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MARCUS TEBID MUNJI for the M. S.
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Title: PERFORMANCE OF THREE INBRED LINES OF HEREFORD CATTLE AND THEIR LINECROSSES

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Dr. Ralph Bogart

Three inbred and relatively unrelated lines of Hereford cattle (1. Lionheart, 2. Prince, and 3. David) developed at the Corvallis branch of the Oregon Agricultural Experiment Station as part of the W-1 project of the Western States were crossed annually from 1963 through 1965 inclusive. Data on 137 inbred and linecross calves born during the three-year period were analysed for four production traits: birth weights, suckling rates of gain, average daily gains and feed efficiency (pounds of feed per 100 pounds of gain). There were 79 male and 58 female calves. Twenty-three of the male calves were inbred while 56 were linecross calves. There were 16 inbred and 42 linecross female calves.

The purpose of the study was to compare the mean performance of any two inbred lines used to make crosses with the mean performance of their reciprocal linecrosses for possible heterotic effects.

All possible diallelic crosses were made among the three lines

in each year and all calves were weaned and feed-tested on a constant-weight basis. Male calves were feed-tested from 450 to 800 pounds and again between 800 and 1000 pounds while female calves were feed-tested from 400 to 750 pounds. They were fed all they could eat for three hours each morning and three hours each evening. The ration and other management details are described. Selection was on an index basis with automatic culling for inherited defects and abnormalities.

Results were reported separately for bull and heifer calves. Comparisons were mostly on a within-sex basis and always on a within-line basis.

For both male and female calves, there was no significant difference between the mean birth weights and mean suckling rates of gain of inbred calves and their reciprocal linecross relatives. There was a non-significant difference between male and female inbred and linecross calves. There was more variability among female than among male calves in suckling gains.

On the average, linecross calves of both sexes at younger ages within lines gained more rapidly and were more efficient than inbred calves, with the exception of the 2 x 3 + 3 x 2 linecross male calves which gained slightly less than their inbred relatives between 450 and 800 pounds body weight. The 1 x 2 + 2 x 1 linecross heifers were significantly superior ($P < 0.01$) by 0.28 pounds per day and showed a saving of about 113 pounds of feed per 100 pounds of gain over their inbred relatives. All linecross calves were non-significantly more efficient in feed utilization than their within-line inbred relatives and there were indications of more heterosis in female than male linecrosses.

However, in the 800 to 1000 pound feed test period in the males, the mean daily gain and mean feed efficiency of each pair of inbred lines exceeded those of the respective reciprocal linecrosses.

This reversal of growth rate and economy of gains between linecross and inbred calves within the 800 to 1000 pound feed-test period seems to indicate that inbred calves of the same chronological age with linecross calves are physiologically younger and consequently less rapid and less efficient in rate and economy of gains at earlier ages. The implication here is that inbreeding depresses early production traits more than it does later-life traits.

Because of the low heterotic effects obtained in this study, the suggestion is being made that, in future crosses of these inbred lines, linecross calves from linecross dams be compared with inbred calves from inbred dams since it is known that inbreeding of both dam and calf affect the performance of the calf.

Performance of Three Inbred Lines of Hereford Cattle and Their Linecrosses

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Marcus Tebid Munji

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Professor of Animal Science
in charge of major

Redacted for privacy

Head of Department of Animal Science

Redacted for privacy

Dean of Graduate School

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INTRODUCTION

The improvement of productive traits in beef cattle is slow due to the long generation interval and the long interval between calvings (442 days in Friesian cattle as reported by El-Sheikh and El-Fouly, 1962) and because of single births. This means that, on the average, cows produce less than one calf per year; consequently, economic improvement can only be made by producing heavier calves at birth, developing cows that provide adequate milk during the suckling period for rapid gains, and selecting for rapid and efficient gaining ability on feed test.

There are high positive correlations between birth weight and subsequent weights on the one hand, and suckling rate of gain and subsequent weights on the other. Limited research also indicates a moderately high repeatability of calf birth weight in certain cows. Since it is generally true that heavier calves within sex at birth will weigh more and gain more rapidly than lighter calves, the inference has, therefore, been made that selection could be effectively performed for such traits as birth weight that are known to be highly heritable and would be reflected in a higher suckling rate of gain which is not highly heritable itself. The biggest drawback to selection at an earlier weight and age is that birth weight and suckling gains are greatly influenced by age of dam, inbreeding of dam, inbreeding of calf, and the maternal environment, and may not necessarily express the genotype of the calf. It therefore becomes necessary to correlate the phenotypic expression of early production traits with the genotype of the calf and one way to do so is through inbreeding to increase homozygosity and prepotency.

Until recently, animal breeders as opposed to plant breeders, have looked at inbreeding with disfavor because of the consequential reduction in vigor and fertility. But, with the discovery of Mendel's laws and the expansion of genetic principles in the 1900's, interest was activated in hybridization, particularly in plant breeding, and to a lesser extent, in animal breeding, where much research has been directed toward the development of inbred lines and subsequent testing of these lines for combining ability in an effort to speed up improvement. Results, so far, have been very successful in plant breeding where hybrid corn has owed its development to inbreeding and linecrossing.

Although several inbred lines have been developed in beef cattle in the Western United States, there is relatively little information on results of topcrossing, linecrossing, or other estimates of combining ability in this class of livestock.

The three inbred lines of Hereford cattle used in this study were developed at Oregon State University, Corvallis, Oregon, between 1948 and 1963 as part of the Western Regional Project W-1 which resulted from the Research and Marketing Act of 1946. In total, there are currently about 66 lines of beef cattle of the principal beef breeds in the W-1 Project of the western states.

Purpose of Study

The purpose of this report, therefore, is to compare the three-year (1963 to 1965) mean performance of three inbred lines (1. Lionheart, 2. Prince, and 3. David) of Hereford beef cattle with the mean performance of their linecrosses for birth weight, suckling rate of gain, postweaning average daily gain, and the economy of feed utilization.

REVIEW OF LITERATURE

The effects of inbreeding on production traits in farm animals have been investigated and reported by several workers. A selected sample of some of the pertinent research results will be reported below, followed by a review of the results of crossbreeding, and finally, by a review of results on other factors, besides inbreeding, influencing birth weight, suckling gain, average daily gain, and feed efficiency.

Effects of Inbreeding on Production Traits

Most evidence indicates that inbreeding adversely affects growth, vitality, and reproductivity of animals. There are two classes of effects which are commonly ascribed to inbreeding: a decline in all elements of vigor such as weight, fertility, and vitality; and, an increase in uniformity within the inbred stock, correlated with which is an increase in prepotency in outside crosses. The decrease in vigor on starting inbreeding in a previously random-bred population should be directly proportional to the increase in the percentage homozygosis (Wright, 1922).

Warwick (1958) states that by 1908 it was already realized by cattle breeders in the United States of America that inbreeding often resulted in a loss of vigor and reproductive ability. At the same time, however, it was also known that inbreeding was a powerful tool for improving the predictability of breeding behavior in plants and animals. Koch (1951), Burgess, Landblom and Stonaker (1954), and Stonaker (1954) reported that, as in other species, inbreeding results in average depression of performance, particularly in reproduction. Burgess and co-workers (1954) stated that weaning weight was adversely affected by both inbreeding of the calf and the inbreeding of the dam but that the former had a greater effect. Woodward and Clark (1959) showed an appreciable increase in the number of stillbirths for inbred lines in contrast to outbred groups of cattle.

Bradford, Chapman and Grummer (1958a) developed and tested inbred lines of swine at the Wisconsin Agricultural Experiment Station to measure the effects of inbreeding on performance traits. They found that performance for all traits decreased as inbreeding progressed. The decrease was most marked for litters out of gilts, and was proportionately greater for the number of pigs raised per litter and total litter weight than for the number of pigs farrowed and individual pig weights. An increase of ten percent in litter inbreeding resulted in decreases of approximately 0. 20 pigs farrowed per litter, 0. 45 pigs raised per litter, six pounds in individual pig weight at five months of age and 75 pounds in total litter weight at five months of age. The corresponding decreases for ten percent increase in inbreeding of dam were zero and 0. 10 pigs, and 1. 5 and 20 pounds, respectively.

Clark, et al. (1963) observed that inbreeding had different effects on birth and weaning weights for male and female calves. The inbreeding of the calf had a more pronounced effect on females than on males. Partial regressions were three times as large for females for birth weight, preweaning gain, and weaning weight than for males. The inbreeding of the calf and dam had an adverse effect on birth and weaning weights. However, inbreeding of the dam had a greater effect on the growth of bulls than on that of heifers. They also found that inbreeding of calf had a large detrimental effect on postweaning weights and gains of the selected population of bulls. Similar inbreeding effects were observed for postweaning weights and gains among females.

Brinks, Clark, and Kieffer (1963b), using data on 1041 male and 986 female calves raised between the years 1934 to 1959 inclusive, observed that inbreeding of dam was associated with a decreased suckling rate of gain, with male calves being more affected than female calves. Alexander and Bogart (1961), on the other hand, found no significant decrease in suckling gain with increased inbreeding of dam. They found a positive effect of inbreeding of dam on postweaning rate of gain. Blackwell, Knox and Shelby (1957) found a significant negative association of daily gain with inbreeding, but only a slight effect of inbreeding on final weight. They also found that total digestible nutrients per pound of gain increased with an increase in inbreeding. Swiger, et al. (1961) found negative effects of both inbreeding of calf and dam for birth weight and preweaning average daily gain for their Lincoln Station data. They also found that inbreeding of calf depressed both 168-day average daily gain and feed consumption at the Lincoln Station. The inbreeding of dam had a negative effect on growth rate and feed consumption for Lincoln data and a positive effect for data from the Fort Robinson Station.

Hoornbeek and Bogart (1966) analysed the 1951 through 1962 data on calves from four inbred lines (1. Lionheart, 2. David, 3. Prince, and 4. Angus) at the Oregon Agricultural Experiment Station and observed that for suckling gain, the lower percentages of inbreeding were associated with higher suckling gain for both males and females. Mildly inbred calves gained more rapidly during the postweaning period than non-inbred calves, but performance decreased as inbreeding increased. They noted that the economy of gain tended to decrease with increased inbreeding, but there were differences among lines. Non-inbred dams in the Hereford lines had calves with a higher suckling gain than inbred dams.

An explanation of the decrease in vigor with increased inbreeding is dependent on the view that Mendelian factors unfavorable to vigor in any respect are more frequently recessive than dominant. This situation is a logical consequence of the two propositions that mutations are more likely to injure than improve the complex adjustments within an organism and that injurious dominant mutations will be promptly weeded out, leaving recessive ones to accumulate and exert their phenotypic influence, especially if they happen to be linked with favorable dominant factors (Wright, 1922).

Crossbreeding and Linecrossing

Hybrid vigor (heterosis), or the superiority of the mean performance of reciprocal F_1 crosses over the mean performance of the two parents, has been closely associated with crossbreeding in general, and topcrossing and linecrossing in particular. Hybrid vigor is of the greatest importance in species with high reproductive rates such as swine and poultry (Craft, 1955), but its importance is increasing in other species of farm animals, including beef cattle.

Crossbreeding is being used by commercial breeders of beef cattle for making combinations not otherwise possible within one breed such as the crossing of a Shorthorn bull with a Holstein cow to combine the milk-producing ability of the dam with the beef character of the sire, and also, for obtaining hybrid vigor in the calves and cows used for producing calves. The greatest advantage from crossbreeding will result from the use of crossbred cows for producing calves since hybrid vigor expresses itself most in traits related to female productivity and the livability of the young in early life

(Bogart, 1959, p. 395-396).

Many of the highly heterotic production traits in farm animals, such as milk and egg production, litter size, and spermatogenesis are sex-limited. In non-sex-limited traits such as growth, there have been indications that different degrees of heterosis exist in males and females (Brown and Bell, 1961; Clark, 1960; Cox, 1960; Gerlaugh, Kunkle and Rife, 1951; Glazener and Blow, 1951; Moreng and Thronton, 1958; Stonaker, 1963; Craig and Chapman, 1953; Brinks, Clark and Kieffer, 1963a). Stonaker (1963) observed that linecross bull calves exceeded inbred bull calves by eight percent while linecross heifer calves exceeded inbred heifer calves by 15 percent or about twice the heterotic increase in the male and heterogametic sex. The sex difference for inbreds was 42 pounds or 12 percent at weaning whereas that for the hybrids was 21 pounds or five percent. The observation of greater heterosis in heifers over bulls and a greater sex difference in inbreds than hybrids suggested a sex x mating system interaction in species where the female is the homogametic sex. Moreng and Thornton (1958) observed the 24- and 28-week weights of purebred and crossbred turkeys, and inbred and linecross turkeys. In both studies, the ratios of hybrid-to-inbred weight were greatest for toms, the homogametic sex in poultry. The ratio of crossbred-to-purebred weights in the toms was 1.09; in the hens it was 1.01. The sex x mating system interaction was more marked in turkeys than in beef cattle, indicating that appreciable amount of the heterosis in turkeys is from toms. Glazener and Blow (1951) presented topcross data on weights of broiler chickens. They showed that the topcross-to-inbred weight ratios were 1.08 for females and 1.14 for males. Craig and Chapman (1953) observed a clear-cut sex difference in 13-week individual body weights of rats. A significant ($P < .05$) interaction was found between sex and mating system (inbred, topcross, and linecross) and a single multiplicative factor of 0.72 was used to adjust male weights to a female weight basis. Linecross progenies were significantly heavier than inbred progenies. Crosses of specific lines were significantly heavier by 13.3 gm than the computed mid-parent weights. The first year results of a linecrossing experiment (Brinks, Clark and Kieffer, 1963a) suggested a corresponding sex difference in heterosis in preweaning gain and weaning weights, with linecross males and females showing a four and eight percent advantage over their inbred contemporaries, respectively.

