex X year interaction, the difference in the weaning weights of the two sexes, and the differences in weaning weights among years. Data obtained on ranches I and II were available for a 3-year period (1952 to 1954). These data were treated in the manner previously described, but the ranch variable and the sex X ranch interaction were also considered.

The Heritability of Weaning Weights

Heritability estimates were calculated within each sex after the weaning weights were adjusted to a standard age of 270 days and to a common age-of-dam basis (5 to 8 years). The correction factors used to make the adjustments were those calculated by procedures outlined in the preceding sections of this paper.

Because of the relatively limited duration of this study (6 years), the heritability estimates were derived from paternal half-sib correlations only. This method of estimation was discussed by Lush (43, p.367-368 and 44, p.293-301). Weaning weights were not available for a sufficient number of immediate ancestors to warrant additional estimates by parent-offspring regressions.

The necessary variance components were those attributable to sires within years and ranches and to error within sires. The procedure described by Anderson and Bancroft (1, p.327-330) was used to determined these components.

As proposed by Hazel and Terrill (22, p.350),

$$\frac{4\ E(E + kS)}{(E + S)^2\sqrt{\frac{1}{2}\ (k-1)kn}}$$

was the formula used to calculate the standard errors of the heritability estimates

(E = error variance component, S = sire variance component, k = calculated average size of the sire subclasses and n = number of sire subclasses). The standard errors multiplied by 1.960 gave the approximate 95 per cent confidence intervals.

RESULTS

The study of weaning weights of range calves, under Southwestern conditions existing from 1949 through 1954, yielded the results presented in the following subsections. These subsections are consistent with those employed in the outline of statistical procedures.

The Influence of Age at Weaning on Weaning Weights

The means of the unadjusted weights and the actual ages at weaning time, with standard deviations and coefficients of variation, are summarized in Table 1. These data show that the bull calves produced on a given ranch in any specific year were heavier at weaning than were the comparable heifers. It is also apparent that differences in the mean ages of the bull and heifer calves could not reasonably account for the observed differences in weaning weights.

As measured by the coefficients of variation (Table 1), the weights of the bull calves were usually more variable than those of the opposite sex. While this was quite consistently true, the differences in variability were small. The data show no pronounced evidence of a sex influence on age variation at weaning time or on mean weaning ages.

Table 1. Mean weaning weights, mean ages, and estimates of variability in weights and ages of calves by sexes within ranches and years.

Year	Ranch[1]	Sex	Number Calves	Weights		Ages		Coefficients of Variation	
				Mean (lbs.)	Standard Deviation (lbs.)	Mean (days)	Standard Deviation (days)	Weight (%)	Age (%)
1949	I	B	49	487	81	256	47	16.6	18.4
		H	51	460	65	260	45	14.1	17.3
1950	I	B	52	515	79	263	42	15.3	16.0
		H	57	457	65	267	39	14.2	14.6
1951	I	B	57	473	70	270	42	14.8	15.6
		H	56	443	64	278	45	14.4	16.2
1952	I	B	34	566	86	279	48	15.2	17.2
		H	26	502	56	280	42	11.2	15.0
	II	B	30	546	50	295	21	9.2	7.1
		H	26	474	62	282	41	13.1	14.5
1953	I	B	32	557	92	272	36	16.5	13.2
		H	33	496	49	272	37	9.9	13.6
	II	B	25	515	76	250	28	14.8	11.2
		H	29	488	65	260	26	13.3	10.0
1954	I	B	26	567	84	283	36	14.8	12.7
		H	28	462	79	268	52	17.1	19.4
	II	B	24	531	70	278	32	13.2	11.5
		H	26	452	43	277	23	9.5	8.3

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[1] Ranch I at Sonoita, Arizona; Ranch II at Arivaca, Arizona.

The mean weaning weights and ages for the 20-day age arrays are recorded by sexes on ranches within years in Tables 2, 3, 4, and 5. These data are presented graphically in Figures 1 and 2, where linear associations of mean weights with mean ages are apparent. It may be seen also that the slope of a linear regression line fitted to the bull data would be steeper than a line fitted to the date for the opposite sex.

The influences of ages at weaning on weaning weights, within an age range of 121 to 323 days, were estimated by the average regression coefficients shown in Tables 6 and 7. The coefficient representing the bull data (Table 6) indicates that, within the segment of the growth curve considered, a change of 1 day in age was associated with an average change of 1.442 pounds in weight. This estimate of the average daily gain of bull calves was 0.352 pounds per day greater than the estimate of 1.090 pounds per day for heifer calves throughout the same age range (Table 7). Both regression coefficients were significant at the 1 per cent level of probability. Likewise, the coefficients calculated for the ranch-within-year subclasses were consistently significant at the same probability level.

The differences among the subclass regressions, within sexes, were insignificant at the 5 per cent level

Table 2. Means of unadjusted weaning weights and mean ages of bull calves in 20-day age arrays within years (ranch I).

Year	Observations	Twenty-Day Age Arrays										
		340-321	320-301	300-281	280-261	260-241	240-221	220-201	200-181	180-161	160-141	140-121
1949	Number		8	14	6	4	6	3	3	4	1	
	Weight (lbs.)		557	551	466	504	459	415	379	361	298	
	Age (days)		305	292	270	248	234	206	194	164	159	
1950	Number		11	13	8	5	7	4	1	1	2	
	Weight (lbs.)		572	551	520	514	476	442	410	420	346	
	Age (days)		309	288	270	256	232	206	196	165	152	
1951	Number	1	15	15	7	6	6	2	1	3	1	
	Weight (lbs.)	393	525	484	488	463	437	464	383	361	234	
	Age (days)	322	307	291	274	254	229	216	185	170	150	
1952	Number	2	14	5	4	2	3	1		1	2	
	Weight (lbs.)	622	609	598	556	592	529	409		393	353	
	Age (days)	321	312	293	279	258	236	219		162	152	
1953	Number		3	16	5	3	3	1				1
	Weight (lbs.)		576	589	610	531	433	422				312
	Age (days)		303	292	272	247	230	207				135
1954	Number		6	14	3	1	1					1
	Weight (lbs.)		606	589	517	567	446					284
	Age (days)		306	294	270	248	239					129

Table 3. Means of unadjusted weaning weights and mean ages of bull calves in 20-day age arrays within years (ranch II).

Year	Observations	Twenty-Day Age Arrays										
		340-321	320-301	300-281	280-261	260-241	240-221	220-201	200-181	180-161	160-141	140-121
1952	Number		15	10	2	1	2					
	Weight (lbs.)		568	537	548	500	454					
	Age (days)		309	293	278	260	234					
1953	Number			3	6	9	3	3	1			
	Weight (lbs.)			565	527	549	478	418	390			
	Age (days)			291	268	252	227	210	188			
1954	Number		2	13	6	2					1	
	Weight (lbs.)		540	535	562	510					320	
	Age (days)		307	289	274	254					142	

Table 4. Means of unadjusted weaning weights and mean ages of heifer calves in 20-day age arrays within years (ranch I).

Year	Observations	Twenty-Day Age Arrays										
		340-321	320-301	300-281	280-261	260-241	240-221	220-201	200-181	180-161	160-141	140-121
1949	Number		6	20	4	6	4	6		3	2	
	Weight (lbs.)		483	489	467	477	423	412		395	330	
	Age (days)		306	293	268	248	232	212		167	150	
1950	Number		10	16	14	6	6		2	1	2	
	Weight (lbs.)		490	497	468	429	399		369	349	288	
	Age (days)		307	291	269	251	230		185	180	150	
1951	Number	1	21	15	9	2	1	2	1	2	1	1
	Weight (lbs.)	546	471	452	440	444	410	370	372	328	299	259
	Age (days)	323	309	290	272	252	228	214	199	164	158	121
1952	Number		12	5	2	2	3	1			1	
	Weight (lbs.)		520	532	472	491	485	438			333	
	Age (days)		310	290	274	250	229	208			151	
1953	Number		4	13	6	6	1		2		1	
	Weight (lbs.)		549	515	493	482	413		442		332	
	Age (days)		308	293	274	252	236		189		150	
1954	Number		8	8	6	2		1			1	2
	Weight (lbs.)		480	502	477	476		387			310	284
	Age (days)		307	291	267	252		206			143	134

Table 5. Means of unadjusted weaning weights and mean ages of heifer calves in 20-day age arrays within years (ranch II).

Year	Observations	Twenty-Day Age Arrays										
		340-321	320-301	300-281	280-261	260-241	240-221	220-201	200-181	180-161	160-141	140-121
1952	Number		13	3	3	4	2				1	
	Weight (lbs.)		494	500	501	438	445				255	
	Age (days)		311	292	269	250	228				142	
1953	Number			8	4	11	4	2				
	Weight (lbs.)			542	514	478	416	412				
	Age (days)			291	272	252	232	208				
1954	Number		2	12	6	2	4					
	Weight (lbs.)		498	460	468	442	388					
	Age (days)		301	292	275	251	234					

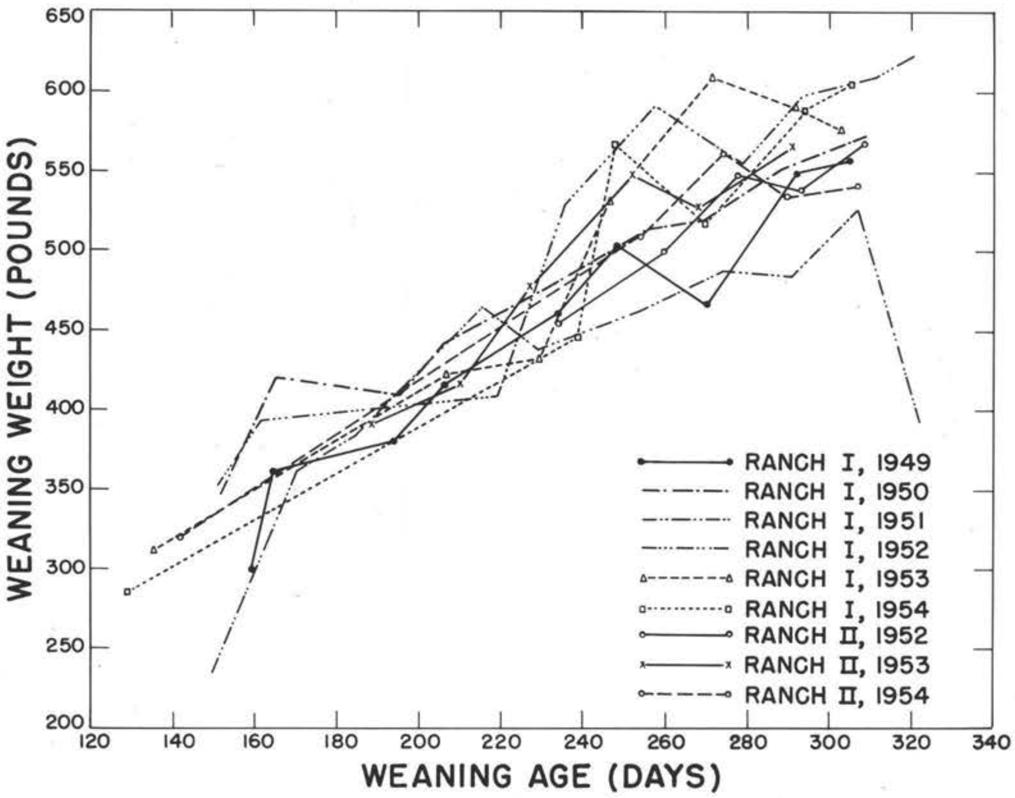

Figure 1. Means of unadjusted weaning weights of bull calves in 20-day age arrays plotted against the corresponding mean ages (by ranches within years).

