Heritability of 18 month weight of heifers and the relationship of this weight to the birth and weaning weight of the heifers first calf
by John A Marchello

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Animal Industry
Montana State University

Abstract:
The heritability of 18 month weight of heifers and the relationship of this weight to the birth and weaning weights of the heifer's first calf was studied in the Hereford experimental herd at the North Montana Branch Station over a 26-year period. Heritability was estimated by the paternal half-sib correlation method and involved 481 animals. All heifer weights were corrected to 18 months of age by regressing weight on age at the time the weight was taken. The effects of age at calving, years, and lines, were removed by analysis of variance. The estimate of heritability of 18 month weight after adjusting for unequal subclasses, was 0.36.

Correlations between 18 month weight of heifers and birth weight and weaning weight of the heifer's first calf were found to be 0.27 and 0.24, respectively. This portion of the study involved 631 heifers and their first calves. Weaning weights were corrected for sex and age of calf and birth weights were corrected for sex.

Analysis of variance indicated that the differences due to sex in both weaning and birth weight were highly significant. Furthermore a highly significant sex-year interaction was found for weaning weights.

This indicates the use of a constant figure for correcting weaning weights for sex is erroneous. In this study, weaning weights were corrected for sex on a within year basis.

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A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Animal Industry

at

Montana State College

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following staff members of Montana State College: to Dr. D. W. Blackmore for his invaluable suggestions and guidance throughout my graduate program and in the preparation of the manuscript; to Associate Professor A. E. Flower for his advice and encouragement throughout my graduate program; to Dr. O. O. Thomas and Dr. E. R. Hehn for their helpful suggestions during the preparation of the manuscript.

Appreciation is extended to the staff at the North Montana Branch Station for their help in collecting these data.

Grateful and sincere appreciation is expressed to my wife, Bonnie Gail, for her assistance in preparing the manuscript. Without her help, understanding, and encouragement this thesis could never have been completed.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

INDEX TO TABLES

INDEX TO FIGURES

ABSTRACT

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Correlations between 18 month weight of heifers and birth weight and weaning weight of the heifer's first calf were found to be 0.27 and 0.24, respectively. This portion of the study involved 631 heifers and their first calves. Weaning weights were corrected for sex and age of calf and birth weights were corrected for sex.

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INTRODUCTION

In recent years, increased emphasis has been placed on the selection of replacement heifers. Many breeders are placing emphasis on the yearling fall weight (18 month weight) of heifers with the hopes that weight-for-age will tend to improve productivity of their herds. A knowledge of the heritability of 18 month weight in range beef heifers would be desirable in selection of replacement heifers. Since the 18 month weight is being used as a criterion for selecting replacement stock, it would also be desirable to know what relationship 18 month weight of heifers has with such characteristics as birth and weaning weight of their first calves.

Many workers have reported that the performance of a heifer's first calf is quite indicative of the performance of her future calves. With these points in mind, a study was conducted to estimate the heritability of 18 month weight of heifers and to determine the relationship between this weight and such characteristics as weaning and birth weight of their first calves.

REVIEW OF LITERATURE

A. Weaning Weight: Factors Influencing and Their Adjustment

It is well recognized that many factors influence weaning weights. For the most part, it appears that (1) age of calf at weaning, (2) sex of calf, and (3) age of dam, have the greatest influence on weight of calf at the time of weaning.

1. Effect of age of calf on weaning weight

The growth of range calves was nearly linear up to 155 days of age and then increased at a decreasing rate as reported by Johnson and Dinkel (1951). Their study was confined to calves raised under South Dakota range conditions which ranged in age from 155 to 225 days.

Brody (1921) found that monthly gain increased up to five months of age, which was the point of most growth throughout life.

The growth curve of calves between 150 and 230 days was found to be linear, with calves of different weight growing at different rates as reported by Dunn (1957). This study was confined to 164 purebred beef calves at the Iowa Station. There was no tendency for growth to be curvilinear over the period observed.

Lush and Kincaid (1930) studied the growth of range cattle in Texas and showed that weights increased rapidly from mid-April to mid-July and more slowly thereafter. Growth curves of calves born in different years were similar but had different details. The curves were greatly influenced by differences in availability of forage.

Pahnish, *et al.* (1958b) found that the weight-age relationship was essentially linear between the ages of 121 and 323 days.

Van Dyne (1956), in studying the effects of grazing intensity on weaning weights, found that calves produced by cows pastured on lightly grazed areas, had a growth curve from birth to weaning which was linear. Average age of calves at weaning was approximately 220 days. Calves produced by cows pastured on moderately grazed areas, had a growth curve which was linear until they reached an age of 190 days, with a slight tapering off thereafter. Cows pastured on heavily grazed areas produced calves having a growth curve that was linear to 150 days of age, then tapering off slightly until 190 days of age, with a slight increase thereafter. This study was conducted at the Cottonwood Range Field Station, South Dakota from 1952 to 1954.

It was reported by Urick (1958) that the growth of calves from 140 days to 220 days of age was linear in a study conducted at the North Montana Branch Experiment Station. For each day increase in age, calves gained 2.03 pounds.

2. Methods of correcting weaning weight to a standard age

Johnson and Dinkel (1951) studied monthly weights of 297 beef calves to calculate correction factors for adjusting weaning weights of range calves to a standard age. One set of linear correction factors was developed to adjust weights taken between 120 and 155 days to a standard age of 155 days. Two sets of factors were developed for the period from 155 to 225 days of age which corrected weights to the standard age of 190 days.

Weaning weight adjustments for age of calf was studied in a purebred and a grade herd of Hereford cattle by Evans, et al. (1955). It was found that regressions of weaning weight on age of calf differed significantly ($P \leq .05$) between the purebred and grade herds, amounting to 0.908 and 1.080, respectively. Due to the different regressions between the two herds, prediction equations were developed for adjusting weaning weight to a standard age of 210 days, they are as follows:

$$\bar{W} \doteq 425w/(X + 215) \text{ for purebreds.}$$

$$\bar{W} = 342w/(X + 132) \text{ for grades.}$$

Where $\bar{W}$ is the adjusted weaning weight, w is the actual weight and X is the actual age of the calf.

By using weaning weights of Hereford calves, Pahnish, et al. (1958b) developed a correction factor for the adjustment of weaning weight to a standard age of 270 days under southwestern range conditions. These workers found that growth rates of the calves within sexes were essentially linear between the age of 121 and 323 days. These rates were represented by linear regression coefficients. The coefficients representing the daily growth rates of bull and heifer calves, with 95 percent confidence intervals, were 1.442 ± 0.146 and 1.090 ± 0.120, respectively. Each coefficient was significant at the one percent level of probability. A highly significant difference between the average coefficients resulted in the conclusion by the workers that a separate correction factor should be used to adjust the weaning weight of calves of each sex to a standard age of 270 days.

Rollins and Wagnon (1956) in studying optimum and sub-optimum nutritional regimes, adjusted calf weaning weights to 240 days of age. This adjustment was made by taking a linear interpolation or extrapolation based on the actual weaning weight and a weight obtained approximately a month prior to weaning.

Koch (1951) regressed weaning weight on age at weaning and found that for each day increase in age the animal increased in weight by 2.27 pounds. This study was conducted at the U. S. Range Livestock Experiment Station, Miles City, Montana. The author stated two reasons why the regression value was so high: One, the data are from the Line 1 cattle which are the most rapid-gaining cattle at the Miles City station; and two, the nutrient value of the forage on this range does not decline as greatly about weaning time in the fall as it does on some ranges.

Because the average weaning age of calves was approximately 210 days at the Georgia Coastal Plain Experiment Station, McCormick and Southwell (1956) used this age as the standard for correcting weaning weights. The correction of weaning weight to 210 days of age was done by pro-rating gains during the 28-day weight bracketing this age. Occasionally, with late calves, gains in the last 28-day pre-weaning period were used to estimate 210-day weights even though the calves had not reached this age. Examination of the data indicated that gains were linear or nearly so during the period of 6 to 8 months of age, thus, indicating that this method gives satisfactory estimates of 210-day weights.

By having monthly weights on each calf, it was possible to standardize each calf's weaning weight to 240 days of age using its own successive monthly weights for a linear interpolation. This method was presented by Rollins and Guilbert (1954).

Botkin and Whatley (1953) adjusted weaning weights of calves to a standard age of 210 days. The formulae used in this adjustment are as follows:

$$\text{Age intercept} = \text{Average age} - \frac{\text{Average weaning weight}}{\text{Regression coefficient}}$$

$$\text{Corrected weight} = \text{Actual weight} \times \frac{\text{Standard age} - \text{Age intercept}}{\text{Actual age} - \text{Age intercept}}$$

Ages of calves used in this study varied from 120 to 260 days. In using this method, it was assumed that growth is linear during that portion of the growth curve to which corrections were applied.

Sawyer, _et al_. (1948) corrected for age of calf at weaning by use of regression of weight on age. It was found that for each day increase in age, the calves in this study gained 1.28 pounds.

Weaning weights were corrected to 180 days of age, based on a regression coefficient of 1.5 pounds per day by Peacock, _et al_. (1956). This work was conducted at the University of Florida Experiment Station using commercial and purebred Brahman, Hereford, Devon, Shorthorn, and Shorthorn-Brahman cattle.

Koger and Knox (1945) studied the weaning weights of range Hereford cows for an 8-year period and regressed weight on age in order to determine a correction factor to correct weaning weight to a constant age. These workers developed the following formula:

$$W = w \quad d(0.0069w - 1.525)$$

Where---W is the corrected weight,

---w is the actual weaning weight,

---and d is the standard age minus the age at weighing.

