



Time trends, sex and age of dam correction factors, and genetic parameters for production traits in Angus and Hereford cattle
by Terry C Nelsen

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
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Abstract:

Field records of 6200 purebred calves from 6 Angus herds and 7700 purebred calves from 9 Hereford herds were analyzed by least squares analysis. Herd, year, year within herd, sire within year within herd, sex, age of dam and interactions among these factors along with partial regressions on day of birth and age at weaning were included in various combinations as independent variables in three basic least squares models. Response variables were birth weight, pre- and postweaning average daily gains, weaning and final test weights. The objectives of the study were to analyze time trends, to calculate and evaluate sex and age of dam correction factors, and to estimate genetic parameters. Time trend analyses showed that birth and weaning weights increased significantly in the time period (1959 to 1973) of the study. There was a nonsignificant increase in postweaning gain and no change in final test weight. Correction factor analyses showed that multiplicative factors were generally preferred over additive in the Angus data except for the age of dam corrections for preweaning gain and weaning weight, where no decision was reached. In the Hereford data, multiplicative factors were preferred in both birth weight adjustments and in weaning weight age of dam adjustments. Additive factors were preferred in both Hereford preweaning gain adjustments and in weaning weight age of dam adjustments. Decision criteria for additive vs. multiplicative correction factors were the factors' ability to affect major sources of variance, interactions, and individual sex and age of dam subclass variances. Estimates of heritability for birth weight, preweaning average daily gain, weaning weight, postweaning average daily gain and final test weight, respectively, were: .39, .29, .27, .20, and .25 for Angus combined sex analysis; .52, .32, .28, .23 and .16 for Angus bull analysis; .33, .15, .15, .27, and .16 for Angus heifer analysis; and .62, .32, .33, .16 and .40 for Hereford bull analysis. Estimates of heritability from Hereford weaning weight only analyses were .28 for males, .23 for females and .23 for the combined analysis of sexes.

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TIME TRENDS, SEX AND AGE OF DAM CORRECTION FACTORS,
AND GENETIC PARAMETERS FOR PRODUCTION
TRAITS IN ANGUS AND HEREFORD CATTLE

by

TERRY C NELSEN

A thesis submitted in partial fulfillment
of the requirements for the degree

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ABSTRACT

Field records of 6200 purebred calves from 6 Angus herds and 7700 purebred calves from 9 Hereford herds were analyzed by least squares analysis. Herd, year, year within herd, sire within year within herd, sex, age of dam and interactions among these factors along with partial regressions on day of birth and age at weaning were included in various combinations as independent variables in three basic least squares models. Response variables were birth weight, pre- and postweaning average daily gains, weaning and final test weights. The objectives of the study were to analyze time trends, to calculate and evaluate sex and age of dam correction factors, and to estimate genetic parameters. Time trend analyses showed that birth and weaning weights increased significantly in the time period (1959 to 1973) of the study. There was a nonsignificant increase in postweaning gain and no change in final test weight. Correction factor analyses showed that multiplicative factors were generally preferred over additive in the Angus data except for the age of dam corrections for preweaning gain and weaning weight, where no decision was reached. In the Hereford data, multiplicative factors were preferred in both birth weight adjustments and in weaning weight age of dam adjustments. Additive factors were preferred in both Hereford preweaning gain adjustments and in weaning weight age of dam adjustments. Decision criteria for additive vs. multiplicative correction factors were the factors' ability to affect major sources of variance, interactions, and individual sex and age of dam subclass variances. Estimates of heritability for birth weight, preweaning average daily gain, weaning weight, postweaning average daily gain and final test weight, respectively, were: .39, .29, .27, .20, and .25 for Angus combined sex analysis; .52, .32, .28, .23 and .16 for Angus bull analysis; .33, .15, .15, .27, and .16 for Angus heifer analysis; and .62, .32, .33, .16 and .40 for Hereford bull analysis. Estimates of heritability from Hereford weaning weight only analyses were .28 for males, .23 for females and .23 for the combined analysis of sexes.

INTRODUCTION

As the beef cattle industry strives towards more efficient cattle better suited to their environment, it becomes more and more important for the scientific community to provide the industry with more accurate methods of evaluating their cattle and choosing their breeding stock.

The objectives of this study were: to estimate the genetic parameters within production traits in Montana Angus and Hereford cattle by use of field records obtained from different herds throughout the state; to examine time trends as possible indicators of direct and indirect responses to selection in herds that had been practicing selection programs; and to calculate and then evaluate different adjustment factors to reduce the effects of sex and age of dam on the important production traits in these herds. The production traits included in this study were birth, weaning and final test weights and pre- and postweaning average daily gains. Genetic parameters are important because they are used to predict direct and correlated responses to selection. Past responses to selection can be estimated by analysis of time trends. Correction factors for the environmental effects allow a producer to evaluate the genetic value of his cattle more accurately. If the animals records can all be placed on an equal basis as far as environmental effects are concerned, then the differences among them can be considered mainly genetic, although some environmental effects and some random variation will remain.

LITERATURE REVIEW

General

The continuous variation in production traits of beef cattle is caused by both genetic and environmental factors. This review of literature deals with methods of estimating the relative magnitude of these two general factors and specific elements within them. Methods of standardization (correction factors) for age of dam and sex effects will be included. The majority of the studies cited deal specifically with Angus and Hereford cattle although studies with other beef breeds, dairy breeds, and even other mammals are included when pertinent.

Age of dam and sex effects can be adjusted for by either additive or multiplicative factors. Both methods will equalize means but they have different effects on variance. Additive factors do not alter the relative variances and thus are applicable when standard deviations of the classes are equal. Multiplicative factors will change the variation in proportion to the square of the ratio used. A ratio greater than one will increase the variation and a ratio of less than one will decrease it. Also, multiplicative factors can alter an interaction effect while additive factors cannot.

Birth Weight

The major environmental sources of variation in birth weight generally agreed upon in the literature are breed of calf, sex of calf, and age of dam. Other environmental sources considered are gestation length, season of birth, weight of dam, and herd effects.

Specific genetic sources of variation reported are sire effects and inbreeding.

It has been well established that there are breed differences in calf birth weights. Comparative studies involving Angus and Hereford have shown Angus calves to be consistently 3 to 5 kg lighter at birth. Studies by Sagebiel et al. (1967), Cobb et al. (1964), and Taylor et al. (1960) found differences of 3.7 (31.8 vs. 28.1), 3.6 (30.7 vs. 29.23), and 5.7 (67.6 vs. 61.9) kg, respectively, with Herefords the heavier. Burris and Blunn (1952) reported Herefords to be 1.5 (30.7 vs. 29.2) kg heavier than Angus (this smaller difference is due in part to their adjusting their data for a difference in gestation length).

Meiske et al. (1964), Meade et al. (1959), and Rife et al. (1943) also reported Angus to have birth weights significantly lighter than Herefords.

Studies of the effect of sex on birth weight have shown that bull calves weigh approximately 2.2 kg more at birth than heifers. Burris and Blunn (1952) found male Angus to be 2.4 kg (30.4 vs. 28.0) heavier than female Angus and male Herefords 2.0 kg (31.7 vs. 29.7) heavier than female Herefords. Taylor et al. (1960) reported a male advantage of 2.0 kg (29.1 vs. 27.1) in Angus and 2.3 kg (31.8 vs. 29.5) in Herefords. Marlowe (1962) studied 5067 Angus and 4778 Hereford calves and found a difference of 2.0 kg (28.0 vs. 26.0)

and 1.8 kg (31.8 vs. 30.0), respectively, between sexes within breeds. Koch et al. (1959) found bulls outweighing heifers by a 2.4 kg (33.2 vs. 30.8) average in a study group composed of Hereford, Angus and Shorthorn calves. In studies of large numbers of Herefords, Brinks et al. (1961) with 4432 calves, found males heavier by 2.4 kg (36.0 vs. 33.6) and Koch et al. (1959) with 3462 calves, by 2.3 kg (36.0 vs. 33.7). Other beef cattle studies by Koch et al. (1973) and Dawson et al. (1947) and dairy cattle studies by Legault and Touchberry (1962), Fitch et al. (1924) and Eckles (1919) also found birth weight superiority in favor of males in the area of 2 to 3 kg. Smaller but significant ($P < .01$) differences in Herefords were found by Lasley et al. (1961) of 1.1 kg (32.6 avg.) and Rice et al. (1954) of 1.0 kg (331.1 vs. 32.1). A partial regression of birth weight on sex of calf was found to be significant for Angus but not for Shorthorns in a report by Foote et al. (1960).

Age of dam affects birth weight in that younger and older cows have smaller calves. A cow's first calf is generally her smallest after which the birth weights will increase until she attains mature weight and age and thereafter decrease. Beef cattle generally reach their "peak" at 5 to 10 years of age. Marlow (1962) reported that both Angus and Hereford birth weights increased approximately .75 kg. for each year increase in age of dam, up to 6 or 7 years of age, and then decreased. Burris and Blunn (1952) found that Angus and

Herefords both "peaked" at 9 to 10 years. Hereford studies by Burfening and Kress (1973), Koonce and Dillard (1967), Lasley et al. (1961) and Knapp et al. (1942) reported peak production at 5, 8 to 11, 6 and 5 years, respectively.

Gestation length is generally accepted to be positively correlated with birth weight. Burris and Blunn (1952) regressed birth weight on gestation length in days and reported a coefficient of .171 kg/day. Knapp et al. (1941) found a correlation of .60 between gestation length and birth weight. Rice et al. (1954) and Long et al. (1948) also reported positive ($P < .01$) correlations.

It has been established that while breed and sex affect birth weight directly, there is also strong evidence that breed, and to a lesser extent sex, also affect gestation length and thus exert an indirect influence on birth weight. The Angus breed is reported to have a shorter gestation period than the Hereford and within the breeds the bull calves are carried longer. Burris and Blunn (1952) reported a difference in gestation length of 2.2 days (282.9 vs. 280.7) and 1.4 days (286.8 vs. 285.4) within Angus and Hereford, respectively, between sexes with males having the longer gestation period. The overall breed difference was 4.4 days (286.1 vs. 281.7) with Herefords the longer. All the differences were significant ($P < .01$). Livesay and Bee (1945) found overall that Angus gestation lengths were shorter by 2.5 days (285.2 vs. 282.5, ($P < .01$) and within the breeds males were

longer by .5 days (292.7 vs. 282.2) in Angus and .2 days (285.2 vs. 285.0) in Herefords. Thorton and Wiltbank (1959), Wheat and Riggs (1958) and Rife et al. (1943) also reported breed differences of 7.7 (287.2 vs. 279.5), 5.4 (284.9 vs. 279.5) and 16.2 (289.0 vs. 272.8) days, respectively, with Angus again having the shorter gestation length. The difference of 16.2 days is by far the largest found in the literature and may be due to a relatively smaller number of animals in the study, 36 Angus and 36 Herefords. A study of Herefords by Rice et al. (1954) found that bull calves were carried .8 days (287.3 vs. 286.5) longer than heifers but the difference was not significant.

In studies where the calving season extended over several months, the season or month of birth was reported to have an effect on birth weight. Lasley et al. (1961) and Loganathan et al. (1965) found this effect ($P < .01$) in Hereford calves.

Knapp et al. (1942) reported that the year of a calf's birth had an effect on its birth weight, especially in years following extreme range conditions. Similar results ($P < .01$) were reported in Hereford cattle by Burfening and Kress (1973), Koonce and Dillard (1967) and Loganathan et al. (1965). Burris and Blunn (1952) reported that year effects, when analyzed within breed and sex, were not significant. They reasoned that similarities in management practices from year to year nullified any year effects. Burfening

and Kress (1973) and Flower et al. (1963) also reported that Hereford calves' specific birth dates were a major ($P < .01$) source of variation on their birth weights.

The weight of the dam was reported as a major ($P < .01$) effect on the birth weight of Herefords by Gregory et al. (1950) and of Short-horns by Dawson et al. (1947). Meiske et al. (1964) found a significant effect in Angus and Herefords, but the relationship lost its significance when the variation due to age of dam was removed. Eckles (1919) reported a weight of dam effect on the birth weight of dairy calves while Foote et al. (1959) found a similar effect ($P < .05$) in Holstein calves.

Barlowe et al. (1974) and Koonce and Dillard (1967), analyzing Angus and Hereford calves, respectively, found major ($P < .01$) herd effects on birth weight in their results. The majority of the studies in the literature deal with one herd or are analyzed on a within herd basis.

The analysis of sire effects on birth weight is complicated by the fact that sires are not chosen at random. Normally, a sire selection program tends to group like sires, thus reducing variation. Dairy studies by Eckles (1919) found that sire effects were not significant within a breed but were significant on crossbred calves. Fitch et al. (1924) reported a nonsignificant trend in dairy cattle but noted that the ability to sire large calves is an individual characteristic, to

a limited degree. In a later study Foote et al. (1959) reported significant sire effects in Holsteins. In beef cattle, sire effects ($P < .01$) were reported by Lasley et al. (1961) and Rice et al. (1954) with Herefords, and Brown and Galvez (1969) with Hereford and Angus. Gregory et al. (1950) reported important ($P < .05$) sire effects with Herefords. Lasley's group also reported a sire effect on gestation length in Herefords. Thorton and Wiltbank (1959) reported sire effects on gestation length in Angus ($P < .01$) but not in Herefords ($P < .05$).

Burfening and Kress (1973) and Flower et al. (1963) reported that among linebred Herefords the specific line has an important ($P < .01$) effect on birth weight.

Many studies have been done on the effects of inbreeding on birth weight in beef cattle. The reader is referred to Brinks and Knapp (1975) for a review of literature for both beef and dairy breeds. Studies of the effect of inbreeding of calf on birth weight have provided the following regression coefficients (kg per 1% inbreeding): $-.0424$ in males and $-.0300$ in females, Brinks and Knapp (1975); $-.001$, Nelms and Stratton (1967); $-.06$ for males and $-.18$ for females, Brinks et al. (1965); $-.09$, Swiger et al. (1961a). A nonsignificant ($P < .05$) regression was reported by Bovard et al. (1963) in Angus calves. Alexander and Bogart (1961) also reported nonsignificant effects of inbreeding in Angus and Herefords, but they attributed this result to a low replacement rate in their herds which resulted in more than the usual percentage of mature cows in their study. They suggested that calves

of younger dams may be affected more by inbreeding than those of mature dams. The inbreeding of the dam appears to have a lesser effect on the birth weight of her calf than does the calf's inbreeding. Regressions on inbreeding of dam include: $-.077$ in male calves and $.0007$ in females, Brinks and Knapp (1975); $-.03$, Swiger et al. (1962) and $.01$ and $.06$ in two herds, Swiger et al. (1961). Results of 0 and negligible were reported, respectively, by Nelms and Stratton (1967) and Bovard et al. (1963).

The results of heritability studies for birth weight of Angus and Hereford calves are shown in table 1. The method used most often to estimate heritability in cattle involves the correlation among paternal half-sibs (for a review of methods of estimating heritability, see Falconer, 1960). Exceptions to the paternal half-sib method in table 1 are: Brown and Galvez (1969) used an average of several methods including regressing offspring on sire, paternal half-sib and paternal half-sib corrected for inbreeding; Koch and Clark (1955b) regressed progeny average on sire ($h^2=.35$) and offspring on dam ($h^2=.44$); and Knapp and Nordskog (1946) regressed offspring on sire ($h^2=.34$). In published summaries of birth weight heritabilities, Preston and Willis (1974) gave a preferred value of $.38$ using all breeds and Petty and Cartwright (1966) reported a weighted average of $.44$ in beef breeds alone.

Repeatability is defined by Falconer (1960) as "a correlation

TABLE 1. HERITABILITY OF BIRTH WEIGHT ESTIMATES

h^2	Breed ^a	Sex ^b	No. calves	Reference
.00	H	M,F	214	Thorton <u>et al.</u> (1960)
.13	A	M,F	175	Thorton <u>et al.</u> (1960)
.14	H	F	350	Pahnish <u>et al.</u> (1964)
.15	H	M,F	580	Miguel and Cartwright (1963)
.17	A	M,F	932	Brown and Galvez (1969)
.22	H,A,S	M,F	502	Burris and Blunn (1952)
.22	H	M,F	793	Swiger (1961)
.23	H	M	177	Knapp and Nordskog (1946)
.32	H	M	370	Pahnish <u>et al.</u> (1964)
.34	H	M	177	Knapp and Nordskog (1946)
.35	H	M,F	85	Koch and Clark (1955b)
.35	H	MF	4553	Koch and Clark (1955a)
.36	H	M,F	789	Brown and Galvez (1969)
.38	H	F	5192	Brinks <u>et al.</u> (1964)
.42	H	M	177	Knapp and Nordskog (1946)
.44	H	M,F	4234	Koch and Clark (1955b)
.53	H	M	177	Knapp and Nordskog (1946)
.59	H	M	542	Shelby <u>et al.</u> (1957)
.67	H	M,F	351	Lasley <u>et al.</u> (1961)
.72	H	M	635	Shelby <u>et al.</u> (1955)
.88	H	M,F	469	Loganathan <u>et al.</u> (1965)

^a H = Hereford, A = Angus, S = Shorthorn.

^b M = male, F = female.

between repeated measurements of the same individual" and "therefore expresses the proportion of the variance of single measurements that is due to permanent, or non-localized, differences between individuals, both genetic and environmental." Values for repeatability of birth weight as a trait of the dam are shown in table 2. Petty and Cartwright (1966) calculated a weighed average of .25 in their summary.

TABLE 2. REPEATABILITY OF BIRTH WEIGHT ESTIMATES

Re-	Breed ^a	No. dams	No. offspring	Reference
.10	A	325	932	Brown and Galvez (1969)
.11	PH	100	493	McCormick <u>et al.</u> (1956)
.18	H,A,Sh	103	458	Taylor <u>et al.</u> (1960)
.18	H	-	620	Botkin and Whatley (1953)
.19	H	245	789	Brown and Galvez (1953)
.20	Mixed	370	892	Petty (1966)
.26	H	1166	4849	Koch and Clark (1955b)
.27	H	648	3342	Kress and Burfening (1972)
.28	H	-	-	Meade <u>et al.</u> (1959)
.30	H,A,Sh	364	1038	Taylor <u>et al.</u> (1960)
.35	A	-	-	Meade <u>et al.</u> (1959)

^a A = Angus, H = Hereford, PH = Polled Hereford, Sh = Shorthorn.

Prewaning Average Daily Gain

The preweaning growth rate of a calf is a reflection of its dam's maternal ability, its environment and its own genes. Its dam's maternal ability is determined by her age, environment, and genotype. Its environment is made up of natural effects, such as weather and pasture condition, and management effects, such as birth date, creep-feeding, nutrition level, age at weaning, etc. Its genes are determined by its parents and variations in their relationship caused by inbreeding, crossbreeding or linebreeding.