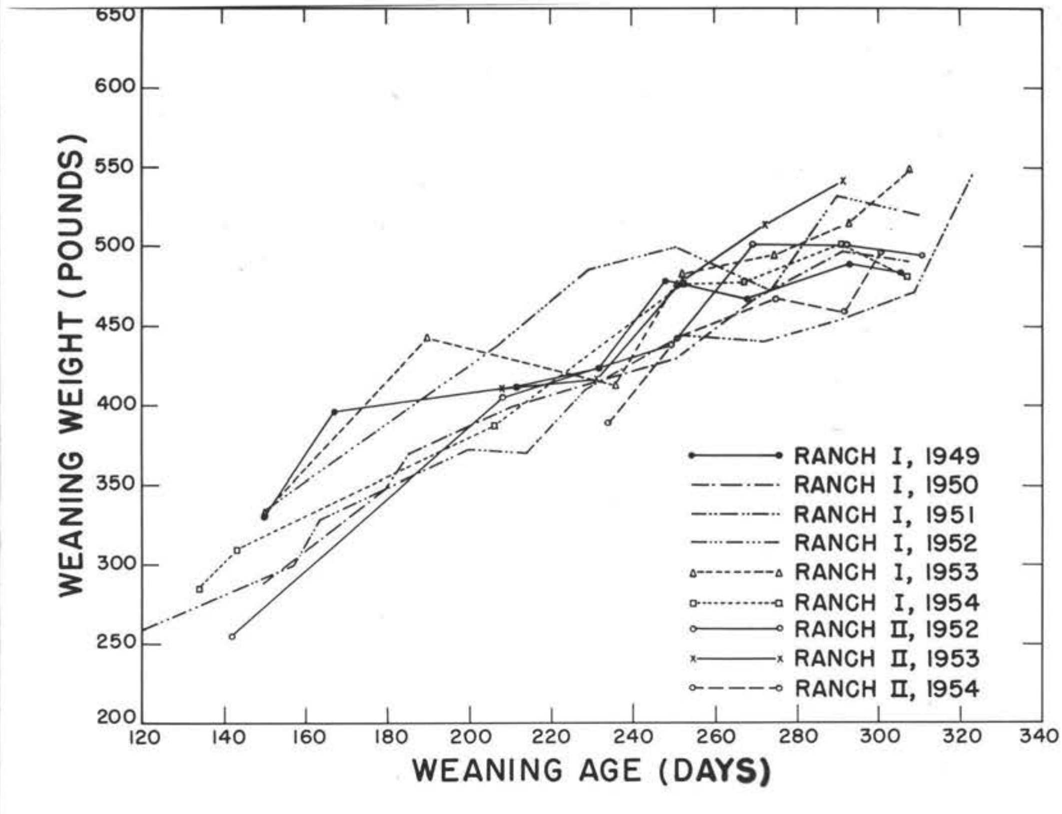

Figure 2. Means of unadjusted weaning weights of heifer calves in 20-day age arrays plotted against the corresponding mean ages (by ranches within years).

Table 6. Regression of unadjusted weaning weights of bull calves (Y) on actual weaning ages (X) by ranches within years.

Year	Ranch	D.F.	Sums of Squares and Products Sx^2	Sxy	Sy^2	Values of b and 95 Per Cent Interval	Errors of Estimate Sums of Squares	D.F.
1949	I	48	105,260	158,519	314,062	1.506**	75,336	47
1950	I	51	92,037	125,744	320,445	1.366**	148,649	50
1951	I	56	100,357	109,915	275,900	1.095**	155,517	55
1952	I	33	76,070	115,486	246,139	1.518**	70,813	32
1952	II	29	12,721	20,398	72,198	1.603**	39,490	28
1953	I	31	40,592	72,981	262,273	1.798**	131,059	30
1953	II	24	18,263	30,975	139,350	1.696**	86,815	23
1954	I	25	32,510	59,611	174,765	1.834**	65,461	24
1954	II	23	23,460	29,255	114,299	1.247**	77,818	22
Sums:		320	501,270	722,884	1,919,431	1.442** ±0.146	850,958	311

**Statistically significant at the 1 per cent level of probability.

Table 7. Regression of unadjusted weaning weights of heifer calves (Y) on actual weaning ages (X) by ranches within years.

Year	Ranch	d.f.	Sums of Squares and Products			Values of b and 95 Per Cent Interval	Errors of Estimate	
			Sx^2	Sxy	Sy^2		Sums of Squares	d.f.
1949	I	50	101,735	90,668	213,813	0.891**	133,008	49
1950	I	56	84,471	109,197	237,346	1.293**	96,186	55
1951	I	55	109,888	114,768	225,562	1.044**	105,697	54
1952	I	25	43,888	39,609	79,512	0.903**	43,765	24
1952	II	25	42,464	45,040	97,588	1.061**	49,816	24
1953	I	32	44,014	47,681	77,750	1.083**	26,096	31
1953	II	28	18,469	33,054	117,731	1.790**	58,574	27
1954	I	27	72,829	84,478	166,894	1.143**	71,826	26
1954	II	25	13,287	14,482	46,712	1.098**	30,928	24
Sums:		323	531,045	578,977	1,262,908	1.090** ±0.120	615,896	314

**Statistically significant at the 1 per cent level of probability.

of probability (Tables 8 and 9). A test of homogeneity of the average regression coefficients for the 2 sexes indicated a highly significant difference.

As determined from the data in Tables 6, 7, 8, and 9, age discrepancies accounted for about 50 per cent of the variation in the unadjusted weaning weights of calves of each sex on ranches within years.

The Influence of Age of Dam on Weaning Weights

When the age-adjusted weaning weights were divided into age-of-dam subclasses as described in the statistical procedure, a curvilinear influence of age of dam was indicated. This is pictured graphically in Figure 3, where the average weights of the calves weaned by cows from 3 to 9 years of age (over the 6-year period) were plotted by sexes. Here it may be seen that the relative trends reflected by the two sets of data are similar, although the weights of heifer calves produced by 8-year-old cows were light in comparison with the adjacent weights or with the relative weights of bull calves weaned by cows of the same age. These data also indicate a greater age-of-dam influence on the weaning weights of bull calves than on those of heifer calves.

Since the preliminary examination of the data suggested that cows of certain ages weaned calves of similar weights, these comparable age-groups were consolidated.

Table 8. Analysis of errors of estimate from average regression (from analysis of data on bull calves in Table 6).

Source of Variation	D.F.	Errors of Estimate Sums of Squares	Errors of Estimate Mean Squares
Deviations from average regression within subclasses	319	876,956	
Deviations from individual subclass regressions	311	850,958	2736
Differences among subclass regressions	8	25,998	3250

Table 9. Analysis of errors of estimate from average regression (from analysis of data on heifer calves in Table 7).

Source of Variation	D.F.	Errors of Estimate Sum of Squares	Errors of Estimate Mean Squares
Deviations from average regression within subclasses	322	631,673	
Deviations from individual subclass regressions	314	615,896	1961
Differences among subclass regressions	8	15,777	1972

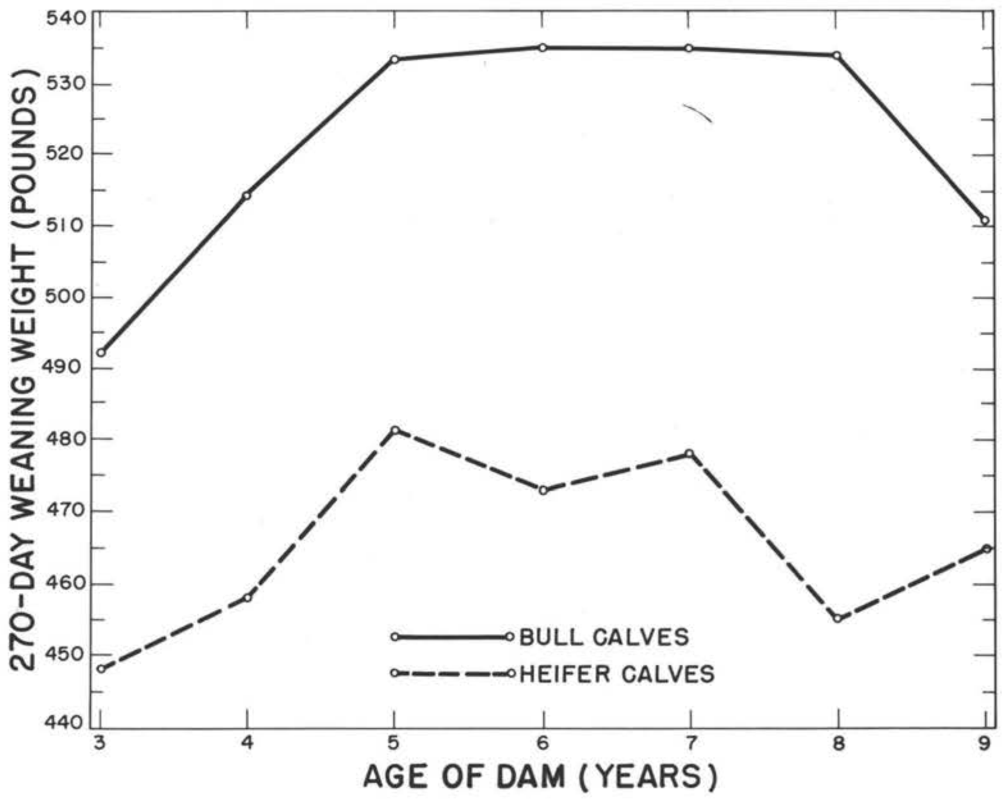

Figure 3. Weighted averages of age-adjusted weaning weights of bull and heifer calves by age-of-dam subclasses (1949 through 1954).