3. Effect of sex on weaning weight

It has been established by many workers that sex has a definite effect on weight at weaning. However, the extent of the effect varies greatly with location of the animals being studied and the year.

a. Studies on the sex effect at the Miles City Station

Work at the U. S. Range Livestock Experiment Station, Miles City, Montana by numerous workers over the past 20 years indicates that sex effect will vary greatly with years and also the result of sex effect will vary with method used to study the effect.

Knapp and Phillips (1942a) studied the difference in performance between sexes in offspring sired by the same bull. A significant difference between sires was observed in weaning weights the second year of the study but there was no significant difference between sexes by the same sire. During the third year of the trial, the authors found one sire that produced heifer calves weighing 27 pounds more than his steer offspring at weaning and this sire also produced proportionately heavier heifers than steers when compared with other bulls the fourth year of the trial. It was concluded from this study that some sires apparently produce better gaining heifers than steers, or better gaining steers than heifers.

In another study conducted by Knapp, et al. (1942b), it was found that male calves averaged 22 pounds heavier than female calves, this difference was highly significant statistically. When the effects of differences in age at weaning were removed by analysis of covariance, sex accounted for about seven percent of the total variation in weaning weight.

Rice, et al. (1954) in studying the length of gestation and its relationship to weaning weight, found that bull calves averaged 28.8 pounds heavier than heifer calves at weaning. This difference was highly significant statistically.

Koch (1951) in studying the weight of calves at weaning as a permanent production characteristic of selected range Hereford cows, found selected bull calves to be 44 pounds heavier than heifer calves at a weaning age of 182 days. In contrast, the steer calves were only 13 pounds heavier than heifer calves. Whereas in 1955, Koch and Clark found that bull calves only averaged 26.2 pounds heavier at weaning than heifers. Because the physiological effects of castration could not be separated from the effects of selection for size, records for bull and steer calves were not evaluated separately.

Clark, et al. (1958) found differences in weaning weight due to sex to be highly significant statistically. Weaning weight of bulls, steers, and heifers averaged 418, 382, and 368 pounds, respectively. On an average, bulls exceeded heifers in weaning weight by 50 pounds, and steers did so by 14 pounds. It was concluded by the authors that since differences between bulls and steers were influenced to some extent by selection of the larger calves for retention as bulls through the pre-weaning period, these data do not provide a completely valid comparison of weaning weights of bulls and steers. This conclusion may also be made for the differences between bulls and heifers in this study. Data used in this study were collected over a 27-year period.

b. Studies on the sex effect at other stations

Koger and Knox (1945) used high-grade Hereford cows and bulls to study what effect sex differences have on weaning weights of beef calves. These workers found that the average difference in weaning weight over an 8-year period was 26 pounds in favor of the steers. In all instances, the males were heavier than the females. Differences due to sex were greater for offspring sired by one sire than offspring sired by another sire, but these differences were not great enough to be statistically significant. Whereas, Koger and Knox (1947) found that the weaning weights of steer calves, adjusted to an age of 205 days, were 30 pounds greater than those of heifers.

Weaning weights of Hereford calves were studied by Chambers, et al. (1953) to determine what effect sex had on these weights. Males were found to be 25 pounds heavier at weaning than heifers. It was indicated that correction for sex can be done by totaling male and female weaning weights and determining the average of each. The difference then, can be added to the weight of each heifer, thus, correcting female weights to that of males for weight difference due to sex.

Pahnish, et al. (1958b) analyzed data collected under southwestern range conditions on Hereford cattle to determine what correction factor could be developed for the correction of weaning weight differences due to sex. It was found that the linear regression coefficients representing the daily growth rates of bull and heifer calves, with 95 percent confidence intervals, were 1.442 ± 0.146 and 1.090 ± 0.120, respectively. Each coefficient was significant at the one percent level of probability.

Rollins and Guilbert (1954) in studying factors affecting growth of calves during the suckling period in the purebred Hereford herd at the

the California Agricultural Experiment Station at Davis, California, found that at a weaning age of 240 days, male calves were 68 pounds heavier than female calves. In contrast, Rollins and Wagnon (1956) found, in studying the relationship of nutrition to weaning weight, that in one group of calves being studied, the males weighed 31 pounds heavier at weaning than the females. In the other group of animals under consideration, males weighed 18 pounds more at weaning than females.

In a study conducted by Peacock, et al. (1956) using commercial and purebred Brahman, Hereford, Devon, Shorthorn, and Shorthorn x Brahman crosses, it was found that male calves averaged 28.3 pounds heavier at weaning time than heifer calves. The difference in weight due to sex was obtained from within sub-group averages. This difference was highly significant statistically.

Gregory, et al. (1950) reported no appreciable difference between sexes in weaning weight or gain for the Herefords at the North Platte Station. However, differences of 14 pounds in weaning weight and 11 pounds in gain were noted between males and females at the Valentine Station; these differences were not significant.

In a study conducted at the Georgia Coastal Plain Experiment Station using data from purebred and grade Polled Hereford herds, McCormick, et al. (1956) found that bull calves were 38 pounds heavier than heifer calves at 210 days of age in the purebred herd. However, in the grade herd, these workers found no significant or consistent difference between steers and heifers.

Burgess, et al. (1954) in developing descriptive constants to reduce variation in weaning weight, found that bull calves were 14 pounds heavier at weaning than the average of bull, heifer, and steer calves. It was also evident that steer and heifer calves were six and eight pounds, respectively, under the average for the three mentioned above.

It was reported by Evans, et al. (1955) that bull calves averaged 6.1 percent or 22 pounds heavier ($P < .05$) and steer calves averaged 4.1 percent, or 17 pounds heavier ($P < .05$) than heifer calves at weaning in a purebred and grade herd, respectively. This study was conducted at the Dixon Spring Experiment Station, Robbs, Illinois on 1,737 purebred and grade Hereford calves over the period 1944 through 1953.

Marlowe and Gaines (1958) in studying the influence of sex on preweaning growth of Virginia beef calves, found that bull calves would grow approximately five percent faster than steer calves. The workers also found that steer calves would grow approximately eight percent faster than heifer calves.

Lasley, et al. (1958) in studying the influence of heredity on fertility and weaning weights of beef cattle found that weaning weights should be corrected for sex before selections are made. An average of nine studies showed that bull calves will average about 28 pounds heavier than heifer calves at weaning.

Urick (1958) in analyzing data collected on the inbred lines of cattle at the North Montana Branch Station found that male calves were 20.6 pounds heavier at weaning than female calves. This difference was highly significant statistically. The author assumed that no sex-year interaction existed. However, Pahnish (1958a), working with Hereford cattle, maintained under southwestern range conditions found a highly significant sex-year interaction. This is also substantiated by Blackmore (1954), who found a highly significant sex-year interaction when observing the sex effect on six month weight of inbred dairy calves. This worker also found a highly significant sex-year interaction in body measurements taken at six months, one year, and two years of age. Sawyer, et al. (1948) in working with Hereford cattle also found a sex-year interaction but the interaction lacked statistical significance.

The presence of an interaction between sex and year indicates that the animals of different sex respond differently in different years. The existence of a sex-year interaction would also indicate that the use of a specific figure for correction of weaning weights would be erroneous.

4. Effect of age of dam on weaning weight

Knapp, et al. (1942b) found that age of cow affected weaning weights in the following manner:

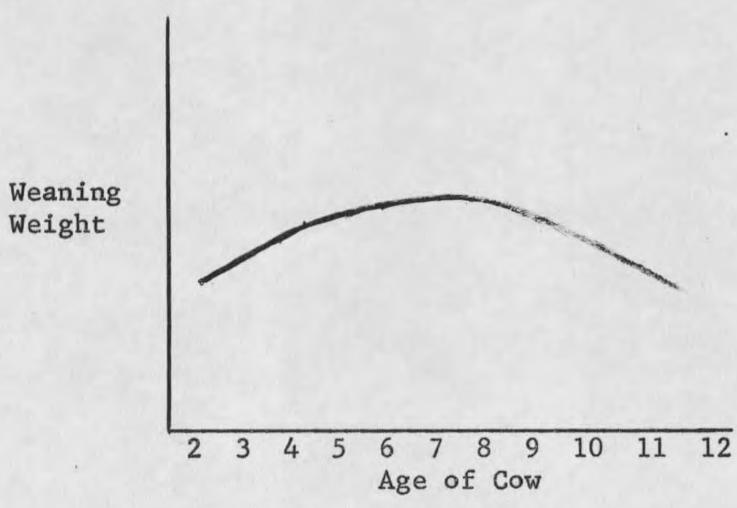

Figure 1. Effect of age of cow on weaning weight of calf.

Knox and Koger (1945) studied the effect of age on the weight and production of range cows. Both weight and production were greatest at the ages of six to eight years. At a weaning age of 205 days, calves from 2-, 3-, and 4-year-old cows were 60, 42, and 18 pounds lighter than those from 6-year-olds.

According to Botkin and Whatley (1953) 3- and 4-year-old cows produce calves whose weaning weights are 35 and 15 pounds, respectively, under the average for mature cows. Cows were considered mature at five years of age.

Rollins and Guilbert (1954) found that calves from 3- and 4-year-old cows are 21 and 13 pounds lighter at weaning than calves from 7- to 10-year-old cows. The effect of age of dam was smaller for female than for male calves. Cow productivity reached its highest point at six to seven years of age.