Stonaker (1962, 1963) concluded, from some of the above observations, that heterosis in body weight (and other non-sex-limited traits) of different species of animals is largely due to the contribution of the sex chromosome. He suggests that this disproportional contribution to heterosis by the sex chromosomes be called homogametic heterosis. He estimated that 50, and 70-80 percent of the heterosis in beef cattle and turkeys, respectively, is attributed to the action of the extra sex chromosome in the homogametic sex. This conclusion is debatable since Stonaker, himself, noted as many others have, that males were heavier than females in cattle, chickens, and turkeys. It therefore seems that maleness and homogametic heterosis (if it exists) combine to produce greater growth in males. The most logical implication here is that of testosterone, the male hormone, acting in conjunction with the sex chromosome.

Bradford, Chapman and Grummer (1958b) tested inbred lines of swine in linecrossing and topcrossing combinations and observed that linecrossing resulted in a recovery of the vigor lost during inbreeding. However, there was no advantage for the linecrosses over the outbred controls. Topcrosses by inbred boars of predominantly Landrace breeding were significantly heavier at five months of age than non-topcrosses in the same herd. Their results showed that inbred and linecross boars differed in their performance in topcrossing. Chambers and Whatley (1951) observed in Duroc swine that hybrid vigor was evident in both the number of pigs per litter and total litter weights at birth and increased as litters became less dependent on the direct mothering ability of the dams. Heterosis was expressed to a greater extent in the increased viability of the pigs and the productivity of the two-line-cross gilts than in increased growth rate of individual pigs. There was a significant difference in the performance of two-line-cross litters raised by inbred sows and the performance of outbred litters produced in the same season.

Gerlaugh, et al. (1951) reported that reciprocal crosses of Hereford and Angus breeds had a heterotic advantage over the purebreds of 3.9 percent for steers and 5.8 percent for heifers. Holt (1955) concluded that the average of the weaning weights of crossbred calves was superior to that of the parental breeds by 3.5 percent.

Vernon, Harvey and Warwick (1964) observed that calves produced by F_1 cows mated to Angus sires weighed more (398 pounds) at 180 days than calves produced by any of the other 25 crossbred groups used. In reciprocal crosses, the F_1 dams produced calves which weighed more at 180 days than did either the Angus (52 pounds more) or the backcross (11 pounds more) dams. Brahman-Angus crossbred-type calves averaged 31 pounds heavier at 180 days than those from the Africander-Angus crossbreds.

Heterotic effects between Hereford, Angus, and Shorthorn breeds were studied (Wiltbank, et al., 1966) from data on 182 heifer calves from three-year-old dams and 171 heifer calves from two-year-old dams. Significant ($P < 0.01$) heterotic effects were observed for age at puberty, independent of heterotic effects on average daily gain. Heterotic effects on age and weight at puberty were greatest for the Hereford x Shorthorn and their reciprocal crosses. The Herefords were older and heavier at first estrus than either the

Shorthorn or the Angus. The authors observed that the heterosis reported here was a characteristic of the breeds used rather than of any specific sire-lines within the breeds.

Damon et al. (1961) and Flower et al. (1963) observed heterosis in beef cattle crosses. In comparing inbreds and linecrosses of Hereford cattle, Flower and co-workers noted linecross hybrid advantages of 0. 1, 4. 6, 4. 3, and 4. 7 percent for birth weight, weaning weight, post-weaning daily gain, and final body weight respectively. Damon, et al. (1961) noted a highly significant heterotic effect for 180-day weight, rate of gain on feed test, slaughter grade, and weight per day of age. Rhoad (1940) demonstrated that Brahman-Angus crosses were distinctly superior to Angus in heat tolerance as measured by rectal temperature. He concluded that the difference in the physiological response of these cattle to tropical climatic conditions are genetic in origin.

Two theoretical explanations (Poehlman, 1959, p. 35-36, 253-254) are generally given to explain the phenomenon of hybrid vigor:

> The most widely accepted explanation is based on the assumption that hybrid vigor results from bringing together favorable dominant genes. According to this theory, genes that are favorable for vigor and growth are dominant, and genes that are harmful to the individual are recessive. The dominant genes contributed by one parent may complement the dominant genes contributed by the other parent so that the F_1 will have a more favorable combination of dominant genes than either parent. . .

> Another theory explains hybrid vigor on the basis of heterozygosity being superior to homozygosity, the most vigorous individual being the one with the greatest number of heterozygous alleles. This theory is based on the supposition that there are contrasting alleles, for example a_1 and a_2, for a single locus. Each allele produces favorable yet different effects in the plant (individual)... The phenomenon of the heterozygote (a_1a_2) being superior to the homozygotes (a_1a_1 or a_2a_2) is termed overdominance.

Hybrid vigor can therefore be explained by the theories of dominance, overdominance, and epistatic gene interactions.

Other Factors Affecting Production Traits in Beef Cattle

In addition to inbreeding of calf and dam, several other factors have been shown to influence birth weight, suckling gains, weaning weight, gain on feed test, and economy of gains in beef cattle. Such factors include sex of calf, age of dam, date and season of birth of calf, size of calf at birth, milk-producing ability of the dam, effects of year and line, gestation length, and calving interval. Because the sex of the calf is the main trait considered in the present study, more emphasis has been placed on the review of literature pertaining to it. There shall be little or no literature review on some of the remaining factors.

Genetic improvement of any trait depends in part on the heritability of that trait and, the effective heritability in turn depends on the accuracy of recognizing major environmental factors affecting the trait so that adjustments can be made for them. Bonnier, Hansson, and Skjervold (1948) stated that heredity plays a very prominent role in the expression of practically all types of characters.

It has therefore been found necessary to review some of the heritability estimates of performance traits reported in the literature even though no estimates are made in the present study. Heritability estimates from the literature are reported in Table 1.

Table 1. Heritability estimates for performance traits in beef cattle.

Birth wt.	Weaning gain	Feed test gain	Feed econ.	Authors
0.35	0.21	-	-	Koch & Clark (1955b)
0.44	0.07	-	-	Koch & Clark (1955c)
0.42	0.12	0.40	-	Koch & Clark (1955d)
0.59	0.40	0.46	0.32	Shelby, *et al.* (1957)
0.72	0.23	0.60	0.22	Shelby, *et al.* (1955)
0.38	0.40	0.50	-	Brinks, *et al.* (1964)
-	-	0.60	0.46	Swiger, *et al.* (1965)

There is some evidence that heritability estimates of weaning traits are considerably lower for males than for females (Carter and Kincaid, 1959a; Pahnish, *et al.*, 1961, 1964; Blackwell, *et al.*, 1962; Brinks, et al., 1963b). Pahnish, *et al.* (1964) found that heritability estimates for weaning weight, grade, or condition score were higher for heifers than for bull or steer calves. Koch (1951) reported that the extent to which weaning weight of calves was a permanent characteristic of range Hereford cows was estimated at 0.52. Lehmann, et al. (1961) found no correlation between growth rate and type. Knapp and Black (1941) stated that approximately 80 percent of a calf's mature skeletal size is attained by weaning time, whereas only 40 percent of its mature weight has been realized by this time. Christian, Hauser, and Chapman (1965b) reported a correlation coefficient of 0. 62 between birth weight and weaning weight on a within-sex basis. This value is in agreement with those reported by Gregory, Blunn and Baker (1950), and Drewry, Brown and Honea (1959). Ragab and El-Salam (1963b) reported correlation coefficients between birth weight and body weights at 6, 12, 18 and 24 months of age as 0. 3067, 0. 7499, 0. 8316, and 0. 8516 for male calves and 0. 2579, 0. 6296, 0. 7299 and 0. 7727 for female calves, but concluded that these correlations were all of a phenotypic nature and therefore could not be used for selection purposes. Shelby, et al. (1963) reported moderate to high correlations between all weights and average daily gain and so concluded that growth rate at different ages was controlled by many of the same genes. They, however, noted that weaning weight was a better predictor of the breeding value for feed test gain and final weight than birth weight. Botkin and Whatley (1953) found that gain from birth to weaning made the greatest portion of weaning weight and so the repeatability of gain from birth to weaning seemed quite comparable to weaning weight as a guide in selection. Birth weight was considered inferior as a guide in selection except in the production of veal (Forrest, 1964).

Birth weight has received more attention both in the literature and in research on performance traits than any other trait. This is partly because birth weight is one of the first measurements that can be recorded with accuracy and partly because birth weight is fairly highly heritable. Heavier calves at birth have generally grown faster to weaning and to final weights than lighter calves. Sex of calf plays a prominent role on birth and subsequent weights.

It has long been noted that bull calves are significantly heavier at birth than heifer calves. Among beef breeds, sex differences reported range from 3.7 to 5.8 pounds with bull calves averaging about 4.7 pounds heavier than heifers (Burris and Blunn, 1952; Dawson, Phillips and Black, 1947; Gregory, Blunn and Baker, 1950; Knapp, Lambert and Black, 1940; Knapp and Phillips, 1942; Woolfolk and Knapp, 1949; Koch and Clark, 1955a; Danusoury, 1963; Brinks, et al. 1961; Koch, et al., 1959; Flower, et al., 1963; Burgess, Landblom and Stonaker, 1954; and Kassab and Stegenga, 1964a). Regab and El-Salam (1962) reported a significant influence of sex of calf on birth weight, and weights at 4, 6, 12, 18 and 24 months of age in Egyptian cattle. The difference between the mean birth weight of females and that of the males was 0.76 kg (1.68 pounds where 1 kg = 2.2046 pounds) in favor of the males. Kassab and Stegenga (1964a) reported an average birth weight of 35.8 kg (78.93 pounds) with male calves being 3.04 kg (6.7 pounds) significantly heavier than females. Brinks, et al. (1961) reported a highly significant ($P < 0.01$) difference between bull and heifer calves in birth weight. Heifers weighed seven and six percent less than bulls at birth and at weaning, respectively. Dawson, Phillips and Black (1947) found that the largest calves at birth tended to reach weaning weights and slaughter weight at a younger age. Dahmen and Bogart (1952) found that birth weight has a significant effect on both rate and economy of gains. Burris and Blunn (1952) noted that cows were nine to ten years before maximum birth weight of their calves was reached. About ten percent of the sex difference in birth weight was attributed to differences in the gestation length of the two sexes. Alim (1964) analysed the birth weights of 275 Kenana calves born in Sudan between 1951 and 1959 inclusive and noted that male calves averaged 3.7 pounds heavier than female calves. Bradley, et al. (1966) found steers (males) significantly ($P < 0.05$) heavier at birth, weaning, and final weights and made faster pre- and post-weaning gains than heifers. Koch, et al. (1959) found that bull calves averaged 5.2 pounds or 1.076 times heavier than heifers at birth and gained 0.113 pounds more per day or 1.073 times greater than heifers. Flower, et al. (1963) found a significant sex difference between bulls and heifers, with bulls weighing 5.2 pounds and 28 pounds more at birth and weaning respectively. Lawson and Peters (1964) found that male calves averaged 5.5 pounds heavier ($P < 0.01$) at birth than heifer calves.

The workers studying the influence of the physiological age of dam on birth weight have generally concluded that birth weights of calves increase with increases in the age of the dam until the cow is six to eight years of age, with the greatest change being between the first and second calves (Burris and Blunn, 1952; Eckles, 1919; Knapp, Lambert and Black, 1940; Knapp, et al., 1942; Kassab and Stegenga, 1964a; and Koger, et al., 1962).

Knapp and Phillips (1942), Flower, et al. (1963), and Dawson, Phillips and Black (1947) found that weaning weight of calves increased with increase in age of dam up to six years of age of dam and then declined. Knox and Koger (1945) found that weaning weight increased with age of dam until cows were seven years old and then declined, and that age of dam had a highly significant effect on birth weight, weaning weight and feed test gain. Venge (1948) found that calves born at first calving weighed 8 to 12 percent less than those born by full-grown dams. He concluded that weight of the calf at birth is influenced more strongly by the dam's physiological age than by her absolute size (weight). However, Vaccaro and Dillard (1966) studied the relationship between weight changes of the dam during the last third of gestation and the first six months of lactation with the calf's birth weight and the calf's gain in different periods from birth to 180 days of age, and concluded that, on the average, cows lost weight during the period from 90 days before calving to right after calving and during the first 60 days of lactation and that heavier cows at 90 days before calving tended to produce heavier calves at birth and throughout the suckling period. Each kilogram (2. 2046 pounds) of increase in dam's weight resulted in an increase of about 0. 025 kg in calf's birth weight. Lawson and Peters (1964) found that birth weight increased with increase in age of dam from two years to maturity (five years) and then declined.