The mean weights of calves for the consolidated groups, by ranches within years, are shown in Figures 4 and 5. Because the light weights of heifer calves by 8-year-old cows were inconsistent with the remainder of the data and were contradictory to much of the evidence presented in the literature cited, the cows were initially grouped as follows: 3; 4 and 9; 5, 6, 7, and 8.

In Figures 4 and 5, the indications of linear relationships between the weights of the calves and the consolidated age-of-dam subclasses may be seen. In addition, it is evident that changes in age of dam were accompanied by greater changes in the mean weights of bull calves than in those of heifer calves.

The estimates of age-of-dam influences on weaning weights within sexes are represented by the average regression coefficients reported in Tables 10 and 11. The average regression coefficients, with 95 per cent confidence intervals, were 24.517 ± 6.777 and 11.949 ± 6.227 for bull and heifer calves respectively. Both coefficients were significant at the 1 per cent level of probability. The coefficients for the ranch-within-year subclasses were not consistently significant, however, for either sex at even the 5 per cent level.

Analyses of the errors of estimate within sexes are shown in Tables 12 and 13. The differences among

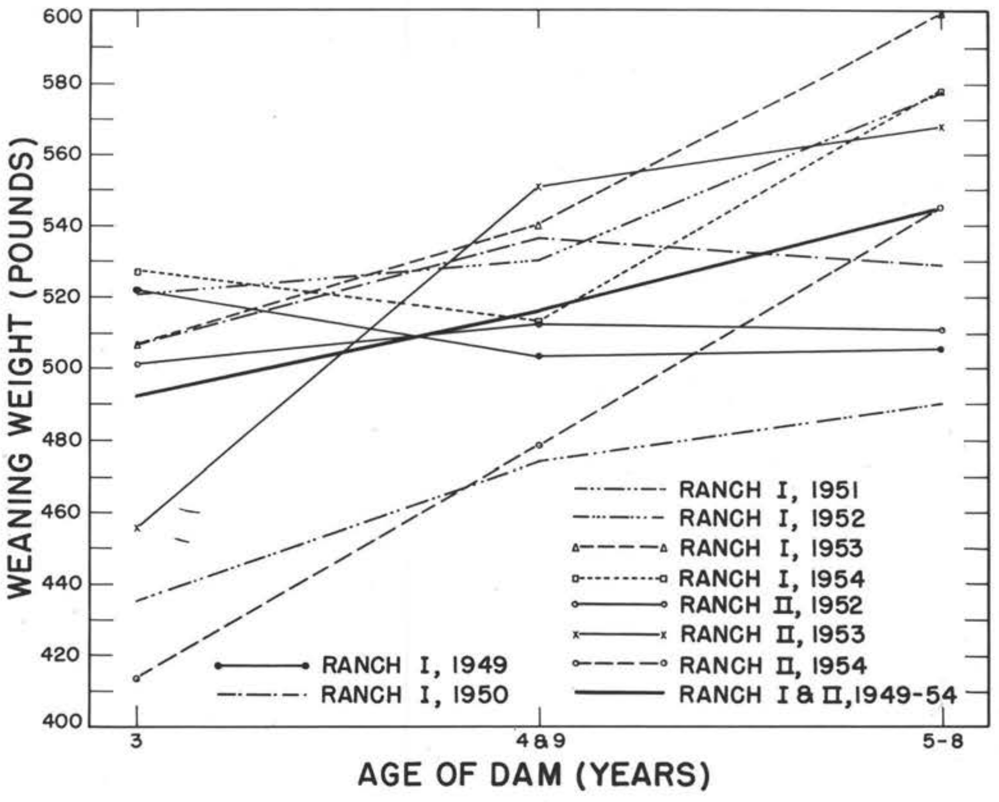

Figure 4. Average age-adjusted weaning weights of bull calves by consolidated age-of-dam subclasses on ranches within years.

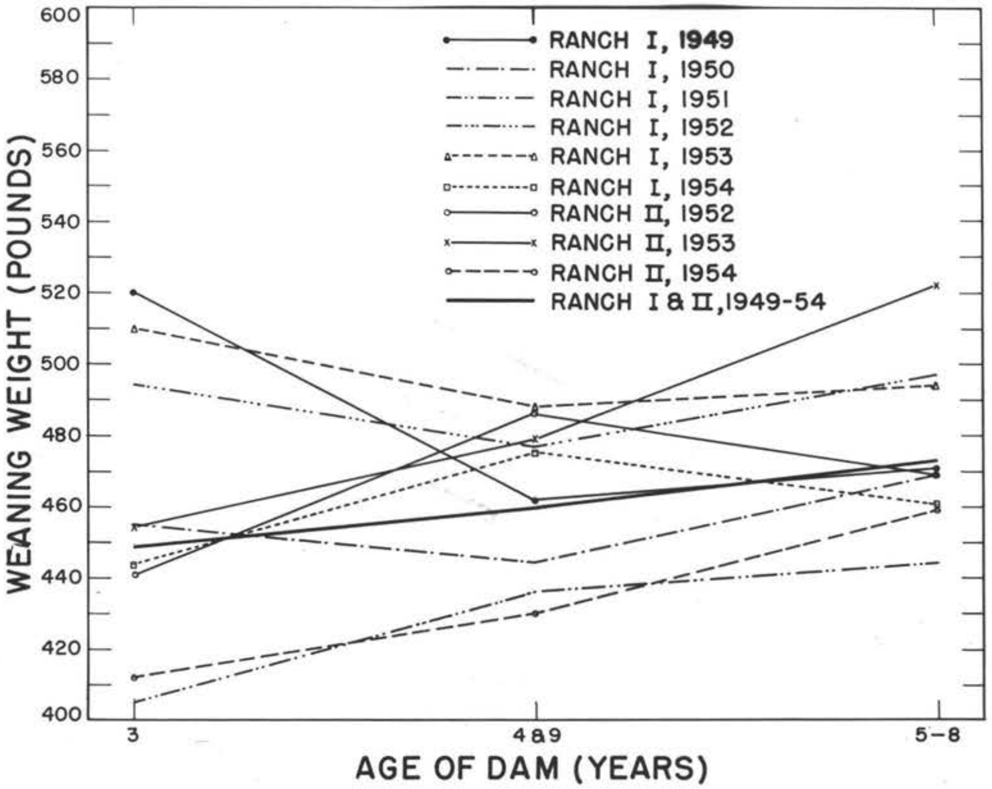

Figure 5. Average age-adjusted weaning weights of heifer calves by consolidated age-of-dam subclasses on ranches within years.

Table 10. Regression of weights of bull calves adjusted to 270 days of age (Y) on age of dam[1] (X).

Year	Ranch	d.f.	Sums of Squares and Products			Values of b and 95 Per Cent Interval	Errors of Estimate	
			Sx^2	Sxy	Sy^2		Sums of Squares	d.f.
1949	I	48	24,245	-142	75,641	-5.857	74,809.323	47
1950	I	51	34.827	350	149,231	10.050	145,713.614	50
1951	I	56	38.316	993	167,334	25.916**	141,599.346	55
1952	I	33	21.441	652	71,260	29.150**	51,433.313	32
1952	II	29	13.200	36	39,954	2.727	39,855.818	28
1953	I	31	25.875	1,207	136,451	46.647**	80,147.657	30
1953	II	24	13.440	647	87,938	48.140**	56,791.497	23
1954	I	25	19.385	530	70,576	27.341*	56,085.414	24
1954	II	23	9.625	639	78,605	66.390*	36,182.039	22
Sums:		320	200.354	4,912	876,990	24.517** ± 6.777	682,618.021	311

[1] To obtain a linear influence of age of dam, the cows were grouped in 3 age categories as follows: 3; 4 and 9; 5, 6, 7 and 8.

**Statistically significant at the 1 per cent level of probability.

*Statistically significant at the 5 per cent level of probability.

Table 11. Regression of weights of heifer calves adjusted to 270 days of age (Y) on age of dam[1] (X).

Year	Ranch	d.f.	Sums of Squares and Products			Values of b and 95 Per Cent Interval	Errors of Estimate	
			Sx^2	Sxy	Sy^2		Sums of Squares	d.f.
1949	I	50	15.647	-82	136,927	-5.241	136,497.269	49
1950	I	56	37.930	326	99,884	8.595	97,082.102	55
1951	I	55	36.214	658	105,700	18.170*	93,744.292	54
1952	I	25	14.346	75	45,424	5.228	45,031.905	24
1952	II	25	21.846	301	49,588	13.778	45,440.742	24
1953	I	32	16.061	-59	20,788	-3.673	20,571.264	31
1953	II	28	18.828	667	67,510	35.426**	43,880.884	27
1954	I	27	12.964	26	69,141	2.006	69,088.856	26
1954	II	25	12.462	314	30,903	25.197**	22,991.268	24
Sums:		323	186.298	2226	625,865	11.949** ± 6.227	574,328.582	314

[1] To obtain a linear influence of age of dam, the cows were grouped in 3 age categories as follows: 3; 4 and 9; 5, 6, 7, and 8.

**Statistically significant at the 1 per cent level of probability.

*Statistically significant at the 5 per cent level of probability.

Table 12. Analysis of errors of estimate from average regression (from analysis of data on bull calves in Table 10).

Source of Variation	D.F.	Errors of Estimate	
		Sums of Squares	Mean Squares
Deviation from average regression within subclasses	319	756,564.433	
Deviation from individual subclass regressions	311	682,618.021	2,194.913
Differences among subclass regressions	8	73,946.412	9,243.302**

**Statistically significant at the 1 per cent level of probability.

Table 13. Analysis of errors of estimate from average regression (from analysis of data on heifer calves in Table 11).

Source of Variation	D.F.	Errors of Estimate Sums of Squares	 Mean Squares
Deviation from average regression within subclasses	322	599,267.420	
Deviation from individual subclass regressions	314	574,328.582	1,829.072
Differences among subclass regressions	8	24,938.838	3,117.355

subclass regressions for bull calves were highly significant (Table 12), whereas differences for the heifer calves were insignificant at the 5 per cent level of probability (Table 13). A test of homogeneity of the average regression coefficients for the 2 sexes indicated that the difference was highly significant.

From the data presented in Tables 10, 11, 12, and 13, it was determined that the age of dam accounted for 13.7 and 4.2 per cent of the variation in age-adjusted weaning weights of the bull and heifer calves respectively (on ranches within years).

The association of mean weaning weights with the magnitude of age-of-dam influence, for calves of each sex, is indicated in Table 14. Although the hypothesis that beta is equal to zero was accepted in both cases, an appreciable positive association between the two variables was evident in the bull data. A slight negative association was exhibited by the data for the opposite sex.