According to Koch and Clark (1955a) calves from 3-, 4-, and 5-year-old cows, in comparison with calves from cows 6 to 10 years of age, weighed 44, 20, and 9 pounds less at weaning. This study was conducted at the Miles City Station, using records of 5,952 Hereford calves.

Clark, et al. (1958) found that the average weaning weights increased considerably as age of dam advanced from three to five years but increased little as it advanced from six to eight years. Weaning weights of bull, steer, and heifer calves from 3-year-olds averaged 37, 45, and 42 pounds less than those of calves from 6- to 10-year-olds, and weaning weights of bull, steer, and heifer calves from 4-year-olds averaged 7, 18, and 21 pounds less than those calves from cows in the 6- to 10-year-old age group. Differences associated with age of dam, which were highly significant statistically, accounted for eight percent of the total variance in weaning weight.

Urick (1958) at the North Montana Branch Station, found that 2-, 3-, and 4-year-old cows produced calves that were 39, 22, and 8 pounds, respectively, under the average for mature cows; considering that cows from 5 to 10 years of age are mature. These differences were highly significant statistically.

B. Birth Weight: Factors Influencing, and Their Adjustment

Because weight at birth is mostly under the influence of the maternal environment, it is reasonable to assume that the factors affecting birth weight are less variable than those affecting weaning weight. It appears that the following factors have the greatest influence on weight at birth: (1) age of cow at the time the calf was born, (2) sex of the calf, and (3) length of gestation.

1. Effect of sex on birth weight

In 1955a, Koch and Clark, using data collected at the U. S. Range Livestock Experiment Station, Miles City, Montana, found that bull calves averaged 5.6 pounds heavier than heifer calves at birth.

Dawson, et al. (1947) found that the male calves averaged 4.2 pounds heavier than the female calves in a herd of Shorthorn cattle. However, the greatest effect on birth weight in this study was due to age of dam.

Burris and Blunn (1952) found that the male calves of Angus, Hereford, and Shorthorn, averaged 5.3, 4.5, and 4.9 pounds heavier, respectively, at birth than females. Differences between years were not significant statistically. The workers stated that 10 percent of the sex difference was due to differences in gestation length.

According to Clark, et al. (1958) birth weight differed importantly between sexes, males averaging 5 pounds heavier (79 pounds) than females (74 pounds). Differences due to sex, which were highly significant statistically, accounted for about 16 percent of the total variance in birth weight.

Woolfolk and Knapp (1949) measured the effects of three rates of stocking on gain in range calves at the U. S. Range Livestock Experiment Station, Miles City, Montana. Among calves produced on range areas subjected to light, medium and heavy grazing, respectively, bulls were 3.3, 4.6, and 4.8 pounds heavier at birth than heifers.

In a study conducted at the Miles City Station, Knapp, et al. (1942b) found that male calves were 6 pounds heavier at birth than female calves. This difference due to sex, was highly significant statistically.

Gregory, et al. (1950) using Hereford calves at the North Platte and Valentine substations of the Nebraska Experiment Station, found that the average birth weight of males exceeded that of females by five pounds at the North Platte station and by four pounds at the Valentine station. The difference in birth weight due to sex was highly significant statistically at both substations.

According to Nelms and Bogart (1956) difference in suckling gains exhibited by the two sexes is largely due to a difference in birth weight. The males are heavier at birth and carry this advantage through the suckling period. Also, the larger calves at birth gain more rapidly during the suckling period. The regression coefficient of rate of gain during the suckling period on birth weight was 0.0115. This indicates that for each change of 10 pounds in birth weight there is an associated difference in rate of gain of 0.115 pounds per day. Thus, it appears that bulls and heifers of the same birth weight gain at approximately the same rate during the suckling period. Hereford and Angus calves were used in this study.

2. Effect of age of dam on birth weight

According to Knapp, et al. (1942b) calves from 2-year-old cows were about 10 pounds lighter at birth than calves from mature cows. Changes in age of cow had little effect on birth weight after four years of age. Whereas, Burris and Blunn (1952) found that birth weight reached its maximum when cows of the Angus, Hereford, and Shorthorn breeds, respectively, were 10 to 11, 11 to 12, and 10 to 11 years old. These workers found that calves from 2- to 3-year-old cows averaged 4.7, 4.9, and 6.0 pounds lighter at birth than calves from 4- to 5-year-old cows, and calves from 3- to 4-year-old cows averaged 3.0, 1.3, and 1.9 pounds lighter than those from 4- to 5-year-old cows, respectively, for the breeds mentioned above.

Botkin and Whatley (1953) in studying the repeatability of production in Hereford cows found that the birth weights of offspring from 3- and 4-year-old cows were 4 and 2 pounds, respectively, under the average for offspring from mature cows. Cows were considered mature at five years of age.

Calves from 3-, 4-, and 5-year-old cows, in comparison with calves from cows 6 to 10 years of age, weighed 5, 2, and 1 pound less at birth, according to Koch and Clark (1955a). The difference between 6 and 10 years in age of dam was found to have little effect on characteristics of the calves.

Clark, et al. (1958) found that age of dam had an effect on the birth weight of calves from 3-year-old cows as compared with calves from older cows, but otherwise was of little importance in relation to birth weight. Male and female calves from 3-year-olds average 4 pounds lighter at birth than those from 5- to 10-year-old cows. Male and female calves from 4-year-olds averaged 1 and 2 pounds lighter, respectively, than those from the older class.

3. Effect of gestation length on birth weight

Dawson, et al. (1947) found the gestation period for male and female calves to be 281.6 days and 280.7 days, respectively. It was concluded by the authors that males would tend to be heavier at birth than females. This study was conducted on a beef Shorthorn herd at Beltsville, Maryland.

According to Burris and Blunn (1952) the average length of gestation for Angus, Hereford, and Shorthorn cattle is 281.7, 286.1, and 284.3, respectively. These differences were highly significant statistically. The difference between the mean birth weights of the Hereford and Angus and the Hereford and Shorthorn calves were statistically significant while the difference between the Angus and Shorthorn calves was not. Differences in gestation length accounted for 7.9 percent of the variation in calf birth weight. When the effect of age of dam was removed, differences in gestation length accounted for 7.3 percent of the variance of calf weight. When birth weights were adjusted for differences in gestation lengths, the adjustment reduced the sex difference in the Angus and Hereford breeds but not the Shorthorn. About 10 percent of the sex difference in birth weight was attributable to difference in gestation length of the two sexes.

In 1950, Jasper studied 53 cases of prolonged gestation in bovine animals. Nearly all of the calves from these cows were males. The author reported that the prolonged periods ranged from 20-88 days. Weights of calves removed from the cows in this condition were abnormally large with one reported to weigh 217.8 pounds.

Rice, et al. (1954) using data collected from 443 Hereford range cows bred to 8 different bulls by artificial insemination, found that the mean gestation length for 212 heifer calves was 286.5 ± 6.18 days and for 231 bull calves, it was 287.3 ± 6.21 days, this difference was not statistically significant. Male calves average 3 pounds heavier at birth than female calves; this difference was highly significant statistically. It was concluded that the difference in length of gestation for male and female calves may partially account for the difference in weight at birth.

According to Knapp, et al. (1940) there is about two days difference between length of gestation period of beef Shorthorn dams giving birth to bull calves, and dams giving birth to heifer calves. Analysis of variance showed that this difference was statistically significant. It was the opinion of the authors that this difference may account partially for difference in birth weight between sexes. These data also indicated that as the gestation period increased, birth weight increased.

Eckles (1919) found that as length of gestation increased, birth weights increased. Gestation length ranged from 274 to 285 days, with birth weight averaging 37 and 82 pounds, respectively, for these extremes. This study involved approximately 100 animals.

C. Heritability and Repeatability of First Calf Record

According to Lush, (1940) the idea of heritability concerns whether the difference actually observed between individuals arose because they started life with different genotypes or were exposed to different environmental forces. Every characteristic is both hereditary and environmental since its expression can be changed by appropriate changes either in its heredity or in the environment under which that genotype develops.

Heritability may be defined as the fraction of the observed variance which was caused by differences in heredity.

All ways of estimating heritability rest on the degree to which animals with similar genotypes resemble each other more than less closely related animals do. As far as the animal itself is concerned, its genotype functions as a unit. This functioning of the genotype as a whole is meant in the broad definition of "heredity". It should be kept in mind that the gene, not the whole genotype, is the unit concerned in transmission from parent to offspring. By adding all average effects of the constituent genes, an "expected" value can be determined which is an estimate of heritability. Assuming that each gene substitution has in every genotype exactly the same effect as the average effect which it actually does have in that population.

The records of 532 calves dropped in a purebred Polled Hereford herd during the period 1939-1953 and of 423 calves born in a grade herd and sired by Polled Hereford bulls during the period 1936-1948 were studied by McCormick, et al. (1956). These workers found that the repeatability of birth weight of calves from the same cow was low (0.11). Repeatability of

210-day weight in the two herds was 0.42 and 0.38, respectively. Heritability and repeatability figures were determined by the use of paternal half-sib correlations estimated from analysis of variance.

A study conducted by Lasley, et al. (1958) on beef cattle indicates that about one-third of the variation in weaning weight is due to inheritance and about two-thirds is due to environment. Weaning weights of different calves from the same cow were found to be about 50 percent repeatable, indicating that the weight of the first calf at weaning from a cow is a good indication of what she can be expected to do at later calvings.