Koger, et al. (1962) found that the lactation status of the dam in the breeding season was the most important factor affecting calving and weaning percentage.

Schultze (1965) studied birth weights of 300 Holstein calves in Nebraska and found that longer average calving intervals followed the birth of large calves, indicating, he concluded, that reproductive difficulties are more associated with the bearing of large calves than small calves, expecially by first calving heifers. Dams bearing calves weighing over 100 pounds at birth had an average calving interval of 447 days with 34 percent of the dams with a calving interval of over 450 days. Dams with calves weighing over 110 pounds at birth had subsequent calving intervals of 469 days while those with calves less than 90 pounds had an average calving interval of 417 days. First calving heifers bearing calves over 100 pounds in birth weight had an average calving interval of 470 days. Most of the heavy calves were bull calves. When the birth weight of the calf exceeded nine percent of the dam's body weight, reproductive efficiency was likely to be interferred with and calving interval prolonged. However, the bearing of very small calves has definite economic disadvantages.

Forrest (1964) noted no correlation between birth weight and the rate of gain at any time after the steers weighed 200 pounds. He concluded that birth weight is of importance in veal but not in beef production. Birth weight was positively correlated with body weight of steers up to seven months of age.

The weaning weights of beef calves has been shown to be largely a function of the birth weight, preweaning nutrition, age of dam, and sex of calf.

The difference between male and female beef calves at weaning has been reported as 22, 23, 26, 32, 28, and 3 to 14 pounds by Knapp, et al. (1942), Koch (1951), Koch and Clark (1955a), Koger and Knox (1945), Woolfolk and Knapp (1949), and Gregory, Blunn and Baker (1950) respectively. Christian, Hauser and Chapman (1965b) reported sex differences in weaning gains which were in agreement with those reported by Neville (1962), and Brinks, et al. (1961). Gains by eight-month-old bull calves were about 15 pounds more than those of comparable females. Christian and co-workers noted that male calves consumed less feed per pound of body weight.

Ragab and El-Salam (1962b) reported a highly significant difference of 9.62 kg (21.21 pounds) at weaning (four months of age), in favor of males between the sexes in Egyptian cattle. Neville (1962) found that steers were not significantly heavier than heifers at weaning (four months), but became significantly heavier at eight months of age. Calves that were heavier at birth were heavier at weaning and at eight months of age. Brinks, Clark and Kieffer (1963a) found a sex difference in heterosis of preweaning gain and weight, with linecross males and females showing a four and eight percent advantage respectively over their inbred contemporaries. Kassab and Stegenga (1964b) reported sex differences between male and female calves for birth weight and weight at 52 weeks of 4.1 kg (9.04 pounds) and 44.9 kg (98.99 pounds) respectively in favor of steers.

In contrast, Sawyer, Bogart and Oloufa (1948) found evidence that heifer calves under adverse range conditions were heavier at weaning than steer calves although the differences were not significant. Knapp and Phillips (1942) found that in 1940, one sire produced heifers weighing 27 pounds more than male calves at weaning. The same sire produced proportionately heavier heifers than steers when compared with other bulls in 1941.

It has long been known that the weaning weight of beef calves is influenced more by the dam's milk-producing ability than by any other single factor (Gifford, 1953; Drewry, Brown and Honea, 1959;

Neville, *et al.*, 1962). The age of dam also has significant effects on weaning weight of the calf (Knapp, *et al.*, 1942). Gifford (1953) reported that milk production in Hereford cows was greatest at six years of age. Drewry and co-workers (1959) found that older cows were heavier milk producers and that calves suckling heavier-producing cows made larger total gains from birth to six months of age, but required more milk per pound of gain. Further evidence from their study indicates that the relationships among factors associated with mothering ability change as the calf increases in age. Marlowe and Gaines (1958) stated that the age of dam was the most important source of variation, particularly among younger-age groups. The greatest differences were between first and second-calving heifers with maximum production in weaning weight in the six to ten-year-old group.

Swiger (1961), Woodward and Clark (1959), and Carter and Kincaid (1959a) reported positive associations between weaning weight and subsequent gains but Black and Knapp (1936) found a negative association between weaning weight and postweaning performance. Chrisian, Hauser and Chapman (1965b) and Swiger (1961) found that good preweaning environment handicapped early postweaning gains but enhanced later gains.

Postweaning gains and economy of gains are also influenced by sex and to a lesser extent by other factors. Morrison (1936) showed that bulls grow faster in both weight and height than heifers in all breeds of dairy cattle studied. Lush (1930) observed the growth of range cattle for several years and concluded that steers consistently grew at a faster rate and consumed less feed per pound of gain than heifers. Dahmen and Bogart (1952) found that bulls gained faster and were more efficient than heifers. The sex difference between bulls and heifers for feed efficiency was significant. Nelms and Bogart (1955) found that bull calves decreased more rapidly in economy of gains from 500 pounds to 800 pounds of body weight than heifers but that bulls were more efficient than heifers at 800 pounds.

The ability to gain rapidly is one of several valuable economic traits in beef cattle (Gregory, 1965) because (1) there is a high genetic association between postweaning growth rate and the economy of gains; (2) many of the costs of production are on a per head or per unit time basis; and (3) when killed on a weight-constant basis, faster-gaining beef cattle are younger at slaughter (more tender) than slow-gaining ones.

Winters and McMahon (1933), Bogart and Blackwell (1950), Blackwell (1951), and Black and Knapp (1936) reported a relatively close positive association between postweaning rate of gain and economy of gain, with rate of gain accounting for from 70 to 100 percent of the total variation in efficiency of gain when animals under test are fed on a weight-constant basis. Bogart and Blackwell (1950) suggested that selection for efficient gains can be made by selecting for postweaning rate of gain because growth rate data can more accurately be collected and also because of the high genetic correlation between the two traits. Dahmen and Bogart (1952) found that birth weight and age-on-test accounted for 40 percent of the variations in feed test gains. They noted that for each pound of increase in birth weight there resulted a corresponding increase of 0. 010 pound in gains per day. Birth weight also had a significant effect on feed efficiency during the feed test. Each pound of increase in birth weight resulted in a two-pound saving in total digestible nutrients (TDN) for each 100 pounds of gain in live weight. They found a correlation coefficient of 0. 42 between birth weight and economy of gains, indicating that 18 percent (r = . 18) of the variance in economy of gains is accounted for by the variations in birth weight. Nelms and Bogart (1955) found that heavier calves at birth were more efficient during feed test. For each increase in birth weight of ten pounds there was a corresponding reduction of one pound in TDN per 100 pounds of gains when based on efficiency corrected for maintenance and a reduction of 17 pounds in TDN per 100 pounds of gain when based on uncorrected efficiency. Faster-gaining calves utilized feed more efficiently than those gaining less rapidly. For each increase in gain per day of one pound there was a saving of 124 pounds in TDN per 100 pounds of gain based on uncorrected efficiency and 65 pounds based on corrected efficiency. From 90 to 94 percent of the variation in feed efficiency were accounted for by birth weight, age-on-test, and rate of gain.

Swiger, et al. (1965) reported 1.09 as the estimate of genetic correlation between daily gain and gains per unit of total digestible nutrients in beef cattle. Lindholm and Stonaker (1957) found a negative and probably large genetic correlation between growth rate and feed per pound of gain. Rollins, et al. (1962) reported a correlation of - 0.60 between rate and economy of gains while Shelby, et al. (1963) found a high correlation between all weights and postweaning daily gain, and concluded that growth rate at different ages was controlled by many of the same genes. Koch, et al. (1963) obtained a genetic correlation of 0.79 between feed efficiency and feed consumption. They estimated that, where it is not possible to measure feed consumption and compute feed efficiency, selection for rate of gain would lead to 81 percent as much genetic improvement as selecting directly for feed efficiency.

This review of literature has considered the effects of various factors on pre- and postweaning performance traits; correlations of growth in early periods where economic advantages could result from selection at an earlier age with growth in later periods; and heritabilities of traits, with inference to the economic desirability of certain performance traits over others.

MATERIALS AND METHODS

The following is a brief description of the management of the inbred Hereford cattle lines, the source of the data used in the present study, and the kind of analysis performed on the data.

Management of Inbred Hereford Cattle Lines

The foundation inbred Hereford cattle lines used in this study were named (1) Lionheart, (2) Prince and (3) David. Each line had been inbred for at least 12 years (1950-1963). The Lionheart line had been closed to outside genetic material since 1950 but an interchange of breeding females was made between the Prince and David lines prior to 1950 and each line was inbred until 1962. No outside bulls have been used in any of the three lines since 1948.

The management of the inbred lines was similar from year to year, with calves weaned at 425 pounds or during the first part of November, allowed an adjustment period in the barn until they reached 500 pounds. They were then individually fed a high-roughage ration (1953) until they reached 800 pounds in body weight. Selection was based on pre- and postweaning performance plus the score for conformation of the animals at 800 pounds, all on an index basis. Abnormalities and inherited defects were considered on a minimum culling basis (Hoornbeek, 1964; Hoornbeek and Bogart, 1966).

By 1962, it was felt that inbreeding had proceeded far enough in each of the three Hereford lines and that diallel linecrosses should be made among the three lines to test for combining ability as expressed by heterosis or the superiority of the mean performance of each linecross over the mean performance of the corresponding inbred lines. Performance data on the 1962 linecross and inbred progenies were analysed by Hoornbeek (1964).

Source of and Treatment of Data

The data used in the present study were collected from beef cattle bred at the Oregon Agricultural Experiment Station, Corvallis, from 1963 to 1965 inclusive as part of the W-1 Project of the western states. The data consisted of performance records on birth weights, suckling rate of gain, postweaning rate of gain, and feed efficiency using 137 Hereford beef calves. There were data on 79 male and 58 female calves born over the three-year period. Of the male calves, 23 were inbred and 56 were reciprocal linecross calves and there were 16 inbred and 42 reciprocal linecross female calves (Table 2).

The mating scheme for the years 1963, 1964, and 1965 was as follows:

Line of sire	Line of dam: 1	2	3
1	1 x 1	1 x 2	1 x 3
2	2 x 1	2 x 2	2 x 3
3	3 x 1	3 x 2	3 x 3

Where 1, 2, and 3 represent Lionheart, Prince, and David inbred lines respectively and 1 x 1, 2 x 2, and 3 x 3 are the inbred progenies while the rest are linecross progenies.

The numbers of animals obtained from the above mating scheme for the three-year period are presented in Table 2 by sex and mating system.

Table 2. Numbers of animals by sex and mating system.

Line of sire	sex	Line of Dam 1		Line of Dam 2		Line of Dam 3		Totals MM	Totals FF
1	M	9		6		14		29	
	F		7		11		3		21
2	M	12		8		6		26	
	F		9		5		6		20
3	M	8		10		6		24	
	F		9		4		4		17
Total	MM	29		24		26		79	
Total	FF		25		20		13		58

M = male, F = female

The management of the calves was similar from year to year for the entire three-year period (1963-65). All calves were weighed at birth and were weaned, feed-tested, and scored for condition and conformation on a constant-weight basis. Preweaning weights were recorded every two weeks. Male and female calves were weaned at 425 and 375 pounds respectively, allowed a 25-pound adjustment period, and put on feed test at 450 and 400 pounds respectively. Feed test weights were recorded every week till female calves reached 750 pounds and male calves reached 800 pounds of body weight. Male calves were feed-tested till they reached 1000 pounds of body weight when they were sent to a commercial slaughter house.

All calves were fed a roughage and grain mixture in a pelleted form. This ration was 65 percent digestible and included among other things 9. 5 percent digestible protein and 8. 6 digestible fiber. Salt was added to the ration. Calves were individually fed all they could eat during the course of three hours each morning (7 until 10 A. M.) and three hours each evening (4 until 7 P. M.). Drinking water was available at all times. Records were kept on feed consumed by each calf during the feed test period.

Selection of replacement stock was based on an index composed of suckling gains, gains during feed test, feed consumption per unit of gain and score for type and conformation. The index for each animal was constructed as follows (Alexander and Bogart, 1961):

$$\frac{S - \bar{S}}{s_S} + \frac{F - \bar{F}}{s_F} - \frac{E - \bar{E}}{s_E} + \frac{G - \bar{G}}{s_G}$$

where:

S = suckling gain

F = feed test gain

E = feed consumption per unit of gain

G = score

$\overline{S}, \overline{F}, \overline{E}, \overline{G},$ = within-line, within-year means for respective traits.

s = standard deviation

Abnormalities and inherited defects were considered on a minimum culling basis. Cows and heifers which failed to settle two years in a row were automatically culled. Two bulls were used in each line and linecross each year. These bulls were usually performance-tested the previous year.