The age of dam effect was called "the most important source of variation" for preweaning growth rates in an Angus, Hereford and Shorthorn study by Marlowe and Gaines (1958). Major ($P < .01$) age of dam effects on preweaning gain of Angus and Hereford calves were reported by Schaeffer and Wilton (1974a), Kress and Webb (1972), Cunningham and Henderson (1965a), and Marlowe et al. (1965). Brinks et al. (1972) with Herefords and Brinks et al. (1962) with Hereford bulls also found an age of dam effect ($P < .01$) on preweaning average daily gain. Humes et al. (1973) found an age of dam effect on preweaning average daily gain to be highly significant ($P < .01$) in Hereford bull calves and significant ($P < .05$) in heifer calves. Other studies by Tanner et al. (1970), with Angus, and Nelms and Bogart (1956) with Angus and Hereford, found that the age of dam effect on preweaning average daily gain only approached significance. Nelms and Bogart noted that there

was a large difference in gains of calves with two-year-old dams as compared to gains of calves with older dams. Schaeffer and Wilton (1974b) found an additive correction factor to be preferable to multiplicative when correcting preweaning gain of age of dam effects.

Age of dam by sex interaction effects on preweaning growth rates were reported in Angus calves ($P < .05$) by Barlow et al. (1974) and in Angus and Herefords ($P < .01$) by Schaeffer and Wilton (1974a). However, the same effect was found to be not significant in Angus and Hereford studies by Kress and Webb (1972) and Cunningham and Henderson (1965a). Schaeffer and Wilton (1974a) also reported on other effects on preweaning gain caused by interactions involving age of dam. Their results included: Age of dam by feeding system (creep), not significant; age of dam by level of herd performance, significant ($P < .01$); age of dam by sex by level of herd performance, not significant; and age of dam by sex by feeding system (creep), significant ($P < .05$) in Herefords but not significant ($P > .05$) in Angus.

The year of a calf's birth was found to have an effect ($P < .01$) on its preweaning gain in both Angus and Hereford in studies by Kress and Webb (1972), Cunningham and Henderson (1965a), Marlowe et al. (1965) and Alexander and Bogart (1961). Angus studies by Barlow et al. (1974) and Tanner et al. (1970) also found major ($P < .05$ and $P < .01$, respectively) year effects on preweaning gain. Brinks et al. (1972) and Mahmud and Cobb (1963) reported similar results ($P < .01$) in Hereford calves.

Humes et al. (1973) found a year effect ($P < .05$) on preweaning average daily gain in Hereford males but not ($P > .05$) in females.

Barlow et al. (1974) reported that year by herd, year by sex and year by age of dam interaction effects on preweaning average daily gain were all significant ($P < .05$) in Angus calves. Tanner et al. (1970) also found year by sex interaction effects ($P < .01$) on preweaning average daily gain in Angus calves.

Mahmud and Cobb (1963) reported with Herefords that the specific ranch on which a calf is raised has a major effect ($P < .01$) on its preweaning gain. Barlow et al. (1974) reported similar results ($P < .05$) in Angus calves.

Creep-feeding was reported to be a major ($P < .01$) effect on the preweaning growth rates of Angus and Hereford calves in a study by Schaeffer and Wilton (1974). Marlowe et al. (1967) reported that creep-fed Angus and Hereford calves grew .04 (.78 vs. .73) and .07 (.80 vs. .73) kg per day faster than their non-creep-fed contemporaries. Marlowe and Gaines (1958) reported that analysis of a group of Angus, Hereford and Shorthorn calves showed that creep-fed calves gained .05 (.80 vs. .75) kg per day faster than non-creep-fed.

A sex by feeding level (creep) interaction effect on preweaning gain was reported in Angus ($P < .05$) and in Herefords ($P < .01$) by Schaeffer and Wilton (1974a).

Mahmud and Cobb (1963) reported that the specific age of a Hereford calf within the preweaning period has substantial ($P < .01$) effect on its rate of gain. Brinks et al. (1962), however, reported that the age effect on preweaning growth rate was nonsignificant in Hereford bull calves. Marlowe and Gaines (1958) reported that the age effect on preweaning growth rate was greater for creep-fed Angus, Hereford and Shorthorn calves than for non-creep-fed calves. Marlowe et al. (1965), however, found age was a major effect ($P < .01$) on the preweaning growth rate of both creep and non-creep-fed Angus calves and in non-creep-fed Herefords but not in creep-fed Hereford calves. Kress and Webb (1972) found that the age at weaning had an effect ($P < .01$) on preweaning growth rate in Angus calves but did not significantly affect the same period of growth in Herefords.

Kress and Webb (1972) regressed preweaning gain on birth date and found a significant ($P < .05$) effect in Herefords and a highly significant ($P < .01$) effect in Angus. Marlowe et al. (1965) and Nelms and Bogart (1956) found month of birth to be a major ($P < .01$ and $P < .05$, respectively) effect on preweaning gain in both Angus and Herefords. Humes et al. (1973) found no significant effect of birth date on the preweaning gain of Hereford male calves, but did find an effect ($P < .05$) on the gain of Hereford females. Marlowe and Gaines (1958) reported in Angus, Hereford and Shorthorns that season of birth had a "significant" effect on the preweaning gains of non-creep-fed calves.

but was of "little practical importance" in the gains of creep-fed calves.

The actual birth weight of a calf was reported to have a major effect ($P < .05$) on preweaning gain in an Angus and Hereford study by Nelms and Bogart (1956). Birth weight was reported by Christian et al. (1965) to have an effect ($P < .05$) on the growth rate of Hereford calves during their first 60 days of age.

Alexander and Bogart (1961) and Nelms and Bogart (1956) both reported that line of calf effects were an important ($P < .01$ and $P < .05$, respectively) source of variation for the preweaning growth rates of Angus and Hereford calves. Humes et al. (1973) reported that line of sire was an influence ($P < .05$) on the preweaning gains of female Hereford calves, but not on the gains of male Herefords. Line of dam had an opposite effect on preweaning gain in their study; there was no significance for female calves but definite significance ($P < .05$) for male calves. Brinks et al. (1972) concurred to a large degree with Humes and coworkers' line of dam results, but Brinks and coworkers found nonsignificance for both sexes for the effects of line of sire on preweaning growth rates of the calves in their study. Brinks and Humes and their respective coworkers both reported line of dam by line of sire interaction effects on preweaning gain to be nonsignificant for Hereford male calves. Brinks found a highly significant ($P < .01$) effect for female Hereford calves while Humes reported nonsignificance. Brinks and coworkers also found no significant

effects on preweaning gain due to interactions between line of sire and years and line of dam and years. Kress et al. (1973) found that line of sire and line of dam were both important ($P < .01$) sources of variation for the preweaning gain of Hereford cattle. The interaction between line of sire and line of dam was also significant ($P < .05$). They noted in their study that "there tended to be an inverse relationship between rankings of line of sire and line of dam." Mahmud and Cobb (1973) and Thrift et al. (1970) reported sire effects on preweaning gains to be important ($P < .01$ and $P < .05$, respectively) in Hereford calves. Tanner et al. (1970) analyzed sire within year and found it to be a major ($P < .01$) effect on the preweaning gains of Angus calves. Kress and Webb (1972) used the same type of analysis and found highly significant sire effects ($P < .01$) in Angus calves and significant sire effects ($P < .05$) in Herefords. Gregory et al. (1950) found no important sire effects on preweaning gains in two Hereford herds, but they suggested that their results may have been influenced by the small number of cattle involved in the study.

Tanner et al. (1970) and Thrift et al. (1970) both reported no significant effects on preweaning gain of a sire by sex interaction. However, Kress and Webb (1972) found a sex by sire within year interaction effect on preweaning gains in both Angus ($P < .01$) and Herefords ($P < .05$).

Sex has been reported to be a major ($P < .01$) effect on preweaning gains in Angus and Hereford calves in studies by Schaeffer and Wilton

(1974a), Kress and Webb (1972), Marlowe et al. (1965) and others. Brinks and Knapp (1975), Brinks et al. (1972), Tanner et al. (1970), Mahmud and Cobb (1963), and Koch et al. (1959) all working with Angus and/or Herefords, reported that male calves gained .04 to .06 kg per day more than females from birth to weaning. Bovard et al. (1963) obtained higher estimates of male advantage for preweaning gain of .10 kg per day for Angus and .09 kg per day for Herefords. Nelms and Bogart (1956), however, found sex effects on preweaning gains of Angus and Hereford calves to be nonsignificant when corrections were made for birth weight. They suggested the male and female calves having the same birth weights would gain alike up to weaning.

To adjust preweaning average daily gain for sex effects, both Brinks et al. (1961) and Koch et al. (1959) used a multiplicative adjustment factor since variance among bull calves was larger than among heifer calves. Schaeffer and Wilton (1974b), however, preferred additive factors.

The preweaning gain of a calf can also be affected by its dam's or its own level of inbreeding. Brinks and Knapp (1975) in their extensive study on inbreeding found that the inbreeding of the calf caused a $-.0012$ kg per day change in the preweaning average daily gain per one percent increase in inbreeding of male calves and a $-.0014$ change in female calves. Inbreeding of the dam had a larger effect; $-.0022$ kg per day in males and $-.0011$ kg per day in females. it is of

interest to note that the inbreeding of the dam had twice as much effect on male calves as on female calves. Brinks and Knapp theorized that "males have more potential and are handicapped more by decreased milk production." Their findings were supported by Humes et al. (1973) who found that the inbreeding of the dam decreased preweaning gain of Hereford bull calves by .006 kg per day and of female calves by .003 kg per day per one percent increase in inbreeding. Swiger et al. (1961a) found that a one percent increase in inbreeding of the calf decreased preweaning gain of all calves by .005 kg per day in one Hereford herd but had no effect in another herd. Also, they found that a one percent increase in the inbreeding of the dam caused a -.0006 kg per day change in the preweaning gains of the calves in one herd and -.0005 kg per day change in the other.

The heritability of preweaning gain is generally estimated to be .30. A preferred value of .27 was reported by Preston and Willis (1974). Petty and Cartwright (1966) reviewed 31 estimates by various methods up to 1966. Their overall unweighted average was .26, which rose to .31 when weighted by number of records per method. Koch et al. (1973) used paternal half-sib methods to estimate heritability of preweaning gain in 3462 Herefords and arrived at estimates of .13 for bulls and .21 for heifers.

Weaning Weight

Weaning weight is influenced by much the same factors as pre-weaning gain. However, the importance of weaning weight is such that it is treated separately in the literature and thus will be accorded a separate section in this review.

Sex is generally considered a main effect on weaning weight.

Bulls are heavier than steers which are in turn heavier than heifers. When comparing bulls to steers however, it is important to remember that the effects of castration can be confounded with the effects of selection plus there may be stress effects on the steers from the actual castration.

Differences between steers and heifers in Hereford studies ranged from 7.5 to 14.5 kg at 180 to 240 days in reports by Tanner et al. (1970), Linton et al. (1968), Sewall et al. (1963), Brinks et al. (1961), Urlick (1958), Evans et al. (1955), Koch and Clark (1955a) and Koger and Knox (1945). More extreme differences in Herefords of .9 and 17.7 kg were reported by Burgess et al. (1954) and Bradley et al. (1966), respectively. An Angus study by Tanner et al. (1970) reported a difference in weaning weight between steers and heifers of 12.1 kg., with steers the heavier. A combined Angus-Hereford study by Cundiff et al. (1966a) found steers 5.1 kg heavier than heifers at weaning. Differences between Hereford bulls and heifers were reported in the area of 10 to 15 kg by Linton et al. (1968), Harwin et al. (1966),

Manyard and Dinkel (1965a) and Evans et al. (1955). Brinks et al. (1961) and Brown (1958) found differences of 24.1 and 48.6 kg, respectively, between bulls and heifers at weaning. In a study of two different Angus herds, O'Mary and Ament (1961) found weaning weight differences between bulls and heifers of 22.8 and 30.5 kg. Cundiff et al. (1966a) reported a difference in weaning weight of 25.3 kg with bulls the heavier in a combined Angus-Hereford study. Brown (1960) and Brown (1958) combined bulls and steers together in two Hereford and three Angus herds, and compared the combined average weaning weights to those of the heifers. He reported Hereford results of 11.4 and 25.9 kg in favor of the males and Angus results as 10.0, 10.5 and 15.0 kg advantage for males. All of the above differences were reported as highly significant ($P < .01$). A significant ($P < .05$) difference between sexes was reported by Bradley et al. (1966) and Evans et al. (1955) with the males were again being larger. Sawyer et al. (1948) found heifers heavier at weaning, but the difference was not significant. Gregory et al. (1950) found a nonsignificant sex effect but they attributed this result to a very large standard deviation.

Age of dam by sex of calf interaction effects on weaning weight were reported as nonsignificant in combined Angus-Hereford studies by Cardellino and Frahm (1971), Cundiff et al. (1966a), Manyard and Dinkel (1965a) and Kress and Webb (1972). Their results were supported in Hereford studies by Linton et al. (1968), Cooper et al. (1965),

and Swiger (1961). An interactive effect ($P < .05$) of age of dam by sex of calf was reported in Herefords by Harwin et al. (1966).

Sex by year interactive effects on weaning weight have been reported as highly significant ($P < .01$) by Cooper et al. (1965), Blackmore et al. (1960), Pahnish et al. (1961) and Linton et al. (1968). Linton postulated that the reason for the interaction is that bull calves are more sensitive to the environment. Tanner et al. (1970) also found a sex by year interactive effect on weaning weight, although their level of significance was less ($P < .05$). Studies by Cardellino and Frahm (1971), Harwin et al. (1966) and Swiger (1961) all reported nonsignificant sex by year interactive effects on weaning weight, although Harwin and his co-workers did report a trend. Sex by ranch and mating system interactive effects ($P < .05$) on weaning weight were reported by Pahnish et al. (1961) and Harwin et al. (1966), respectively. Sex by season of birth interaction was reported by Cooper et al. (1965) to have a major ($P < .01$) effect on weaning weight. However, Cundiff et al. (1966a) called the same effect "small" and Sellers et al. (1969) called it "unimportant". In studies analyzing the effect of sex by sire interactions on weaning weight of purebred calves, Tanner et al. (1970) with Angus and Pahnish et al. (1961) and Koger and Knox (1945) with Herefords all reported nonsignificance. Kress and Webb (1972) found a sex by sire within year effect in Herefords ($P < .05$) but not in Angus ($P > .05$). Wilson et al. (1967) reported a sex by sire interactive

effect ($P < .05$) on weaning weight in Angus-Holstein x Polled Hereford calves. Interaction effects of pasture unit and management by sex on weaning weight were both reported to be nonsignificant in a combined Angus-Hereford study by Cundiff et al. (1966a). An interaction that was found to be significant ($P < .01$) for weaning weight was the age of calf (in days) at weaning by sex interaction, which was reported by Swiger (1961). He reported that bull calves grew at a faster rate than heifer calves. Cardellino and Frahm (1971) reported that sex by breed interactive effects on weaning weight were nonsignificant in their study of Angus and Herefords.

Cundiff et al. (1966a) found that variances of the three sexes were significantly different in both creep and non-creep-fed Angus and Hereford calves. They reported that multiplicative factors removed the sex by management type (creep feeding) interaction effects and thus were preferable. The ratios (.89 for bulls, 1.00 for steers and 1.02 for heifers) were the same for both types of management. Sellers et al. (1970) also found a heterogeneity of variance between the sexes and so used multiplicative correction factors. These factors were: .97, 1.00 and 1.07 for Angus bulls, steers and heifers, respectively, and .93, 1.00 and 1.08 for Herefords. Minyard and Dinkel (1965a) used a multiplicative factor of 1.082 to adjust the weaning weight of Hereford heifers to that of bulls. They tried both multiplicative and additive adjustment factors and found that the

multiplicative factors reduced the sex effects more than did the additive factors. Linton et al. (1968) reported that a multiplicative factors of 1.071 to adjust Hereford heifers' weaning weights to those of Hereford bulls was better at equalizing the standard deviations than was an additive factor. The Beef Improvement Federation recommends general multiplicative factors of .95, 1.00 and 1.05 for bulls, steers and heifers, respectively (B.I.F., 1972).

The age of dam effect on weaning weight is considered an important effect throughout the literature. Hereford studies by Linton et al. (1968), Swiger et al. (1962), Brinks et al. (1962) and others all found major ($P < .01$) age of dam effects on weaning weight. Angus studies by Tanner et al. (1970) and Hohenboken and Brinks (1969) found significant ($P < .05$ and $P < .01$, respectively) effects, also. Studies involving both Angus and Hereford calves by Cardellino and Frahm (1971), Cundiff et al. (1966a) and Cunningham and Henderson (1965a) reported major ($P < .01$) age of dam effects on weaning weight. Warren et al. (1965) found age of dam effects ($P < .01$) on weaning weight in a study of 25,000 Angus, Hereford and Santa Gertrudis. Brown (1960) found age of dam effects on weaning weight at 60, 120, 180 and 240 days to be highly significant ($P < .01$) in a herd of Herefords and one of Angus. In a second herd of Angus, he found the age of dam effects highly significant ($P < .01$) at 60 and 120 days, significant ($P < .05$) at 180 days and nonsignificant ($P > .05$) at 240 days.

All of the above studies found that a cow reaches her most productive age when she is 6 to 8 years old.

Cardellino and Frahm (1971) found an age of dam by breed effect ($P < .01$) on weaning weight in their Angus-Hereford study. They obtained within breed multiplicative age of dam correction factors of: 1.15, 1.08, 1.02 and 1.00 for 2-, 3-, 4- and 5- to 9-year-old Angus dams, respectively; and 1.23, 1.09, 1.01 and 1.00 for Hereford dams of the same respective ages. They then compared their factors with the general beef cattle age of dam correction factors for weaning weight (1.15, 1.10, 1.05 and 1.00) as recommended by the Beef Improvement Federation (B.I.F., 1972). They reported that within herd factors were preferable, if possible, but the general factors were adequate except for the calves of two-year-old Hereford heifers, which would be under-corrected. Sellers et al. (1970) also reported age of dam by breed interactive effects on weaning weight, but the effects were not of sufficient magnitude to consider separate correction factors for Angus and Hereford. Their multiplicative correction factors were 1.12, 1.07, 1.03, 1.00 and 1.05 for bull calves of cows aged < 34 mos., 34 to 45 mos., 4 to 5 yrs., 6 to 12 yrs., and 12 yrs., respectively. Steer and heifer correction factors for the same respective ages of cows were 1.11, 1.06, 1.02, 1.00 and 1.02 and 1.09, 1.06, 1.02, 1.00 and 1.04, respectively. Cundiff et al. (1966b) divided ages of dam into < 28 mos., 28 to 30 mos., 31 to 33 mos., 34 to 39 mos., 40 to 45

mos., 4, 5, 6 to 13 yrs., 14 yrs., and 15+ years. The respective multiplicative correction factors were: 1.18, 1.14, 1.11, 1.09, 1.05, 1.04, 1.02, 1.00, 1.01, and 1.05. However, they recommended using additive factors of: 29.3, 23.5, 19.9, 16.1, 9.1, 6.8, 3.9, 0, 2.6, and 9.3 kg. Their reason for this recommendation was "although additive adjustments could not equalize the variances, they would at least not cause further divergence, as would multiplicative adjustments."