Chambers' and Kieffer's (1958) list of heritability estimates of cow productivity were obtained from intra-sire and intra-season regression of daughter's production on that of her dam in a high grade Hereford herd of approximately 100 cows. Hereitability estimates are as follows:

Source	Heritability
First Record of Dam and Daughter	.30
1957 Record of Daughter and Dam	.38
Life-time Record of Daughter and Dam	.86
1956 & 1957 Records of Daughter and Dam	.90

The authors indicated that although the amount of data used in this study is quite limited, the estimates are consistent and suggest that the selection of replacement heifers from the more productive dams should be effective in raising the average weaning weight. They also stated that selection of heifers based on the average of two or more records of their dam should be much more effective than that based on the first record or any single record.

In a study with purebred Hereford cattle at the University of California, Rollins, et al. (1952) using variance and covariance analyses found the repeatability of growth rate of calves from birth to 4 months of age from the same cow sired by the same bull to be 37 percent. The repeatability of growth rate from 4 months of age to 8 was 26 percent.

Chambers, et al. (1953) found that the weaning weight of the first calf is a good indication of future production by a heifer. In this study, using Hereford cattle, the repeatability of weaning weight of calves produced by the same cow was 51 percent. This would indicate that a large amount of selection emphasis can be placed on weaning weight of the first calf produced by a heifer.

Rollins and Wagnon (1956) analyzed weaning weights obtained from two experimental range herds which were similar in breeding but were maintained under different nutritional regimes. These workers found the repeatability of weaning weight of calves from the same dam to be 51 percent in one herd and 34 percent in the other herd.

Koch and Clark (1955b) calculated the repeatability for several economic characteristics in beef cattle. These workers found that birth weight was 26 percent repeatable and weaning weight was 34 percent repeatable. The data for this study were collected at the U. S. Range Livestock Experiment Station, Miles City, Montana.

Stonaker (1959) found the correlation between calves from the same dam to be 0.49. It was found that this correlation is slightly lower when successive calves are by a different sire.

Studies by Koger and Knox (1947), Koch (1951), and Botkin and Whatley

(1953) indicate that repeatability of first calf record is high enough to permit reasonably accurate selection of cows for high life-time production on the basis of the first calf weaned.

According to Koger and Knox (1947) the repeatability of the weaning weights of calves from range cows was investigated by determining the correlation between various combinations of records and by analysis of variance of weights of calves from cows with five consecutive records. It was found that the average correlation of the weaning weight of all adjacent calves was 0.49. The correlation of the weight of first calf with that of the second calf was 0.66. When the first record was compared with the average of various members of subsequent records, the correlation coefficient varied from 0.51 to 0.53. When the average of the first two records was compared with various combinations of subsequent records, the coefficients varied from 0.54 to 0.59, being only slightly higher than when one record was included in the initial observation. Analysis of variance showed that after the influence of age of dam was removed, the permanent differences between cows amounted to 51 percent of the remaining variance. This is in close agreement with the findings of Koch (1951) who found that differences between cows accounted for 52 percent of the variation in weaning weight. Therefore, the extent to which the weaning weight of calves is a permanent characteristic of range cows, as determined from this study, is 0.52. The repeatability of 0.52 is based on differences between cows which made their records during a 10 year interval and may, therefore, be slightly high for comparing cows born in the same year. Inbred Hereford cattle were used in this study, average inbreeding of all calves was 12.4 percent and average inbreeding of all dams was 5.9 percent.

Botkin and Whatley (1953) in determining the repeatability of weaning weight and birth weight from 200 Hereford range cows maintained at the Stillwater (151 cows) and Fort Reno (49 cows) Experiment Station in Oklahoma, found the repeatability to vary somewhat from the figures obtained in the above studies. Two methods of analysis were used to determine the repeatability of weaning weight and birth weight from the same cow at the Stillwater Station. They are as follows: intraclass correlation between calves by the same cow, and regression of subsequent records on earlier records by the same cow. Estimates of repeatability for weaning weight were 0.43 and 0.49, and for birth weight they were 0.18 and 0.14, respectively, for the methods of analyses used. Correlations between first and second records for both traits were determined for the group of cows at the Fort Reno Station. Correlations were as follows: for weaning weight, 0.66; and for birth weight, 0.25.

D. Heritability of Long Yearling Weight

By the use of the paternal half-sib correlation, Knapp and Nordskog (1946) found 15 month weight to be 81 percent heritable. By the parent-offspring regression method they found weight at 15 months to be 94 percent heritable. These estimates of heritability were based on only 177 steers from 23 bulls. It was recognized that the number of animals involved in this study was too small to give reliable estimates of heritability.

Tyler, *et al.* (1948) in a study of heritability of body size in Holstein and Ayrshire cattle reported for Holsteins, heritability estimates of 35 to 65 percent at 18 months of age. In Ayrshire cattle, heritability of body size was estimated at 20 to 40 percent at 18 months of age. The intrasire regression of daughter's measurements on dam's measurements and the paternal half-sib correlations were used to estimate the heritability figures.

Knapp and Clark (1950) found the heritability of 15 month weight to be 86 percent when they used paternal half-sib correlation method of calculation. When regression of offspring on parent was used as a method of estimating heritability it was found that 15 month weight was 92 percent heritable. All animals used in this study were Herefords produced at the U. S. Range Livestock Experiment Station, Miles City, Montana, or at the North Montana Branch Station, Havre, Montana.

Wagnon and Rollins (1959) estimated heritability of long yearling (600 days of age) weight for range beef heifers raised under two different management schemes. Under one plan, (herd A) the heifers were supplemented to promote continuous growth during the fall and winter (post-weaning) when the range was nutritionally deficient, while heifers under the other plan (herd B) were not supplemented and almost invariably lost weight during the period in question. Heritability estimates of long yearling weight were 0.44 for herd A, and -.19 for herd B. Heritabilities were estimated by the paternal half-sib correlation method.

E. Correlation of Dam's Weight with Birth and Weaning Weight

Kransnow and Pak (1937) studied the relationship of birth weight of Russian Tagil calves to their dam's weight. These animals were maintained under two nutritional regimes which were termed as satisfactory and unsatisfactory. Correlations between birth weight and dam weight on satisfactory nutrition were 0.56 for male calves and 0.42 for female calves. In the unsatisfactory nutritional group correlations were found to be 0.56 for male and 0.41 for female calves.

Kusner (1936) reviewed studies involving correlations between birth weight and dam weight along with subsequent development of the calf. This study was conducted on Kozak-Kalmuch and their crosses with Herefords in two herds. Correlation of the weight of dam with that of the daughter's weight at birth was found to be 0.39 and 0.42 in the two herds, and of daughter's weight at 18 months 0.30 and 0.50. Correlations between birth weight and 18 month weight varied from 0.43 to 0.68, and that between weight at 6 months and at 18 months from 0.68 to 0.78.

Gregory, et al. (1950) calculated correlation and regression coefficients for different calf-cow weight relationships. The correlation of the birth weights of all calves and the weight of the cows immediately after calving was 0.21 for the North Platte data. The correlation of the birth weights of all calves and the weight of the cow on the last weigh-day before calving was 0.32 for the Valentine data. The correlation coefficients for calf gains from birth to weaning with cow gains from calving to weaning were -0.12 and -0.34 for the North Platte and Valentine data, respectively. Correlation coefficients for the weights of the calves at weaning and the weights of the cows at weaning were 0.20 for the North Platte data and -0.11 for the Valentine data.

According to Dawson, et al. (1947) a highly significant correlation 0.49 was found between the weights of the dams just after calving and the birth weights of calves in a beef Shorthorn herd at Beltsville, Maryland. A highly significant multiple correlation of 0.56 was found between the birth weights of the calves and the ages and weight of the dams.

Knapp, et al. (1942b) reported a correlation of 0.26 between birth weight of calf and previous fall weight of dam. These workers also found a correlation of 0.01 between weaning weight and previous fall weight of dam. Weaning weights were found to be more closely correlated with spring weight of dam and still more closely with weight of dam at weaning than with previous fall weight. This study was based on data collected at the Miles City Station from 1926 to 1940 on Hereford cattle.

In 1958, Clark, et al. studied the correlations between various production factors on 7,436 observations at the U. S. Range Livestock Experiment Station, Miles City, Montana. Correlation can be found in Table I.

TABLE I. PHENOTYPIC CORRELATIONS BETWEEN VARIOUS PRODUCTION FACTORS IN BEEF COWS WITHIN YEAR OF BIRTH, AGE OF DAM, AND SEX.

	Correlation with indicated factor			
Prod. Factors	Weaning Weight1/	Wt. of Cow in Previous Fall	Wt. of Cow in Spring	Wt. of Cow in Fall
Birth Weight	0.41**	0.24**	0.29**	0.20**
Weaning Weight	------	0.11**	0.20**	0.07**

** Significant at the 1 percent level.
1/ 180-day weaning weight.

McCleery and Blackwell (1954) found the partial regression of weaning weight of calf on weight of dam at 18 months of age varied from 0.10 to 0.13 pounds in three pooled analyses. These values were statistically significant. According to the authors, weight of dam at 18 months of age under the conditions in which these data were obtained, is an important factor in accounting for some of the differences in weaning weight. This study was conducted at the New Mexico Agriculture Experiment Station on grade Hereford cattle. The results of the three analyses are present in Table II.