The assumption was made that age of dam, line, age of calf, milk-producing and other effects were random and so were not given serious consideration in this study. The effects of sex of calf and year of birth were analysed. Inbred line mean performances were compared with the mean performance of their corresponding mean reciprocal linecross performance for birth weight, suckling gain, feed test gain and feed efficiency.

Analysis of Data

A simple Student's t-distribution test (Li, 1964) was run on all data to determine significance between mean performance of inbred lines (first population) compared with the mean performance of the reciprocal crosses (second population). For example, the 1 x 1 + 2 x 2 were compared with the 1 x 2 + 2 x 1 for significance of heterotic effects. Two levels of significance were chosen: the five percent ($P < 0.05$) level was considered significant; the one percent ($P < 0.01$) was considered highly significant. Highly significant differences between means were indicated by two asterisks and significant differences between means by one asterisk. Differences between means approaching significance were indicated by the plus symbol (+).

The following Student's t-distribution formula was used:

$$t = \frac{\bar{y}_1 - \bar{y}_2}{s_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)},$$

where

$\bar{y}_1$ = mean inbred performance

$\bar{y}_2$ = mean reciprocal linecross performance

s_p^2 = pooled estimate of variance

n_1, n_2 = the number of observations in the inbred and reciprocal linecross groups, respectively.

The null hypothesis was that there was no significant difference between the mean performance of the inbred lines and their corresponding reciprocal linecross mean performance. The alternate hypothesis was that mean performances were significantly different (two-tail test).

RESULTS AND DISCUSSIONS

Unadjusted means of performance traits by sexes are presented in Table 3 (male calves) and Table 4 (female calves) for all four traits analysed in this study. Most analyses were on a within-sex basis partly because of the differential sex birth weight and subsequent growth rate advantages reported in the literature in the favor of bull over heifer calves and partly because the bull and heifer calves in the present study were weaned and feed-tested at different body weights. Heifers were weaned at 375 pounds and feed-tested between 400 - 750 pounds of body weight respectively while bull calves were weaned at 425 pounds and feed-tested between 450 - 800 pounds and 800 - 1000 pounds respectively.

A preliminary study of Tables 3, 4 and 5 indicates that all mean birth weights for male calves were greater than those for female calves but the mean differences in suckling rates of gain between males and females were small (Table 5). There was, however, greater between-matings variability in the mean rate of suckling gains among heifer calves than there was among bull calves (Tables 3 and 4). It is apparent from Table 5, however, that bull and heifer calves from identical matings differed more in mean birth weight than they did in mean suckling rate of gain. The mean birth weights of male calves were consistently higher than those of female calves.

Table 3. Mean performance of inbred male calves compared with their reciprocal linecrosses during 1963-65.

Mating system combinations	Number of calves	Birth weight lb	Suckling gains (lb/day)	Feed test gain 450-800 lb	Feed test gain 800-1000 lb	Feed efficiency 450-800 lb	Feed efficiency 800-1000 lb
1 x 1 + 2 x 2	17	81.24	1.77	2.90	3.06*	598.76	763.24
1 x 2 + 2 x 1	18	78.11	1.77	3.04	2.83	575.50	794.78
1 x 1 + 3 x 3	15	79.20	1.71	2.77	2.98	627.33	749.07*
1 x 3 + 3 x 1	22	78.59	1.77	3.00*	2.92	592.91+	806.41
2 x 2 + 3 x 3	14	76.21	1.63	2.89	2.95	598.21	744.07
2 x 3 + 3 x 2	16	78.56	1.76	2.86	2.89	596.38	782.63

*Significantly superior ($P < 0.05$)

+Approaches significance

(All comparisons are on a within-line basis)

Table 4. Mean performance of inbred female calves compared with their reciprocal linecrosses during 1963-65.

Mating system combinations	No. of calves	Birth weight (lb.)	Suckling gains lb/day	Feed test gain lb/day	Feed efficiency lb feed/100 lb gain
1 x 1 + 2 x 2	12	73.08	1.70	2.03	856.25
1 x 2 + 2 x 1	20	72.45	1.63	2.31**	743.40*
1 x 1 + 3 x 3	11	72.36	1.80	2.06	820.91
1 x 3 + 3 x 1	12	70.67	1.76	2.23+	745.50*
2 x 2 + 3 x 3	9	75.89+	1.67	2.07	816.33
2 x 3 + 3 x 2	10	63.90	1.48	2.20	733.10

**Highly significantly superior

*Significantly superior

+Approaches significance

Table 5. Mean performance of calves by mating system and sex of calf during 1963-65.

Mating system combinations	Sex	No. of calves	Birth weight (lb)	Suckling gains lb/day
1 x 1 + 2 x 2	M	17	81.24	1.77
1 x 1 + 2 x 2	F	12	73.08	1.70
1 x 2 + 2 x 1	M	18	78.11	1.77
1 x 2 + 2 x 1	F	20	72.45	1.63
1 x 1 + 3 x 3	M	15	79.20	1.71
1 x 1 + 3 x 3	F	11	72.36	1.80
1 x 3 + 3 x 1	M	22	78.59	1.77
1 x 3 + 3 x 1	F	12	70.67	1.76
2 x 2 + 3 x 3	M	14	76.21	1.63
2 x 2 + 3 x 3	F	9	75.89	1.67
2 x 3 + 3 x 2	M	16	78.56	1.76
2 x 3 + 3 x 2	F	10	63.90	1.47
	M	102	78.71	1.74
	F	74	71.51	1.67

The 1 x 1 + 3 x 3 heifer calves gained faster than the 1 x 1 + 3 x 3 bull calves in the preweaning period but the difference was not significant. For reasons given above, results are reported separately for bull and heifer calves.

Mean Performance of Male Calves

The mean performances of male calves were analysed separately for pre- and postweaning performance traits.

Mean Preweaning Performance of Male Calves

The mean birth weights and suckling rates of gain for male calves were analysed and are presented in Tables 3, 6, 7 and 8. Unadjusted mean birth weights for both sexes are presented in Tables 5 and 9 while unadjusted mean suckling gains are given in Tables 5 and 10 for both sexes. Tables 6, 7 and 8 each show the mean performance of one pair of inbred lines for comparison with their respective reciprocal linecrosses. The significance of the mean differences between male and female calves was not analysed.

There was no significant difference between the inbred and linecross male calves for both birth weight and suckling rate of gain (Table 3). The variability between the inbred and linecross calves was greater for mean birth weights than for mean suckling rates of gain. On the average, the 1 x 1 + 2 x 2 and the 1 x 1 + 3 x 3 inbreds

Table 6. Mean performance of inbred male calves of the Lionheart and Prince lines and their reciprocal linecrosses by years (1 x 1 + 2 x 2 vs 1 x 2 + 2 x 1) for four traits.

Year	Mating systems	Number of calves	Birth weight lb	Suckling gain (lb/day)	Feed test gain 450-800 lb/day	Feed test gain 800-1000 lb/day	Feed efficiency 450-800 lb feed/100 lb gain	Feed efficiency 800-1000 lb feed/100 lb gain
1963	1x1 + 2x2	5	87.00	1.67	2.86	3.21	592.80	737.40
	1x2 + 2x1	7	79.57	1.71	2.84	2.64	598.14	861.00
1964	1x1 + 2x2	8	76.50	1.92	2.79	3.03	612.63	815.38
	1x2 + 2x1	5	81.00	1.92	2.89	2.79	607.20	815.20
1965	1x1 + 2x2	4	83.50	1.59	3.18	2.92	578.50	691.25
	1x2 + 2x1	6	74.00	1.72	3.38	3.08	522.67	700.50

Table 7. Mean performance of inbred male calves of the Lionheart and David lines and their reciprocal linecrosses by years (1 x 1 + 3 x 3 vs 1 x 3 +3 x 1) for four traits.

Year	Mating systems	Number of calves	Birth weight lb	Suckling gain (lb/day)	Feed test gain 450-800 lb/day	Feed test gain 800-1000 lb/day	Feed efficiency 450-800 lb feed/100 lb gain	Feed efficiency 800-1000 lb feed/100 lb gain
1963	1x1 +3x3	5	82.00	1.66	2.66	3.15	626.00	739.20
	1x3 +3x1	9	76.78	1.66	3.08	2.91	552.56	832.22
1964	1x1 +3x3	4	75.25	1.96	2.74	3.02	648.75	824.25
	1x3 +3x1	5	77.80	1.94	2.79	3.04	651.60	828.60
1965	1x1 +3x3	6	79.50	1.57	2.89	2.81	614.17	707.17
	1x3 +3x1	8	81.13	1.80	3.05	2.86	601.63	763.50

Table 8. Mean performance of inbred male calves of the Prince and David lines and their reciprocal linecrosses by years.

Year	Mating systems	Number of calves	Birth weight lb	Suckling gain (lb/day)	Feed test gain 450-800 lb/day	Feed test gain 800-1000 lb/day	Feed efficiency 450-800 lb feed/100 lb gain	Feed efficiency 800-1000 lb feed/100 lb gain
1963	2x2 +3x3	2	77.50	1.32	2.73	3.05	621.00	789.50
	2x3 +3x2	7	77.86	1.86	2.77	2.80	588.57	813.00
1964	2x2 +3x3	6	74.17	1.83	2.93	3.04	579.33	814.00
	2x3 +3x2	5	77.40	1.72	2.88	3.04	597.40	801.00
1965	2x2 +3x3	6	77.83	1.54	2.90	2.84	609.50	659.00
	2x3 +3x2	4	81.00	1.65	3.00	2.84	608.75	706.50

weighed more at birth than their respective linecrosses but the mean 2 x 3 + 3 x 2 reciprocal linecrosses showed slight heterotic effects of 2.35 pounds in birth weight and 0.13 pounds per day in suckling gains.

There was no significant mean difference between the inbred and the linecross calves in birth weight and suckling rate of gain respectively as shown by Figures 1 and 2.

Briefly, Table 5 shows that the sex of calf had no significant influence on birth weight and suckling rate of gain. However, the variability of sex effects was greater for birth weight than for suckling rate of gain. On the average, all male calves weighed more than female calves within and between lines at birth. The 2 x 3 + 3 x 2 reciprocal linecrosses showed a maximum mean difference of 14.66 pounds between male and female calves, in favor of males. Interestingly enough, the 2 x 2 + 3 x 3 inbred relatives of the above linecrosses showed the least mean difference of 0.32 pounds in favor of male calves. Greater variabilities between sexes in mean birth weights and mean suckling gains respectively are shown in Tables 9 and 10 than in Table 5 partly because the former Tables were based on smaller and often disproportionate numbers of animals (no female calf from 1 x 3 in 1963) and partly because environmental differences and dam effects between years might have been great. Male and female calves gained at approximately the same rate throughout the suckling period. The variability in mean suckling rate of gain

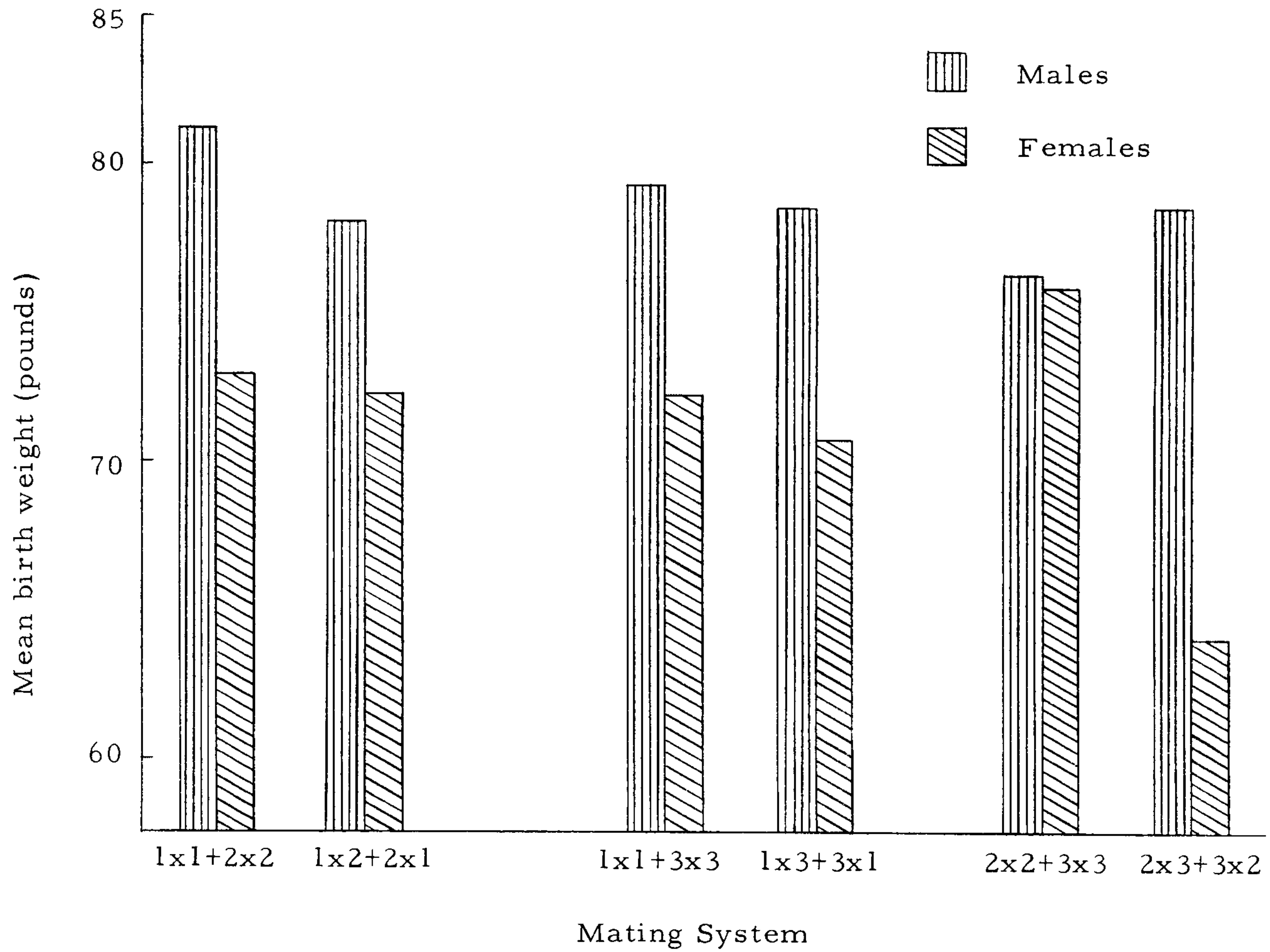

Figure 1. Three-year (1963-1965) mean birth weight of inbred and linecross Hereford calves by sex of calf.