Because 8-year-old cows produced relatively light heifer calves and heavy bull calves, the evaluation of this age group remained uncertain. To determine the grouping of cow ages that would result in the greatest reduction in weight variation for calves of both sexes, the cows were regrouped as follows: 3; 4, 8, and 9;

Table 14. Estimated influences of variation in mean age-adjusted weaning weights of calves upon the magnitude of age-of-dam effects.[1]

Sex	Observations	Sums of Squares and Products			b	Errors of Estimate	
		Sx^2	Sxy	Sy^2		Sums of Squares	d.f.
Male	9	5,624	1,826.170	4,340.197	0.3247	3,747.221	7
Female	9	3,980	-274.395	1,456.344	-0.0689	1,437.426	7

[1] Regression coefficients obtained for the ranch-within-year subclasses (Tables 10 and 11) were regressed upon the mean age-adjusted weaning weights of the subclasses from which they were derived.

5, 6, and 7. All analyses were then repeated.

After regrouping the cows into the alternative age categories, the average regression coefficient calculated from the bull data was about 1 pound less than the 24.517 pounds previously determined; the previous value of 11.949 derived from the heifer data was increased by 1.74 pounds. Both coefficients were significant at the 1 per cent level of probability. In agreement with the initial calculations, the differences among subclass regressions were highly significant for the males and insignificant at the 5 per cent level of probability for the females (Tables 15 and 16). As before, the difference between the average regression coefficients for the two sexes was highly significant.

Upon completion of the calculations described, the portions of the weight variation removable by adjustments for age of dam were estimated from Tables 10, 11, 15, and 16. The age-of-dam factor accounted for 11.5 per cent of the variation in age-adjusted weaning weights of the bull calves on ranches within years. It accounted for only 5.3 per cent of the analogous variation in the weights of heifer calves.

The Influence of Sex on Weaning Weights

The means of the weaning weights adjusted for age of calf and age of dam are presented by sexes within ranches

Table 15. Analysis of errors of estimate from average regression (after regressing age-adjusted weaning weights of bull calves on ranches within years upon the alternative age-of-dam subclass consolidations[1]).

Source of Variation	D.F.	Errors of Estimate	
		Sums of Squares	Mean Squares
Deviation from average regression within subclasses	319	776,186.024	
Deviation from individual subclass regressions	311	713,968.648	2,295.719
Differences among subclass regressions	8	62,217.376	7,777.172**

[1] Cows were grouped in the following age categories to obtain an alternative estimate of age-of-dam influence by linear regression: 3; 4, 8, and 9; 5, 6, and 7.

**Statistically significant at the 1 per cent level of probability.

Table 16. Analysis of errors of estimate from average regression (after regressing age-adjusted weaning weights of heifer calves on ranches within years upon the alternative age-of-dam subclass consolidations[1]).

Source of Variation	D.F.	Errors of Estimate	
		Sums of Squares	Mean Squares
Deviation from average regression within subclasses	322	592,694.410	
Deviation from individual subclass regressions	314	573,534.021	1,826.541
Differences among subclass regressions	8	19,160.389	2,395.049

[1] Cows were grouped in the following age categories to obtain an alternative estimate of age-of-dam influence by linear regression: 3; 4, 8, and 9; 5, 6, and 7.

and years in Table 17. The average weight of the male calves was appreciably greater than that of the females in each ranch-within-year subclass. The differences between the weights of calves of opposite sex changed considerably from year to year on ranch I, ranging from 44 to 99 pounds over a 6-year period. Furthermore, the sex differences were consistently greater on ranch I than on ranch II from 1952 through 1954. Although ranch II produced the heavier heifer calves in 1953, ranch I produced the heavier calves of both sexes in all other cases.

An evaluation of the sex X sire interaction within ranches and years is summarized in Table 18. Here it may be seen that the interaction between these two variables was insignificant at the usual levels of probability.

The difference in the weaning weights of bull and heifer calves produced on ranch I from 1949 through 1954 was highly significant (Table 19). Differences among weaning weights among years also were significant at the 1 per cent level of probability. In addition, a highly significant sex X year interaction was apparent.

When the data obtained on both ranches from 1952 through 1954 were combined in a single analysis, the weaning weights of male and female calves were found to differ significantly at the 1 per cent level of probability (Table 20). Furthermore, the differences in

Table 17. Adjusted weaning weights of calves by sexes within ranches and years.

		Adjusted Weights[a]				
		Bulls		Heifers		Differences[b]
Year	Ranch	Number	Weight (lbs.)	Number	Weight (lbs.)	(B - H) (lbs.)
1949	I	49	519	51	475	44
1950	I	52	539	57	468	71
1951	I	57	491	56	442	49
1952	I	34	570	26	498	72
	II	30	525	26	472	53
1953	I	32	577	33	501	76
	II	25	561	29	507	54
1954	I	26	569	28	470	99
	II	24	529	26	452	77

[a] Adjusted to 270 days of age and to a 5- to 8-year-old dam equivalent.

[b] Average weight of bulls minus average weight of heifers.

Table 18. Sex X sire influence on weaning weights within ranches and years (1949 through 1954).

Source of Variation	Sums of Squares	D.F.	Mean Squares	F
Sex X sire within ranches and years	33,622	23	1,461.8	0.74
Calves within sires, ranches, and years	1,171,403	597	1,962.1	

Table 19. Analysis of sex and year effects on weaning weights (ranch I, 1949 through 1954).

Source of Variation	Sums of Squares	D.F.	Mean Squares	F
Sex	534,819	1	534,819.0	243.71**
Year	309,413	5	61,882.6	28.20**
Sex X Year	37,455	5	7,491.0	3.41**
Calves within sexes and years	1,073,086	489	2,194.5	

**Significant at 1 per cent level of probability.

Table 20. Analysis of sex, ranch, and year effects on weaning weights (1952 through 1954).

Source of Variation	Sums of Squares	D.F.	Mean Squares	F
Sex	437,614	1	437,614.0	225.63**
Ranch	55,150	1	55,150.0	28.44**
Year	52,182	2	26,091.0	13.45**
Sex X ranch	10,218	1	10,218.0	5.27*
Sex X year	10,395	2	5,197.5	2.68
Ranch X year	16,710	2	8,355.0	4.31*
Calves within sexes, ranches, and years	634,229	327	1,939.5	

**Significant at 1 per cent level of probability.
*Significant at 5 per cent level of probability.

weaning weights between ranches and among years were significant at this same probability level. The sex X ranch and ranch X year interactions were significant at the 5 per cent level. Contrary to the evidence obtained on ranch I over a longer period, the sex X year interaction was insignificant.

The Heritability of Weaning Weights

The estimates of the heritability of weaning weight by paternal half-sib correlations, within sexes, are shown in Tables 21 and 22. These calculations are accompanied by summaries of the complete variance analyses, the expected mean squares, and estimates of the proportions of the total variation attributable to each of the variables considered.

Attention is invited to the marked difference in the heritability estimates and the differences in the apparent influences of the other variables upon the sexes. The estimated heritability of weaning weight for bull calves was 28 per cent, whereas the estimate for heifer calves was 57 per cent. That fraction of the total variance attributable to error was similar for both sexes. While sires accounted for a larger proportion of the weight variation in heifer calves, ranch differences accounted for more of the variability in the weights of the bull calves. Year differences accounted for 11 and

Table 21. Variance analysis and estimated heritability of weaning weight of bull calves.

Source of Variation	Sums of Squares	D.F.	Mean Squares	Expected Mean Squares
Total	1,027,129	328	3,131.49	$V_e + 11.663V_s + 40.459V_r + 55.316V_y$
Between years	216,133	5	43,226.60	$V_e + 11.725V_s + 40.727V_r + 54.737V_y$
Between ranches within years	54,393	3	18,131.00	$V_e + 11.906V_s + 28.302V_r$
Between sires within ranches and years	89,503	23	3,891.43*	$V_e + 9.690V_s$
Within sires within ranches and years	667,100	297	2,246.13	V_e

Variance component	Calculated Variance	Per cent	Heritability estimate with 95% confidence interval
Error (V_e)	2,246.13	69	$= \frac{4V_s}{V_s + V_e} = 0.28 \pm 0.32$
Sires (V_s)	169.79	5	
Ranches (V_r)	489.84	15	
Years (V_y)	347.76	11	
Total (V_t)	3,253.52	100	

*Statistically significant at the 5 per cent level of probability.

Table 22. Variance analysis and estimated heritability of weaning weight of heifer calves.

Source of Variation	Sums of Squares	D.F.	Mean Squares	Expected Mean Squares
Total	747,112	331	2,257.14	$V_e + 12.795V_s + 41.349V_r + 55.572V_y$
Between years	128,371	5	25,674.20	$V_e + 12.658V_s + 41.363V_r + 55.286V_y$
Between ranches within years	14,314	3	4,771.33	$V_e + 12.445V_s + 27.945V_r$
Between sires within ranches and years	100,124	23	4,353.22**	$V_e + 9.504V_s$
Within sires within ranches and years	504,303	300	1,681.01	V_e

Variance Component	Calculated Variance	Per cent
Error (V_e)	1,681.01	72
Sires (V_s)	281.17	12
Ranches (V_r)	-14.63	0
Years (V_y)	380.55	16
Total (V_t)	2,328.10	100

Heritability estimate with 95% confidence interval $= \frac{4V_s}{V_s + V_e} = 0.57 \pm 0.41$

**Statistically significant at the 1 per cent level of probability.

16 per cent of the weight variance of bull and heifer calves respectively.

DISCUSSION AND CONCLUSIONS

The Influence of Age at Weaning on Weaning Weights

Because the increase in weight during the growing period is a function of time, the discrepancy in weaning age is one of the environmental variables masking hereditary influences upon the weaning weights of beef calves. For this reason, the adjustment of observed weights to a common age equivalent is essential. The calves involved in the current study varied from 121 to 323 days of age, with a mean age of about 270 days. This mean value was selected as the standard age.

Prior to the statistical treatment of the data, preliminary observations were made to ascertain the approximate weight-age relationship within the segment of the growth curve involved and to determine the advisability of treating the two sexes as a single population.

The unadjusted data (Table 1) show that the mean weaning weight of bull calves was consistently heavier than that of heifer calves in the same subclass. Furthermore, the mean weaning ages associated with the weight comparisons were not sufficiently discrepant to account for the heavier weights of the males. When a 5-pound advantage in birth weight was allowed for the bull calves (Roubicek _et_ _al_. 56, p.14), this also failed to add materially to the explanation. A part of the differences was therefore attributed to more rapid gains by the bull calves. That the latter was apparently true between the ages of 121 and 323 days may be seen by comparing Figures 1 and 2. This evidence, combined with evidence that the weights of bull calves were slightly but quite consistently more variable than those of the heifer calves (Table 1), lent support to a supposition that each sex represented a distinct population.

The mean weights in the 20-day age arrays (Figures 1 and 2) indicate that the growth rates of both sexes were more linear than curvilinear. It must be recognized, however, that the plotted means were not all derived from the same number of observations (Tables 2, 3, 4, and 5). In general, the means of the arrays near the ends of the distributions were based upon the fewest observations and should, on the average, provide the least accurate estimates. On the other hand, these means adhered reasonably well to the general trends.