TABLE II. PARTIAL REGRESSION COEFFICIENTS OF 18 MONTH WEIGHT ON WEANING WEIGHT

	18 Month Wt.	Standard Deviation	Degrees of Freedom
Weaning Wt. 1/	0.11	40.25	1437
Weaning Wt. 2/	0.13	50.75	1257
Weaning Wt. 3/	0.10	37.16	1345

1/ Estimates based on pooled data within years ignoring inbreeding of dams.
2/ Estimates based on pooled data within years including inbreeding of dams.
3/ Estimates based on pooled data within sires and years ignoring inbreeding of dams.

Munoz and Rigor (1940) studied the weights of 85 Scindi cows and of their 41 male and 44 female calves. These workers found the correlation between birth weight and dam's previous fall weight for male calves to be 0.63 and for female calves -0.29. When the data for the two sexes were combined the correlation was 0.22. This study was conducted at the Alabany Stock Farm, Philippine Islands.

MATERIAL

A. General

The data used in this study were collected at the North Montana Branch Experiment Station, Havre, Montana from 1933 through 1958. Records on approximately 718 inbred Hereford cows and their calves were analyzed. Because this study was limited to first-calf heifers, only 2- and 3-year-old animals were used. The reason for having two age groups, was that from 1933 to 1952 heifers were bred to calf as 3-year-olds, whereas, from 1952 through 1958 heifers were bred to calf at 2 years of age.

Weights used in analyses were 18 month weight of heifers (fall weights) and birth and weaning weight of their calves. The time at which 18 month weight was taken varied from year to year. It ranged from the 15th of October to the 12th of November. In the earlier years of this study, weights were taken three days in succession and the average of the three was used as the final 18 month weight for that year. Through the later years of this study, 18 month weight was based on only one day of weighing.

Weaning weights were taken at the same time 18 month weights were taken each year. Time of weaning varied over the 26 years as indicated above. In the earlier years of this study, final weaning weights were found by averaging weights taken three days in succession.

Weighing conditions were quite variable with weather having the greatest influence. In some years, large amounts of snow had fallen prior to weigh date, whereas, in other years very little, if any, snow had fallen prior to weigh date.

Birth weights were taken within six hours after the calves were dropped. At this time, the calves were eartagged for identification, this identification remained with each animal throughout its life. If any of the calves were kept as replacements, the identification number was placed on the animal permanently by use of branding irons. The identification system consisted of three digits which also identified the year the animal was born.

Bulls are put in the breeding pastures on the 15th of June each year and removed during the latter part of August. Calving starts about the first of March and continues through the latter part of May with very few calves being born after May 1st.

B. Inbreeding of the Animals

A spot check to determine inbreeding coefficients of the animals used in this study revealed that in 1959 the average inbreeding coefficient ranged from 12 to 15 percent depending on which line was considered. Inbreeding in this herd has developed since 1946 when the first inbred line was started at the Havre Station.

C. Breeding Projects

The present project at the Havre Station concerns the testing of three closed lines of purebred Hereford cattle by mating them to an unrelated fourth line of high quality Hereford grade cattle (tester line). This tester line of cattle consists mainly of the Miles City Line I cattle, which are well known for their high producing ability. Every two years, a high producing bull, as measured by the performance of his progeny, is selected at the Miles City Station to be used as the sire of the tester line of cattle at Havre.

In brief, the purpose of this project is to measure the general and specific combining ability of the three purebred lines. The specific combining ability is measured by selecting the two highest gaining bull calves as measured over a constant feeding period after weaning from each of the three purebred lines. Each of the six selected young bulls are then bred to 15-20 cows from the tester line. Following weaning, the steer and heifer offspring of the six young bulls are fed under feedlot and range pasture conditions, respectively, for a time constant period. After the feeding period, the steers are slaughtered to determine carcass merit. The performance of each bull's offspring is used to measure his producing ability. If any of the six young bulls have a higher producing record than the sire of their respective lines, the young bull becomes the sire of his line. The producing record of each young bull, as mentioned previously, is measured by the performance of his progeny when mated to tester stock.

Measuring of the general combining ability of the three purebred lines is just being initiated. This will involve mating young bulls from the purebred lines to commercial cattle and crossing the purebred lines. The present project was initiated in 1946. Prior to that time, the breeding project at this station was designed to compare large and small type Hereford cattle, and to study various nutritional regimes.

D. Winter Feeding and Management

The winter feeding generally starts in December at the Havre station. The winter ration for the cows consists of about 50 percent cereal straws and about 50 percent of legume and grass hay fed once a day. The cows are fed approximately what roughage they will clean up each day. This amounts to about 20 pounds per head. The hay portion of the ration is gradually increased through gestation and calving with a corresponding decrease in cereal straws. Therefore, at about the beginning of the calving period the cow's ration consists primarily of legume and grass hay. Heifers calving for the first time are wintered separately from the older cows and fed a roughage ration consisting largely of grain hay and alfalfa. Their daily allowance amounts to approximately 17-20 pounds per head. Thus, the heifers are in better body condition by calving time than the older cows.

E. Grazing and Management

Following calving, the cows and heifers are turned out on crested wheat grass pastures from the middle of April through May. About June 1, the cows and calves are trailed to the mountain pasture where they are grazed until about the 1st of November.

As described in the "Annual Grazing Report" from the North Montana Branch Station, the mountain range vegetation consists largely of grasses such as Timothy (Phleum pratense), June grass (Koelaria cristata), Idaho fescue (Festuca idahoensis), Rough fescue (Festuca scabrella), and Mountain brome (Bromus marginatus).

The grazing period begins about June 1 and continues through the latter part of October. The grazing and stocking rates in this area are regulated by the Forest Service personnel. The grasses are about six inches in height before the cattle are turned in the pastures.

F. Weather Conditions

Extreme temperatures occur in the Havre area in summer and winter.

The United States Weather Bureau office at Havre has recorded an absolute minimum of -57 degrees Fahrenheit, and an absolute maximum of 108 degrees Fahrenheit during the last 74 years. The warming effect of the winter winds (chinook) often causes a violent fluctuation in temperature; as much as 80 degrees rise in temperature has been reported in a single hour.

The average annual precipitation at the station is 11.51 inches. Approximately one-third of the annual precipitation falls during the months of May and June, and 65 percent of the total moisture is obtained during the spring and summer growing period; April through September. The snowfall in the winter months at the station is light and seldom is there more than six inches of snow on the ground at one time. Chinook winds, which are a common occurrence, reduce the snow cover.

Climatic conditions at the mountain summer grazing pasture differ considerably from those at the station. Temperatures range from five to ten degrees cooler and approximately five to seven more inches of precipitation are recorded during the months of June, July, and August than at the station. Thus, grazing conditions may be considered much better on the summer range than at the station, which is more typical of the plains area.

METHODS AND RESULTS

A. Treatment of the Observations

1. Long yearling weight and its adjustment

A preliminary study of the data showed that the age of the heifers at the time of weighing, ranged from 69 to 84 weeks. Due to this large variation in age, all yearling weights were corrected to 18 months of age. The correction factor used was 13 pounds for one week change in age. This value was obtained by determining the regression of weight on age when weight was taken.

2. Age of calf at weaning and its adjustment

Due to large variation in ages of calves at weaning, all weaning weights were adjusted to 180 days of age. Since most calves are born in late March and early April and weaned in mid-October in this region, 180 days was chosen as the standard age.

Many workers have reported that the growth curve of calves from birth to weaning is linear. On this basis, all calf weights were adjusted to 180 days of age by the use of the following formula:

Adjusted 180 day weight = (Daily gain from birth to weaning x 180) + Birth weight.

3. Sex effect on weaning weight and its adjustment

A review of the literature indicated that sex had a definite effect on weaning weight in most localities. The data from a sample 6 years (every fifth year) were analyzed to get an indication of the effect of sex. Variance table for this analysis can be found in Table III.

The analysis of variance showed that the effect of sex of calf on weaning weight was highly significant in these data, as was the year effect. This indicates that weaning weights should be corrected for sex to reduce error when these weights are used in other calculations.

TABLE III. ANALYSIS OF VARIANCE OF WEANING WEIGHT TO DETERMINE SEX EFFECT.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	Calculated F Value
Year	5	109410	21882	124.33**
Sex	1	27815	27815	158.04**
Sex x year	5	7104	1421	8.07**
Error	138	24336	176	------
Total	149	168665	-----	------

** Significant at the 1 percent level.

The existence of a highly significant sex-year interaction indicates that a single correction value applied to all data would be invalid. Therefore, weaning weights were corrected within years. This was done by calculating the average weaning weight for male calves and the average weaning weight for female calves within years. The difference between averages was determined and this difference was added to the 180 day weight of all calves in the lighter group for that year.

Female calves out-weighed the males in four of the 26 years studied. The extreme difference in favor of males was found in 1934 when the male calves averaged 56 pounds heavier at weaning than females. The largest difference in favor of the female calves was found in 1958 when females averaged 25 pounds heavier at weaning than males. These differences are based on 180 day weaning weights. The average weaning weight for each sex for each year can be found in Table IV. No attempt was made to distinguish bull calves from steer calves in this study because the number of bull

TABLE IV. AVERAGE WEANING WEIGHT FOR FEMALES AND MALES IN THIS STUDY FOR EACH YEAR.