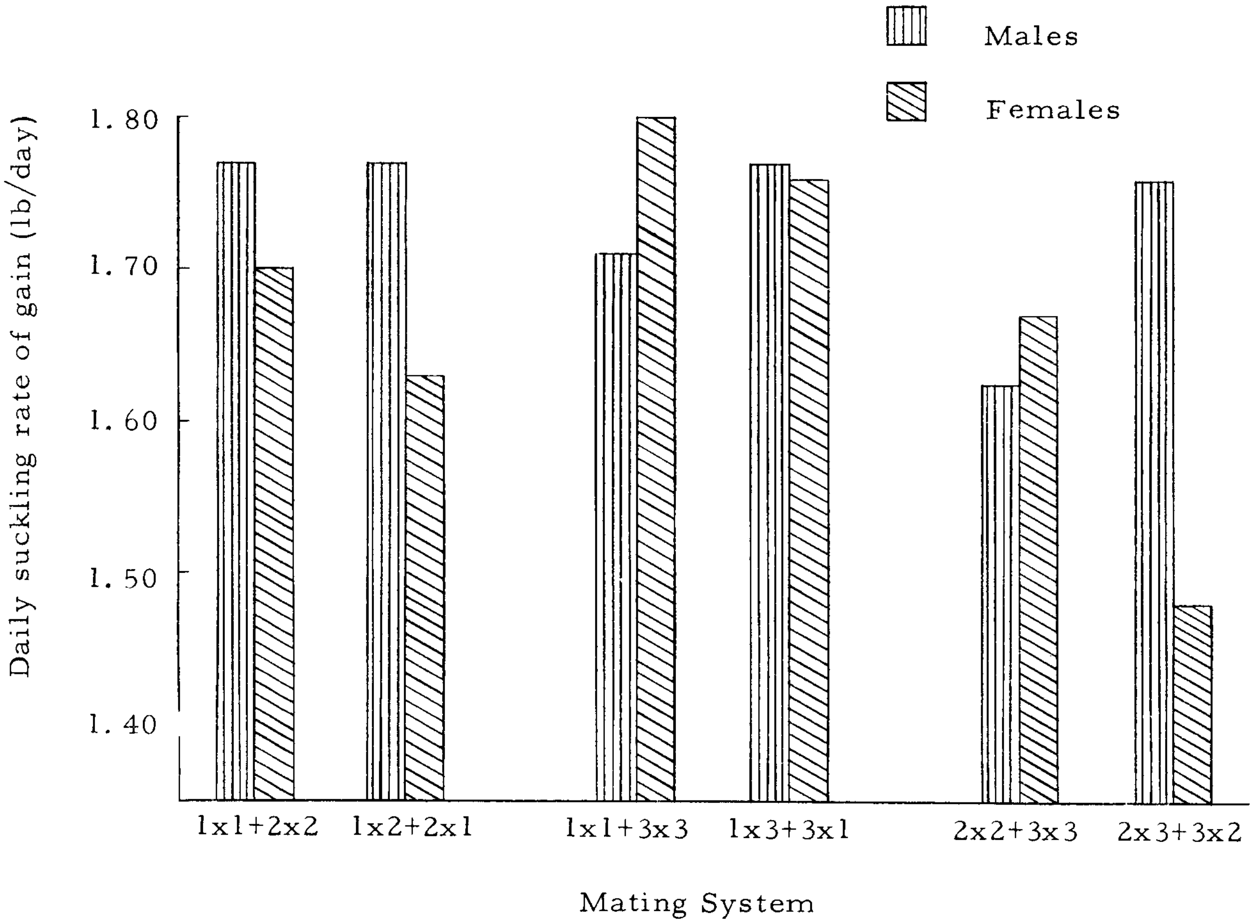

Figure 2. Three-year mean suckling rate of gain of inbred and linecross Hereford calves by sex of calf.

Table 9. Unadjusted mean birth weights of inbreds and linecrosses by year, mating system and sex of calf.

		Mating Systems								
Year	Sex	1 x 1	2 x 2	3 x 3	1 x 2	2 x 1	1 x 3	3 x 1	2 x 3	3 x 1
1963	M	86.25	90.00	65.00	73.00	80.67	75.33	79.67	80.25	74.67
	F	67.50	76.00	80.00	82.00	72.33	-	70.25	63.00	65.00
1964	M	78.00	75.60	67.00	83.50	79.33	77.67	78.00	78.00	77.25
	F	76.00	78.00	67.00	70.00	61.50	65.00	70.00	72.00	66.00
1965	M	86.00	81.00	76.25	77.67	70.33	84.00	76.33	86.00	79.67
	F	69.33	76.00	74.00	79.00	76.50	77.50	68.50	57.50	66.00
1963 to 1965	M	83.44	78.75	72.83	78.83	77.75	78.93	78.00	80.83	77.20
	F	70.71	76.40	75.25	75.73	68.44	73.33	69.78	62.67	65.75
1963 to 1965	M				78.11		78.59		78.56	
	F				72.45		70.67		63.90	

Table 10. Unadjusted mean suckling gains (lb/day) of inbreds and linecrosses by years, mating system and sex of calf.

Year	Sex	Mating Systems								
		1 x 1	2 x 2	3 x 3	1 x 2	2 x 1	1 x 3	3 x 1	2 x 3	3 x 2
1963	M	1.75	1.34	1.30	2.33	1.60	1.68	1.61	1.95	1.73
	F	1.72	1.50	1.74	1.91	1.81	-	1.57	1.61	1.31
1964	M	2.04	1.85	1.72	2.21	1.74	2.09	1.71	1.44	1.80
	F	2.01	1.84	2.38	1.48	1.53	1.74	1.95	1.94	1.44
1965	M	1.64	1.54	1.54	1.76	1.67	1.84	1.74	1.73	1.63
	F	1.71	1.44	1.37	1.45	1.78	1.81	1.80	1.13	1.51
1963 to 1965	M	1.82	1.71	1.53	2.00	1.66	1.83	1.68	1.83	1.72
	F	1.80	1.56	1.81	1.59	1.68	1.78	1.75	1.50	1.44
1963 to 1965	M				1.77		1.77		1.76	
	F				1.63		1.76		1.48	

between males and females ranged from 0.01 pound per day in the 1 x 3 + 3 x 1 to 0.29 pound per day in the 2 x 3 + 3 x 2 linecross.

These findings fail to support Stonaker's theory of homogametic heterosis where the homogametic sex is supposed to show greater heterotic effects than the heterogametic sex.

The above findings agree fairly well with those of Damon, et al. (1961) and Flower, et al. (1963) where little or no heterotic effects between linecross and inbred calves were reported for preweaning traits. Hoornbeek analysed the 1962 inbred and linecross calves of the same inbred lines used in the present study and found no significant differences between inbred and linecrosses for suckling gain.

Mean Postweaning Performance of Male Calves

The mean postweaning daily gain and mean feed efficiency (pounds of feed per 100 pounds of gain) for male calves are presented in Tables 3, 6, 7 and 8. Unadjusted three-year average daily gains and mean feed efficiencies are presented in Tables 11 and 12 respectively for both males and females.

Postweaning performance was analysed separately for average daily gain and feed efficiency.

Postweaning Average Daily Gain of Male Calves

Male calves were feed-tested from 450 pounds to 800 pounds

Table 11. Unadjusted mean postweaning daily rate of gain of inbreds and linecrosses by year, mating system and sex of calf.

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">Sex</th><th colspan="9">Mating Systems</th></tr>
<tr><th>1 x 1</th><th>2 x 2</th><th>3 x 3</th><th>1 x 2</th><th>2 x 1</th><th>1 x 3</th><th>3 x 1</th><th>2 x 3</th><th>3 x 2</th></tr>
<tr><td>1963</td><td>M_1</td><td>2. 77</td><td>3. 22</td><td>2. 23</td><td>2. 70</td><td>2. 87</td><td>3. 14</td><td>2. 98</td><td>2. 88</td><td>2. 63</td></tr>
<tr><td></td><td>M_2</td><td>3. 21</td><td>3. 19</td><td>2. 90</td><td>2. 61</td><td>2. 65</td><td>3. 02</td><td>2. 69</td><td>2. 81</td><td>2. 77</td></tr>
<tr><td></td><td>F</td><td>2. 14</td><td>1. 86</td><td>2. 05</td><td>2. 25</td><td>2. 08</td><td>-</td><td>2. 39</td><td>1. 98</td><td>2. 25</td></tr>
<tr><td>1964</td><td>M_1</td><td>2. 61</td><td>2. 89</td><td>3. 12</td><td>2. 99</td><td>2. 83</td><td>2. 61</td><td>3. 05</td><td>3. 11</td><td>2. 82</td></tr>
<tr><td></td><td>M_2</td><td>3. 02</td><td>3. 04</td><td>3. 04</td><td>2. 92</td><td>2. 71</td><td>3. 04</td><td>3. 04</td><td>3. 17</td><td>3. 01</td></tr>
<tr><td></td><td>F</td><td>1. 94</td><td>2. 08</td><td>1. 70</td><td>2. 38</td><td>2. 37</td><td>2. 09</td><td>2. 18</td><td>2. 39</td><td>2. 41</td></tr>
<tr><td>1965</td><td>M_1</td><td>3. 16</td><td>3. 21</td><td>2. 75</td><td>2. 33</td><td>3. 43</td><td>2. 90</td><td>3. 29</td><td>2. 75</td><td>3. 08</td></tr>
<tr><td></td><td>M_2</td><td>2. 87</td><td>2. 97</td><td>2. 77</td><td>3. 18</td><td>2. 97</td><td>2. 76</td><td>3. 04</td><td>3. 17</td><td>2. 73</td></tr>
<tr><td></td><td>F</td><td>1. 99</td><td>2. 51</td><td>2. 70</td><td>2. 53</td><td>2. 09</td><td>2. 12</td><td>2. 14</td><td>2. 21</td><td>2. 31</td></tr>
<tr><td>1963 to 1965</td><td>M_1</td><td>2. 81</td><td>3. 01</td><td>2. 73</td><td>3. 11</td><td>3. 00</td><td>2. 94</td><td>3. 11</td><td>2. 89</td><td>2. 84</td></tr>
<tr><td></td><td>M_2</td><td>3. 07</td><td>3. 04</td><td>2. 84</td><td>3. 00</td><td>2. 74</td><td>2. 93</td><td>2. 91</td><td>2. 93</td><td>2. 86</td></tr>
<tr><td></td><td>F</td><td>2. 02</td><td>2. 03</td><td>2. 13</td><td>2. 39</td><td>2. 21</td><td>2. 11</td><td>2. 26</td><td>2. 13</td><td>2. 32</td></tr>
<tr><td>1963 to 1965</td><td>M_1</td><td></td><td></td><td></td><td colspan="2">3. 04</td><td colspan="2">3. 00</td><td colspan="2">2. 86</td></tr>
<tr><td></td><td>M_2</td><td></td><td></td><td></td><td colspan="2">2. 83</td><td colspan="2">2. 92</td><td colspan="2">2. 89</td></tr>
<tr><td></td><td>F</td><td></td><td></td><td></td><td colspan="2">2. 31</td><td colspan="2">2. 23</td><td colspan="2">2. 20</td></tr>
</table>

M_1 = Daily rate of gain for male calves weighing 450-800 pounds.