Linton et al. (1968) studied 4700 calves in one Hereford herd in which no culling of cows was based on weaning weights. They theorized that this type of herd would "present a true picture of age of dam effect". Their additive adjustment factors were 14.50, 3.90, 0, 2.51, 10.00, and 21.80 kg for the weaning weights of calves from ≤ 3 , 4 to 5, 6 to 8, 9 to 10, 11 to 12, ≥ 13 year old dams, respectively. The multiplicative factors for the same respective ages of dams were 1.092, 1.023, 1.000, 1.015, 1.065 and 1.045. They found that when all ages of dam were considered, the additive factors did not increase the variability as much as the multiplicative factors did, and thus were more desirable. However, when the class for dams aged 13 and over was omitted, the multiplicative factors were "more successful in equalizing the variability."

The majority of interactions affecting weaning weight that involve age of dam have been reported as not significant. Age of dam interactive effects with management (creep), pasture type, and season of birth were all reported as nonsignificant on weaning weight by

Cundiff et al. (1966a). Age of dam by age of calf, and by mating system interaction effects on weaning weight were reported nonsignificant by Swiger (1961) and Harwin et al. (1966), respectively. An age of dam interactive effect on weaning weight that has been reported as significant is age of dam by year. Although Cardellino and Frahm (1971) failed to find significance, Hohenboken and Brinks (1969), Harwin et al. (1966), Cooper et al. (1965) and Swiger (1961) all reported the effect as highly significant ($P < .01$). The reasoning expressed here is that mature cows are better able to stand the stress of extreme years. Linton et al. (1968) found an age of dam by year interaction effect ($P < .01$) on the weaning weight of Hereford heifer calves, but the effect was not significant for Hereford bull calves.

In a study of Angus calves, O'Mary et al. (1959) reported a positive ($P < .05$) correlation coefficient of .51 between cow weight and adjusted 180-day weight of her calf. Another Angus study by Smith and Fitzhugh (1968) failed to show significance but they did report a trend that "heavier dams tend to wean heavier calves." Gregory et al. (1950) reported the same nonsignificant trend in one Hereford herd but no trend in a second Hereford herd. Sawyer et al. (1963) reported, "Although the relationships were fairly low, correlations and regressions dealing with the relationship of cow weights with calf performance indicated that heavier cows tend to produce calves that gain faster and are heavier from birth through 18 months of age." A Hereford study by Knapp et al. (1942) found size of dam effects on weaning weight to

be nonsignificant.

Urlick (1958), in a long term Hereford study, found no significant difference in the subsequent performance of cows calving first as two-year-olds versus those calving first as three-year-olds.

In analyzing breed effects on weaning weight among the Angus and Hereford breeds, Gregory et al. (1966a,b) reported Angus bull calves outweighed Hereford bull calves at 200 days by 5 kg (198 vs. 193), but heifer calves were the same (1976 kg) for each breed. Meade et al. (1959) reported that Angus males and females outweighed their Hereford counterparts by (13) (188 vs. 175) and 22 (187 vs. 165) kg, respectively, at 205 days. Neither of the above studies reported a level of significance for breed differences. Sagebiel et al. (1967) found only a 1 kg (154 vs. 153) nonsignificant difference between Angus and Hereford calves for 205-day weaning weight. Cardellino and Frahm (1971), after adjusting for sex and year, found no significant difference between Angus and Hereford's weaning weight at 205 days. However, they did find an effect ($P < .01$) if they analyzed only calves from 2- and 3-year-old dams. The calves from the young Angus cows were 4.2 kg (180.5 vs. 176.3) heavier at 205 days than the Hereford calves. Cundiff et al. (1966a) found in their Angus-Hereford study of 14,000 cattle that there was a breed effect ($P < .01$) on weaning weight with Angus the heavier by 2.2 kg. However, they reported that while the effect was highly significant, it was responsible for less than 1% of the total variation in weaning weight.

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Breed by age of dam and by sex interactions have previously been discussed. Breed by month of birth interaction effects on weaning weight were reported as "small and relatively unimportant" by Cundiff et al. (1966a) when comparing Angus and Hereford. Cardellino and Frahm (1971) reported Angus and Hereford breed by year interaction effects on weaning weight as highly significant ($P < .01$). Sellers et al. (1970) reported breed by management (creep feeding) interaction effects on weaning weight as important ($P < .01$).

The effect that individual sires exert on the weaning weight of their calves was found to be significant ($P < .01$) when analyzed within year by Tanner et al. (1970) and Hohenboken and Brinks (1969) in Angus studies. In Hereford studies of sire effects on weaning weight, Thrift et al. (1970) reported a significant ($P < .05$) effect. Pahnish et al. (1961), reported a significant ($P < .05$) effect on bull calves. Knapp et al. (1942) reported a "significant" sire effect on the weaning weight of Hereford calves. Brown (1960) analyzed sire effects on weight at four ages in one Hereford and two Angus herds. He reported the Hereford data showed sire effects to be significant ($P < .01$) at 60, 120, 180 and 240 days of age. One Angus herd showed high significance ($P < .01$) at 60, 120 and 180 days of age but dropped to a lower level of significance ($P < .05$) at 240 days. The second Angus herd showed a significant effect ($P < .01$) at 60 days but not at 120, 180 and 240 days.

Sire by sex interaction effects on weaning weight were previously discussed under the section on sex effects. A year by sire within ranch interaction was found to exert no significant effect on weaning weight in a Hereford study by Busch and Dinkel (1967).

Year effects on weaning weight are generally agreed upon in the literature to be significant, especially in those years with extreme environmental conditions. Hereford studies by Linton et al. (1968), Harwin et al. (1966), Busch and Dinkel (1967), and others found year effects on weaning weight to be highly significant ($P < .01$). Tanner et al. (1970) reported the same significance ($P < .01$) of year effects on Angus weaning weights. Combined Angus-Hereford studies by Cardellino and Frahm (1971) and Pherigo et al. (1969) also reported highly significant ($P < .01$) year effects on weaning weight. Brown (1960) found year effects on weight in Herefords to be nonsignificant at 60 days, significant ($P < .05$) at 120 days, and highly significant ($P < .01$) at 180 and 240 days. In one Angus herd, he found year effects on weaning weight to be nonsignificant at 120 days, significant ($P < .05$) at 60 and 180 days, and highly significant ($P < .01$) at 240 days. His second Angus herd showed nonsignificance at 60 and 180 days and high significance ($P < .01$) at 120 and 240 days. Cundiff et al. (1966a) in an extensive Angus-Hereford study, chose to consider years as random effects and pooled the data over the years.

In correcting for year effects on weaning weight, Linton et al. (1968) found additive correction factors to be preferable while Sewall et al. (1963) preferred multiplicative factors.

Interactions involving year by age of dam, by sex, and by breed have previously been discussed in their respective sections. Other interaction effects on weaning weight involving year include: year by ranch, which was reported ($P < .05$) by Pahnish et al. (1961) and ($P < .01$) by Busch and Dinkel (1967); and year by mating system, found to be non-significant by Harwin et al. (1966). A year by month of birth interaction effect on weaning weight was found to be highly significant ($P < .01$) by Cooper et al. (1965). Linton et al. (1968) found the year by month of birth interaction effect to be highly significant ($P < .01$) in bull calves but nonsignificant in heifer calves.

Season or month of birth can have a major effect on weaning weight, especially with range cattle in areas of more variable climate. Sellers et al. (1969), Cundiff et al. (1966a) and Sewall et al. (1963), and others all reported effects ($P < .01$) of month or season of birth on weaning weight. Linton et al. (1968) reported month of birth effects ($P < .01$) on the weaning weight of bull calves but a lesser effect ($P < .05$) in heifer calves. Brown (1960) found season of birth effects ($P < .01$) on weight in a Hereford and one of the Angus herds at 60, 120, 180 and 240 days. The second Angus herd showed nonsignificance at 60 and 180 days, but high significance ($P < .01$) at 120 and 240 days.

Sewall et al. (1963) used multiplicative correction factors for season of birth effects on weaning weight while Sellers et al. (1969) and Cundiff et al. (1965) preferred additive factors.

Interaction effects on weaning weight involving month or season of birth that have not been previously discussed are month of birth by pasture type and by management (creep feeding) which were both reported as significant by Cundiff et al. (1966a).

Pherigo et al. (1969) reported that the specific birth date of a calf has an effect on its weaning weight in extreme years. They found that calves born later in the year are significantly ($P < .05$) lighter at weaning when late summer rainfall is less than normal. Kress and Burfening (1972) and Brinks et al. (1962) reported, however, that the regression of 180-day weight on the birth date of Hereford calves was nonsignificant.

Gregory et al. (1950) reported that calves that have relatively heavier birth weights "tended to maintain this advantage, and thus be heavier at weaning." Knapp et al. (1942) reported that calves "heavier at birth tend to be heavier at weaning." Actual values for birth weight-weaning weight correlations will be discussed in a later section along with other performance trait relationships.

The herd or ranch effects on weaning weight were found to be highly significant ($P < .01$) by Pahnish et al. (1961). Cundiff et al. (1966a) considered herd effects to be random but they did find area of

the state and pasture type to exert major influence ($P < .01$) on weaning weight, although the pasture effects were only 1% of the total variation. Sellers et al. (1969) found area of the state effects on weaning weight to be "unimportant."

The age of the calf when it is weaned is important because the calf is growing and adding weight every day. Age of calf effects on weaning weight were found to be highly significant ($P < .01$) by Hamann et al. (1963), Minyard and Dinkel (1965a), Burgess et al. (1954) and others.

As long as the growth is linear, the effects of age of calf can be corrected for relatively simply. Periods of a calf's life that have been found to be linear include: 120 to 250 days, Cunningham and Henderson (1965a); 140 to 220 days, Urlick (1958); 145 to 265 days, Warren et al. (1965); 155 to 225 days, Johnson and Dinkel (1951); and 175 to 245 days, Sawyer et al. (1948). Pahnish et al. (1958) found growth rate was "essentially linear" at 121 to 323 days when analyzed within sexes and they recommended using separate correction factors to adjust for age of calf within each sex.

An age of calf by year interaction effect on weaning weight was reported as nonsignificant by Swiger (1961). An age of calf by sex interaction effect on weaning weight was previously discussed under sex interactions.

Harwin et al. (1966) found a highly significant ($P < .01$) difference between linecrossing and inbreeding systems for weaning weight.

Cundiff et al. (1966a) found that creep feeding had a major ($P < .01$) effect on weaning weight. Sellers et al. (1969) used an additive correction factor to correct for creep feeding effects on weaning weight.

The inbreeding of the calf has been shown to have a detrimental effect on its weaning weight. The effect is in the area of $-.30$ to -1.00 kg change in weaning weight per 1% increase in inbreeding. Estimates include: $-.21$ (Nelms and Stratton, 1967); $-.22$ (Koch, 1951); $-.32$ (Swiger et al. (1962); $-.54$ (McCleery and Blackwell, 1954); $-.63$ (Nelms and Stratton, 1964); $-.80$ (Burgess et al. 1954); $-.27$ in males and $-.96$ in females (Brinks et al. 1965); and $-.36$ in females and $-.61$ in males (Dinkel et al. 1968). Brinks and Knapp (1975) in their extensive survey of western area experiment stations found a change in weaning weight of $-.29$ kg in males and $-.30$ kg in females per 1% increase inbreeding in the calf.

The results of analyzing effects of the inbreeding of the dam on weaning weight are more varied in the literature. Results range from a positive regression reported by McCleery and Blackwell (1954) and no effect reported by Nelms and Stratton (1964) to -1.15 kg decrease in weaning weight per 1% increase in inbreeding of dam found by Koch (1951). Intermediate results include: $-.07$ and $-.02$ in two herds

(Swinger et al. 1961a); $-.10$ (Swiger et al. 1962); $-.52$ (Burgess et al. 1954); $-.23$ in males and $-.68$ in females (Dinkel et al. 1968); and $-.85$ in males and $-.15$ in females (Brinks et al. 1965). Brinks and Knapp (1975) found changes in weaning weight per 1% increase in the inbreeding of the dam of $-.40$ kg in males and $-.24$ kg in females.

Table 3 shows some estimates of heritability of weaning weight obtained by using the paternal half-sib method with calves of both sexes analyzed together. The arithmetic mean of $.31$ compared well with the weighed mean of $.28$ reported by Petty and Cartwright (1966) and the preferred value of $.30$ by Preston and Willis (1974). (Petty and Cartwright (1966) weighted estimates by the number of parents.) The weighted means of $.41$ and $.39$ in table 3 were obtained by weighing each estimate by the number of sires and number of calves, respectively. Estimates in which the number of sires were not reported were not included in the mean weighted by sires. The weighted means are certainly influenced by the large number of animals in the Harricharan et al. (1967) study. Omitting this large study lowered the sire weighted and calf weighted means to $.25$ and $.31$, respectively.

Table 4 shows the paternal half-sib estimates of heritability of weaning weight analyzed within sex. The means are generally in agreement with those in table 3. It is of interest to note that the means for females are consistently higher than those for males. This difference is maintained in all the studies which include both males and females.

TABLE 3. PATERNAL HALF-SIB ESTIMATES OF HERITABILITY OF WEANING WEIGHT - MIXED SEXES OF CALVES

h^2	Breed ^a	No. sires	No. calves	Reference
.10	H	17	720	Pahnish <i>et al.</i> (1964)
.11	H	8	414	Lasley <i>et al.</i> (1961)
.11	A	-	212	Brown (1958)
.14	A,H, PH	15	915	Cundiff <i>et al.</i> (1975)
.15	H	187	3739	Swiger <i>et al.</i> (1962)
.18	H	12	942	Sewall <i>et al.</i> (1963)
.21	A,H, Sh	115	1987	Lehmann <i>et al.</i> (1961)
.23	PH	72	679	McCormick <i>et al.</i> (1956)
.24	H	137	4553	Koch and Clark (1955b)
.24	H	28	1306	Mahmud and Cobb (1963)
.24	H	-	580	Miguel and Cartwright (1963)
.25	H	23	748	Swiger (1961)
.26	H	-	255	Brown (1958)
.26	H	6	270	Gregory <i>et al.</i> (1950)
.28	A,H,Sh	240	1671	Swiger <i>et al.</i> (1963)
.30	H	23	326	Magee <i>et al.</i> (1961)
.30	A,H,Sh	-	993	Dickerson <i>et al.</i> (1974)
.30	H	45	569	Rollins and Wagnon (1956)
.32	A	120	2351	Minyard and Dinkel (1956b)
.33	H	-	1915	Minyard and Dinkel (1956b)
.40	H	70	679	Busch and Kinkel (1967)
.49	A	25	1861	Hamann <i>et al.</i> (1963)
.48	A,H,Sh	-	733	Swiger <i>et al.</i> (1962)
.52	H	4	69	Gregory <i>et al.</i> (1950)
.54	A	1288	17023	Harricharan <i>et al.</i> (1967)
.58	A,H,Sh	-	480	Swiger <i>et al.</i> (1965)
.81	A,H	-	2550	Francoise <i>et al.</i> (1973)

Arithmetic mean of h^2 = .31

Weighted (by No. of sires) mean of h^2 = .41

Weighted (by No. of calves) mean of h^2 = .39

^a A = Angus, H = Hereford, PH = Polled Hereford, Sh = Shorthorn.

TABLE 4. PATERNAL HALF-SIB ESTIMATES OF HERITABILITY OF WEANING WEIGHT - ANALYZED WITHIN SEX

h^2 male	h^2 female	No. sires	No. calves	Reference
.12	-	23	177	Knapp and Nordskog (1946)
.23	-	88	635	Shelby <u>et al.</u> (1955)
.24	-	87	616	Shelby <u>et al.</u> (1963)
.28	-	110	880	Knapp and Clark (1950)
.28	-	11	329	Pahnish <u>et al.</u> (1961)
.33	-	43	336	Wilson <u>et al.</u> (1962)
.38	-	56	473	Wilson <u>et al.</u> (1963)
.43	-	116	542	Shelby <u>et al.</u> (1957)
.81	-	19	118	Lindholm and Stonaker (1957)
-	.42	25	165	Wagnon and Rollins (1959)
-	.43	-	3584	Brinks <u>et al.</u> (1964)
-	.57	11	332	Pahnish <u>et al.</u> (1961)
-	.57	26	140	Wagnon and Rollins (1959)
.08	.31	78	919	Blackwell <u>et al.</u> (1962)
.08	.69	38	212	Carter and Kincaid (1959a)
.15	.25	-	3462	Koch <u>et al.</u> (1973)
.37	.43	-	1121	Koch <u>et al.</u> (1968)
.05	.23	-	370	Pahnish <u>et al.</u> (1963)

Arithmetic mean - males = .27
 females = .39

Weighted (by No. of sires) mean - males = .28
 females = .46

Weighted (by No. of calves) mean - males = .25
 females = .39

Overall arithmetic mean = .35

Overall weighted (by No. of sires) mean = .32

Overall weighted (by No. of calves) mean = .32

Other estimates of the heritability of weaning weight have been done by regression of the offsprings' records on the dams' record. Estimates from this method are: .11 (Koch and Clark, 1955c); .08 (Sewall et al. 1963); .13 (Petty, 1966); and .84 and -.13 in two herds (Rollins and Wagnon, 1956). This method may be biased by maternal effects, however, and therefore may not be as accurate as the paternal half-sib correlation.

Another method of estimating the heritability of weaning weight is regressing of the offsprings' records on the sires' record. Estimates found by this method include: .25 (Koch and Clark, 1955c); .27 (Brown and Gacula, 1964); .39 (Petty, 1966); and .54 (Gregory and Stewart, 1962). Knapp and Nordskog (1946) reported a heritability of weaning weight of 0.00 when using this method. However, they found that if they analyzed within years they found a result of .30. Koch and Clark (1955b) felt that this method may be biased by the effects of the paternal grand dam.

Koch and Clark (1955d) reported a heritability of weaning weight of .19 using a path coefficient method. Chambers et al. (1958) used a high-low method with 59 pairs of cattle and found a value of .28.

Table 5 shows some results of estimates of repeatability of weaning weight in various beef breeds. The methods most commonly used to estimate repeatability are correlations of adjacent records, correlation of the first record with an average of subsequent records and intraclass correlations.