	Males		Females			Males		Females	
Year	No.	Wt.	No.	Wt.	Year	No.	Wt.	No.	Wt.
1933	16	346	10	322	1946	18	405	10	382
1934	2	354	9	298	1947	19	415	8	411
1935	15	353	9	336	1948	34	397	16	372
1936	13	334	15	333	1949	9	406	4	390
1937	8	374	17	332	1950	11	408	8	403
1938	11	351	5	325	1951	13	415	8	376
1939	8	352	11	358	1952	12	401	14	384
1940	15	384	7	361	1953	18	398	12	368
1941	14	399	8	397	1954	7	342	22	329
1942	18	420	15	401	1955	18	390	24	378
1943	13	365	17	366	1956	15	362	34	358
1944	16	356	17	330	1957	23	346	17	340
1945	21	354	15	344	1958	15	323	11	348

calves involved was small. Average 180 day weaning weight for males over the 26-year period was 375 pounds and for females it was 359 pounds. The average weaning weight combining sexes over the 26-year period, was 367 pounds. The sex ratio was approximately 1:1 with 393 males and 341 females appearing.

4. Sex effect on birth weight and its adjustment

The effect of sex on birth weight was studied using the same data as were used in the study of sex effect on weaning weight, with the exception of one year. The results are shown in Table V.

TABLE V. ANALYSIS OF VARIANCE OF SEX EFFECT ON BIRTH WEIGHT

Source	Degrees of Freedom	Sums of Squares	Mean Squares	Calculated F Value
Year	4	2847.96	711.99	7.68**
Sex	1	430.96	430.96	4.65**
Sex x year	4	82.96	20.74	0.22
Error	109	10101.08	92.67	----
Total	118	13462.96	------	----

** Significant at the 1 percent level.

Since there was a non-significant sex-year interaction all birth weights were corrected by using the average difference in birth weight of the two sexes over the 26-year period. The average birth weight of males over the 26-year period was 76 pounds and the average female birth weight was 70 pounds. These averages involved 393 male calves and 341 female calves. Due to the 6 pound advantage of the males at birth, 6 pounds were added to the birth weight of each female calf, thus correcting birth weight for sex.

B. Heritability

1. Heritability of 18 month weight

Heritability in the narrow sense is the fraction of the phenotypic variance which is due to the average effects of the genes of the individuals of the population. Its magnitude is important in choosing the method of selection and the breeding plan, in determining the relative amount of emphasis to be given each trait when selecting breeding stock, in estimating the rate of progress in a selection program.

The methods used to estimate heritability are based on the fact that related individuals generally resemble each other more closely than unrelated individuals. The present study utilizes the correlation between paternal half-sibs to estimate heritability.

The structure of the breeding herd used in this study makes the following statistical model appropriate for expressing the individual datum as a linear function of certain parameters and random variables.

$$Y_{ijklm} = u + a_i + c_{ij} + d_{ijk} + s_{ijkl} + e_{ijklm}$$

Where---u is the general mean of all calves,

---a_i is an average effect peculiar to animals of $\underline{i}$th age,

---c_{ij} is an average effect peculiar to animals of $\underline{i}$th age born in $\underline{j}$th year,

---d_{ijk} is an average effect peculiar to animals of $\underline{i}$th age born in $\underline{j}$th year in $\underline{k}$th line,

---s_{ijkl} is an average effect peculiar to animals of $\underline{i}$th age born in $\underline{j}$th year in $\underline{k}$th line sired by $\underline{l}$th sire,

---e_{ijklm} is a random effect peculiar to the specific animal.

This model is appropriate for the "nested" or "hierarchal" classification.

The assumptions in the foregoing model are that Y_{ijklm} is distributed with expected values of the effects as follows: an overall mean equal u and $Ea_i = Ec_{ij} = Ed_{ijk} = Es_{ijkl} = Ee_{ijklm} = 0$ with $Ea_i^2 = \sigma_a^2$, $Ec_{ij}^2 = \sigma_c^2$, $Ed_{ijk}^2 = \sigma_d^2$, $Es_{ijkl}^2 = \sigma_s^2$, $Ee_{ijklm}^2 = \sigma_e^2$ (E = average value in repeated sampling).

It is assumed, then that each of the elements other than u, have zero means and have variances as indicated above.

Basically, in a statistical analysis of data which have equal subclasses it is reasonable to assume that each subclass is contributing equally to each variance component. Therefore, in analyzing data in which unequal subclasses prevail, it would also be reasonable to assume that the subclasses with smaller numbers are contributing disproportionately to the variance components when compared to the subclasses with larger numbers. If this situation exists, the coefficients of the variance components for the various classifications would be overestimated and should be corrected.

As a result of the above reasoning, components of variance were estimated according to the method set forth by King and Henderson (1954). Formulae used for this determination are as follows:

$$X = \frac{(N-k)}{65}$$

Where---X = to the estimate of the coefficient of variance component due to sires,

---65 = degrees of freedom for sires,

---N = number of observations,

---$k = \sum_a \sum_c \frac{\sum_d na_{jk}^2}{na_{ij}}$

$$TEMS = \sigma_e^{\,2} + X\,\sigma_s^{\,2}$$

Where--- $\sigma_e^{\,2}$ = calculated variance for error found in Table VI,

--- $\sigma_s^{\,2}$ = calculated variance due to sires found in Table VI,

---TEMS = true estimate of mean squares for sires.

Since the paternal half-sib method of estimating heritability requires only the estimate of variance due to sires and variance for error, calculations for the coefficients of the estimate of variance components for the various classification were limited to the coefficient component due to sires, (Table VI).

Variance due to sires was found to be overestimated approximately fourfold (3.6), indicating that unequal subclass numbers have a great influence on variance due to sires.

TABLE VI. ANALYSIS OF VARIANCE TABLE FOR 18 MONTH WEIGHT WITH UNEQUAL SUBCLASSES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Calculated F Value
Ages	1	218050.08	218050.08	80.99**
Years / Ages	18	797861.48	44325.64	16.46**
Lines / Years	32	213612.90	6675.40	2.48**
Sires / Lines	65	238062.98	3662.51	1.36*
Error	364	980030.54	2692.39	------
Total	480	2447621.98	-------	------

* Significant at the 5 percent level.

** Significant at the 1 percent level.

Heritability within age, year, and line subgroups was estimated by the following formula:

$$H^2 = \frac{4\,\sigma_s^2}{\sigma_e^2 + \sigma_s^2}$$

From simple Mendelian genetic theory, it may be shown that the additive genetic variance in a population mating at random is derived as follows: one-fourth from the sires, one-fourth from the dams and one-half from sampling at meiosis. When the environment is random for all individuals in a population, the variance among half-sibs contains one-fourth of the additive genetic variance plus all of the environment variance ($\sigma_s^2/4 + \sigma_e^2$), assuming no dominance and very little epistasis, and assuming that the sires have equal additive genetic variance. Therefore, the sire's component of variance would contain one-fourth of the additive genetic variance, ($\sigma_s^2/4$). It follows then, that the estimate obtained in the above formula should be multiplied by four.

The major advantage of using paternal half-sib correlation to estimate heritability is that this value contains only the additive plus a small fraction of the epistatic portion of the hereditary variance. The accuracy of this method of estimation depends on the degrees of freedom available for estimating the difference between sires. It is limited by the fact that error due to sampling or incorrect estimation of environmental influences are multiplied by four.

The estimate of heritability for 18 month weight was found to be 0.36. According to most workers, this estimate would rank in the medium range when comparing high, medium, and low estimates of heritability.

If the original estimated variance component due to sires, as found in Table VI, had been used to estimate heritability, the estimate would have exceeded 1.2. Without a doubt this figure would have been out of reason, actually, it is impossible to have a true heritability exceeding one.

C. Regression and Correlation

1. General

In this portion of the study, the relationship between dam's 18 month weight and the birth and weaning weight of her first calf was estimated by the use of regression and correlation coefficients.

Analysis of variance and covariance was used to determine sums of squares and sums of the products for each classification, (Table VII). With the prevalence of unequal subclasses, analysis of variance was run according to the statistical model found on page 45. The following statistical model was used for the analysis of covariance in this portion of the study:

$$Y_{ijklm} = u + a_i + c_{ij} + d_{ijk} + s_{ijkl} + BX_{ijklm} + e_{ijklm}$$

Where---u is an average effect peculiar to all animals,

---a_i is an average effect peculiar to all animals of ith age,

---c_{ij} is an average effect peculiar to all animals of ith age born in jth year,

---d_{ijk} is an average effect peculiar to all animals of ith age born in jth year in kth line,

---s_{ijkl} is an average effect peculiar to all animals of ith age born in jth year in kth line sired by lth sire,

---B is the slope of the common regression line in the population,

TABLE VII. ANALYSIS OF VARIANCE AND COVARIANCE OF BIRTH, WEANING, AND 18 MONTH WEIGHT.

Source	Variable Pair 1/		Degrees of Freedom	Sum of Squares	Mean Squares	Calculated F. Value
Ages	1	1	1	542044.86	542044.86	163.34**
Years/ages	1	1	25	1785395.35	71415.81	21.52**
Lines/years	1	1	37	256343.46	6928.20	2.09**
Sires/lines	1	1	132	430554.94	3261.78	0.98
Error	1	1	431	1429947.76	3317.74	
Total	1	1	626	4444286.37		
Ages	1	2	1	-54297.65	-54297.65	
Years/ages	1	2	25	47846.59	1913.86	
Lines/years	1	2	37	3787.12	102.35	
Sires/lines	1	2	132	12027.68	91.12	
Error	1	2	431	47705.32	110.69	
Total	1	2	626	57069.06		
Ages	1	3	1	-141772.29	-141772.29	
Years/ages	1	3	25	22797.05	9119.04	
Lines/years	1	3	37	59677.28	1612.90	
Sires/lines	1	3	132	75869.09	574.77	
Error	1	3	431	251376.85	583.24	
Total	1	3	626	473126.98		
Ages	2	2	1	5439.10	5439.10	105.35**
Years/ages	2	2	25	3873.53	154.94	3.00**
Lines/years	2	2	37	3562.17	96.27	1.86**
Sires/lines	2	2	132	8169.27	61.89	1.20
Error	2	2	431	22252.60	51.63	
Total	2	2	636	43296.67		
Ages	3	3	1	37080.67	37080.67	20.64**
Years/ages	3	3	25	397163.24	15886.53	8.84**
Lines/years	3	3	37	148949.28	4025.66	2.24**
Sires/lines	3	3	132	217526.73	1647.93	0.92
Error	3	3	431	774247.44	1796.40	
Total	3	3	626	1574967.36		

1/ Variable pair
The number 1 indicates 18 month weight.
The number 2 indicates birth weight.
The number 3 indicates 180 day weaning weight.