M_2 = Daily rate of gain for male calves weighing 800-1000 pounds.

F = Daily rate of gain for females weighing 400-750 pounds.

Table 12. Unadjusted mean performance in pounds of feed per 100 pounds of gain of inbreds and line-crosses by year, mating system and sex of calf.

Year	Sex	Mating Systems								
		1 x 1	2 x 2	3 x 3	1 x 2	2 x 1	1 x 3	3 x 1	2 x 3	3 x 2
1963	M_1	606.50	538.00	704.00	621.00	594.33	546.50	564.67	573.75	608.33
	M_2	725.50	785.00	794.00	804.00	870.50	825.17	846.33	797.25	834.00
	F	767.00	971.00	747.00	710.33	755.67	-	678.25	740.67	772.00
1964	M_1	670.00	578.20	585.00	573.50	629.67	681.67	606.50	579.00	602.00
	M_2	822.67	811.00	829.00	790.50	831.67	826.00	832.50	779.00	806.50
	F	898.00	748.00	935.00	762.80	758.50	802.00	760.33	689.00	712.00
1965	M_1	585.50	571.50	628.50	511.67	533.67	633.20	549.00	666.00	589.67
	M_2	763.50	619.00	679.00	694.67	706.33	787.40	723.67	707.00	706.33
	F	883.00	635.00	622.00	675.33	798.00	773.50	801.50	737.00	731.00
1963 to 1965	M_1	623.00	571.50	633.83	550.50	588.00	606.43	569.25	590.00	600.20
	M_2	766.33	759.75	723.17	744.83	819.75	811.86	796.88	779.17	784.70
	F	854.14	859.20	762.75	724.64	766.33	783.00	733.00	730.83	736.50
1963 to 1965	M_1				575.50		592.91		596.38	
	M_2				794.78		806.41		782.63	
	F				743.40		745.50		733.10	

M_1 = Feed efficiency for males weighing 450-800 pounds.

M_2 = Feed efficiency for males weighing 800-1000 pounds.

F = Feed efficiency for females weighing 400-750 pounds.

and from 800 pounds to 1000 pounds of body weight. Some significant differences were noted between mean performance of inbred lines and their reciprocal linecrosses in both feed test periods.

For male calves from 450 to 800 pounds body weight, the average daily gains of all linecross calves exceeded the means of their inbred relatives. The difference of 0.23 pound per day or 8.3 percent between the mean 1 x 1 + 3 x 3 and the mean 1 x 3 + 3 x 1 was significant, while other differences were not significant.

Strangely enough, the daily gain situation reversed for all animals in the 800-1000 pound body weight feed-test groups where the average daily gains of the inbreds exceeded those of their corresponding linecrosses. The only significant difference was in favor of the 1 x 1 + 2 x 2 over the 1 x 2 + 2 x 1 calves. The difference was also 0.23 pound per day, or 7.5 percent. This could be called negative heterosis.

One possible explanation for the superiority of the mean performance of the linecrosses over the inbreds in the 450-800 pound body weight is that the inbred calves were physiologically younger than their corresponding linecross relatives. As the inbred calves matured into the 800 to 1000 pound body weight group, they excelled the linecrosses.

Feed Effiency. Generally speaking, feed efficiency results followed the same pattern as those for average daily gains. The mean linecross performance exceeded the mean inbred performance in the 450-800 pound body weight class but the reverse was true in the 800 to 1000 pound feed test period. The same 1 x 3 + 3 x 1 linecrosses that significantly excelled in the 450-800 pound feed test period in average daily gain approached significance in their 450-800 pound feed efficiency. However, their 1 x 3 + 3 x 3 inbred relatives did significantly better in feed effiency in the 800-1000 pound period than their reciprocal linecrosses. The saving for the latter period was 57.34 pounds of feed per 100 pounds of gain in favor of the inbreds.

Mean Performances of Female Calves

The mean performances of female calves were also analysed separately for pre- and postweaning performance traits.

Mean preweaning performance of female calves

The mean birth weights and suckling rates of gain for female calves were analysed and are presented in Table 4. The mean performances of the heifers in each pair of inbred lines and their reciprocal linecrosses are presented in Tables 13, 14 and 15.

respectively. Unadjusted mean birth weights are presented for both sexes in Tables 5 and 9 while unadjusted mean suckling gains are reported in Tables 5 and 10 for both sexes. Figures 1 and 2 also show non-significant differences between inbred and linecross female calves.

As in the males, there was no significant difference in birth or suckling gains between inbred and linecross calves for birth weight or suckling gains. All mean birth weights of inbred calves exceeded those of their linecross relatives. The birth weight difference between the mean 2 x 2 + 3 x 3 and the mean 2 x 3 + 3 x 2 approached significance (Table 4). The variability in mean birth weight differences ranged from 0.63 pound between 1 x 1 + 2 x 2 and 1 x 2 + 2 x 1 to 11.99 pounds between the 2 x 2 + 3 x 3 and their 2 x 3 + 3 x 2 relatives. Both differences were in favor of inbreds over linecrosses. The mean suckling gains of each inbred pair of lines also exceeded that of the corresponding reciprocal linecrosses. The range of suckling gain variability here was from a minimum of 0.04 pound per day between 1 x 1 + 3 x 3 and 1 x 3 + 3 x 1 to a maximum of 0.19 pound per day between the 2 x 2 + 3 x 3 and their 2 x 3 + 3 x 2 relatives (Table 4).

Mean Postweaning Performance of Female Calves

The average postweaning daily gain and mean feed efficiency for female calves are presented in Tables 4, 13, 14 and 15. Unadjusted average daily gains for the three years and unadjusted mean feed efficiencies are presented in Tables 11 and 12 respectively for both males and females.

Postweaning performance was analysed separately for average daily gain and pounds of feed per 100 pounds of gain.

Feed Test Gain. There were heterotic effects for average daily gain in all female linecrosses (Table 4). The difference between the mean daily gains of linecrosses and the mean daily gains of their inbred relatives ranged from a minimum of 0.13 pound per day to a maximum of 0.28 pound per day.

The only highly significant ($P < 0.01$) difference between inbreds and linecross mean performance was noted in average daily gains between the 1 x 1 + 2 x 2 and their 1 x 2 + 2 x 1 relatives. The difference was 0.28 pound per day in favor of the linecrosses. The difference between the mean 1 x 1 + 3 x 3 and 1 x 3 + 3 x 1 approached significance while that between the 2 x 2 + 3 x 3 and 2 x 3 + 3 x 2 was not significant.

These results follow the same trend as the data for the males between 450-800 pounds, where the linecross calves gained more rapidly than the inbreds. It would be of interest to divide the

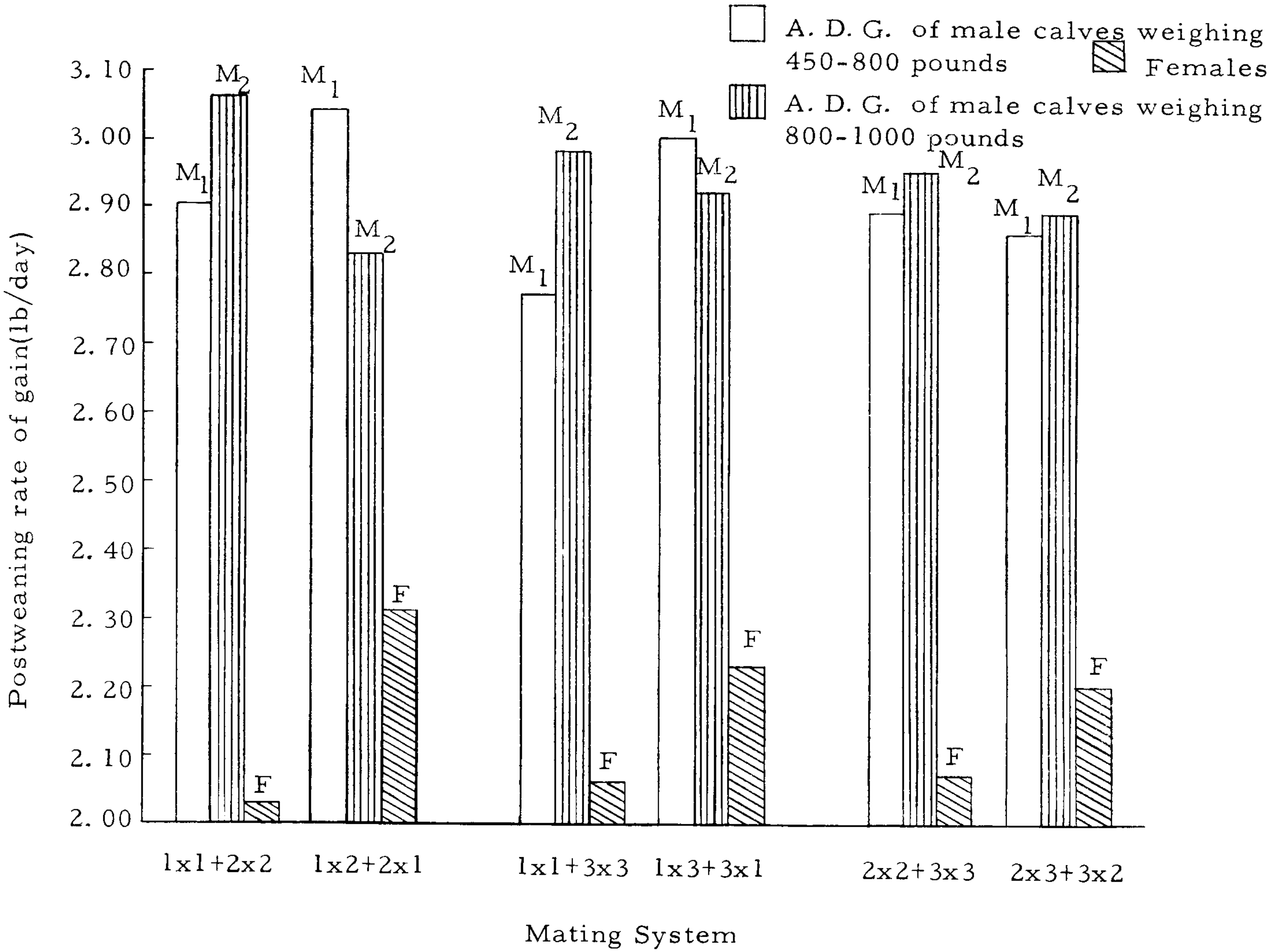

Figure 3. Three-year postweaning average daily gains (lb/day) of inbred and linecross Hereford calves by sex of calf.

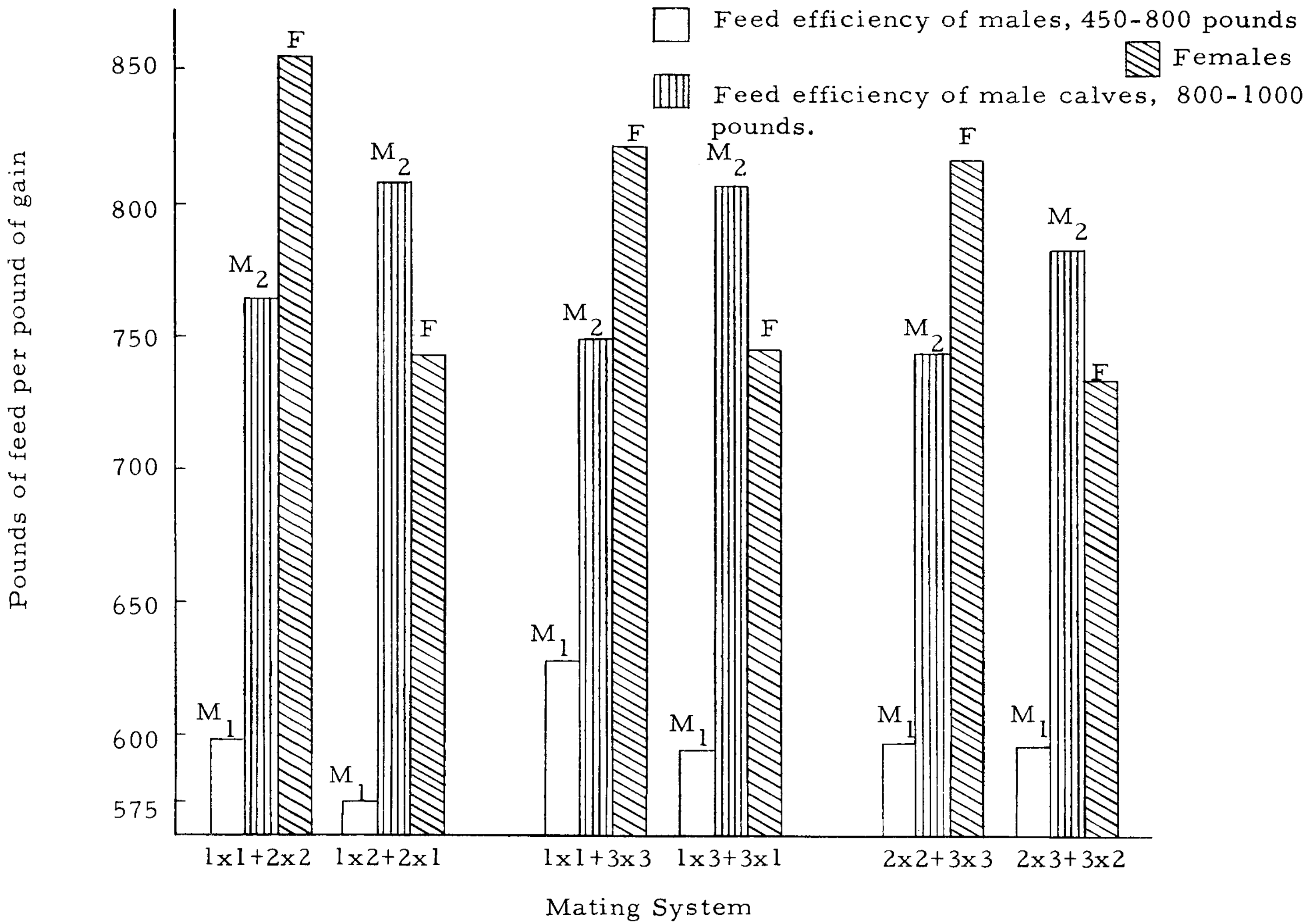

Figure 4. Three-year mean feed efficiency (pounds of feed per pounds of gain) of inbred and linecross Hereford calves by sex of calf.