Also worthy of consideration is the fact that the observations constituting all arrays in a subclass were obtained on or about the same date. This required the assumption that date of birth had a negligible influence upon rate of gain from birth to the actual weaning age. The data did not permit a suitable evaluation of the accuracy of such an assumption.

The assumption of a linear weight-age relationship, verified to some degree by the evidence presented in Figures 1 and 2, is supported only in part by reports noted in the literature review. Prior work of this nature was confined largely to animals that were weaned considerably younger. The assumption that the growth rate is uniform between the ages of 120 and 260 days of age was adequately supported (2, 7, 21, 34, 45, 54, and 57), but the reported curves were not extended to include more advanced weaning ages.

Following the preliminary evaluations previously discussed, the 20-day age arrays were discarded. Individual days within the age range functioned as the arrays in the subsequent analyses. The data were initially divided into 20-day arrays only for convenience in examining trends and for statistical measurements of the deviations from linearity, had the latter been considered necessary.

The analyses of the data, with the average regression coefficients representing rate of gain from 121 to 323 days of age, are summarized in Tables 6 and 7. The sexes were considered separately, and the data were analyzed by ranches within years to eliminate the average effects of these variables. An earlier examination of the data revealed that, in each subclass, the sire and age-of-dam influences were apparently distributed at random. The year 1952 was an exception because 2 sires were denied the opportunity to produce extremely late calves. There were, however, very few calves in this category. Since the sire and age-of-dam influences were well distributed, these factors were not considered in the regression of weight on weaning age.

The average regression coefficients differed significantly from zero at the 1 per cent level of probability. The coefficient for bull calves, with the 95 per cent confidence interval, was 1.442 ± 0.146. The coefficient for the heifer calves was 1.090 ± 0.120. These coefficients estimate the average daily gains between the ages of 121 and 323 days. The maximum adjustment would be required to convert 121-day weights to the 270-day equivalents. If the population parameters estimated by the coefficients are within the confidence intervals calculated, the maximum conversion errors that could occur would be 22 and 18 pounds for bull and heifer calves respectively. From the standard deviations of the actual weaning ages within subclasses (Table 1) and the number of observations constituting the arrays (Tables 2, 3, 4, and 5), it may be determined that these extreme adjustments would be few in number.

Insignificant differences among the subclass regressions (Tables 8 and 9) led to the conclusion that the subclasses within sexes were from a common population. The use of average regression coefficients to estimate daily gains within sexes thus received support.

A test of homogeneity of the average regression coefficients for the two sexes indicated that the difference in growth rate between the ages of 121 and 323 days was highly significant. This supported the earlier supposition that separate estimates were desirable. While a single coefficient was considered applicable to both sexes in most of the literature cited, this probably resulted from the fact that prior studies were based upon animals weaned at earlier ages and that steers or a combination of steers and bulls often constituted the male sex. Rollins and Guilbert (53, p.521-522), however, reported weights indicating that the gains of their bull calves (from 4 to 8 months of age) must have exceeded the gains of the heifer calves by an amount similar to that reported in this paper. Rice (51, p.20) also found that bull calves gained 0.16 pound per day more than heifers and used separate factors to adjust weaning weights to a standard age of 205 days.

After it was determined that the average regression coefficients were justifiable estimates of an assumed linear weight -age relationship between the ages of 121 and 323 days, the weights of calves at the more extreme ages were adjusted to the 270-day equivalents. The estimating equation, as used by Hitchcock et al. (23, p.8), was $CW = W - bA + bK$; where CW was the corrected weight, W was the actual weight, A was the actual age, K was the constant age, and b was the average regression coefficient. These adjusted weights were compared with those of calves that were actually weighed near the standard age. When comparisons were made within sire and age of dam, the adjusted weights were generally within the expected range. There was inconclusive evidence that penalties were imposed against calves weaned at 160 days of age or less, but only about 3 per cent of all calves were in this category.

Linear regression of weight on age accounted for about 54 and 50 per cent of the within-subclass variation in the weaning weights of bulls and heifers respectively. The relative amount of initial weight variation eliminated by adjusting weights to a standard age basis is, of course, dependent upon the actual age variation when the weights are obtained. It is believed, however, that the age variation encountered in the present study reflects what one might anticipate in many Southwestern range herds during the formative years of a weight selection program.

Although the variability in weaning weights may be reduced appreciably by statistical adjustment of these weights to a constant age, a physical reduction of age differences is highly desirable. Even with all other extraneous variables eliminated, the differences among age-adjusted weights need not be true indications of genetic differences at the standard age. An adjustment factor limits all animals to the same rate of gain between the actual age and the common age at which all weights are compared. Adjusted weights can, therefore, reflect the summation of genetic influences only up to the ages at which the actual weights are obtained. For this reason, the plans for a selection program should include a method of reducing the number of late calves as rapidly as feasible.

Influence of Age of Dam on Weaning Weights

That the weaning weights of beef calves are influenced by age of dam has been demonstrated many times, and reports offering such evidence were cited in the review of literature. Age of dam is, therefore, an environmental variable that must receive appropriate consideration before genetic contributions to the differences in weaning weights can be determined.

Even though the influence of age of dam on weaning weights has received much attention, prior studies determined this influence on the weights of calves weaned somewhat younger than the 270-day mean age of those upon which this report was based.

A preliminary examination of the current data was conducted after all weaning weights were adjusted to a constant age of 270 days by the linear regression coefficients previously discussed in this paper. The data were then grouped by sexes and further classified by ranches within years. The mean weights of calves weaned by cows ranging from 3 to 9 years of age were examined within the ranch subclasses. When the presence of a curvilinear trend was established, the age-of-dam subclasses were averaged over years and ranches. These averages determined the curves plotted in Figure 3.

It may be seen in Figure 3 that the age-of-dam influence on the weaning weights of each sex was curvilinear, although the curve representing the heifer data was somewhat eratic. Even though the latter was true, the relative influences of all but the 8-year-old cows were similar for the two sexes. This exceptional group produced heifer calves that were much lighter in weight than those produced by cows of adjacent ages. Such results were contrary to expectations based upon evidence provided by the data on the bull calves and by reports found in the literature (2, 6, 9, 27, 33, 35, 51, 53, and 57). For these reasons, the initial analysis of the data was based upon the assumption that the apparent influence of 8-year-old cows on heifer weights was attributable to chance deviations.

A further examination of the data plotted in Figure 3 showed that age of dam exerted a more pronounced influence upon the weights of male calves than upon those of the opposite sex. This suggested a sex X age-of-dam interaction which indicated that the two sets of data should receive separate attention.

The curves plotted in Figure 3 also show that cows of several ages weaned calves of similar weights. By grouping these ages, on the basis of similarities in the weights of the offspring, it was possible to express the age-of-dam influences in terms of straight lines (Figures 4 and 5). For this purpose, the ages were grouped as follows: 3; 4 and 9; 5, 6, 7, and 8. It may be seen in Figures 4 and 5 that 3-year-old cows produced the lightest calves, and the calves weaned by those 4 and 9 years of age were intermediate between the high and low groups.

The relative age-of-dam influencesindicated by the above groups are in general agreement with several reports found in the literature. These relative influences are in close agreement with those reported by Koch and Clark (35, p.394), although the weight intervals between their 3 age groups were not as uniform. Four-year-old cows produced calves of about intermediate weights according to several authors (2, 9, 53), but these workers found that 9-year-old cows produced heavy calves. That cows ranging from 5 to 8 years of age produced heavy calves of similar weights was reported in various publications (2, 6, 9, 33, and 35).

Grouping of cows by ages associated with the production of calves of similar weights was considered desirable since it offers an advantage to stockmen for whose use the age-of-dam corrections are ultimately intended. By converting the weights of all calves to the equivalent of those produced by cows from 5 to 8 years of age, adjustments need be applied to somewhat less than half of all weights.

Having combined the age-of-dam subclasses into arrays as previously described, average regression coefficients provided estimates of the age-of-dam influences. The analyses are summarized in Tables 10 and 11. The sexes were treated separately, in conformity with the evidence presented in Figures 4 and 5. The data were analyzed by ranches within years to remove the average effects of these variables. An examination of the date showed that sire influences were randomly distributed, so sire subclasses were omitted. Because of the uniform intervals between adjacent mean weights of the arrays, values of -1, zero and +1 represented these arrays along the X axis.

The average coefficient, with 95 per cent confidence interval, derived from regression of the weaning weights of bull calves on the age-of-dam classes previously described was 24.517 ± 6.777 (Table 10). A like analysis of the heifer data resulted in a value of 11.949 ± 6.227 (Table 11). These coefficients indicated that bull and heifer calves weaned by 3-year-old cows were approximately 50 and 24 pounds lighter, respectively, than those weaned by cows ranging from 5 to 8 years of age. If the population parameters are within the confidence intervals indicated, the maximum possible errors in adjusting weights of calves by 3-year-old cows to the equivalent of those weaned by cows ranging from 5 to 8 years of age would be about 14 and 12 pounds for bull and heifer calves respectively.

Both of the average regression coefficients were highly significant, but the coefficients calculated within subclasses were not consistently significant at even the 5 per cent level of probability. The lack of significance was probably attributable, in part, to the limited size of the subclasses. Even though significance was lacking in several instances, most of the subclass coefficients were positive values. Notable exceptions, however, were those calculated for ranch I in 1949 (Tables 10 and 11). For that particular year, the coefficients representing both sexes were negative and of similar magnitude. The agreement between these values (both in trend and magnitude) suggest that something other than chance variation may have been involved, but a plausible explanation was not apparent.

The analyses of errors of estimate indicated that the average regression coefficient was a satisfactory estimate of age-of-dam influences on the weights of heifer calves (Table 13), but the analogous estimate did not apply as well to the opposite sex (Table 12). In the latter instance, the differences among subclass coefficients were highly significant. As shown in Tables 10 and 11, the subclass coefficients based on the bull calf data fluctuated over a much wider range than did those determined from the heifer data. This suggests that the age of dam influence on the weights of bull calves may vary sufficiently from year to year and ranch to ranch, even within a climatic and topographic area, to limit the value of a general correction factor.

The earlier assumption that age of dam influences on weaning weights differed sufficiently between sexes to warrant separate evaluations was supported by a test of homogeneity of the average regression coefficients. A highly significant difference between these average values indicates that each sex should be treated as a distinct population.

As determined from the data in Tables 10, 11, 12, and 13, age-of-dam influences accounted for 13.7 and 4.2 per cent of the within-subclass variation in age-adjusted weaning weights of bull and heifer calves respectively.