** Significant at the 1 percent level.

---X_{ijklm} is the deviation of an animal of ith age born in jth year in kth line sired by lth sire, from the the total mean,

---e_{ijklm} is a random effect peculiar to all animals.

2. Relation between 18 month weight of dam and birth weight of her first calf

The correlation coefficient between 18 month weight of dam and her first calf's birth, and the regression coefficient of birth weight on 18 month weight are presented in Table VIII. The effects of differences due to age at calving, years, lines, and sires, were removed by analysis of variance, (Table VII).

TABLE VIII. RELATION BETWEEN 18 MONTH WEIGHT OF DAM AND BIRTH AND WEANING WEIGHT OF HER FIRST CALF.

	Correlation Between 18 Month Weight and--	Regression on 18 Month Weight
Birth Weight	0.267**	0.03**
Weaning Weight	0.239**	0.18**

** Significant at the 1 percent level.

Although the regression and correlation coefficients are quite small, they are highly significant statistically. The test for the significance of regression is presented in Table IX. This indicates that the relationship between 18 month weight of dam and the birth weight of her first calf is small but real.

3. Relation between 18 month weight of dam and weaning weight of her first calf

The effects of differences due to ages at calving, years, lines and sires, were removed by analysis of variance, (Table VII).

TABLE IX. TEST OF SIGNIFICANCE OF REGRESSION OF BIRTH WEIGHT ON 18 MONTH WEIGHT.

Variation Due to--	Degrees of Freedom	Sums of Product	Mean Product	Calculated F Value
Regression	1	3.69	3.69	33.54**
Variation from Regression	429	47.94	.11	-----
Total	430	51.63	----	-----

** Significant at the 1 percent level.

The correlation coefficient between 18 month weight of dam and her first calf's weaning weight and regression coefficient of weaning weight on weight at 18 months are presented in Table VIII. Coefficients are based on 627 observations made over a 26-year period. Both coefficients were found to be highly significant, however, they are small and indicate that the relationship between the two weights is of little value. The test for the significance of the regression of weaning on 18 month weight is presented in Table X.

TABLE X. TEST OF SIGNIFICANCE OF REGRESSION OF WEANING WEIGHT ON 18 MONTH WEIGHT.

Variation Due to--	Degrees of Freedom	Sums of Product	Mean Product	Calculated F Value
Regression	1	102.53	102.53	25.96**
Variation from Regression	429	1693.87	3.95	-----
Total	430	1796.40	----	-----

** Significant at the 1 percent level.

DISCUSSION

A. General

In selecting replacement heifers, the breeder should consider the fact that great differences in a cow's production occur between years, largely because of differences in environmental factors. However, many workers have shown that the repeatability of a cow's first calf record is quite high (50 percent), although, in some years it may merely reflect favorable environmental conditions. With the estimate of heritability of 18 month weight in the present study where year effects were removed, it is reasonable to expect that a breeder can make progress in increasing weight for age, by selecting heifers that are above the average in weight at 18 months.

It also can be concluded from the results of this study, that when weaning weight of calves are used as a basis of comparison between various cows in the herd, they should be adjusted to a constant age and corrected for sex differences as well as being corrected for age of dam as shown by other workers. It is evident that no constant figure can be set forth to correct for sex differences due to the prevalence of the sex-year interaction.

If birth weight is used as a selection criterion the results indicate that female weights should be corrected to that of males. This can be attained by adding six pounds to the female calf's birth weight. As other workers have indicated, the effect of age of dam on birth weight is great enough to warrant correction for that also.

Although, the results of the present study show that the relationship between 18 month weight of heifers and the birth and weaning weights of their first calves is small, this relationship should not be ignored. It indicates that major emphasis should be placed on other characteristics when a breeder is selecting replacement stock with the objective of increasing production (weaning weight).

B. <u>Effect of Sex on Birth and Weaning Weight</u>

Inasmuch as weaning weights and birth weights are of primary importance to the breeder of range cattle, it would be desirable to know what factors are influencing these weights. One of the major factors affecting the variation of these weights is sex. Comparison of the sex differences shown in Table III and V indicates that the difference between male and female calves was considerable in these data for both birth and weaning weight. Differences in weaning weight for each of the 26 years studied due to sex can be found in Table IV, this also illustrates the variation in sex effect in different years.

One of the interesting points in the present study is the occurrence of a highly significant sex-year interaction in weaning weight indicating that the relative magnitude of response of the sexes to years was different. With this prevalence, it is reasonable to assume that physiologically some years favored male calves and some years favored female calves. This physiological favoritism can possibly be attributed to endocrine function and light adaptation, as there is an increasing amount of evidence indicating that the functional states of the gonads and other endocrine glands are influenced markedly by temperature, light, and nutrition. According to Turner (1955), hormones are preeminently important coordinatory agents in post-embryonic individuals, and it appears that they normally come into operation during relatively late embryonic stages. It is important to recognize that hormones and other circulating and diffusing agents would be unable to produce local effects if a pattern of differential sensitivity were not present before-hand in the reacting system. In other words, hormones are able to modify differences established during the various phases of development, but are powerless to produce the difference. It is difficult to conceive the exact mechanism by which developmental patterns are caused to appear in a reacting system by a complex of genes which is believed to be distributed without change to every cell in the organism. Nevertheless, it must be assumed that these latent patterns are present, in order to account for the differential effects produced by specific chemical agents which diffuse indiscriminately throughout the body.

The existence of a highly significant sex-year interaction has not been considered by many workers in this field. Some of the workers failed to test for such an interaction, while others assumed no interaction. However, the existence of the sex-year interaction is in agreement with Blackmore (1954), who found a highly significant sex-year interaction working with dairy cattle and Pahnish (1958a), who found a significant interaction working with Hereford cattle under southwestern range conditions.

The existence of a sex-year interaction implies that the use of a specific correction for sex is erroneous. The use of a correction factor for correcting female weaning weights to that of males, would bias weaning weights in the years that female calves averaged higher than male calves. Therefore, a better method for correcting difference due to sex in weaning weight is on a within year basis. This can be done by determining the difference between the average male and female weaning weights for a given year and adding this difference to the sex which has the lower average weaning weight for that specific year.

The highly significant difference in birth weight due to sex in this study is in agreement with numerous workers. Specifically the actual six pounds advantage of male calves over female calves at birth is in close agreement with the findings of Clark, et al. (1958); Knapp, et al. (1942b); and Koch and Clark (1955a) who found a 5, 6, and 5.6 pound difference in favor of male calves, respectively.

The advantage in weight of the male calves at birth can be partially attributed to the fact that male calves have a longer intra-uterine life. The above statement is substantiated by the work of Dawson, et al. (1947), Jasper (1950), Rice, et al. (1954), and Burris and Blunn (1952), who found that the gestation period for males is from 1 to 5 days longer than females. Since the greatest development of the fetus occurs in the last two months of gestation, it is reasonable to expect that a few days increase in gestation length in favor of male calves would give them the advantage in weight at the time of parturition.

The existence of a non-significant sex-year interaction in this phase of the study is not surprising because birth weight is for the most part under the influence of maternal environment. Year effects would tend to be reduced since a high plain of nutrition was maintained through the gestation period each year. With this, it would be reasonable to assume that prenatal life should be similar each year and affect male and female calves in the same manner.

It has been established by many workers that the larger cows tend to have the larger calves at birth. This would favor selecting replacement heifers that are above the average in 18 month weight. As has been mentioned previously, an advantage in weight at birth will be carried through weaning; accordingly, weaning weight will be increased somewhat by selecting replacement heifers that are above the average in 18 month weight.

C. Heritability

One of the most striking features of the heritability estimate obtained in this study, is that it is so much lower than estimates obtained by other workers using the paternal half-sib method of estimation. Knapp and Nordskog (1946) found 15 month weight to be 81 percent heritable, and briefly made reference to 18 month weight being 61 percent heritable, whereas, in 1950 Knapp and Clark found 15 month weight to be 86 percent heritable. These estimates exceed the estimate obtained in this study approximately threefold. An explanation of the large differences in these estimates seems in order.

Inasmuch as the animals in the present study were maintained primarily on grass it would be reasonable to expect a lower heritability figure than those obtained by the workers indicated above, since the above workers estimated heritability on animals maintained in the feedlot. However, it would be unreasonable to expect this variation in management to account for the total difference that existed.

Knapp and Nordskog (1946) as was mentioned previously made reference briefly in their publication that weight of heifers at 18 months of age at the Miles City station was approximately 61 percent heritable. According to these workers, the animals used in obtaining the estimate of heritability (0.61) were maintained primarily on pasture with the exception of the winter feeding period. This regime is similar to the regime the animals were subjected to in the present study. It is still recognized that the above estimate exceeds that which was obtained in the present study by approximately twofold, which further emphasizes the point that nutritional regime does not solely account for the apparent difference in the heritability estimates.