Table 13. Mean performance of female Lionheart and Prince inbred lines and their reciprocal linecross calves by years.

Year	Mating system combinations	No. of calves	Birth weight	Suckling gain	Feed test gain	Feed efficiency
1963	1x1 + 2x2	5	72.60	1.59	1.97	889.40
	1x2 + 2x1	6	77.17	1.86	2.17	733.00
1964	1x1 + 2x2	3	76.67	1.95	1.98	848.00
	1x2 + 2x1	9	66.22	1.50	2.37	760.89
1965	1x1 + 2x2	4	71.00	1.65	2.12	821.00
	1x2 + 2x1	5	78.00	1.58	2.35	724.40

Table 14. Mean performance of female Lionheart and David inbred lines and their reciprocal linecross calves by years.

Year	Mating system combinations	No. of calves	Birth weight	Suckling gain	Feed test gain	Feed efficiency
1963	1x1 + 3x3	4	73.75	1.73	2.10	757.00
	1x3 + 3x1	4	70.25	1.57	2.39	678.25
1964	1x1 + 3x3	3	73.00	2.14	1.86	910.33
	1x3 + 3x1	4	68.75	1.90	2.16	770.75
1965	1x1 + 3x3	4	70.50	1.63	2.17	817.75
	1x3 + 3x1	4	73.00	1.80	2.13	787.50

Table 15. Mean performance of female Prince and David inbred lines and their reciprocal linecross calves by years.

Year	Mating system combinations	No. of calves	Birth weight	Suckling gain	Feed test gain	Feed efficiency
1963	2x2+3x3	5	77.60	1.59	1.93	881.40
	2x3+3x2	4	63.50	1.53	2.05	748.50
1964	2x2+3x3	2	72.50	2.11	1.89	841.50
	2x3+3x2	2	69.00	1.69	2.40	700.00
1965	2x2+3x3	2	75.00	1.41	2.61	628.50
	2x3+3x2	4	61.75	1.32	2.26	734.00

postweaning feed-test period of heifers into two parts as is being done for bull calves and to find out if inbred calves would catch up with and exceed their linecross relatives in the second period as was the case for male calves.

Feed Efficiency for Female Calves

On the average, reciprocal linecross female calves were more efficient in the utilization of feed than inbred calves of the same lines (Table 4). There were significant differences between the mean 1 x 1 + 2 x 2 and the mean 1 x 1 + 3 x 3 inbred calves and their respective reciprocal linecrosses. The 1 x 2 + 2 x 1 linecross calves saved about 111 pounds of feed per 100 pounds of gain as compared with their inbred relatives. The 1 x 3 + 3 x 1 and the 2 x 3 + 3 x 2 linecross calves saved, on the average, 45.41 and 83.23 pounds of feed respectively but the latter difference lacked significance, perhaps because of the greater variability in feed efficiency for the 2 x 3 + 3 x 2 than for the 1 x 3 + 3 x 1.

In general, results for both males and females agree fairly well with some of those reported in the literature. Gregory, et al. (1966) noted that heterotic effects on growth rate decreased with increasing age and so heterosis was related to age of calf. They noted non-significant heterotic effects for feed efficiency. This agrees with the superiority of the mean 1 x 1 + 3 x 3 over their linecrosses but not with results for the bull calves between 450-800 pound body weight and feed test results for heifer calves.

Results in both male and female calves indicate a fairly high correlation between average daily gains and feed efficiency within lines. The lines that excelled in average daily gains also excelled in feed efficiency.

Both male and female linecross calves gained more rapidly than their respective inbred relatives during the 400-800 pound body weight feed-test period. During the feed-test period between 800 to 1000 pound body weight, the inbred males gained more rapidly and were more efficient gainers than the linecross males. There is indications here that inbreeding depresses early growth traits but has little or no influence on later growth traits. Inbred animals at maturity would, therefore, tend to gain more rapidly and utilize feed more efficiently than the linecrosses. This means that at an early age, inbred animals of the same chronological age with linecross animals are physiologically younger than the linecross animals.

Results also suggest that more heterosis was expressed in female than male linecross calves. However, the total heterosis expressed in this study was inadequate, perhaps because the linecross calves were reared by inbred dams. It would be interesting to compare linecross calves from linecross dams with inbred calves from inbred dams in future linecross studies among these same lines.

CONCLUSIONS

The following general conclusions appear justified from the results of the present study involving inbred and reciprocal linecross calves:

1. Linecrossing did not significantly affect the average birth weight of the calves. The mean birth weights were approximately equal for inbred and linecross male and female calves. However, all mean birth weights of inbred heifer calves exceeded those of their linecross relatives. The difference between the mean birth weights of 2 x 2 + 3 x 3 and the 2 x 3 + 3 x 2 heifers approached significance.

2. Male calves of each line and linecross were heavier at birth than female calves.

3. There was no significant difference between inbred and linecross calves in suckling rates of gain. The within-sex, within-line suckling gain differences were small, particularly among male calves.

4. On the average, both male and female linecross calves gained more rapidly than their respective inbred relatives during the early part of the feed test period (400 to 800 pounds). During the feed-test period between 800 to 1000 pound body weight the inbred males gained more rapidly and were more efficient than the linecross males. This seems to indicate that inbreeding depresses early

growth but has little or no influence on later growth rates. As the inbred animals approached maturity, they tended to gain more rapidly and to utilize feed more efficiently than the linecrosses. It would be interesting to feed-test the heifers in two periods to see if the results would simulate those for male calves.

5. More heterosis was expressed in females than in males. If heterosis or the mean superiority of the linecrosses over their inbred relatives is a measure of recovered vigor lost to inbreeding, then the conclusion could be made here that female calves were more inbred than male calves.

6. Relatively speaking, the heterosis expressed in this study was inadequate. There are indications that the inbreeding of the inbred dams used in linecrosses may be depressing the calf's ability to express heterosis. It might therefore be more meaningful in future linecrossing to compare the mean performance of inbred calves from inbred dams with that of linecross calves from linecross dams, since the inbreeding of both the dam and calf influence the performance of the calf.

BIBLIOGRAPHY

Alexander, G. I. and Ralph Bogart. 1961. Effect of inbreeding and selection on performance characteristics of beef cattle. Journal of Animal Science 20:702-707.

Alim, K. A. 1964. Factors affecting birth weights of Kenana calves in the Sudan. Empire Journal of Experimental Agriculture 32:307-310.

Black, W. H. and Bradford Knapp Jr. 1936. A method of measuring performance in beef cattle. Proceedings of the American Society of Animal Production 29:72-77.

Blackwell, Robert L. 1951. Relation of gain to feed efficiency in beef cattle. Master's thesis. Corvallis, Oregon State College. 54 numb. leaves.

Blackwell, R. L, J. H. Knox and C. E. Shelby. 1957. Genetic components of variance and covariance in weaning, yearling and feedlot performance of Hereford steers. (Abstract) Journal of Animal Science 16:1018-1019.

Blackwell, R. L., et al. 1962. Genetic analysis of economic characteristics in young Hereford cattle. Journal of Animal Science 21:101-107.

Bogart, Ralph. 1959. Improvement of livestock. New York, The MacMillan Company. 436 p.

________________. 1965. Crossing lines of cattle within a breed. In: Seventh Annual Beef Cattle Day Report. Corvallis, Oregon State University. 16 p.

Bogart, Ralph and R. Blackwell. 1950. More beef with less feed. Corvallis, Oregon State College. 4 p. (Oregon Agricultural Experiment Station Bulletin 488).

Bonnier, G., A. Hansson and H. Skjervold. 1948. Studies on monozygous cattle twins. IX. The interplay of heredity and environment on growth and yield. Acta Agriculturae Suecana 3:1-57. (Abstracted in: Animal Breeding Abstracts 16: No. 1351-1948).

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

Bradford, G. E., A. B. Chapman and R. H. Grummer. 1958a. Effects of inbreeding, selection, linecrossing and topcrossing in swine. I. Inbreeding and selection. Journal of Animal Science 17:426-440.

________________. 1958b. Effects of inbreeding, selection, and linecrossing and topcrossing in swine. II. Linecrossing and topcrossing. Journal of Animal Science 17:441-455.

Bradley, N. W., et al. 1966. Effects of sex and sire on performance and carcass traits of Hereford and Hereford-Red Poll calves. Journal of Animal Science 25:783-788.

Brinks, J. S., R. T. Clark and N. M. Kieffer. 1963a. Sex differences in response to inbreeding in a line of Hereford cattle. (Abstract) Journal of Animal Science 22:816.

________________. 1963b. Sex differences in response to inbreeding in a line of Hereford cattle. Proceedings of the western section, Society of Animal Science 14:V-1-V-6. 1963.

________________., et al. 1961. Adjusting birth weight, weaning weight, and preweaning gain for sex of calf in range Hereford cattle. Journal of Animal Science 20:363-367.

________________., et al. 1962a. Mature weight in Hereford range cows-heritability, repeatability, and relationship to calf performance. Journal of Animal Science 21:501-504.

________________. 1962b. Genetic and environmental factors affecting performance traits of Hereford bulls. Journal of Animal Science 21:777-780.

________________. 1964. Estimates of genetic, environmental and phenotypic parameters in range Hereford females. Journal of Animal Science 23:711-716.

Brown, W. P. and A. E. Bell. 1961. Genetic analysis of a "plateaued" population of Drosophila melanogaster. Genetics 46:407-425.

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

Burris, Martin J. and Cecil T. Blunn. 1952. Some factors affecting gestation length and birth weight of beef cattle. Journal of Animal Science 11:34-41.

Carter, R. C. and C. M. Kincaid. 1959a. Estimates of genetic and phenotypic parameters in beef cattle. II. Heritability estimates from parent-offspring and half-sib resemblances. Journal of Animal Science 18:323-330.

________________. 1959b. Estimates of genetic and phenotypic parameters in beef cattle. III. Genetic and phenotypic correlations among economic characters. Journal of Animal Science 18: 331-335.

Chambers, Doyle and J. A. Whatley. 1951. Heterosis in crosses of inbred lines of Duroc swine. Journal of Animcal Science 10: 505-515.

Christian, L. L., E. R. Hauser and A. B. Chapmen. 1965a. Heritability estimates in beef cattle based on identical and fraternal twin data. Journal of Animal Science 24:643-650.

________________. 1965b. Association of preweaning traits with weaning weight in cattle. Journal of Animal Science 24:652-659.

Clark, T. B. 1960. Crossbreeding in turkeys. II. Summary on heritability, growth, and body characteristics. Morgantown, West Virginia University. 30 p. (West Virginia Agricultural Experiment Station, Bulletin 455T).

Clark, R. T., et al. 1963. Beef cattle breeding research in the Western Region. Corvallis, Oregon State University. 71 p. (Oregon Agricultural Experiment Station, Research Bulletin 73).

Cox, D. F. 1960. The relation between sex and survival in swine. Journal of Heredity 51:284-288.

Craft, W. A. 1955. Advancing the livestock industry through research in genetics and animal breeding. Journal of Animal Science 14:295-299.

Craig, James V. and A. B. Chapman. 1953. Experimental test of predictions of inbred line performance in crosses. Journal of Animal Science 12:124-139.