TABLE 5. ESTIMATES OF REPEATABILITY OF WEANING WEIGHT IN BEEF CATTLE

r_e	No. dams	No. calves	Reference
.16	-	-	Meade <u>et al.</u> (1959)
.25	1501	4722	Hohenboken and Prinks (1969)
.29	680	2664	Boston <u>et al.</u> (1975)
.31	1166	4849	Koch and Clark (1955b)
.31	309	665	Berg (1961)
.32	301	1151	Hoover <u>et al.</u> (1956)
.34 ^c	301	1151	Hoover <u>et al.</u> (1956)
.34	89	256	Rollins and Wagnon (1956)
.37	1608	-	Brinks <u>et al.</u> (1964)
.38	90	332	McCormick <u>et al.</u> (1956)
.42	-	-	Meade <u>et al.</u> (1959)
.42	-	2351	Minyard and Dinkel (1960)
.42	378	866	Minyard and Dinkel (1965b)
.42	95	462	McCormick <u>et al.</u> (1956)
.43	151	603	Botkin and Whatley (1953)
.43	439	840	Drewery and Hazel (1966)
.44	648	3342	Kress and Burfening (1972)
.45	80	260	Lueker <u>et al.</u> (1963)
.47	370	892	Petty (1966)
.49	-	-	Stonaker (1958)
.49	436	1698	Koger and Knox (1947)
.50	183	634	Boston <u>et al.</u> (1965)
.51	97	317	Rollins and Wagnon (1956)
.52	-	1066	Sewall <u>et al.</u> (1963)
.52	180	745	Koch (1951)
.66 ^a	-	142	Koger and Knox (1947)

Arithmetic mean = .41

Weighted (by No. of dams) mean = .36

Weighted (by No. of calves) mean = .37

^a Angus

^b Hereford

^c Second record regressed on first.

Postweaning Average Daily Gain

Postweaning average daily gain can mean either feedlot or pasture gain, depending on the management system.

There is some disagreement in the literature whether there is any residual age of dam effect on postweaning average daily gain.

Burfening and Kress (1973), Francoise et al. (1973), and Brinks et al. (1962) all found no important age of dam effects on the postweaning gain of Hereford calves. Their results were supported by Tanner et al. (1970) with Angus calves, and Swiger et al. (1963) with Angus, Hereford and Shorthorn, who also found no major age of dam effects on postweaning average daily gain. Harricharan et al. (1967) reported age of dam had "little effect" on the postweaning average daily gain of Angus calves.

Significant ($P < .05$) age of dam effects on postweaning average daily gains of Angus, Hereford and Shorthorns were reported by Schalles and Marlowe (1967) and of Herefords by Shelby et al. (1963). Flower et al. (1963), working with inbred Herefords, reported that age of dam effects on postweaning average daily gain were highly significant ($P < .01$) for heifers but nonsignificant for bulls and steers. Blackwell et al. (1958) found that there was an age of dam effect on postweaning average daily gain but that it was the opposite of the age of dam effect on weaning weight. They theorized that their results indicated "a compensating effect for the better or poorer than average maternal environment supplied to the calf by the mother because of her age."

Year effects on postweaning average daily gain were reported to be a major ($P < .01$) source of variation by Burfening and Kress (1973), Dinkel and Busch (1973), Tanner et al. (1970), and others. Different results were reported by Schalles and Marlowe (1967) who found no major year effects on the postweaning average daily gain of Angus, Hereford, and Shorthorn. Mason et al. (1958) reported that Angus and Hereford postweaning average daily gains, after being corrected for sex effects, were not significantly affected by years.

Year by sex within ranch interaction effects on postweaning average daily gain were reported as nonsignificant in Hereford calves by Dinkel and Busch (1973). Pani et al. (1973) reported the same (not significant) results in the pasture gains of Hereford heifers, but feedlot gains of Hereford bulls were affected ($P < .01$) by sire by year interaction effects. A year by ranch interaction was found to be important ($P < .01$) on postweaning gain in Dinkel and Busch's (1973) Hereford study.

The analysis of sex effects is complicated by management schemes which normally treat sexes differently after weaning. Francoise et al. (1970) with Angus, found that there are sex effects ($P < .01$) on postweaning average daily gain when the sexes are treated alike. Mason et al. (1958) found a male to female ratio in mean postweaning average daily gain of 1.39 in Angus and 1.28 in Herefords. Mason and coworkers, Tanner and coworkers, and Dahmen and Bogart (1952) all found that sex by year interaction effects on postweaning average daily gain were

nonsignificant. Mason and coworkers also found that a sex by line by year interaction was nonsignificant on postweaning average daily gain.

The calf's specific age during the postweaning period did not significantly affect its growth rate in Hereford studies by Flower et al. (1963) and Brinks et al. (1962). Shelby et al. (1963) found, however, that age of weaning had an effect ($P < .05$) on the postweaning average daily gain of Hereford steers.

There is little agreement in the literature concerning line effects on postweaning average daily gain. Burfening and Kress (1973) found no significance in Herefords. Mason et al. (1958) found high significance ($P < .01$) in Angus and Herefords together. Flower et al. found high significance ($P < .01$) in inbred heifers, but no significance in bulls and steers from the same herd. Shelby et al. (1955) analyzed line effects on postweaning average daily gain on a within year and a within sires basis and found no significant effects in either case with Hereford steers. Moore et al. (1961) reported that the line of sire was an important ($P < .01$) source of variation on the postweaning average daily gain of Hereford bulls. Moore and coworkers also reported a line by sire interaction effect ($P < .01$) on postweaning gain.

The effect that an individual sire has on the postweaning gain of his calves was reported as "significant" in Herefords by Woodward and Clark (1950) and Knapp and Phillips (1942). Knapp and Nordskog (1946) also found Hereford sire effects ($P < .01$) on postweaning gain.

Tanner et al. (1970) analyzed Angus sires within years and also found this to be a major ($P < .01$) effect on postweaning gain. Shelby et al. (1955) reported similar ($P < .01$) results with Hereford steers when analyzed within lines.

On the other hand, sire effects on postweaning gain were reported to be nonsignificant in Hereford studies by Pani et al. (1973) and Thrift et al. (1970). Thrift and coworkers and Tanner and coworkers both reported a sire by sex interaction effect on postweaning gain to be nonsignificant.

The relative postweaning growth rate of Angus and Hereford cattle is somewhat of a sensitive subject among producers of the respective breeds. Researchers are wary of reporting one breed's superiority over another. However, Schalles and Marlowe (1967), Sagebiel et al. (1967) and Gregory et al. (1966a,b) all reported that within their respective studies, Hereford cattle had higher postweaning growth rates than did Angus. Schalles and Marlowe reported that the difference was significant ($P < .05$). Sagebiel and coworkers reported that the difference was .06 kg per day (.90 versus .84) in favor of the Herefords.

Little work has been done on the effects of inbreeding on postweaning growth. The most comprehensive study available, Brinks and Knapp (1975), found that a 1% increase in the inbreeding of the calf caused a $-.0016$ and $-.0015$ kg per day change in the postweaning gains

of male and female calves, respectively. They reported that a 1% increase in the inbreeding of the dam caused the postweaning gains of males and females to change by $-.0009$ and $+.0006$ kg per day, respectively. Swiger et al. (1961a) found that a 1% increase in the inbreeding of the calf caused a change of $-.075$ kg per day in postweaning gains in one Hereford herd and $-.0033$ kg per day in another. A 1% increase in the inbreeding of the dam caused changes of $-.0054$ and $+.0035$ kg per day in the postweaning growth rates of calves in the two respective Hereford herds.

The heritability of postweaning gain is generally estimated in the moderate to high category. Preston and Willis (1974) reported a preferred value of $.52$ for feedlot gain based on 56 estimates of all types of beef cattle. Petty and Cartwright (1966) reported weighted estimates of $.52$ for feedlot gain based on 33 estimates and $.30$ for pasture gain based on 16 estimates. Dickerson et al. (1974) reported an estimate of $.26$ for heritability of feedlot gain in Angus, Hereford and Shorthorn. Dinkel and Busch (1973) found a heritability estimate of $.55$ for feedlot gain of Hereford steers, while Koch et al. (1973) found estimates of $.29$ and $.65$, respectively, for the heritability of postweaning gains in Hereford bulls and heifers. Francoise et al. (1973) reported that the heritability estimates for postweaning gain of males and females, respectively, were $.34$ and $.79$ in Angus and $.11$ and $.65$ in Herefords. Harricharan et al. (1967) reported a $.47$ estimate for the heritability of postweaning gain in Angus.

Final Weight

Final or yearling weight is calculated at anywhere from 300 to 600 days. It is normally the time that the calf is taken off its postweaning test and normally about a year of age.

Even though the calf is now at least three months past weaning, researchers have found residual age of dam effects on final weight. Burfening and Kress (1973) and Brinks et al. (1962) reported age of dam effects ($P < .05$ and $P < .01$, respectively) on the final weight of Hereford cattle. Harricharran et al. (1967) found a "noticeable" age of dam effect on Angus calves' final weight. Schalles and Marlowe (1967) reported that the 365-day weight of Angus, Hereford and Shorthorn calves was effected ($P < .05$) by age of dam in one herd but not in another. Shelby et al. (1963) reported that three-year-old dams had a major ($P < .01$) effect on the yearling weights of their steer calves when compared to the steer calves of older dams.

On the other hand, Francoise et al. (1973) and Tanner et al. (1970) found no significant age of dam effect on the final weights of Hereford and Angus calves, respectively.

Year effects on final weight were reported as very important ($P < .01$) in Herefords by Burfening and Kress (1973), Dinkel and Busch (1973) and Shelby et al. (1955). Important ($P < .05$) year effects on yearling weight were reported by Tanner et al. (1970) with Herefords and by Schalles and Marlowe (1967) with Angus, Hereford and Shorthorns.

Year by sex and year by ranch interactions were reported as major ($P < .01$) sources of variation for final weight by Tanner et al. (1970) and Dinkel and Busch (1973), respectively. Dinkel and Busch (1973) also reported that a year by sire within ranch interaction did not significantly affect the final weights of Hereford cattle.

In studies where the two sexes were treated alike, researchers have found a substantial sex effect on yearling weight. Sex effects ($P < .01$) on yearling weight were reported in Herefords by Francoise et al. (1973) and Thrift et al. (1970) and in Angus by Tanner et al. (1970).

Sire effects on yearling weight were reported to be nonsignificant in Herefords by Pani et al. (1973) and Thrift et al. (1970). Tanner et al. (1970), however, analyzed sire effects within years and found a major ($P < .01$) effect. Also, Knapp and Nordskog (1946) reported finding a sire effect ($P < .01$) on the final weights of Herefords. Tanner and coworkers and Thrift and coworkers both analyzed sire by sex interactions (Tanner used sex within year) on Angus and Hereford calves, respectively, and both found no significant effect. Pani and coworkers found that a sire by year interaction did have a major ($P < .01$) effect on the yearling weight of Hereford bulls but no significant effect on that of Hereford heifers.

Burfening and Kress (1973) reported that the line of a Hereford calf influenced ($P < .01$) its final weight. Shelby et al. (1955) found that lines when analyzed within years and sires had no significant

effect on the final weight of Hereford steers.

Two other lesser studied effects on yearling weight are age and breed. Brinks et al. (1962) reported that age at weighing was a major ($P < .01$) effect on the final weight of Herefords. Schalles and Marlowe (1967) reported a breed effect ($P < .05$) on the yearling weights of the British breeds, with Hereford and Shorthorns being heavier than Angus.

Brinks and Knapp (1975) reported that a 1% increase in the level of a calf's inbreeding caused a change of $-.4394$ and $-.12517$ kg, respectively, in male and female final weights. A 1% increase in the inbreeding of the dam caused changes in the final weights of males and females of $-.3074$ and $.1336$ kg, respectively.

Estimates of the heritability of final weight are generally quite high. Preston and Willis (1974) reported a preferred value of $.77$ based on 30 estimates for various breeds of beef cattle weighed after a performance test. Petty and Cartwright (1966) reported a weighted estimate for the heritability of final feedlot weight as $.58$ based on 31 estimates. Their weighted estimate of yearling pasture weight heritability was $.41$ based on 13 estimates. Dickerson et al. (1974) reported the heritability of the yearling weight of Angus, Hereford and Shorthorn cattle was $.48$. Koch et al. (1973) estimated the heritability of the yearling weight was $.23$ and $.52$ for Hereford bulls and heifers, respectively. Dinkel and Busch (1973) found a value of $.85$ for the heritability of final feedlot

weight of Hereford steers. In Angus cattle, Harricharan et al. (1967) reported a yearling weight heritability of .58. Francoise et al. (1973) studied yearling weight per day of age and found heritabilities in Angus of .06 and .29 and in Herefords of .65 and .78 for males and females, respectively. Cundiff et al. (1975) studied Angus, Hereford and Polled Herefords and found yearling weight heritability estimates of .22 within herds and .21 between herds.

Correlations among the various traits are generally in excess of .30. Exceptions may be the genetic correlation between preweaning gain and feedlot gain which has been estimated from -.08 to .47. Table 6 is a summary of the major beef cattle studies reporting genetic and phenotypic correlations. The Petty and Cartwright (1966) review contains the pre-1966 studies.

TABLE 6. GENETIC (r_g) AND PHENOTYPIC (r_p) CORRELATIONS AMONG THE PRODUCTION TRAITS

Traits	r_g	r_p	Reference ^a
Birth weight - preweaning gain	.11 .46 .38 .10 .28	.12 .26 .23 .18 .27	Brinks <u>et al.</u> (1962) Brinks <u>et al.</u> (1964b) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)
Birth weight - weaning weight	.42 .60 .68 .58 .41 .53	.30 .41 .37 .39 .35 .43	Brinks <u>et al.</u> (1962) Brinks <u>et al.</u> (1964b) Shelby <u>et al.</u> (1964b) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)
Birth weight - feedlot gain	.71 .30 .56 .42 .34	.23 .29 .30 .31 .30	Brinks <u>et al.</u> (1962) Shelby <u>et al.</u> (1963) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)
Birth weight - pasture gain	.43	.17	Brinks <u>et al.</u> (1964b)
Birth weight - final weight	.75 .48 .64 .53 .45	.39 .45 .42 .43 .51	Brinks <u>et al.</u> (1962) Shelby <u>et al.</u> (1963) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)
Weaning weight - preweaning gain	.82 .98 .95 .96	.92 .97 .98 .98	Brinks <u>et al.</u> (1962) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)

TABLE 6. (CONTINUED)

Traits	r_g	r_p	Reference
Weaning weight - pasture gain	-.16 .08	.52 .25	Brinks <u>et al.</u> (1964b) Petty and Cartwright (1966)
Weaning weight - feedlot gain	.06 .77 .58 .26 .49 .80 .77 .12	.17 .18 .17 .20 .13 .18 -- -.07	Brinks <u>et al.</u> (1962) Shelby <u>et al.</u> (1963) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973) Dickerson <u>et al.</u> (1974) Dinkel and Busch (1973) Francoise <u>et al.</u> (1973)
Weaning weight - final weight	.67 .86 .79 .95	.62 .58 .65 .82	Brinks <u>et al.</u> (1962) Shelby <u>et al.</u> (1963) Petty and Cartwright (1966) Dickerson <u>et al.</u> (1974)
Weaning weight - yearling (pasture) weight	.75 .67 .61 .94	.66 .64 .45 .67	Brinks <u>et al.</u> (1964b) Petty and Cartwright (1966) Francoise <u>et al.</u> (1973) Dickerson <u>et al.</u> (1974)
Prewaning gain - feedlot gain	-.08 .08 .14 .47	.14 .14 .15 .07	Brinks <u>et al.</u> (1962) Petty and Cartwright (1966) Koch <u>et al.</u> (1973) Koch <u>et al.</u> (1973)
Prewaning gain - pasture gain	.49	.13	Brinks <u>et al.</u> (1964b)

TABLE 6. (CONTINUED)

Trait	r_g	r_p	Reference
Prewaning gain - final weight	.54	.62	Brinks <u>et al.</u> (1962)
	.73	.63	Petty and Cartwright (1966)
	.58	.69	Koch <u>et al.</u> (1973)
	.76	.69	Koch <u>et al.</u> (1973)
	.88	.70	Brown <u>et al.</u> (1973)
	.81	.64	Brown <u>et al.</u> (1973)
Feedlot gain - final weight	.76	.80	Brinks <u>et al.</u> (1962)
	.96	.86	Shelby <u>et al.</u> (1963)
	.86	.77	Petty and Cartwright (1966)
	.66	.73	Francoise <u>et al.</u> (1973)
	.82	.64	Brown <u>et al.</u> (1973)
	1.03	.61	Brown <u>et al.</u> (1973)
	.95	.82	Dickerson <u>et al.</u> (1973)
Pasture gain - yearling weight	.76	.62	Brinks <u>et al.</u> (1964b)
	.81	.63	Petty and Cartwright (1966)

^a The first Koch et al. (1973) reference within each group is with males only, the second is with females only.

MATERIALS AND METHODS

The data for this study were provided by the Montana Beef Performance Association. Records included the production traits of birth weight (either actual or standard), weaning weight, and weight at the end of the postweaning gain test. All calves were not represented in all traits, although all calves had a weaning weight. Factors in the records affecting these traits were breed, herd, birth date, weaning date, pasture unit, sex, sire, dam, age of dam and feeding unit.

Purebred Angus and Hereford calves were included in the data. The two breeds were analyzed separately. Breeds were not simultaneously managed under common environmental conditions; therefore breed effects could not be studied as legitimate sources of variation.

The six Angus and nine Hereford herds were selected on the basis of 1) number of years of performance testing, 2) size of herd, 3) accuracy of data and 4) to provide a cross-section of the state. Figure 1 shows an approximate distribution of the herds within the state. The eastern two-thirds of the state is high prairie and foothills, with an annual precipitation of 25 to 40 cm. The western portion of the state is mountainous with numerous valleys and meadows. Western precipitation varies considerably, from 25 cm in rain shadow areas to 200 cm in high snowfall and western slope regions.

Calves born after June 30 were excluded from the data. Exclusion of the late summer and fall born calves had the effect of eliminating all creep-fed calves.