When the analysis of errors of estimate indicated that an average regression coefficient did not provide an entirely adequate estimate of age-of-dam influences on bull calves, it was believed that these influences might be associated to some degree with mean weaning weights. This could provide a convenient criterion on which to base a variable correction, since an evaluation of year and ranch effects on age-of-dam influences would have little or no predictive value. For this reason, the subclass regression coefficients, within sexes, were regressed on the mean age-adjusted weaning weights of the subclasses from which they were calculated.

The change in subclass regression coefficients per unit change (1 pound) in the mean weights of the subclasses on which they were calculated is reported in Table 14. For neither sex was a significant association between these factors obtained. There was, however, evidence of sufficient association between these factors in the data on bull calves to warrant further consideration as additional data becomes available.

The evaluation of age-of-dam influences was carried one step farther by reconsidering the fact that 8-year-old cows weaned heifer calves that were much lighter in weight than anticipated. This inconsistency was discussed in some detail in the preceding pages. While the observed phenomenon was contrary to published evidence, it seemed possible that the stresses of semi-arid range conditions might hasten the process of physical deterioration. For this reason, the average regression coefficients estimating age-of-dam influences were recalculated with the cow ages grouped as follows: 3; 4, 8, and 9; 5, 6, and 7.

Estimation of the age-of-dam influences by the alternative analyses altered the average regression coefficients by less than 2 pounds. Age-of-dam influences, estimated by these analyses, accounted for 11.5 per cent of the within subclass variation in weaning weights of bull calves (Tables 10 and 15). Only 5.3 per cent of the variability in the weights of heifer calves was attributable to such influences (Tables 11 and 16). The previous values were 13.7 and 4.2 per cent for bull and heifer calves respectively. As shown in Table 15, the differences among the subclass regressions determined from the bull data were still highly significant.

Since the alternative estimates resulted in no appreciable changes in precision, the original estimates (supported by published evidence) were considered the more reliable. While the limitations of these estimates were recognized and further evaluations with additional data were deemed advisable, the following correction factors were tentatively devised to adjust weaning weights to a common age-of-dam basis.

Age of Dam	Correction (lbs)	
	Bulls	Heifers
(yrs)	(add)	(add)
3	50	24
4 & 9	25	12
5 - 8	0	0

The Influence of Sex on Weaning Weights

References cited in the review of literature indicate that male and female calves respond differently to similar environments during the pre-weaning period. As a result of this, male calves are usually heavier than females at weaning time. Sex is, therefore, a genetically determined variable that must receive consideration when the calf production records of cows in a breeding herd are evaluated. If sex subclasses are disproportionate, sex also complicates the comparison of progeny by different sires. In practice, an adjustment of weaning weights to a common sex basis before the above-mentioned evaluations are undertaken is generally deemed convenient or desirable.

Although prior reports have included sex correction factors, most of these were determined under environmental conditions quite difference from those common to the desert grassland areas of the Southwest. Almost all reported correction factors were derived from data on calves weaned considerably younger than the 270-day mean age of those considered in this study. Furthermore, the differences in weaning weights of male and female calves have been inconsistent among reporting stations and among years at the same station (2, 6, 7, 31, 34, 35, 40, 47, 51, 52, 53, and 57). This has been true when the weights of heifer calves have been compared with those of either castrated or intact males.

The absence of a consistent sex difference in weaning weights was apparent in the current study (Table 17). Within ranches, the bull calves were always heavier than females at weaning time, but the size of this disparity varied over the years involved. Also worthy of note is the fact that the difference between sexes was consistently greater on ranch I than on ranch II, but the trend in this difference from year to year was in the same direction on both ranches.

It was considered quite probable that a number of factors or forces might have contributed to the inequalities that have been pointed out. One of these might have been a difference in the physiological response of the sexes to environmental changes associated with different years on the same ranch or with different ranches in the same year. Sire differences could have contributed also if a significant sex X sire interaction, as reported by Knapp and Phillips (31, p.347), were present. Weaning after some calves reached puberty, thus requiring segregation of the sexes before the weaning date, could have injected an additional variable.

The statistical analyses previously outlined were undertaken in an endeavor to explain the observed phenomena and to determine the advisability of recommending a constant sex correction to beef cattle breeders for use in their selection procedures.

The effects of segregating the sexes prior to weaning time were not subject to statistical evaluation. Calves of opposite sex were maintained in adjacent pastures, on the ranch where produced, for at least 3 months prior to weaning in 1951, 1952, 1953, and 1954. The adjacent pastures on each ranch were, however, similar in size; watering facilities were common to both pastures, and forage composition and volume were believed to be comparable.

During the first 2 years (1949 and 1950), the progeny of different sires were maintained in intact groups until weaning time, with only a few of the oldest bull calves being isolated. The pastures to which the sire groups were confined were believed to be comparable, but undetected differences that might have been present should have exerted influences on a similar number of calves of each sex.

The absence of a significant sex X sire interaction (Table 18) indicates that sires did not contribute materially to the difference in the weaning weights of bull and heifer calves. This is in agreement with the conclusion of Koger and Knox (40, p.18), although it is contrary to the findings of Knapp and Phillips (31, p.347).

Since the differences in the weaning weights attributed to sex effects were of appreciable magnitude and were highly significant (Tables 19 and 20), the advisability of adjusting the weights of all calves to a common sex basis before evaluating cow or sire production records was apparent. Tests of significance of various interactions were then made to determine whether a constant adjustment factor could be presumed to have a broad application. Analyses of differences in the weaning weights in different years or on different ranches were incidental to these tests and are not to be construed as an indication that constant adjustments for these factors were contemplated. Since a variety of variables contribute to ranch and year differences, the observed differences would be of little or no value as future adjustments.

The data collected on ranch I were first analyzed to test the significance of the sex X year interaction because these data were collected over a period of 6 years. As shown in Table 19, this interaction was highly significant. The combined analysis of the data collected on both ranches during the last 3 years of the study produced converse evidence, but fewer years were involved. The sex differences on ranch I in 1949 and 1951 were considerably smaller than at any other time (Table 17) and thus contributed materially to the sex X sire interaction variance in the first analysis.

While one might suspect that the absence of complete segregation of sexes in 1949 and 1950 should have resulted in greater uniformity of treatment and relatively uniform sex differences, this was not true. The difference in the weaning weights of bull and heifer calves was relatively small in 1949, but the difference in 1950 was large and comparable to most of the differences obtained after the practice of complete segregation was introduced. There appear to have been no changes in the treatment of the sexes in 1950 that should account for this inconsistency. The comparatively small difference in 1951, after the practice of segregating the sexes was introduced, could have resulted from inequalities in forage condition. There was, however, no subjective evidence that this was the case.

The analysis of the data collected on both ranches from 1952 to 1954 shows that the sex X ranch interaction was significant at the 5 per cent level of probability (Table 20). This was interpreted as an indication that the difference in the weaning weights of bulls and heifers was not the same on both ranches from 1952 to 1954. Here again the segregation of sexes could have been a contributing factor. On the other hand, the calves produced on ranch II during this period were significantly lighter in weight than those produced on ranch I. Existing evidence suggests that this difference was of nutritional origin. If such were the case, a difference in the physiological response of the sexes could have contributed to the observed sex X ranch interaction.

There are several points of evidence indicating that nutritional conditions were dissimilar on the two ranches. When the breeding cows were divided between the ranches before the calving season of 1952, the division was made on the basis of past production records. There is no evidence that major differences in the genetic merit of the two groups of females were responsible for the difference in weaning weights observed immediately following the division. Sires do not appear to have been a major contributing factor, since the calves weaned on both ranches in 1952 were by the same sires. Both ranches employed the same supplemental feeding program, but the cattle on ranch I were almost always in higher condition than those on ranch II. It therefore appears that variation in the quality of range forage may have contributed to the differences in weaning weights in the two localities.

The foregoing analyses lead to the conclusion that the employment of a constant factor to compensate for sex differences in weaning weights is of questionable value under conditions of environment and management similar to those encountered in this study. The existing evidence supports a recommendation that each breeder determine his own adjustment factor and that this factor be used only on a given ranch in a given year. It appears that the difference between the mean weaning weights of bull and heifer calves, after adjustment to a constant age-of-calf and age-of-dam basis, could serve as a sex correction within the limitations cited.

The data presented also support the recommendation of most workers in beef cattle breeding research that weight comparisons for selection purposes be confined to ranches within years. The analyses in Tables 19 and 20 show that weaning weights differed significantly between ranches and between years. Furthermore, the difference between ranches varied significantly from year to year.

The Heritability of Weaning Weights

Heritability, being that fraction of the observed variation resulting from genetic differences, is a population parameter of utmost importance to animal breeders. Reliable heritability estimates indicate those observed traits that may be altered appreciably through the application of appropriate breeding and selection methods. If heritability is high, selection on the basis of individual merit should prove effective. If heritability is low, properly designed progeny tests and line or family selections are worthy of consideration. With the aid of a heritability estimate, it is possible to anticipate the rate of change in a given trait if the intensity of selection is specified.

The heritability estimates reported in this paper were based upon the weaning weights of 329 bull calves and 332 heifer calves by 11 different sires. The sire comparisons were made on 2 ranches over a period of 6 years (1949-1954). A minimum of 4 sires were compared on ranch I during each of the first 3 years; during the last 3 years, 2 sires were compared annually on ranch I and like numbers were compared on ranch II. Because some of these sires were used more than 1 year and the data were analyzed by ranch within years, the degrees of freedom for sires within subclasses are in no sense indicative of the number of different sires involved.

Prior to the analyses of the data, the weaning weights were adjusted to a standard age of 270 days and to a constant age-of-dam basis. These adjustments were made within sexes by employing the correction factors reported earlier in this paper.

The influences of inbreeding on the heritability estimates were presumed to be negligible. Detailed pedigrees were not maintained prior to the initiation of the research program. For this reason inbreeding coefficients could be determined only on the basis of fragmentary records. These records produced no evidence of material inbreeding, since the cooperators had purposely avoided the mating of close relatives. At their request, a similar program was followed throughout the period during which these data were collected. An appreciable increase in the degree of inbreeding was further prevented by the introduction of sires that were not closely related to the females in the breeding herds. Five of the 11 sires involved in this study were introduced.

A separate heritability estimate was calculated from the data representing each sex for several reasons. Since the heritabilities were estimated by paternal half-sib correlations, it was conceivable that sires could have a greater influence on the weights of heifer calves than on those of bull calves if the weights were influenced appreciably by sex-linked genes. Furthermore, it was considered probable that similar genotypes might diverge in response under the somewhat different hormonal environments provided by the two sexes. In addition, the differences in weaning weights of calves of opposite sex varied appreciably among subclasses, thus reducing the accuracy of a sex adjustment factor. When the calves were segregated by sexes at the end of the breeding seasons, dissimilarities in range environments undoubtedly contributed something to the observed differences in weights. Although environmental dissimilarities were believed to be of minor consequence, there was no method by which such an assumption could be verified. Lastly, the consolidation of all calves of like sex at the end of the breeding seasons should have contributed to the uniformity of treatment within sexes. As a result, only those range differences that might have existed during the breeding seasons should have influenced the sire variance components.