After an extensive review of the work done by Knapp, et al. (1946 and 1950), it is quite evident that these workers made no attempt to correct the overestimated coefficient of variance component due to unequal subclasses. With the prevalence of unequal subclasses in their study, it is reasonable to expect that the coefficient is larger than one and if it is not corrected, this would tend to overestimate heritability greatly. The workers were aware that their estimates of heritability of 15 month weight were larger than should be expected but they were unable to determine why. This can be attributed to the fact that at the time their studies were conducted, methods were just being developed to estimate coefficients of the variance components.

If the estimated coefficient of variance component had not been corrected in the present study, an estimate of heritability of over 100 percent would have been obtained. This further illustrates the necessity of correcting coefficients when unequal subclasses are used in an analysis. Since heritability is defined as "the fraction of the phenotypic variance which is due to additive effects of the genes of the individuals of the population", it is impossible to have a heritability figure over 100 percent. Although many workers have calculated estimates of heritability for various characteristics over 100 percent, it seems certain that these figures are overestimated.

Although the estimate of heritability of 18 month weight in the present study is in disagreement with some workers, it is in close agreement with the estimate obtained by Wagnon and Rollins (1958) on long yearling weight (approximately 600 days), 36 percent and 44 percent, respectively. The small difference that exists here can be attributed to chance alone.

From the heritability estimate obtained in this study, it is reasonable to assume that a breeder can increase 18 month weight of heifers by selecting replacement heifers on the basis of their 18 month weight.

D. Phenotypic Correlation Between 18 Month Weight of Dam and Production Factors of Her First Calf

1. Weaning weight

The maternal influence of cows on the phenotypic expression for traits in the calf is due to genes transmitted by the cow to the calf, and by the maternal environment provided during part of the calf's life. The contribution of the cow from genes transmitted is the same as that of the sire, except for sex-linked genes. The influence through maternal environment appears in two phases of the calf's life. The first phase is the intrauterine period from conception until birth. The second phase is from birth to weaning.

The unbiased estimate of the relationship between 18 month weight and weaning weight in this study is small, (0.24). It is unbiased in the respect that it has all the influences removed with the exception of the random effect and genetic relationship. The regression of weaning weight on 18 month weight was found to be 0.18, thus, for each pound increase in weight at 18 months, the weaning weight of the calf will increase 0.18 pounds ($P < .01$). This regression coefficient is in close agreement with the findings of McCleery and Blackwell (1954).

The small coefficient of correlation between weight at 18 months and weaning weight would seem to indicate that weight of the cow at 18 months (fall weight) did not materially influence subsequent milk production. According to Knapp, et al. (1942b) the correlation between the spring weight of the cow and weaning weight is 0.20 which is higher than the correlation between previous fall weight and weaning weight but again the correlation is not high enough to be of much value. This seems to indicate that it is not the storage of energy in the body of the cow, but rather the condition of the range and the availability of feed during the suckling period plus the cow's inherent ability to produce, that influences the milk production of the cow and in turn the nutrition of the calf.

Correlation between weight of cow at weaning time and weaning weight is similar to coefficients found for previous fall and spring cow weight, this is in accordance to the findings of Clark, et al. (1958). This also, substantiates the idea that it is the nutrition of the dam during the suckling period that influences the weaning weight of the calf more than any storage of energy which the cow may have.

Since little literature is available on the correlation of 18 month weight of dam and weaning weight of her first calf, it seems advisable to compare the correlation coefficient obtained in the present study to coefficients obtained by other workers using previous fall weight rather than 18 month weight. In this respect, the correlation between weaning weight and 18 month weight in this study is slightly higher than those found by Knapp, et al. (1942b), and Clark, et al. (1958). However, Gregory, et al. (1950) found the correlation between previous fall weight of dam and weaning weight to be 0.20 in one herd, which is in close agreement with the figure obtained in the present study. In another herd, Gregory, et al. (1950) found the correlation between the above weights to be -0.11.

Variation in 18 month weight accounts for only 6 percent of the total variation in weaning weight, from this it appears that genes affecting 18 month weight and weaning weight are quite different. Although it is evident that environmental factors affecting these weights are quite variable because 18 month weights were taken long before the calves were born. Eighteen month weight is affected through a period of two years, whereas, weaning weight is affected through a period of six to eight months. It is apparent that large variations can result. The heritability estimate of weight at 18 months also indicates that the influence for the most part is environmental rather than genetic. In this respect, it would be possible to have genetic and environmental interactions occurring which will further confound the results.

It is unreasonable to say that the existing relationship is of no value. It is valuable in the sense that it points out that a breeder should not place a great amount of emphasis on 18 month weight of heifers if he wants to increase the average weaning weight of his herd. However, a breeder can expect some increase in weaning weight by selecting the heavier heifers at 18 months of age.

2. Birth weight

From the results of this portion of the study, it is evident that birth weight is related to 18 month weight at about the same degree as is weaning weight. However, variation in 18 month weight accounts for approximately one percent more of the variation in birth weight than it did in weaning weight.

The relationship between birth weight and previous fall weight found by Clark, et al. (1958) is similar to the relationship found in this study between weight at 18 months and birth weight. Whereas, the relationship found by Munoz and Rigor (1948) and Kusner (1936) is somewhat in excess of the relationship in the present study. The reason for this is not clear, but may be attributed to the fact that the above work was done outside of the United States and on cattle which are not common to the United States.

Work by Knapp, et al. (1942b) has shown that the correlation between birth weight and previous fall weight of the dam is 0.26, which is in close agreement with the coefficient obtained in the present study. However, when these workers accounted for differences among cows the relationship was reduced to 0.18. This implies that the size of the cow affects birth weight more than changes in condition or fleshing. In other words, it would seem that any change in the weight of the cow due to environmental conditions does not have as much effect on the birth weight of the calf as do differences between size or scale of cows.

Work by Kansnow and Pak (1937) will substantiate the preceding implication, that the size or scale of a cow, rather than her condition has the greatest influence on birth weight. These workers studied the relationship between previous fall weight of dam and birth weight of the calf in two herds maintained under two different nutritional regimes, one satisfactory and the other unsatisfactory. The correlations between the two weights were found to be almost identical for both herds indicating that condition of a cow has a very small influence on the birth weight of her calf.

If size of dam only partially accounts for size of calf at birth, what accounts for the remaining portion? Some hypotheses can be set forth which may partially account for the remaining influences on size of calf at birth.

Since size of dam accounts for only a small portion of influence on birth weight, it would be reasonable to assume that the biggest factor influencing birth weight is the intra-uterine environment. That is, if the dam has the ability to furnish a well-developed vascular system to the fetal membranes, thus, insuring an abundance of nutrients for the fetus and removal of the waste products to permit optimum development, especially in the latter stage of gestation. This is based on the assumption that the dam is receiving an adequate supply of nutrients to meet her increased requirements during gestation.

Another factor which may influence weight at birth is the characteristic gestation length for each cow. It is quite evident that there is some variation in gestation lengths between individual cows and in this way account for some of the variation in weight at parturition.

Work by Knapp, et al. (1940) has shown that birth weight is controlled by size of cow, the calving sequence, and length of gestation period. These workers also found that calves produced by four-year-old cows are the largest, this would indicate that maximum production capacity of the cow has been reached by that age. This finding also supports the conclusion that birth weight is associated with the skeletal size or scale of the cow.

It seems reasonable to expect some increase in birth weight by selecting the largest heifer at 18 months of age. An increase in birth weight is desirable as long as calving difficulties are not encountered, since an advantage in weight at birth is carried through weaning.

SUMMARY

Heritability of 18 month weight of heifers and the relationship of this weight to the birth and weaning weight of the heifer's first calf were studied. The data were collected in the experimental Hereford herd at the North Montana Branch Experiment Station over a 26-year period (1933-1958). Records of 718 heifers and their first calves formed the basis of the study.

Other characteristics studied were the effect of sex on birth and weaning weight and the variation in age at the time heifer fall weights were taken. Analysis of variance indicated that sex had a highly significant effect on birth and weaning weight. In birth weight, males were found to average about six pounds heavier at birth than females. However, in weaning weight, a highly significant sex-year interaction prevailed, indicating that the relative magnitude of response of the sexes was different in different years. With this prevalence, correction for sex effect on weaning weights was made on a within year basis.

By regressing fall weight of the heifers on age at the time fall weight was taken, a correction factor was developed to correct all weights to a standard of 18 months. The correction factor was found to be 13 pounds, for animals between 69 and 84 weeks of age, for each week increase in their age.

Heritability of 18 month weight was estimated by the use of the paternal half-sib correlation method. Eighteen month weight was found to be 36 percent heritable. Effect of differences due to age at calving, years, and lines were removed by analysis of variance. Since unequal subclasses

prevailed in this portion of the study, it was concluded that the coefficient of the variance component due to sires, was overestimated. So steps were taken to correct this coefficient, upon correction it was found that the coefficient was overestimated approximately fourfold, indicating the necessity for correction.

Correlation studies indicated that the relationship between dam's 18 month weight and birth and weaning weight of her first calf are quite small, 0.27 and 0.24, respectively. However, these correlation coefficients are highly significant statistically. Analysis of variance and covariance were used to estimate the relationship between the above weights. Effects of differences according to age at calving, years, lines, and sires were removed by analysis of variance.

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