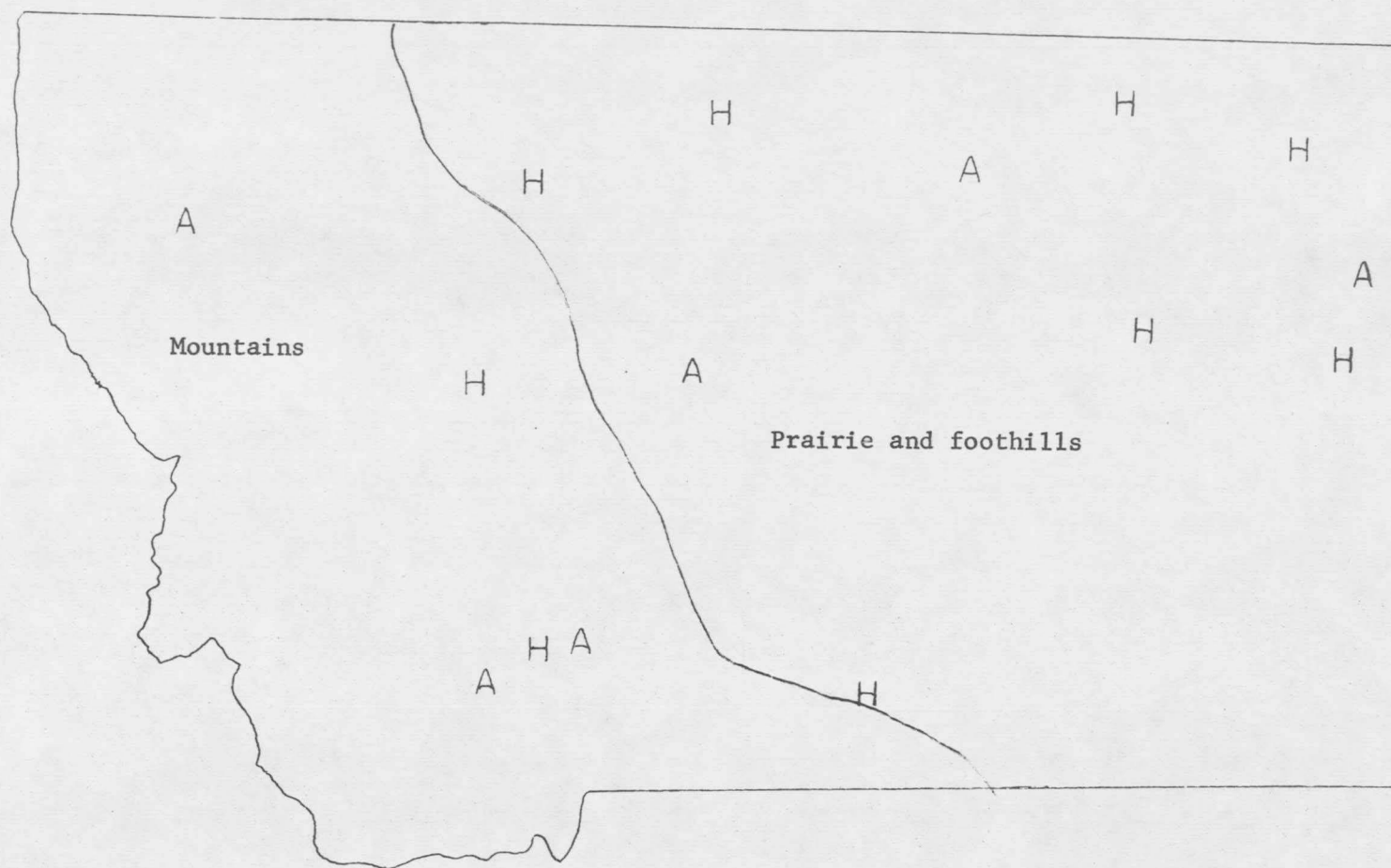


Figure 1. Distribution of the studied herds, Angus (A) and Hereford (H), within the state of Montana.

Records were available from 1958 through 1973 although all herds were not represented in all years.

The pasture unit denoted the specific within herd pasture where the calves were raised from birth to weaning. When pasture units differed within herd and year, the weaning weights were corrected additively within that herd and year. The corrections were made to the pasture unit which contained the greatest number of animals. A total of 525 Angus calves in 18 herd-year subclasses and 731 Herefords in 27 herd-year subclasses were adjusted for pasture units.

Preliminary edits eliminated any steers from the analysis. The Angus data contained nearly equal counts of males and females. Chi-square analysis showed them to be essentially equal in number. The Hereford data showed a wide disparity in sex count overall. However, when year within herd subcells were considered, most of those subcells which contained both sexes contained them in approximately equal numbers. In herd-year subcells which contained unequal numbers of each sex, as determined by Chi-square analysis ($P < .01$), the female records were eliminated.

All dams eleven years of age and older were pooled as one category and other ages were grouped within one year classifications as recommended by B.I.F. (1972).

Additive within herd and year corrections were made for post-weaning feeding unit, if needed. A least squares analysis was made of each herd where there were different feeding units within a sex

and year. A significant feeding unit effect indicated a need for corrections. Corrections were then made to that feeding unit which contained the largest number of animals. Angus feeding unit corrections involved 294 calves in five sex-year-herd subunits. Four hundred three Hereford calves in 17 sex-year-herd subunits were corrected for feeding unit differences.

Only those calves with actual birth weights were included in the analysis of birth weight and preweaning gain. Calves weighing less than 16 kg or more than 50 kg at birth were excluded from the data. This range would eliminate gross record errors but would still include legitimate birth weights. No Angus and four Herefords were eliminated by this edit.

Due to the disparity in the number of each sex represented in the Herefords, one Model I, (described later), run was made with the females corrected additively to bull basis on a within herd basis. Additive adjustments were used to insure that the variances would not be affected.

Weaning weights were available for all calves in the study. Calves weighing less than 90 kg or more than 450 kg were eliminated, leaving a wide enough interval to include any legitimate outliers while removing record errors. For the same reasons, calves weaned at earlier than 100 or later than 300 days were excluded. Thirty Herefords and 21 Angus were eliminated for weaning weight

irregularities, while three Herefords and three Angus were over 300 days of age at weaning.

In order to utilize as many records as possible, two separate Model I (described later) analyses were made with each breed. In the first analysis, only those year-herd subcells with both sexes represented were included. The females were then adjusted to a male basis by an additive within herd correction factor. The second analysis included the adjusted females plus all the males.

Each record which included a final feedlot weight also contained an initial weight at the beginning of the test and the total days on test. The number of days during the warm-up period between weaning date and the initiation of the test were not noted and thus the exact age at the conclusion of the test was not known. However, the warm-up period and the number of days on test were constant within herd, year and sex and valid results could be obtained.

Edits excluded from final weight analysis any animals weighing less than 180 kg or more than 700 kg.

Birth, weaning and final feedlot or pasture weights were analyzed by least squares methods as outlined by Harvey (1975). Each trait was analyzed in a model in which years were treated as fixed effects (Model I). The three weights plus pre- and postweaning gain were analyzed in a model in which the years were considered as random sources of variation within herds (Model II) (Harvey, 1970).

Due to the wide range in area and possibly management practices, it was decided that Model II would be most appropriate for this data. Specific years could not be assumed as having the same effect on all herds. However, Model I was used in order that time trends could be examined. In addition to the scientific interest in time trends as a possible indication of genetic trends, the association which supplied the data had expressed an interest in obtaining time trend results.

The composition of Model I was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \sum_{n=1}^3 b^n(x) + e_{ijk}$$

where Y_{ijk} = an independent observation from a normally distributed population

μ = the overall population mean

$(\alpha_i + \beta_j)$ = a set of fixed effects of the i^{th} classes of α and the j^{th} classes of β expressed as deviations from the overall mean μ (α and β are used as general symbols and are not specific classes).

$(\alpha\beta)_{ij}$ = the set of effects of the ij^{th} $\alpha\beta$ subclasses after the average effects of α and β have been removed and expressed as deviations from the mean μ

$\sum_{n=1}^3 b^n(x)$ = a set of partial regressions of Y_{ijk} on x where n denotes the degree of the regression, $n=1$ is linear, $n=2$ is quadratic and $n=3$ is cubic

e_{ijk} = the variation which cannot be accounted for elsewhere

in the model, assumed to be NID $(0, \sigma_e^2)$

The set $(\alpha_i + \beta_j)$ contained herd, sex, and age of dam effects for both breeds in birth, weaning and final feedlot weights. Year effects were included as simple main effects in all cases except Hereford birth weights where herd-year subcells with equal numbers of each sex were present in only two herds and non-overlapping years. Initial analysis was made on this data with years considered as fixed effects within herds. Within herd additive correction factors for sex differences were calculated from the initial analysis and a second analysis was made with females adjusted to a male basis and all male records from all herds included. A similar analysis was done with weaning weights for both breeds in an effort to include as many records as possible in Model I analysis.

The $(\alpha\beta)_{ij}$ set included sex by herd interactions for all three traits in both breeds. Herd by age of dam interactions were in all analyses except Hereford weaning and final weights. Herd by year interactions were included in all analysis except Hereford birth weight. In weaning weight analysis where the year by herd interaction was not included in initial analysis due to program space limitations, a second analysis was made with herd by year as the lone interaction.

Sex by age of dam interactions were included in all Model I analyses. Sex by year effects were included in birth and weaning weight analyses for both breeds but not in final weight analyses for

either breed. The age of dam by year interaction was not analyzed due to program space limitations.

The $(\sum_{n=1}^3 b^n(x))$ set consisted of birth weight regressed on day of birth and weaning weight regressed on age at weaning.

The composition of Model II was:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \alpha(i)_k + (\alpha\beta)_{ij} + \sum_{n=1}^3 b^n(x) + e_{ijkl}$$

where Y_{ijkl} = an independent observation from a normally distributed population

μ = the overall population mean

$(\alpha_i + \beta_j)$ = a set of fixed effects of the i^{th} classes of α and the j^{th} classes of β expressed as deviations from the overall mean μ .

$\alpha(i)_k$ = a set of random effects where the k^{th} class of α is nested within a i^{th} class of α .

$(\alpha\beta)_{ij}$ = the set of effects of the ij^{th} $\alpha\beta$ subclasses after the average effects of α and β have been removed and expressed as deviations from the mean.

$\sum_{n=1}^3 b^n(x)$ = a set of partial regressions of Y_{ijkl} on x where n denotes the degree of the regression, $n=1$ is linear, $n=2$ is quadratic and $n=3$ is cubic.

e_{ijkl} = the variation of Y_{ijkl} which cannot be accounted for elsewhere in the model, assumed to be NID $(0, \sigma_e^2)$

The set $(\alpha_i + \beta_j)$ contained herd, sex and age of dam effects

in all Model II analyses. The $f_{(i)k}$ set consisted of years nested within herds.

The $(\lambda\beta)_{ij}$ set contained all combinations of fixed effects for all traits in both breeds. Program space limitations in Hereford data necessitated analyzing the weaning weight, postweaning gain and final feedlot weight first with herd by age of dam effects in the model and sex by age of dam omitted and then with sex by age of dam included and herd by age of dam excluded.

The $\sum_{n=1}^3 b^n(x)$ set was comprised of birth weight and preweaning gain regressed on birth date and weaning weight regressed on age at weaning.

After the first Model II least squares runs were made, the effects of sex and age of dam were adjusted, both singly and together and by both additive and multiplicative factors.

To adjust for sex differences, the heifer calves were adjusted to a bull basis except in the case of the industry's recommended factors where both heifers and bulls were adjusted to a steer basis. All correction factors except industry factors (B.I.F., 1972) were calculated and used within each breed. To obtain additive factors, the least squares mean of the heifer calves was subtracted from the mean of the bull calves and this difference was added to each heifer's record. Multiplicative components consisted of a ratio of bulls' means to heifers' means. Each heifer record was then multiplied by this ratio.

Age of dam adjustments were also made both additively and multiplicatively. Corrections attempted to put each record on a mature dam basis. Adjustments were made to either a single age of dam or a set of dam ages. The single age was that age whose least square mean was the greatest among the 10 ages of dams. The first set of dam ages used was the industry recommendation of the average of dams aged 5 to 10 years (B.I.F., 1972). A second set of dam ages used was the mature set whose means were not significantly different as determined by Newman-Keuls' test (Snedecor and Cochran, 1967) for homogeneity of means, if this set differed from the first set.

Additive factors were obtained by subtracting each age of dam mean from the mean of the desired age or set of ages. Multiplicative factors were calculated as ratios of the individual ages of the desired age or set of ages.

Adjustments were made to correct for both age of dam and sex effects. The age of dam factors were considered first and the sex factors second. All possible additive and multiplicative combinations of correction factors were used.

Model III analysis included only those calves with actual birth weights and valid weaning and final weights. Model III contained all the elements of Model II plus the addition of a random sires within random years within fixed herds effect. Model III was used to estimate genetic parameters as outlined by Harvey (1970).

Heritability (h^2) was estimated by paternal half-sib analysis (see Falconer, 1960). The heritabilities were calculated as four times the sire variance component (half-sibs have one-fourth of their genes in common) divided by the sire plus the environmental variance components:

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

The genetic correlations were calculated by four times the between sire covariance component divided by the square root of the product of the sire variance components of the covariates:

$$r_g = \frac{4 \text{Cov } x \ y}{\sqrt{\sigma_x^2 \sigma_y^2}}$$

Birth weight, preweaning, average daily gain, weaning weight, postweaning average daily gain and final weight were all included as dependent variables in Model III analysis. There were only 85 Hereford female complete records available, so the initial Model III analysis was made with 1379 Hereford bull records. A second Model III analysis (Model IIIa) was then done with weaning weight records only of 3934 Hereford bulls and 2065 Hereford heifers.

Additional analyses were made with Model III and Model IIIa to obtain estimates of variances within sex and age of dam classifications. Results were obtained from analyzing individual sexes, ages of dam and sets of ages of dam both before and after corrections factors were used.

TABLE 7. NUMBERS OF RECORDS AVAILABLE FOR EACH ANALYSIS

Type analysis	Birth weight			Preweaning gain			Weaning weight			Postweaning gain			Final weight		
	Male	Fem.	Hds	Male	Fem.	Hds	Male	Fem.	Hds	Male	Fem.	Hds	Male	Fem.	Hds
Model I															
Angus ^a	1579	1636	4	-	-	-	1959	1919	6	1722	1420	5	1722	1420	5
	-	-	-	-	-	-	5971	-	6	-	-	-	-	-	-
Hereford ^a	373	294	2	-	-	-	1535	1422	8	3301	1429	9	3301	1429	9
	1707	-	4	-	-	-	5980	-	9	-	-	-	-	-	-
Model II															
Angus	1623	1696	4	1623	1696	4	2968	2934	5	2017	2669	5	2017	1669	5
Hereford	1781	290	4	1781	290	4	3900	2050	9	3301	1456	9	3301	1456	9
Model III															
Angus	1101	1012	4	1101	1012	4	1101	1012	4	1101	1012	4	1101	1012	4
Hereford ^b	1379	-	3	1379	-	3	1379	-	3	1379	-	3	1379	-	3
	-	-	-	-	-	-	3934	2065	9	-	-	-	-	-	-

^a Model I analysis of Angus weaning and Hereford birth and weaning weights was first carried out with only those sub-cells containing equal numbers of each sex. A second analysis was then done with females corrected to a male basis and all data was included.

^b Model III analysis of Herefords was done with only males represented for each trait and then with both sexes represented for weaning weight only (Model IIIa).

RESULTS AND DISCUSSION

Model I Analysis

Model I analysis was carried out primarily to study time trends. As complete a model as possible was used, but only those main and interaction effects involving years will be discussed in this section. The others will be included in Model II analysis. Pertinent regressions at the linear, quadratic and cubic levels were included in Model I analysis. Those regressions which were significant at the cubic level were retained in Model II while the others were reduced to quadratic and linear levels for further analysis.

Birth weight. The Model I analysis of variance table for birth weight (table 8) shows that all main effects were generally highly significant ($P < .01$). The herd by year interaction was highly significant ($P < .01$) in both breeds. Sex by year interactions were significant ($P < .05$) in the Angus data but not ($P > .10$) in the Hereford data.

Least squares means and standard errors for birth weight were 30.9 ± 1 kg and 28.5 ± 2 kg for Angus male and female calves, respectively. The least squares mean for Hereford female calves was 32.5 ± 3 kg. The least squares mean for Hereford male calves was 34.7 ± 2 kg before adjustments and 35.9 ± 1 kg after females were adjusted to a male basis and herds containing only male birth records were included.

The mean (and standard deviation) for day of year born was 77 (26) days in Angus and 94 (30) days in Herefords. After the Hereford data was adjusted and the bull only sub-units added, the mean (and

standard deviation) was 84 (31) days.

Figures 2 and 3 show the results of regressing least squares means of birth weights of Angus and Hereford calves, respectively, on years.

TABLE 8. LEAST SQUARES ANALYSES OF VARIANCE FOR BIRTH WEIGHT - MODEL I

Source	Angus		Hereford ^a		Hereford ^b	
	df	Mean square	df	Mean square	df	Mean square
Herd (H)	3	975.9**	1	.3	3	1353.6**
Sex (S)	1	1119.6**	1	568.2**	-	-
Age of dam (A)	9	160.9**	9	69.6**	9	198.1**
Year (Y) ^c	10	262.1**	6	88.1**	11	40.6**
H x S	3	27.7*	1	12.9	-	-
H x A	27	21.4**	8	8.4	26	23.2**
H x Y	17	85.54**	-	-	18	29.8**
S x A	9	19.1+	9	18.0	-	-
S x Y	10	21.8*	5	15.0	-	-
Regression on day of birth						
Linear	1	16.0	1	362.3**	1	187.6**
Remainder	3124	10.4	625	12.1	1638	12.0

^a Included only those herd-year subcells with both sexes represented equally.

^b Female birth weights corrected to male basis and all subcells included.

^c Hereford^a - Years analyzed within individual herds.

+ P<.10.

* P<.05.

**P<.01.

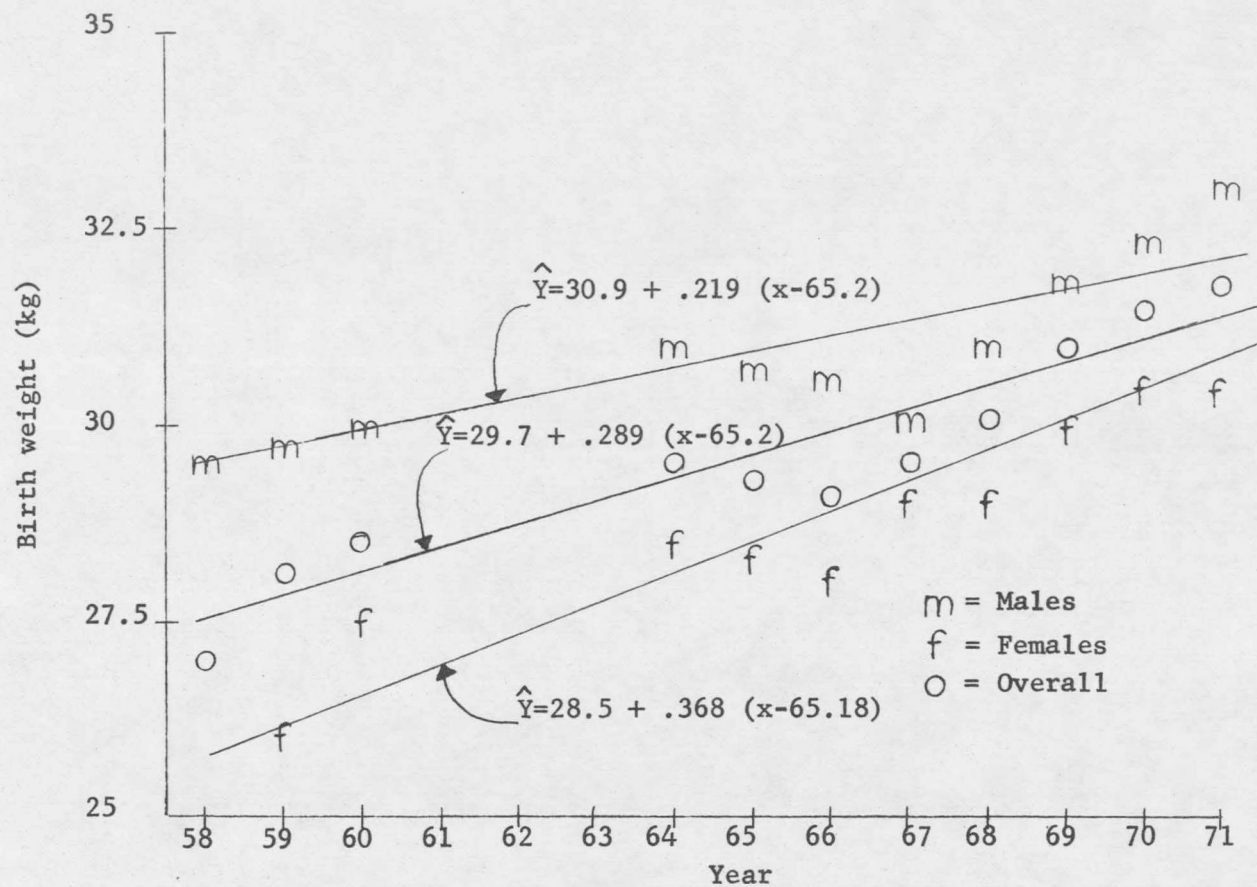


Figure 2. Angus male, female and combined sex birth weight least squares means regressed on years.