The estimation of heritability by half-sib correlation methods assumes that the genetic values among half-sibs are correlated to the degree expected under a system of random mating. The breeding system employed in the experimental herds did not conform to the strict definition of random breeding, but this system should have prevented the concentration of highly divergent pools of weight-influencing genes in the different sire groups. These groups were never treated as closed, single-sire lines. Prior to the investigation, sires produced in the herd or replacement heifers were exchanged among groups to avoid close inbreeding, and heifer replacements were rotated during the experiment for the same reason. Preceding the initiation of the research program, selections were based upon visual appraisal. Weaning weights were not taken. When weights were considered, only visual estimates were employed and no accurate compensation was made for environmental influences. It was therefore assumed that selection for genes conducive to weight alterations was essentially random. When weight records were later employed, the intensity of selection was made as uniform as possible among groups.

The analyses of the data, with the resultant variance components, are summarized in Tables 21 and 22. In addition to the sire and error variance components used in the calculation of heritability estimates, the components associated with ranch and year differences are also shown. While the variation due to ranches and years was removed statistically, no attempt was made to establish correction factors for general use. Because of the many factors contributing to year and ranch differences, the prediction of future influences on the basis of past evidence could be extremely erroneous.

Of particular interest are the comparisons of the relative contributions of ranches and years to the variation in the weaning weights of bull and heifer calves. Ranch differences accounted for 15 per cent of the variation in the weaning weights of the bull calves (Table 21), but this variable contributed nothing to the differences among the weights of the female calves (Table 22). This contrast was consistent with that observed in the study of age-of-dam influences and suggested that the bull calves were more sensitive to environmental differences than were heifers presumed to be similar with respect to autosomal, growth-conditioning genes. If this were true, however, it seems reasonable to assume that year differences also should have exerted a comparatively greater influence upon the weights of male calves. This was not the case. Because of the latter discrepancy, the correct interpretation of these phenomena is not clear.

The estimates of heritability arising from the correlation of paternal half-sibs are shown in Tables 21 and 22. Heritability calculated by this method in a non-inbred population is $\frac{4\ V_s}{V_s + V_e}$, where V_s is the variance due to genetic differences among sires and V_e is the total variance minus V_s. Total variance is, therefore $V_s + V_e$. Since half sibs each receive a sample half of the sire's inheritance, V_s is $\frac{1}{4}\ V_G$, where V_G is the total genetic variance. For this reason, $4\ V_s = V_G$. It is, of course, assumed that epistatic influences are negligible and that the environmental correlations among half-sibs have been properly discounted.

The maternal half-sib correlation yields results somewhat different than the method just described because the numerator of the heritability fraction is $\frac{1}{4}\ V_G$ plus the variance due to permanent differences among cows in their maternal environmental effects plus the covariance between the genetic value of the trait and the maternal environment. The denominator is common to both fractions, since V_e of the paternal half-sib fraction includes the two components mentioned above. These two methods of estimation were adequately contrasted by Koch (36, p.783).

That the paternal half-sib correlation estimates the additive portion of the genetic variance and a small but undetermined amount of the epistatic deviations, to the exclusion of the dominance deviations, was discussed by Koch (36, p.778). With heritability thus defined, the estimates shown in Tables 21 and 22 indicate that about 28 per cent of the total variation in the weights of bull calves and 57 per cent of the variation in the weights of heifer calves should be attributable primarily to additive gene action. It should be emphasized, however, that the total variation in these analyses was that variation remaining after the contributions due to discrepancies in weaning age, age-of-dam influences, year effects and ranch effects were removed.

The approximate 95 per cent confidence intervals reported in this paper (Tables 21 and 22) overlapped to the extent that the difference between the two estimates was considered insignificant. The lower limit for heifers (heritability = 57 per cent) was 16 per cent, and the upper limit for bulls (heritability = 28 per cent) was 60 per cent. Heritability estimates are subject to large sampling errors unless a large number of sire comparisons are involved as evidenced by previous reports (29, 30, 36, and 59). Koch and Clark (36, p.779) alone reported relatively narrow 95 per cent confidence limits, but their estimates were based upon a comparison of 137 different sires and 4553 progeny.

While it is recognized that the segregation of sire progeny during the breeding seasons and the deviations from random mating could have influenced the sire variance components, these factors were presumed negligible because of apparent similarities in range vegetation and because of the selection and replacement practices followed. In view of the large sampling errors generally associated with heritability estimates, it appears that the estimates of 28 and 57 per cent compare favorably with the estimates ranging from 9 to 54 per cent reported heretofore (10, 19, 29, 30, 36, 55, 58, and 59).

SUMMARY

1. Genetic and environmental factors influencing the weaning weights of Southwestern range calves were evaluated. The evaluations were based upon the records of 329 bull calves and 332 heifer calves by 11 sires on 2 ranches over a period of 6 years. The calves were unregistered, purebred Herefords weaned at an average age of approximately 270 days.

2. The growth rates of the calves were essentially linear within sex between the ages of 121 and 323 days. These rates were represented by linear regression coefficients.

3. The linear regression coefficients representing the growth rates of bull and heifer calves, with the 95 per cent confidence intervals, were 1.442 ± 0.146 and 1.090 ± 0.120 respectively. Both coefficients were significant at the 1 per cent level of probability, and a highly significant difference between coefficients resulted in the conclusion that a separate correction factor should be used to adjust the weaning weights of calves of each sex to a standard age.

4. Approximately 54 per cent of the variation among the weights of bull calves, on a given ranch and within a

given year, was removable by using the average regression coefficient of 1.442 pounds per day to adjust the weights to a standard age of 270 days. Adjustment of the weights of heifer calves to this standard age, by employing an average coefficient of 1.090 pounds per day, removed about 50 per cent of the observed variation.

5. Age of dam exerted a significant curvilinear influence upon the age-adjusted weaning weights. The weights of calves produced by cows ranging from 3 to 9 years of age were compared.

6. Cows from 5 through 8 years of age weaned the heaviest calves. That 8-year-old cows produced heifer calves unusually light in weight was assumed to be the result of sampling error. Calves weaned by 3-year-old cows were lightest in weight. Cows at 4 and 9 years of age produced calves of similar weaning weights, and these weights were intermediate between the high and low groups.

7. Age-of-dam influences upon the weaning weights of bull calves differed significantly among the ranch-within year subclasses. For this reason, it appears that an average correction factor could vary considerably in accuracy. Age of dam influences on the weaning weights of heifer calves did not diverge significantly under the

influence of year and ranch effects.

8. Age-of-dam exerted a significantly greater influence upon the age-adjusted weaning weights of bull calves than upon those of the opposite sex. For this reason, a single set of correction factors for both sexes was considered inapplicable.

9. The following age-of-dam adjustment factors were proposed for the removal of approximately 14 and 4 per cent of the or-ranch-within-year variation in age-adjusted weaning weights of bull and heifer calves respectively.

	Correction (lbs.)	
Age of Dam (yrs)	Bulls (add)	Heifers (add)
3	50	24
4 & 9	25	12
5 - 8	0	0

10. A study of the sex influence on 270-day weaning weights revealed a highly significant difference in the weights of bull and heifer calves. This difference ranged from 44 to 99 pounds on ranch I and from 53 to 77 pounds on ranch II. Bull calves were consistently heavier than heifers.

11. An insignificant sex X sire interaction within ranches and years indicated that sires had no appreciable

influence in the weaning weights of the male and female calves.

12. The analysis of the data collected on ranch I over a 6-year period (1949 to 1954) revealed a highly significant sex X year interaction. This was not found true when the combined data from ranches I and II were considered, but the latter analysis covered a period of only 3 years (1952 to 1954).

13. The difference in the weaning weights of the bull and heifer calves varied from ranch to ranch. This was indicated by a significant sex X ranch interaction (5 per cent level).

14. The great variability of sex differences in weaning weights was presumed to be due to different physiological responses of the sexes to changing environments or to differences in treatment resulting from the segregation of the sexes prior to weaning time. While the effects of segregation were not subject to statistical evaluation, the pastures used within ranches were believed to be comparable.

15. A constant factor to adjust the weaning weights of bull and heifer calves to a comparable basis was considered to be of questionable value. The difference in

the weaning weights varied appreciably from year to year on the same ranch (ranch I) and also varied between ranches. For these reasons, breeders operating under conditions of environment and management similar to those involved in this study should find it advantageous to calculate corrections for use on a specific ranch in a specific year. The difference between the means of the weaning weights within ranches and years, after adjustment for age of calf and age of dam, should provide a reasonably realistic correction factor.

16. Highly significant differences in weaning weights among years and between ranches and a significant ranch X year interaction support a recommendation that weight comparisons be confined to single ranches and specific years in commercial practice.

17. Differences in the weaning weights of bull calves among sires within ranches and years were significant at the 5 per cent level of probability. The differences in the weights of the heifer progeny of these sires were significant at the 1 per cent level of probability.

18. Estimates of heritability of weaning weight were determined by paternal half-sib correlations within sexes. The estimate derived from the weights of bull calves, with the approximate 95 per cent confidence

interval, was 0.28 ± 0.32; the analogous estimate derived from the weights of heifer calves was 0.57 ± 0.41. Because of the wide overlap of confidence limits, the difference between the two estimates was considered insignificant.

19. Year effects accounted for approximately 11 and 16 per cent of the variation in the 270-day weaning weights of bull and heifer calves respectively, after the variation attributable to age of dam was removed.

20. Ranch effects accounted for about 15 per cent of the variation in the 270-day weaning weights of bull calves, following adjustments for differences in age-of-dam. Ranch effects did not contribute to the variation in weaning weights of the heifer calves. The reasons for the difference in the response of the sexes to ranch influences was not clear.

BIBLIOGRAPHY

1. Anderson, R. L. and T. A. Bancroft. Statistical theory in research. New York, McGraw-Hill, 1952. 399 p.

2. Botkin, M. P. and J. A. Whatley, Jr. Repeatability of production in range cows. Journal of Animal Science 12:552-560. 1953.

3. Brody, Samuel. Growth and development with special reference to domestic animals. VIII. Relation between weight growth and linear growth with special reference to dairy cattle. Columbia, 1927. 40 p. (Missouri. Agricultural Experiment Station. Research Bulletin 103)

4. Brody, Samuel and Robert C. Proctor. Growth and development with special reference to domestic animals. XXXV. Energetic efficiency of milk production and the influence of body weight thereon. Columbia, 1935. 40 p. (Missouri. Agricultural Experiment Station. Research Bulletin 222)

5. Buiatti, P. G. The heritability of live weight and height at withers and the correlation between them in Chiana heifers. Rivista di Zootecnia 27:59-63. 1954. (Abstracted in Animal Breeding Abstracts 22: no.914. 1954.)