Dahmen, J. J. and Ralph Bogart. 1952. Some factors affecting rate and economy of gains in beef cattle. Corvallis, Oregon State College. 23 p. (Oregon Agricultural Experiment Station, Technical Bulleting 26).

Damon, R. A., Jr., et al. 1961. Genetic analysis of crossbreeding beef cattle. Journal of Animal Science 20:849-857.

Danusoury, M. S. 1963. Factors affecting birth weight of calves in North Sudan dairy cattle. Journal of Animal Production of the United Arab Republic 3:59-70.

Dawson, W. M., Ralph W. Phillips and W. H. Black. 1947. Birth weight as a criteria (criterion) of selection in beef cattle. Journal of Animal Science 6:247-257.

Drewry, K. J., C. J. Brown and R. S. Honea. 1959. Relationships among factors associated with mothering ability in beef cattle. Journal of Animal Science 18:938-945.

Eckles, C. H. 1919. A study of birth weight of calves. Bozeman, Montana State College. 19 p. (Montana Agricultural Experiment Station Research Bulletin 35).

Ellis, G. E., Jr., T. C. Cartwright and W. E. Kruse. 1965. Heterosis for birth weight in Brahman-Hereford crosses. Journal of Animal Science 24:93-96.

El-Sheikh, A. S. and M. H. El-Fouly. 1962. Some factors affecting length of calving interval in a herd of Friesian cattle in the U. A. R. Journal of Animal Production of the United Arab Republic 2:1-12.

England, Noah, et al. 1962. Factors affecting calf weight gains during the suckling period. Proceedings of the Western Section Society of Animal Production 12:IX-1-IX-6.

Forrest, R. J. 1964. The relation between birth weight, subsequent weights, body weight gain, and feed consumption of Holstein-Friesian steers. Canadian Journal of Animal Science 44:187-194.

Flower, A. E., et al. 1963. Comparisons of inbred lines and line-crosses for performance traits in Hereford cattle. Journal of Animal Science 22:914-918.

______________. 1964. Selection intensities and time trends for performance traits in range Hereford cattle under mass and recurrent selection. Journal of Animal Science 23:189-195.

Gaines, J. A., et al. 1966. Heterosis from crosses among British breeds of beef cattle: Fertility and calf performance to weaning. Journal of Animal Science 25:5-13.

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

Gifford, W. 1953. Records - of - performance tests for beef cattle in breeding herds: Milk production of dams and growth of calves. Fayetteville, University of Arkansas. 34 p. (Arkansas Agricultural Experiment Station, Bulletin 531).

Glazener, E. W. and W. L. Blow. 1951. Topcross testings for broiler production. Poultry Science 30:870-874.

Gregory, Keith E. 1965. Symposium on performance testing on beef cattle. Journal of Animal Science 24:248-254.

Gregory, K. E., C. T. Blunn and M. L. Baker. 1950. A study of some factors influencing the birth and weaning weights of beef cattle. Journal of Animal Science 9:338-346.

Gregory, K. E., et al. 1966a. Heterosis effects on growth rate of beef heifers. Journal of Animal Science 25:290-298.

______________. 1966b. Heterosis effects on growth rate and feed efficiency of beef steers. Journal of Animal Science 25:299-310.

Holt, L. H. 1955. Crossbreeding in beef cattle. (Abstract) Journal of Animal Science 14:1185.

Hoornbeek, F. K. 1964. Selection applied, response of traits and combining abilities of inbred lines of beef cattle. Doctoral dissertation, Corvallis, Oregon State University, 124 numb. leaves.

Hoornbeek, F.K. and Ralph Bogart. 1966. Amount of selection applied and response of traits in four inbred lines of beef cattle. Corvallis, Oregon State University. 39 p. (Oregon Experiment Station, Technical Bulletin 96)

Kassab, S. A. 1964. On maternal and some other influences on birth weight, growth, and hair coat in two Dutch cattle breeds. Doctoral dissertation, Wageningen, Netherlands, University of Wageningen. 85 p. (Abstracted in: Animal Breeding Abstracts 32:no. 2828. 1964)

Kassab, S. A. and Th. Stegenga. 1964a. Causes of variation in birth weight of Friesian calves. Journal of Animal Production of the United Arab Republic 4:27-33.

________________. 1964b. Growth in Friesian calves during the first year of age (52 weeks). Journal of Animal Production of the United Arab Republic 4:35-43.

Kincaid, C. M. and R. C. Carter. 1958. Estimates of genetic and phenotypic parameters in beef cattle. I. Heritability of growth rate estimated from response to sire selection. Journal of Animal Science 17:675-683.

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

Knapp, Bradford, Jr., W. V. Lambert and W. H. Black. 1940. Factors influencing length of gestation and birth weight in cattle. Journal of Agricultural Research 61:249-254.

Knapp, B. Jr., and R. T. Clark. 1947. Genetic and environmental correlations between growth rates of beef cattle at different ages. Journal of Animal Science 6:174-181.

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

Knapp, B. Jr. and R. W. Phillips. 1942. Differences in performance between sexes of offspring of beef bulls. Journal of Animal Science 1:346-347.

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

Knox, J. H. and M. Koger. 1946. A comparison of gains and carcasses produced by three types of feeder steer. Journal of Animal Science 5:331-337

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

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

________________. 1955b. Genetic and environmental characters in beef cattle. I. Correlation among paternal and maternal half-sibs. Journal of Animal Science 14:775-785.

________________. 1955c. 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.

________________. 1955d. Genetic and environmental relationships among economic characters in beef cattle. III. Evaluating maternal environment. Journal of Animal Science 14:979-996.

________________. 1951. The correlation between gains made at different periods by cattle. Journal of Animal Science 10:760-767.

Koch, R. M., et al. 1959. Evaluating the influence of sex on birth weight and preweaning gain in beef cattle. Journal of Animal Science 18:738-744.

Koch, R. M., et al. 1963. Efficiency of feed use in beef cattle. Journal of Animal Science 22:486-494.

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

Koger, M., et al. 1962. Reproductive performance of crossbred and straightbred cattle on different pasture programs in Florida. Journal of Animal Science 21:14-19.

Lawson, J. E. and H. F. Peters. 1964. The birth and weaning weights of Highland and Hereford cattle and their reciprocal crosses. Canadian Journal of Animal Science 44:174-178.

Lehmann, R. P., et al. 1961. Selection indexes for weaning traits in beef cattle. Journal of Animal Science 20:53-57.

Li, Jerome C. R. 1964. Statistical inference (Part 1). Ann Arbor, Michigan, Edwards Brothers, Inc. 658 p.

Lickley, Charlene R. et al. 1960. Relationship between mature size, daily gain, and efficiency of feed utilization in beef cattle. Proceedings of the Western Section, American Society of Animal Production 11:IX-1-IX-6. 1960.

Lindholm, H. B. and H. H. Stonaker. 1957. Economic importance of traits and selection indexes for beef cattle. Journal of Animal Science 16:998-1006.

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

Marlowe, T. J. and J. A. Gaines. 1958. The influence of age, sex, and season of birth of calf and age of dam on preweaning growth rate and type of score in beef calves. Journal of Animal Science 17:706-713.

Mason, R. W., R. Bogart and H. Krueger. 1958. Method of adjusting data for differences due to sex. Proceedings of the Western Section of the American Society of Animal Production 9:XLI-1-XLI-6.

Moreng, R. E. and P. A. Thornton. 1958. Hybridization through inbreeding and strain crossing of turkeys. XI World Poultry Congress, Mexico City.

Morrison, F. B. 1936. Feeds and feeding. 20th edition. Ithaca, New York, Morrison Publishing Company. 1050 p.

Nelms, G. and R. Bogart. 1955. Some factors affecting feed utilization in growing beef cattle. Journal of Animal Science 14:970-978.

__________. 1956. 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.

Neville, W. E. Jr. 1962. Influence of dam's milk production and other factors on 120- and 240- day weight of Hereford calves. Journal of Animal Science 21:315-320.

Neville, W. E. Jr., et al. 1962. Influences of dam's milk production and other factors on postweaning performance and carcass characteristics of Hereford cattle. Journal of Animal Science 21:943-949.

North, W. A. 1966. Gonadotropins in pituitaries of inbred and line-cross beef bulls and effects of irradiation of Mammalian pituitary glands on their ability to induce in vitro ovulation of frog ovaries. Doctoral dissertation, Corvallis, Oregon State University, 90 numb. leaves.

Pahnish, O. F., et al. 1961. Influence of sex and sire on weaning weights of Southwestern range calves. Journal of Animal Science 20:454-458.

Pahnish, O. F., et al. 1964. Genetic analysis of economic traits measured in range-raised Herefords at preweaning and weaning ages. Journal of Animal Science 23:562-568.

Pierce, C. D., et al. 1954. Rate and efficiency of gains in beef cattle. II. Some factors affecting performance testing. Corvallis, Oregon State College. 31 p. (Oregon Agricultural Experiment Station, Technical Bulletin 33)

Poehlman, John Milton, 1959. Breeding field crops. New York, Henry Holt and Company, Inc. 427 p.

Ragab, M. T. and M. F. Abd El-Salam. 1962a. The effect of sex and month of calving on body weight and growth rate of Egyptian cattle and buffaloes. Journal of Animal Production of the United Arab Republic 2:109-132.

__________. 1963a. Heritability and repeatability of body weight and growth rate in Egyptian buffaloes and cattle. Journal of Animal Production of the United Arab Republic 3:15-25.

__________. 1963b. Relation and inter-relation between body weights and growth rates of cattle and buffaloes at some different ages of life. Journal of Animal Production of the United Arab Republic 3:27-43.

Rhoad, A. O. 1940. A method of assaying genetic differences in adaptability of cattle to tropical and subtropical climates. Empire Journal of Experimental Agriculture 8(31):190-198.

Rhoad, A. O., R. W. Phillips and W. M. Dawson. 1945. Evaluation of species cross of cattle by polyallele crossing. Journal of Heredity 36:367-374.

Rollins, W. C. 1949. The effect of inbreeding upon growth in Jersey cattle. Genetics 34:724-738.

Rollins, W. C., et al. 1962. Beef cattle performance and progeny tests for gain, efficiency, carcass conformation, and earliness of maturity. Journal of Animal Science 21:200-206.

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

Schultze, A. B. 1965. Can big calves affect breeding performance? Artificial Insemination Digest 13:8.

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

Shelby, J. R., et al. 1957. Heritability of some economic traits in record of performance bulls. (Abstract) Journal of Animal Science 16:1019.

________________. 1963. Estimates of phenotypic and genetic parameters in ten years of Miles City R. O. P. steer data. Journal of Animal Science 22:346-353.

Stonaker, H. H. 1954b. Observations on reproduction, growth, feed utilization and grades of inbred and outbred Hereford cattle. (Abstract) Journal of Animal Science 13:963.

________________. 1962. Homogametic heterosis. Proceedings of the Western Section of the American Society of Animal Production. 13:XXIII-1-XXIII-8.

________________. 1963. A genetic hypothesis for sex-mating system interactions in growth of cattle and poultry. Journal of Animal Science 22:320-325.

Swiger, L. A. 1961. Genetic and environmental influences on gain of beef cattle during various periods of life. Journal of Animal Science 20:183-188.

Swiger, L. A., et al. 1961. Effect of inbreeding on performance traits of beef cattle. Journal of Animal Science 20:626-630.

________________. 1965. Selection indexes for efficiency of beef production. Journal of Animal Science 24:418-424.

Vaccaro, Rodolfo and E. U. Dillard. 1966. Relationships of dam's weight and weight changes to calf's growth rate in Hereford cattle. Journal of Animal Science 25:1063-1068.

Venge, O. 1948. Influence of different factors on birth weight of calves. Nord, JordbrForskn., 1948 (7/8):208-224. (Abstracted in: Animal Breeding Abstracts 17:no. 864. 1949)

Vernon, E. H., W. R. Harvey, and E. J. Warwick. 1964. Factors affecting weight and score of crossbred-type calves. Journal of Animal Science 23:21-27.

Warwick, B. L. and T. C. Cartwright. 1955. Heritability of gain in young beef cattle. Journal of Animal Science 14:363-371.

Warwick, E. J. 1958. Fifty years of progress in breeding beef cattle. Journal of Animal Science 17:922-943.

Wiltbank, J. N., et al. 1966. Effects of heterosis on age and weight at puberty in beef heifers. Journal of Animal Science 25:744-750.

Winters, L. M. and H. McMahon. 1933. Efficiency variations in steers. St. Paul, University of Minnesota. 28 p. (Minnesota Agricultural Experiment Station Technical Bulletin 94)

Woodward, R. R. and R. T. Clark. 1959. A study of stillbirths in a herd of range cattle. Journal of Animal Science 18:85-90.

Woolfolk, E. J. and B. Knapp, Jr. 1949. Weight and gain of range calves as affected by rate of stocking. Bozeman, Montana State College. 22 p. (Montana Agricultural Experiment Station Bulletin 463)

Wright, Sewall. 1922. Coefficients of inbreeding and relationship. American Naturalist 56(645):330-338.