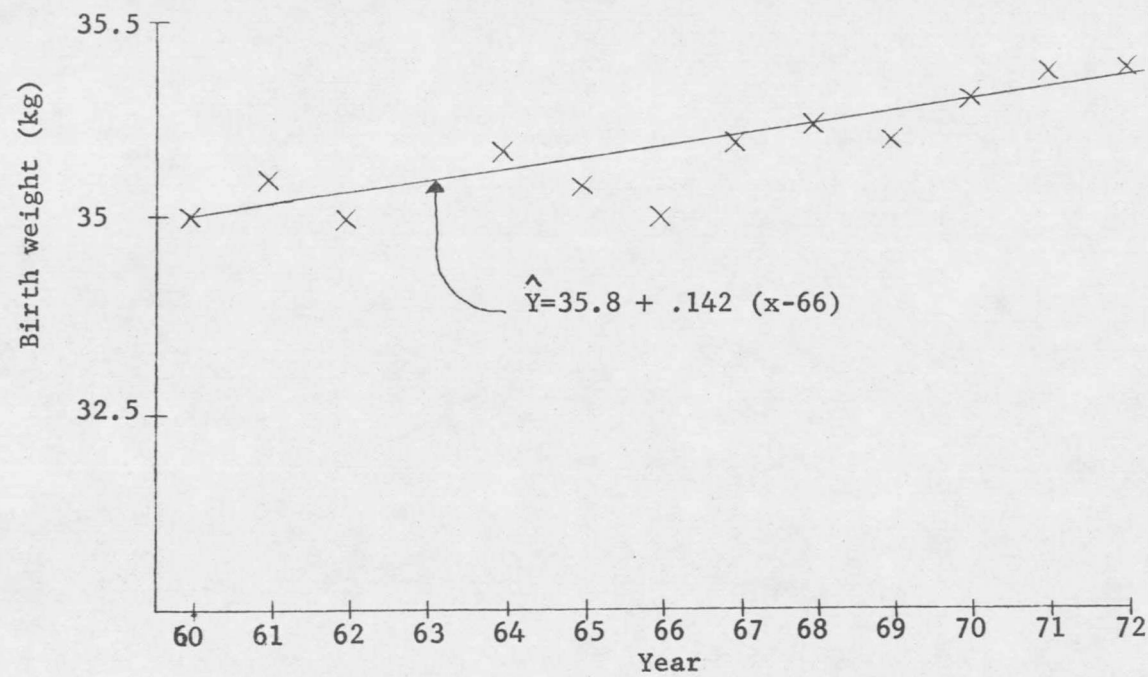


Figure 3. Hereford bull calves birth weight least squares means regressed on years.

The average birth weight of the Angus calves in the study increased at a rate of .29 kg per year. Hereford bull calves' birth weights increased at the rate of .31 kg per year. Appendix figures 23 and 24 show the birth weight least squares means for each herd and year. The figures indicate that the positive regression was not due to either above average herds having records only in the later years or to below average herds having records only in the early years.

The sex by year interaction in Angus is noticeable in figure 2 as a convergence of the male and female regression lines. Although both sexes show positive regressions ($P < .01$), the female calves appeared to show a steeper slope than the males (the slopes are not significantly ($P > .05$) different from one another). One explanation of this phenomenon could be that there are sex-linked genes involved. As selection pressure for increased size was applied, the females responded more than the males due to the presence of additional "positive" genes on their extra x-chromosome or possibly the absence of "negative" genes on the male Y-chromosome. A second explanation could be that selection changed the relative hormone balance of the females. As they were selected for increased size, they were perhaps inadvertently but simultaneously selected for increased levels of androgens. If that was the case, the graph represents a diminishing of sex differentiation overall. A third theory is that the bull

calves are reaching the limit of their dams' uterine capacity. As selection pressure for increased size was applied, the calves increased at a relatively faster rate than the dams. The bull calves were not able to reach their full potential size while the female calves, being of naturally smaller size, were able to grow to a relatively larger size.

The significance of the sex by year interaction is important when considering additive versus multiplicative adjustments for sex effects. An overall additive factor would not be able to decrease the effect of the interaction. The additive factor would tend to overadjust those records represented by the converging end of the graph and under-adjust those records on the opposite end. A multiplicative factor could reduce the interaction effect, but only if the converging end of the graph were in a negative direction. Therefore, if the sex by year interaction is considered important, the way to correct for it would be to use a sliding-type additive factor or a multiplicative factor if the sex differences increased with time.

Weaning weight. The least squares analyses of variance for weaning weights by Model I (table 9) showed that year was a highly significant ($P < .01$) and the herd by year interaction was highly significant ($P < .01$) in both breeds.

Least squares means and standard errors for weaning weight of Angus male and female calves were 219 ± 1 and 195 ± 1 kg, respectively, for the initial analysis and 213 ± 1 for bull calves after sex adjustments and additions of bull only herd-year subcells. The mean (and standard deviation) for age of weaning was 215 (24) days initially and 217 (25) days for the second analysis. Hereford least squares means for weaning weight for the initial analysis were 213 ± 1 kg for males and 193 ± 1 kg for females. After adjusting females to a male basis and including the male only herd-year subcells the least squares mean was 211 ± 1 kg. Means (and standard deviations) for age at weaning were 210 (24) days for initial analysis and 211 (25) days for the second.

The results of regression weaning weight least squares means on years for the sex adjusted data sets are shown in figures 4 and 5. The regression analysis of time trends for weaning weight (figures 3 and 4) exhibit the same general shaped curve for each breed. The overall regression of weaning weight on year was significantly ($P < .05$) positive in both breeds ($R^2 = .68$ for Angus and $.44$ for Herefords). Visually, the figures indicated two linear trends, pre- and post-1965, rather than one algebraic curve. A regression of weaning weight on years through 1965 resulted in a negative ($b = -.46$ kg/yr) non-significant ($P > .05$, $R^2 = .03$) regression in Angus and a better fitted ($R^2 = .75$) but still negative ($b = -2.57$ kg/yr, ($P < .01$) regression in

TABLE 9. LEAST SQUARES ANALYSES OF VARIANCE FOR WEANING WEIGHT - MODEL I

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Males				
Herd (H)	5	191783**	8	224762**
Age of dam (A)	9	31494**	9	54598**
Year (Y)	13	27523**	14	42161**
H x A	45	1008**	-	-
H x Y	25	12917**	51	7004**
Regression on weaning age				
Linear	1	522693	1	661913**
Quadratic	1	34478	1	1302
Cubic	1	4126**	1	153
Remainder	5795	460	5945	639
Both sexes				
Herd (H)	5	59737**	7	37601**
Age of dam (A)	9	21472**	9	27297**
Year (Y)	7	11662**	10	17467**
Sex (S)	1	71373**	1	82122**
H x A	45	1438**	-	-
H x S	5	4474**	7	2065**
A x S	9	1070*	9	1038*
Y x S	7	1104*	10	1169**
Regression on weaning age				
	1	48826**	1	51028**
Remainder	3787	454	2901	470

**P<.01.

* P<.05.

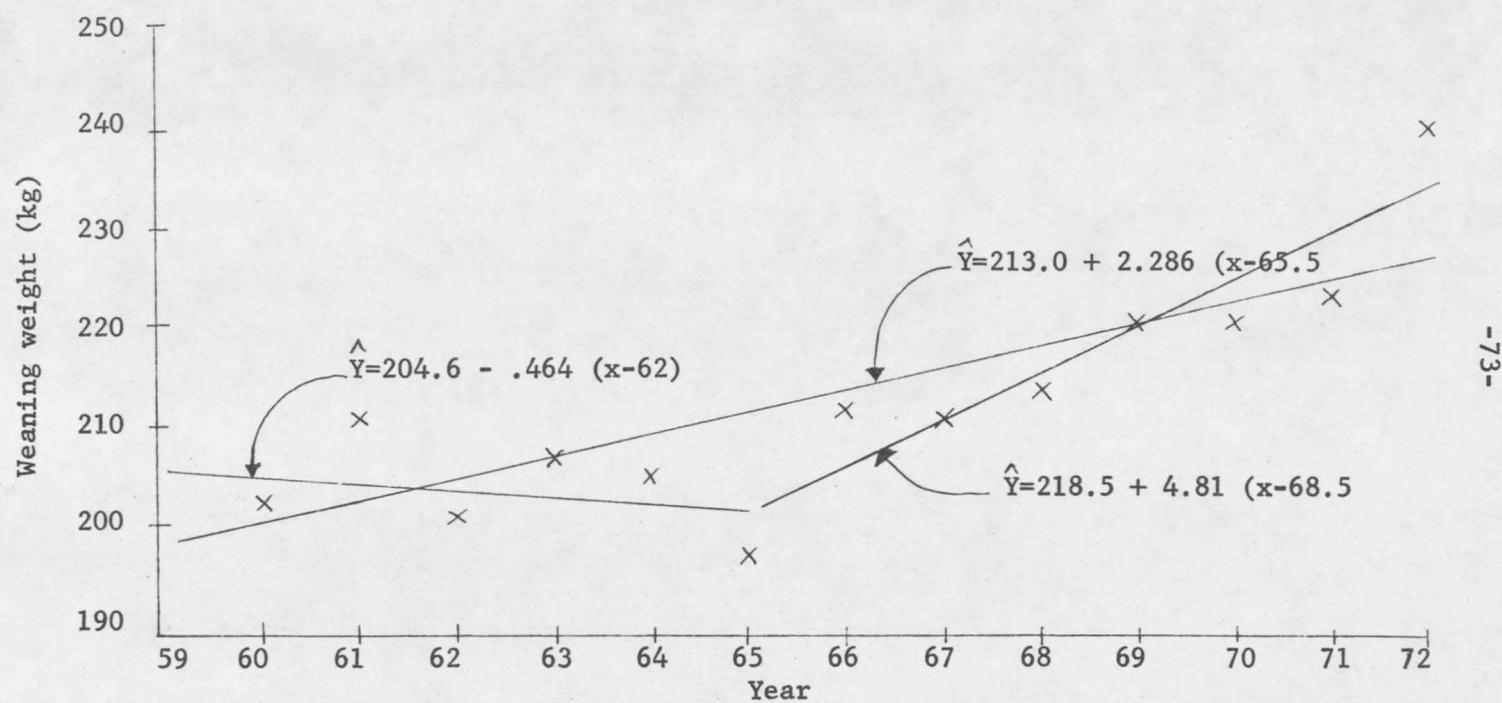


Figure 4. Angus weaning weight least squares means regressed on years.

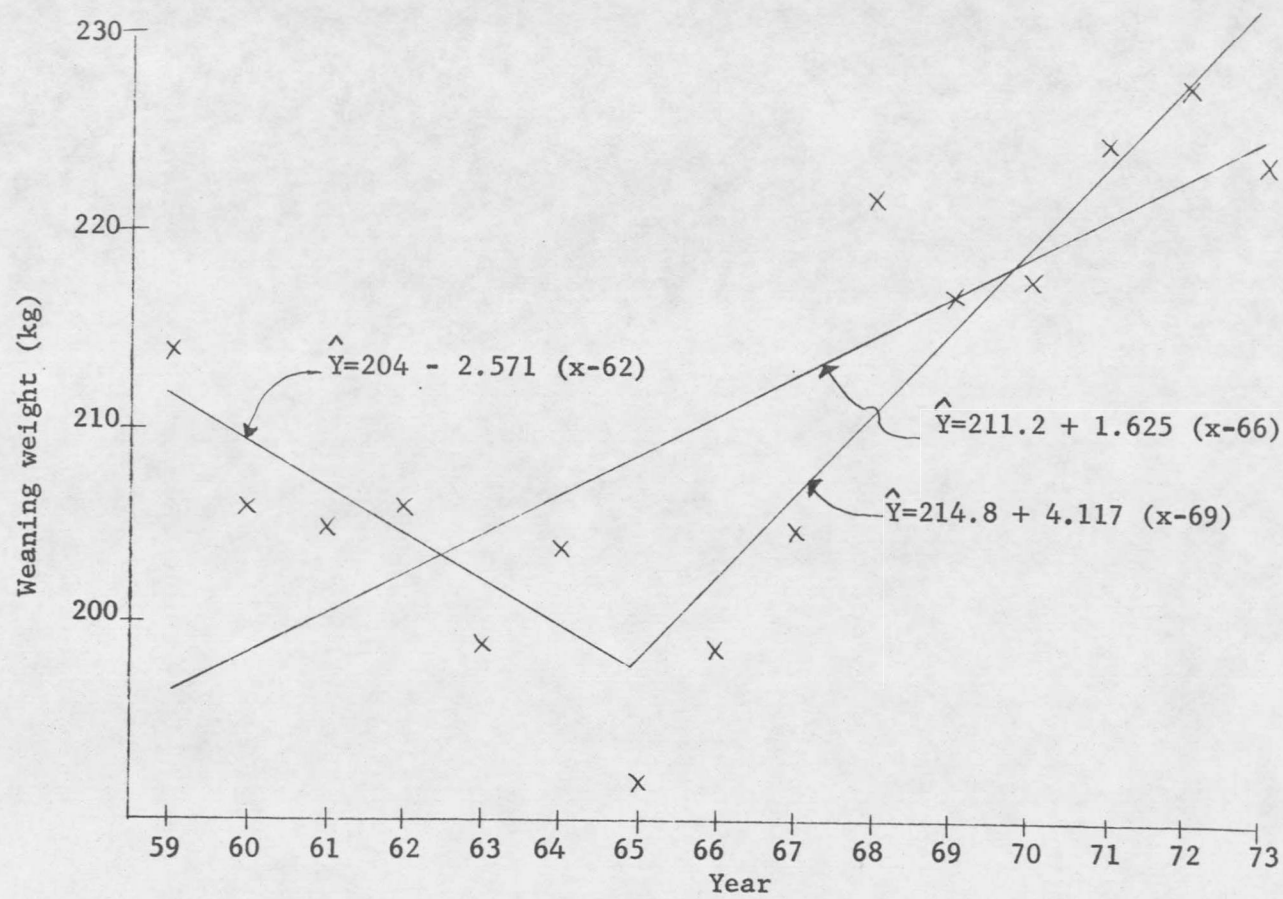


Figure 5. Hereford weaning weight least squares means regressed on years.

Herefords. Regressing weaning weight on years from 1965 on showed significant ($P < .01$), positive (4.81 and 4.12 kg/yr for Angus and Hereford, respectively), and well fitted ($R^2 = .87$ and $.80$, respectively) linear regressions. It should also be noted here that the summer of 1965 was short, wet, cold and stormy, preceded by an especially long hard winter and followed by an early, wet and cold autumn (Climatological Data, 1965). The effect of this particular year is quite noticeable in the weaning weight and to a lesser extent in the birth weight data. The general increase in weaning weights could be due to improved management (environmental) conditions or to genetic improvement or to a combination of the two. In the late 1950's or early 1960's, each of these herds entered into a selection program based on performance records. No assumptions can be made concerning their respective selection programs prior to this time. The shape of the weaning weight time trend (figures 4 and 5) curve lends itself to an interesting speculation. Although these cattle were under selection pressure for increased weights for a period beginning in the late 1950's, it was post-1965 before a steady, significant gain in average weaning weight developed. Major time trend studies on the effects of selection by Wallace (1968), Falconer (1960), Lerner (1958) and others use generations as a time base rather than years. Perhaps it would have been better to use generations rather than years in this study but there was no way to estimate the generation interval in this data.

Rice et al. (1970) give an approximate average generation interval in beef females of 4.5 years. If the period 1959 to 1965 is assumed to be approximately one generation interval, the curves in figures 4 and 5 suggest that one full generation elapsed before the effects of selection were noticeable.

Newman et al. (1973) observed the same type of response curve in their 10-year study of beef Shorthorns selected for increased yearling weight. They reported a 4 to 5 year lag before a regular advance was made in the last 6 years of the study. They reasoned that the response was irregular until a sufficient amount of selection differential was accumulated.

Brinks et al. (1965) noted in a study of Hereford cattle selected for increased weaning weight from 1934 through 1959 that the response (as measured by a regression of weaning weight on years) was greater in the period 1943 to 1959 than it was in the period 1934 to 1943. Chapman et al. (1969) found in a 7-year study of Polled Hereford bulls selected for single traits that the response (as measured by weaning weight regressed on years) was negative over the 7-year period for bulls selected for weaning weight, postweaning rate of gain, yearly type score and an average of these three traits.

Postweaning. Least squares analyses of variance for postweaning gain and final test weight (tables 10 and 11) showed that years and herd by year interactions were highly significant ($P < .01$) sources of

variation for both traits in both breeds.

The least squares means and standard errors for postweaning gains were $.970 \pm .005$ and $.436 \pm .005$ kg/day in Angus males and females, respectively. The least squares means for the same respective sexes in Herefords were $1.084 \pm .004$ and $.591 \pm .007$ kg/day. The disparity between the gains of the sexes is due largely to differences in postweaning environment. The bull calves in this study were put in feedlots and the heifers in pastures or in a feedlot on a growing ration. Angus bull calves were kept on postweaning test for a least square mean period of $162.5 \pm .3$ days and Hereford bulls for $156.7 \pm .3$ days. At the end of the test their respective least square means for final weights were 378 ± 1 and 391 ± 1 kg. Angus heifer calves were on postweaning test for a least square mean period of $164.9 \pm .5$ days and Hereford heifers for $170.0 \pm .4$ days. Their respective final test weights were 274 ± 1 and 298 ± 2 kg. Figures 8 and 9 show regressions of final test weight on years. Fitness of linearity as determined by R^2 was .27 for Angus and .43 for Herefords. The value of this analysis is limited however, because the final test weights were influenced by initial weight and days on test. A more valuable analysis was regression of postweaning gain on years (figures 6 and 7). Although both breeds showed positive regressions of least squares means postweaning gain on years ($.0054$ kg/day/year in Angus and $.0021$ kg/day/year in Herefords), neither regression was significant ($P > .10$). Overall, the results indicated

an increase in weaning weight with time and suggest the possibility that weaning weight increased as a result of direct selection and birth weight increased as a correlated response.

There was no noticeable depression in final test weights or postweaning gains for the year 1965 as there was for birth and weaning weights. A possible explanation is that although the year was cold and wet, it did produce a good hay crop (Ballard and Ryerson, 1973) and calves that survived the weaning period were not nutritionally limited after weaning.