6. Burgess, J. B., Nellie Landblom, and H. H. Stonaker. Weaning weights of Hereford calves as affected by inbreeding, sex, and age. Journal of Animal Science 13:843-851. 1954.

7. Burns, M. A. and G. I. Alexander. The growth rate of beef calves at "Brian Pastures", Central Burnett District. Queensland Agricultural Journal 82:505-508. 1956. (Abstracted in Animal Breeding Abstracts 25: no. 640. 1957.)

8. Chambers, Doyle, M. P. Botkin, and J. A. Whatley, Jr. Weaning weight of calf as a measure of mothering ability of the cow. Stillwater, 1953. 7 p. (Oklahoma. Agricultural Experiment Station. Miscellaneous Publication MP-31)

9. Clum, H. V., R. W. Kidder, and M. Koger. Environmental factors affecting weaning weights of calves at the Florida Everglades Station. Journal of Animal Science 15:1209. 1956. (Abstract)

10. Dawson, W. M. et al. Selection for increased weights of six-month-old beef calves in a Brahman-Angus population. Journal of Animal Science 13:556-562. 1954.

11. Dawson, W. M., T. S. Yao, and A. C. Cook. Heritability of growth, beef characters and body measurements in Milking Shorthorn steers. Journal of Animal Science 14:208-217. 1955.

12. Dinkel, C. A. and A. L. Musson. Beef cattle breeding research in South Dakota. Brookings, 1956. 24 p. (South Dakota. Agricultural Experiment Station. Circular 130)

13. Gerlaugh, Paul, L. E. Kunkle, and D. C. Rife. Crossbreeding beef cattle. Wooster, 1951. 33 p. (Ohio. Agricultural Experiment Station. Research Bulletin 703)

14. Gifford, Warren. Importance of high milk production in beef cows found over-estimated. Journal of Animal Science 8:605-606. 1949. (Abstract)

15. Gifford, Warren. Record-of-performance tests for beef cattle in breeding herds. Fayetteville, 1953. 34 p. (Arkansas. Agricultural Experiment Station. Bulletin 531)

16. Gowen, John W. Milk secretion. Baltimore, Williams and Wilkins, 1924. 363 p.

17. Gramlich, H. J. and R. R. Thalman. Sex and age as factors in cattle feeding. Lincoln, 1930. 55 p. (Nebraska. Agricultural Experiment Station. Bulletin 252)

18. Gray, James R. Southwestern cattle ranches. State College, 1956. 88 p. (New Mexico. Agricultural Experiment Station. Bulletin 403)

19. Gregory, Keith E., Cecil T. Blunn, and Marvel L. Baker. A study of some of the factors influencing the birth and weaning weights of beef calves. Journal of Animal Science 9:338-346. 1950.

20. Guilbert, H. R. and P. W. Gregory. Some features of growth and development of Hereford cattle. Journal of Animal Science 11:3-16. 1952.

21. Guilbert, H. R. and Alex McDonald. Weight records on purebred beef cattle during growth, gestation, and lactation together with data on reproduction. Proceedings of The American Society of Animal Production, 26th annual meeting, 1933, p. 244-253.

22. Hazel, L. N. and C. E. Terrill. Heritability of weaning weight and staple length in range Rambouillet lambs. Journal of Animal Science 4:347-358. 1945.

23. Hitchcock, Glen H. et al. Rate and efficiency of gains in beef cattle. III. Factors affecting weight and effectiveness of selection for gains in weight. Corvallis, 1955. 22 p. (Oregon. Agricultural Experiment Station. Technical Bulletin 34)

24. Johnson, Leslie E. and C. A. Dinkel. Correction factors for adjusting weaning weights of range calves to the constant age of 190 days. Journal of Animal Science 10:371-377. 1951.

25. Kidwell, James F. Some growth relations in range cattle. Journal of Animal Science 13:54-60. 1954.

26. Knapp, Bradford, Jr. et al. Record of performance in Hereford cattle. Bozeman, 1941. 30 p. (Montana. Agricultural Experiment Station. Bulletin 397)

27. Knapp, Bradford, Jr. et al. Growth and production factors in range cattle. Bozeman, 1942. 13 p. (Montana. Agricultural Experiment Station. Bulletin 400)

28. Knapp, Bradford, Jr. and W. H. Black. Factors influencing rate of gain of beef calves during the suckling period. Journal of Agricultural Research 63:249-254. 1941.

29. Knapp, Bradford, Jr. and R. T. Clark. Revised estimates of heritability of economic characteristics in beef cattle. Journal of Animal Science 9:582-587. 1950.

30. Knapp, Bradford, Jr. and Arne W. Nordskog. Heritability of growth and efficiency in beef cattle. Journal of Animal Science 5:62-70. 1946.

31. Knapp, Bradford, Jr. and Ralph W. Phillips. Differences in performance between sexes in offspring of beef bulls. Journal of Animal Science 1: 346-347. 1942. (Abstract)

32. Knapp, Bradford, Jr. and R. R. Woodward. Heritability of weights of beef steers by months during the feeding period. Journal of Animal Science 10:1026-1027. 1951. (Abstract)

33. Knox, J. H. et al. Research on the college ranch. State College, 1951. 32 p. (New Mexico. Agricultural Experiment Station. Bulletin 359)

34. Koch, Robert M. Size of calves at weaning as a permanent characteristic of range Hereford cows. Journal of Animal Science 10:768-775. 1951.

35. Koch, Robert M. and R. T. Clark. Influence of sex, season of birth and age of dam on economic traits in range beef cattle. Journal of Animal Science 14:386-397. 1955.

36. Koch, Robert M. and R. T. Clark. Genetic and environmental relationships among economic characters in beef cattle. I. Correlation among paternal and maternal half-sibs. Journal of Animal Science 14:775-785. 1955.

37. Koch, Robert M. and R. T. Clark. Genetic and environmental relationships among economic characters in beef cattle. II. Correlations between offspring and dam and offspring and sire. Journal of Animal Science 14:786-791. 1955.

38. Koch, Robert M. and R. T. Clark. Genetic and environmental relationships among economic characters in beef cattle. III. Evaluating maternal environment. Journal of Animal Science 14:979-996. 1955.

39. Koger, Marvin and J. H. Knox. A method of estimating weaning weights of range calves at a constant age. Journal of Animal Science 4:285-290. 1945.

40. Koger, Marvin and J. H. Knox. The effect of sex on the weaning weight of range calves. Journal of Animal Science 4:15-19. 1945.

41. Koger, Marvin and J. H. Knox. The repeatability of the yearly production of range cows. Journal of Animal Science 6:461-466. 1947.

42. Lush, Jay L. Animal breeding plans. 3d ed. Ames, Iowa State College Press, 1949. 443 p.

43. Lush, Jay L. Heritability of quantitative characters in farm animals. Hereditas (supplemental volume):356-375. 1949.

44. Lush, Jay L. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Proceedings of the American Society of Animal Production, 33d annual meeting, 1940, p. 293-301.

45. Lush, Jay L. et al. Normal growth of range cattle. College Station, 1930. 34 p. (Texas. Agricultural Experiment Station. Bulletin 409)

46. Lush, Jay L. and Robert R. Shrode. Changes in milk production with age and milking frequency. Journal of Dairy Science 33:338-357. 1950.

47. McCleery, Neil B. and R. L. Blackwell. A study of the effect of mild inbreeding on weaning weight and grade of range calves. Proceedings of the American Society of Animal Production, Western Sextion 5:223-227. 1954.

48. Nelms, G. E. and Ralph Bogart. The effect of birth weight, age of dam, and time of birth on suckling gains of beef calves. Journal of Animal Science 15:662-666. 1956.

49. Nichol, A. A. (Rev. by W. S. Phillips). The natural vegetation of Arizona. Tucson, 1952. 42 p. (Arizona. Agricultural Experiment Station. Technical Bulletin 127)

50. Ragsdale, A. C., E. C. Elting, and Samuel Brody. Growth and development of dairy cattle. I. Weight growth and linear growth. In: Growth and development with special reference to domestic animals. I. Quantitative data. Columbia, 1926. 182 p. (Missouri. Agricultural Experiment Station. Research Bulletin 96)

51. Rice, Frank Joseph. Factors influencing performance in range Hereford cattle. Ph.D. thesis. Columbia, University of Missouri, 1956. 89 numb. leaves.

52. Rice, F. J., A. M. Kelley, and J. F. Lasley. Length of gestation in Hereford cows and its relation to performance. Journal of Animal Science 13: 961-962. 1954. (Abstract)

53. Rollins, W. C. and H. R. Guilbert. Factors affecting the growth of beef calves during the suckling period. Journal of Animal Science 13:517-527. 1954.

54. Rollins, W. C., H. R. Guilbert, and P. W. Gregory. Genetic and environmental factors affecting preweaning growth of Hereford cattle. Journal of Animal Science 11:743. 1952. (Abstract)

55. Rollins, W. C. and K. A. Wagnon. A genetic analysis of weaning weights in a range beef herd operated under optimum and sub-optimum nutritional regimes. Journal of Animal Science 15:125-133. 1956.

56. Roubicek, C. B. et al. Prenatal development. Range cattle production. 2. Tucson, 1956. 34 p. (Arizona. Agricultural Experiment Station. Report 135)

57. Sawyer, W. A., Ralph Bogart, and Mohamed M. Oloufa. Weaning weight of calves as related to age of dam, sex and color. Journal of Animal Science 7:514-515. 1948. (Abstract)

58. Shelby, C. E. _et al_. Heritability of some pre- and post-slaughter characteristics in beef cattle. Journal of Animal Science 13:962. 1954. (Abstract)

59. Shelby, C. E., R. T. Clark, and R. R. Woodward. The heritability of some economic characteristics of beef cattle. Journal of Animal Science 14: 372-385. 1955.

60. Snedecor, George W. Statistical methods. 4th ed. Ames, Iowa State College Press, 1948. 485 p.

61. Stanley, E. B. Nutritional studies with cattle on a grassland-type range in Arizona. Tucson, 1938. 36 p. (Arizona. Agricultural Experiment Station. Technical Bulletin 79)

62. Stanley, E. B. and C. W. Hodgson. Seasonal changes in the chemical composition of some Arizona range grasses. Tucson, 1938. 16 p. (Arizona. Agricultural Experiment Station. Technical Bulletin 73)

63. Stevens, I. M. _et al_. Marketing western feeder cattle. Laramie, 1952. 92 p. (Wyoming. Agricultural Experiment Station. Bulletin 317)