TABLE 10. LEAST SQUARES ANALYSES OF VARIANCE FOR POSTWEANING GAIN
MODEL I

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	4	2.4886**	9	2.5086**
Year (Y)	10	.9921**	11	.9585**
Sex (S)	1	141.4878**	1	180.4075**
Age of dam (A)	9	.0240	9	.0177
H x Y	17	.3849**	50	.7180**
H x S	4	3.4609**	6	2.9965**
H x A	36	.0405**	-	-
S x A	9	.0316*	9	.0098
Remainder	3051	.0158	4635	.0192

** P<.01.

* P<.05.

TABLE 11. LEAST SQUARES ANALYSES OF VARIANCE FOR FINAL TEST WEIGHT -
MODEL I

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	4	145159**	8	212091**
Year (Y)	10	57642**	11	48872**
Sex (S)	1	5377825**	1	2825636**
Age of dam (A)	9	9889**	9	61415**
H x Y	17	13588**	50	33610**
H x S	4	82707**	6	71410**
H x A	36	2385**	-	-
S x A	9	1510	9	616
Remainder	3051	1132	4635	1214

** P<.01.

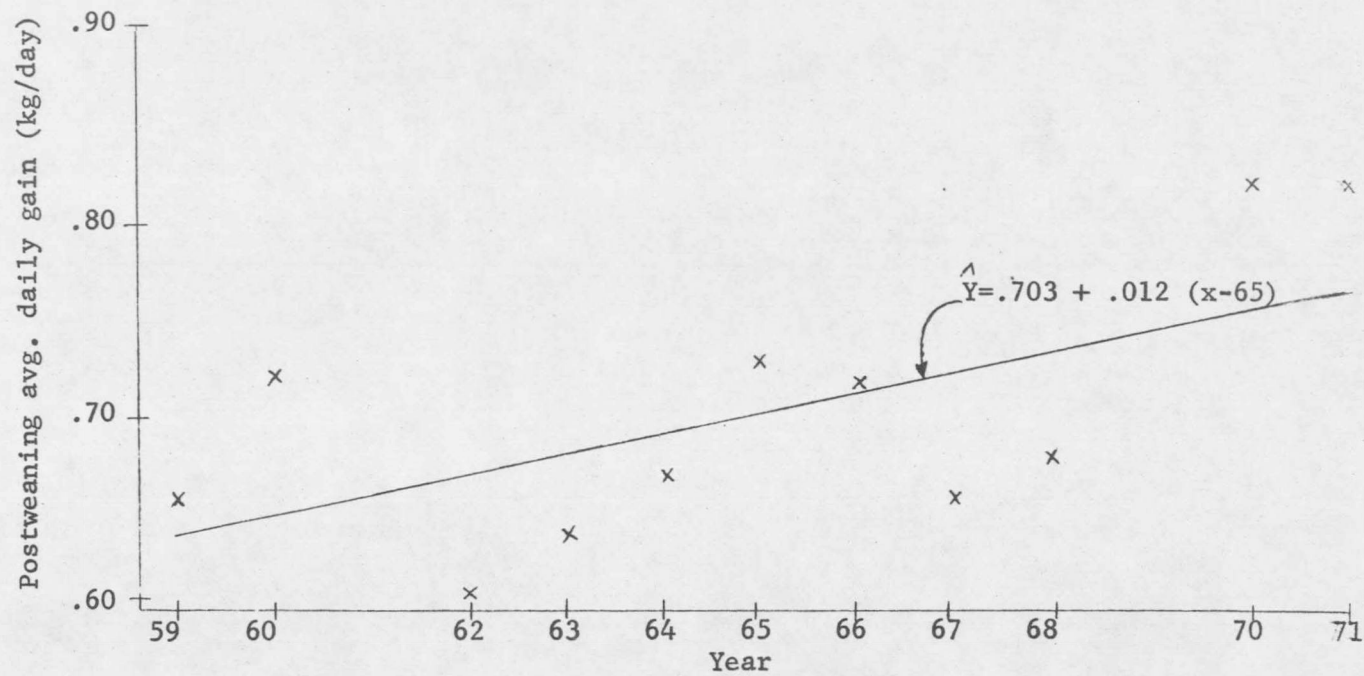


Figure 6. Angus postweaning average daily gain least squares means regressed on years.

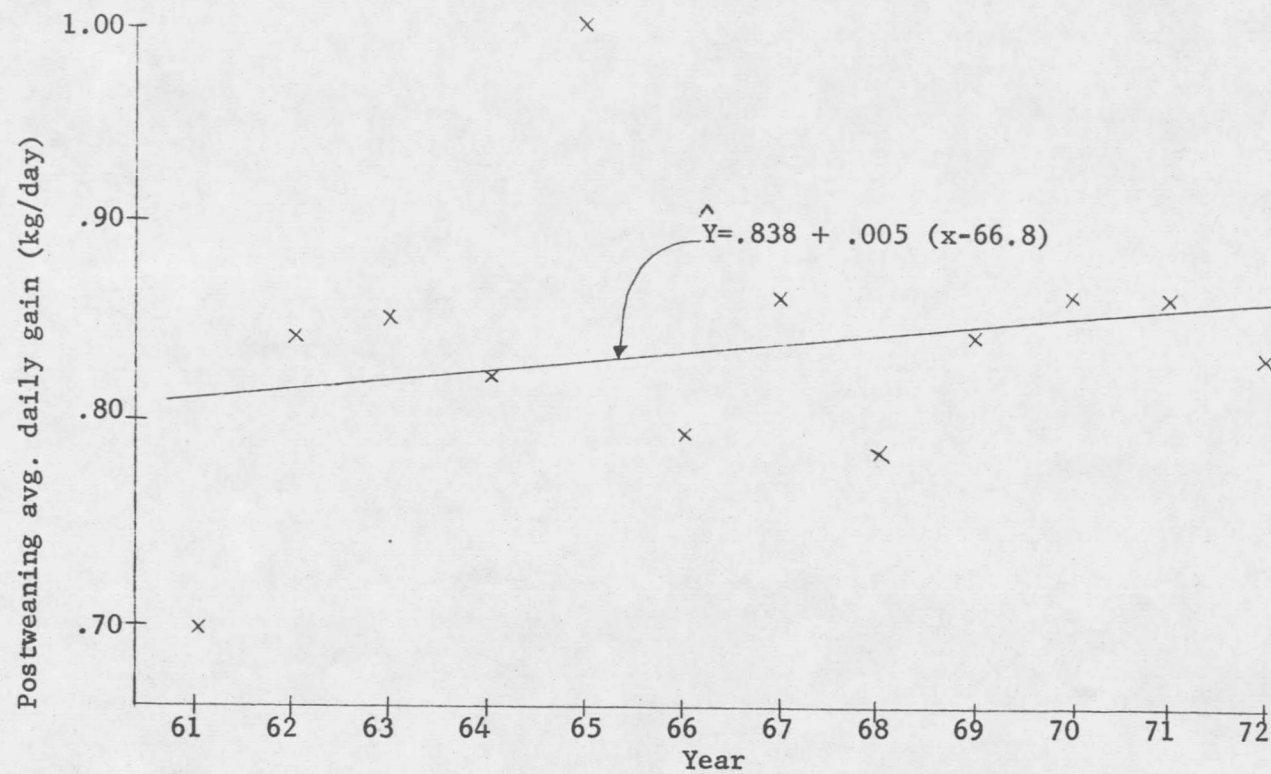


Figure 7. Hereford postweaning average daily gain least squares means regressed on years.

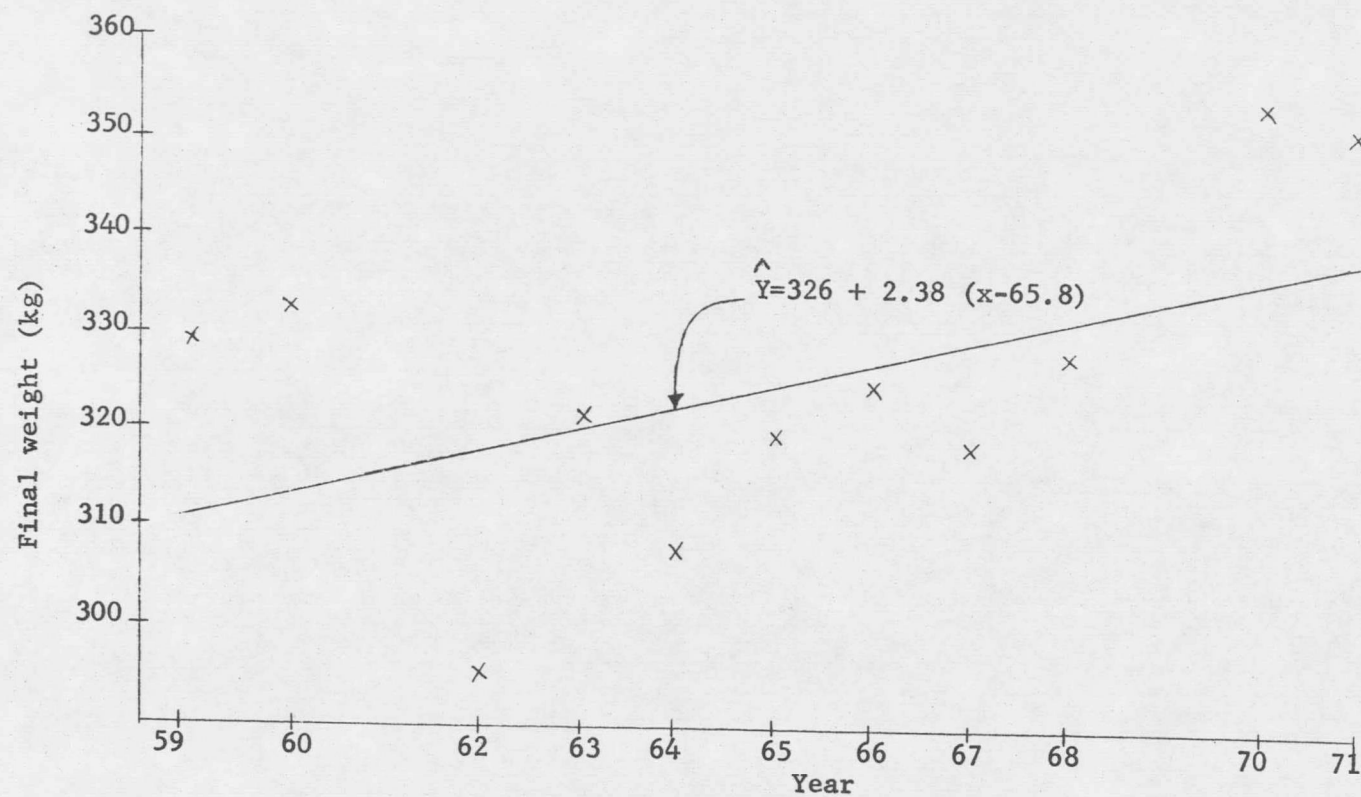


Figure 8. Angus final test weight least squares means regressed on years.

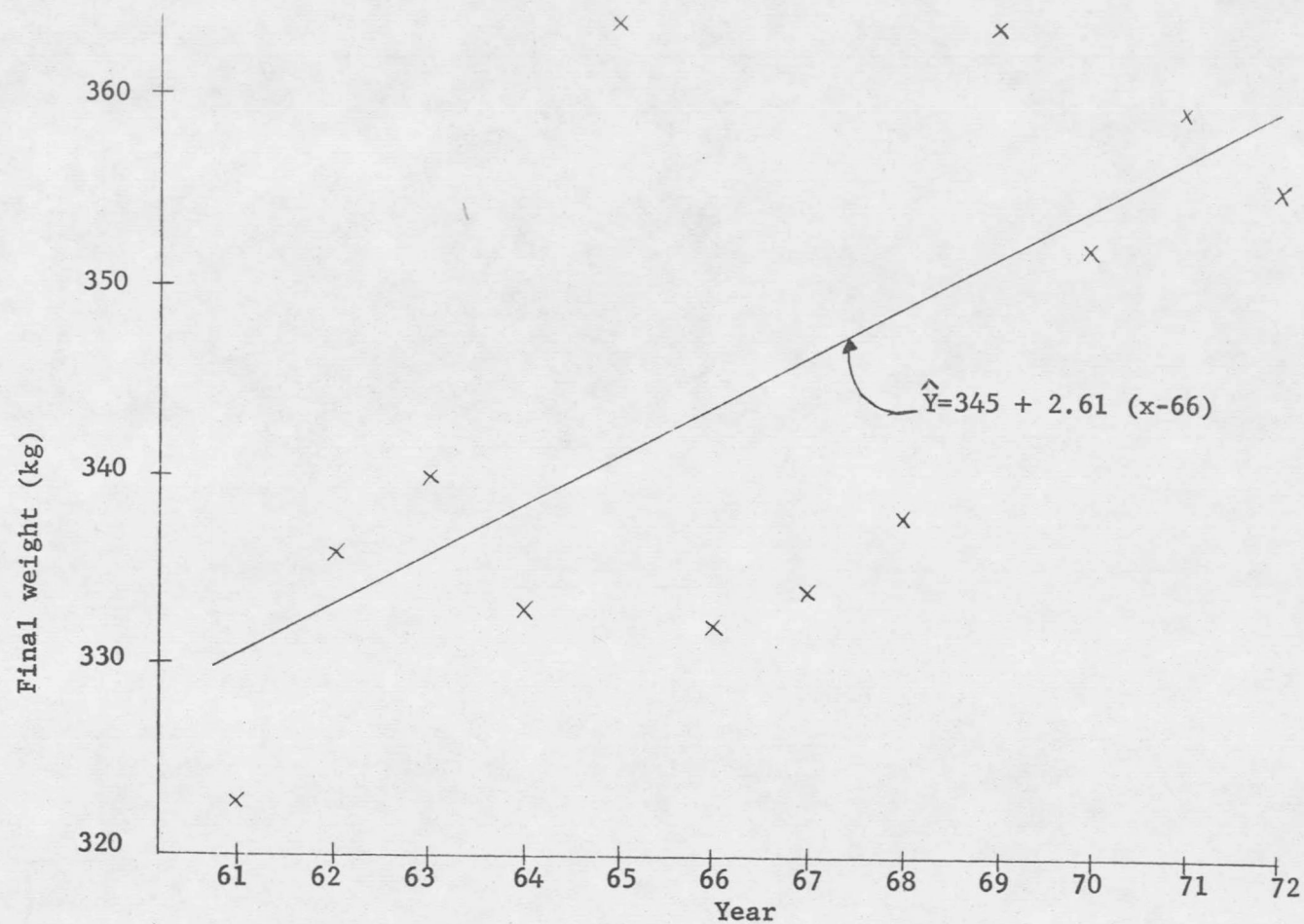


Figure 9. Hereford final test weight least squares means regressed on years.

Model II Analysis

Birth weight. Table 12 presents the analyses of variance for Model II analysis of Angus and Hereford birth weight. All main effects were highly significant ($P < .01$). Sex by herd interaction effects were highly significant ($P < .01$) in Angus but not in Herefords ($P > .10$). The difference between the least squares mean birth weights of the sexes within each Angus herd is shown regressed on the herd average in Appendix figure 25. The regression coefficient was .26 kg difference/kg herd average ($R^2 = .17$, $P > .10$). There was a suggestion of a trend that higher herd averages mean greater sex differences. Further discussion of this "trend" and its possible significance are discussed under Model II analysis of weaning weight. The Hereford birth weight data had both sexes represented in only two herds so trend analysis of this type was not possible in Herefords.

Herd by age of dam interaction effects were significant in both Angus and Herefords ($P < .01$ and $P < .05$, respectively). Figures 10 and 11 show the birth weight and age of dam relationship within herds for Angus and Hereford, respectively. Visually, there appears to be only random fluctuations in the respective curves which cumulatively would have caused the interaction to be statistically significant. The sex by age of dam interaction was significant ($P < .05$) in Angus and approached significance ($P < .10$) in Herefords. Appendix figure 26 shows the least squares means of Angus birth weights for the individual ages of dam

TABLE 12. LEAST SQUARES ANALYSES OF VARIANCE FOR BIRTH WEIGHT -
MODEL II

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	3	1091.60**	3	1445.00**
Years/herd	29	134.70**	31	51.84**
Sex (S)	1	2004.39**	1	587.37**
Age of dam (A)	9	162.59**	9	106.59**
H x S	3	43.97**	1	24.28
H x A	27	20.03**	26	19.67*
S x A	9	23.46**	9	21.65+
Regression on day of birth				
Linear -	1	28.24	1	187.56**
Quadratic -	1	164.93		
Cubic -	1	65.85*		
Remainder	3234	10.32	1991	12.18

+ P<.10.

* P<.05.

**P<.01.

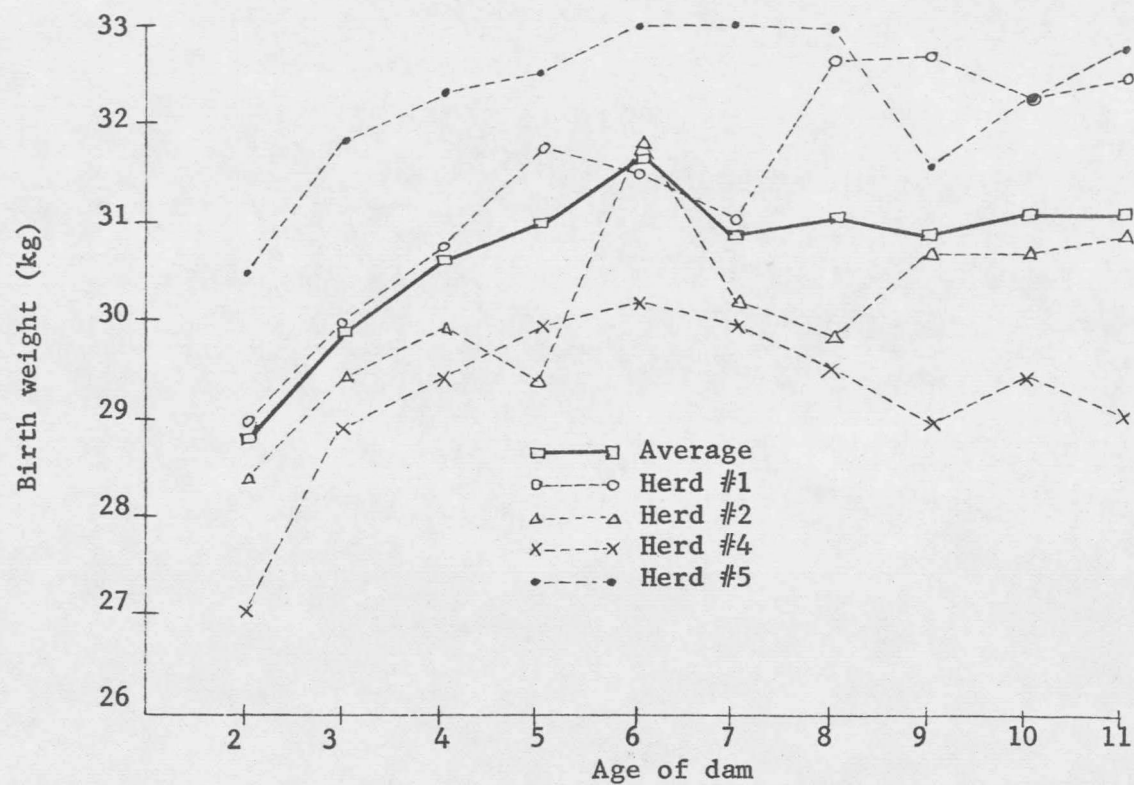


Figure 10. Angus birth weight least squares means for each herd and age of dam.

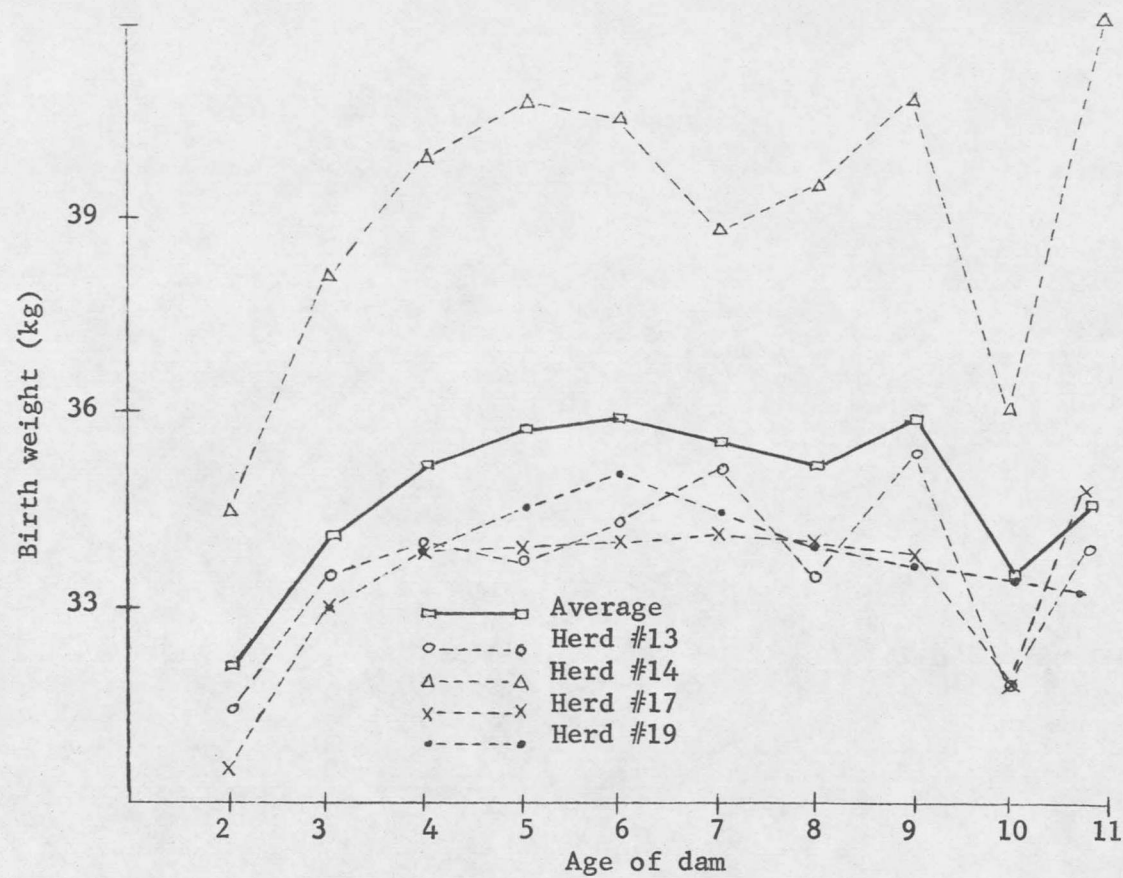


Figure 11. Hereford birth weight least squares means for each herd and age of dam.

within each sex. The difference between the least squares means of the sexes averaged 1.8 kg for dams aged 2, 3 and 4 years and 2.2 kg for mature dams aged 5 years and older. The suggestion of a trend appears to follow one of the theories put forth in Model I analysis of birth weight: uterine space limitations may have caused the birth weight differences of the individual sexes to decrease. The bull calves were reaching the limits of growth due to space limitations in the younger (and thus smaller) dams, while the heifer calves being of naturally smaller size than the bull calves, were able to grow to a relatively larger weight.

The partial regression of birth weight on day of year born was significant ($P < .05$) at the cubic level in Angus. The partial regression equation was $\hat{Y} = 30.68 \text{ kg} + (-.0067 \text{ kg/day}) (X \text{ days} - 77 \text{ days}) + (-.0034 \text{ kg/day}^2) (X \text{ days} - 77 \text{ days})^2 + (.000004 \text{ kg/day}^3) (X \text{ days} - 77 \text{ days})^3$. The mean day of year born for Angus was 77 with a standard deviation of 26 days.

In Herefords, Model I analysis had shown the cubic and quadratic partial regressions of birth weight on day of birth to be unimportant when analyzed separately. Therefore, only the linear partial regression was analyzed in Model II. The highly significant ($P < .01$) linear partial regression coefficient was .016 kg/day. The mean day of birth was 86 with a standard deviation of 31 days. Kress and Burfening (1972) found regression coefficients of .014 and -.009 kg/day for Angus and

Hereford, respectively.

The means for individual sexes are presented in table 13 for both Angus and Herefords. The respective additive and multiplicative sex adjustment factors were female birth weight plus 2.1 kg and female birth weight times 1.07 for Angus and 2.2 kg and 1.06 for Herefords.

It is of interest to note here that Angus had the smaller additive factor and the larger multiplicative factor, indicating that the difference between the mean birth weights of the sexes was less for Angus when compared to Herefords but was larger when compared to the relative overall birth weight means.

TABLE 13. BIRTH WEIGHT LEAST SQUARES MEANS AND CORRECTION FACTORS FOR INDIVIDUAL SEXES

Breed and Sex	No. of calves	Least squares mean	Correction factors	
			Additive	Multiplicative
Angus				
Males	1600	31.7±.31		
Females	1688	29.6±.31	2.1	1.07
Hereford				
Males	1781	36.1±.31		
Females	290	33.9±.39	2.2	1.06

TABLE 14. BIRTH WEIGHT LEAST SQUARES MEANS AND CORRECTION FACTORS FOR INDIVIDUAL AGES OF DAM

Age of dam	No. of calves	Least squares mean (kg)	Correction factors			
			Add.	Mult.	Add.	Mult.
Angus						
			6 years		5-10 years	
2	571	28.8±.34	2.6	1.09	2.2	1.08
3	520	30.0±.34	1.4	1.05	1.0	1.03
4	445	30.5±.34	.9	1.03	.5	1.02
5	348	30.8±.37	.6	1.02	-	-
6	318	31.4±.38	(-)	-	-	-
7	232	31.0±.39	.4	1.01	-	-
8	219	31.0±.40	.4	1.01	-	-
9	168	30.9±.41	.5	1.02	-	-
10	129	31.0±.43	.4	1.01	-	-
11+	338	31.0±.36	.4	1.01	0.0	1.00
Hereford						
2	200	32.2±.59	3.6	1.12	3.2	1.10
3	337	34.3±.41	1.4	1.05	.9	1.03
4	351	35.5±.41	.5	1.01	0.0	1.00
5	272	35.8±.44	0.0	1.00	-	-
6	248	35.9±.46	-	-	-	-
7	208	35.4±.54	.5	1.01	-	-
8	136	35.1±.61	.9	1.02	-	-
9	120	36.0±.62	0.0	1.00	-	-
10	85	33.4±.69	2.7	1.07	-	-
11+	114	36.1±.61	-.9	.99	-.9	.98

31.02

Similar sex differences were found by Burris and Blunn (1952) whose results showed a 9% sex difference in Angus and a 7% difference in Herefords. Marlowe (1962) found a 9% sex difference in the birth weight of Angus calves and a 6% difference in Herefords. Similar percentages but different ranking were found by Taylor et al. (1960) with an Angus sex difference of 7% and a Hereford difference of 8%.

Tables 15 and 16 show the effects that adjusting for sex effects had on individual source and error mean squares in Angus and Hereford birth weights, respectively. Both additive and multiplicative factors within each breed reduced to the sex mean square to essentially the same nonsignificant ($P > .10$) point.

As the multiplicative factors affected the interaction mean squares, they also affected the error mean square, and thus the value of the trait mean square to error mean square ratio (the F-ratio). While the multiplicative sex adjustments reduced the mean squares of the sex by herd interaction by 9 and 7% in Angus and Herefords, respectively, they also reduced the respective F-ratios squares by 9 and 17%. The mean square of the sex by age of dam interaction was increased by 3% in Angus and 10% in Herefords by the multiplicative sex adjustments. The F-ratio for the sex by age of dam interaction was increased by 9% in the Herefords and decreased by 4% in the Angus. In neither breed was the overall level of significance of the interactions changed.

TABLE 15. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR BIRTH WEIGHT IN ANGUS CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment	Mean square	F-ratio ^a
Sex (S)	1	None	-	-	2004.39**	194.22 (.000)
		S	Male	Add	11.68	1.13 (.288)
		S	Male	Mult	.20	.02 (.882)
Age of dam (A)	9	None	-	-	162.59**	15.75 (.000)
		A	6 yrs	Add	2.17	.21 (.992)
		A	5-10 yrs	Add	6.36	.62 (.789)
		A	6 yrs	Mult	.78	.07 (.999)
		A	5-10 yrs	Mult	6.51	.61 (.790)
S x A	9	None	-	-	23.46*	2.27 (.016)
		S	Male	Mult	24.26*	2.18 (.021)
		A	6 yrs	Mult	24.20*	2.19 (.020)
		A	5-10 yrs	Mult	21.89*	2.04 (.031)
S x H	3	None	-	-	43.97**	4.26 (.006)
		S	Male	Mult	40.37*	3.63 (.012)
A x H	27	None	-	-	20.03**	1.94 (.003)
		A	6 yrs	Mult	20.83**	1.89 (.004)
		A	5-10 yrs	Mult	20.47**	1.91 (.003)
Remainder	3234	None	-	-	10.32	
		S	Male	Mult	11.12	
		A	6 yrs	Mult	11.03	
		A	5-10 yrs	Mult	10.74	

**P<.01, *P<.05, taken from individual analysis of variance tables.

^a Associated P-value in parenthesis.

Model III analysis of individual sexes showed that while Angus females has less ($P < .05$) variation in the unadjusted data, the multiplicative correction factors used raised the female variance to such a degree that the disparity was greater than before correction (Appendix table 41). The male variance was 5% larger than the female variance before adjustment and the female was 13% larger than the male variance after multiplicative adjustments. Cundiff et al. (1966) used the ability of the multiplicative factor to equalize the variances as a major influence on their decision to select multiplicative factors over additive for sex adjustments of weaning weight. Obviously, the scalar effects of the multiplicative factor to equalize variances were of no value in this particular Angus birth weight analysis.

There were insufficient numbers of females available for Model III analysis of Hereford birth weight to make valid sex comparisons.

Overall, both additive and multiplicative sex adjustments had the ability to reduce sex effects to nonsignificance. The multiplicative factors were the preferred method of correcting for sex effects in this study due to their ability to reduce the sex by herd interaction.

Figures 10 and 11 show the curves represented by the least squares means of birth weight of the individual ages of dam for Angus and Herefords, respectively. Age of dam, least squares means and adjustment factors calculated from these means are presented in table 14. Table 15 and 16 show the results of using these factors to adjust for age of

TABLE 16. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR BIRTH WEIGHT IN HEREFORD CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment	Mean square	F-ratio ^a
Sex (S)	1	None	-	-	587.37**	48.22 (.000)
		S	Male	Add	1.63	.13 (.719)
		S	Male	Mult	2.17	.17 (.683)
Age of dam	9	None	-	-	106.59**	8.75 (.000)
		A	6 yrs	Add	4.68	.38 (.945)
		A	5-10 yrs	Add	25.85*	2.12 (.025)
		A	6 yrs	Mult	1.67	.13 (.998)
		A	5-10 yrs	Mult	26.57*	2.14 (.023)
S x A	9	None	-	-	21.65+	1.78 (.067)
		S	Male	Mult	23.81*	1.92 (.045)
		A	6 yrs	Mult	25.17*	1.98 (.038)
		A	5-10 yrs	Mult	23.05+	1.86 (.053)
S x H	3	None	-	-	24.28	1.99 (.112)
		S	Male	Mult	22.76	1.83 (.138)
A x H	27	None	-	-	19.67*	1.61 (.024)
		A	6 yrs	Mult	18.02+	1.42 (.074)
		A	5-10 yrs	Mult	18.36+	1.48 (.053)
Remainder	1991	None	-	-	12.18	
		S	Male	Mult	12.43	
		A	6 yrs	Mult	12.73	
		A	5-10 yrs	Mult	12.41	

**P < .01, *P < .05, +P < .10, taken from individual analysis of variance tables.

^a Associated P-value in parenthesis.

dam effects on birth weight for the respective breeds. It is of interest to note the differences in the multiplicative correction factors in the two breeds. The Angus 2, 3 and 4 year old dams required 8, 3 and 2% adjustments, respectively, to adjust to the set of dams aged 5 to 10 years. Their Hereford contemporaries required 10, 3 and 0% adjustments for the same respective ages. The data suggest that the Hereford dams may be less mature at 2 years of age but more mature at 4 years of age than the Angus. At the 2 year old level, the Hereford dams required 2% more adjustment than the Angus dams. By 3 years of age they were equal and by 4 years the Hereford cows were at maturity while the Angus cows still required a 2% adjustment.

Combined Angus-Hereford studies by Kress and Webb (1972) and Burris and Blunn (1952) found that Hereford calves from 2, 3 and 4 year old dams were relatively closer in birth weight to the calves from the set of dams aged 5 to 10 than their Angus contemporaries were. Kress and Webb found that the calves of the 2, 3 and 4 year old Hereford dams were 6, 6 and 1% lighter than the calves from the mature dams (5 to 10 years) and the respective Angus calves were 13, 8 and 4% lighter. Burris and Blunn found the respective differences to be 9, 3 and 1% in Herefords and 12, 9 and 4% in Angus.

In the Angus data, all correction factors neutralized the age of dam effect to approximately the same level, whether additive or multiplicative, or to a single age or to a set of ages basis. The multiplicative adjustment to a 6 year old dam basis caused an increase of 4%

in the age of dam by herd interaction mean square. It also caused a 7% increase in the error mean square. Neither of the interaction effect increases were significant ($P < .05$) and neither caused a change in the overall level of significance for that interaction. Multiplicative adjustments to a set of mature dam ages (5 to 10 years) in Angus birth weights increased the error mean square by 7% and the age of dam by herd interaction mean square by 2% but decreased the age of dam by sex mean square 7%. The interaction mean squares were not altered significantly ($P < .05$) and the levels of significance were unchanged for both. The F-ratios of the respective interactions were reduced by 2 and 10%.

The Hereford age of dam adjustments were complicated by the presence of an unusually low mean for the 10 year old dams. Newman-Keuls test for differences among means showed that ages 4, 5, 6, 7, 8, 9, and 11 were not significantly different while 2, 3 and 10 were. No biological explanation was found for this phenomena and the lower mean for the 10 year old dams was considered a chance occurrence. Adjusting to a single year basis was the only method which removed the overall age of dam effect. After adjusting to a 5 to 10 year old basis or to a 4+ year old basis, the age of dam effect was still significant at the 5% level. Newman-Keuls analysis showed that the means for all ages except the 10 year olds were not significantly different after adjustment. A possible solution would have been adjustment to a 5 to 9 year old group.

If there was a downward trend in birth weights after the dam reached 10 years of age, the trend should have been noticeable in both the 10 and 11+ year old groups. Either the 10 year old group mean was too low, or the 11+ year old group mean was too high. In either case a chance occurrence was probably complicating the data and further analysis of the age of dam effect in Herefords was not attempted for Model II birth weight analysis.

Individual variances for the respective ages of dam obtained in Model III analysis of birth weight are presented in Appendix table 42. Bartlett's test for homogeneity of variances showed that the variances were heterogeneous ($P < .01$) before and after multiplicative age of dam adjustments in both breeds. The range of variances in Angus calves' birth weights for the individual ages of dam was 2.23 (7.01 to 9.24, standard deviation = .84) before adjustment, 1.25 (7.99 to 9.24, standard deviation = .53) after adjusting to a 5 to 10 year old dam basis, and 1.09 (8.15 to 9.24, standard deviation = .47) after adjusting to a 6 year old dam basis. The same respective ranges of variance for Hereford bull calves were 5.68 (7.19 to 12.87, standard deviation = 2.32), 4.35 (7.72 to 12.07, standard deviation = 1.75) and 4.95 (7.92 to 12.87, standard deviation = 1.89). Hence, multiplicative adjustments for age of dam reduced the degree of heterogeneity of age of dam subclass variances but did not eliminate the heterogeneity.

Overall, while adjusting to a single age of dam was preferable in

some aspects to adjusting to a set of ages (i.e., 5 to 10 years), the overall advantage was not sufficient to justify the inconvenience and mathematical uncertainty introduced when more weights are adjusted.

Although the multiplicative factors increased the overall variation, they also tended to make the individual age variations more equal.

In summation, in this study, the multiplicative adjustment to set of mature dam ages was the preferred method for correcting for age of dam effects on birth weight due to their ability to reduce the disparity in individual age of dam variances and their ability to reduce the age of dam by herd interaction effect.

Preweaning average daily gain. The least squares analysis of variance for preweaning average daily gain are presented in table 17. All main effects (herd, year within herd, sex and age of dam) were highly significant ($P < .01$) in both breeds. Herd by sex, herd by age of dam, and sex by age of dam interactions were all significant ($P < .01$, $P < .01$, and $P < .05$, respectively) in Angus. None of the interactions were significant in Herefords. The herd by sex interaction in Herefords contained only one degree of freedom for preweaning gain, as it did in birth weight analysis.

The partial regression on day of year born was significant ($P < .01$) only at the linear level in both breeds. Partial regression coefficients were .0005 kg/day in Angus and .0006 kg/day in Herefords.

TABLE 17. LEAST SQUARES ANALYSES OF VARIANCE FOR PREWEANING AVERAGE
DAILY GAIN - MODEL II

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	3	1.9332**	3	1.2711**
Year/herd	29	.3543**	31	.1564**
Sex (S)	1	4.7240**	1	.6741**
Age of dam (A)	9	.2970**	9	.0427**
H x S	3	.3994**	1	.0027
H x A	27	.0139**	26	.0085
S x A	9	.0139*	9	.0078
Regression on day of birth linear -	1	.1640**	1	.1298**
Remainder	3234	.0071	1991	.0094

**P<.01.

* P<.05.

Table 18 presents the least squares means and the adjustment factors based on these means for individual sexes of both breeds. Correction factors were female gain plus .103 kg/day and female gain times 1.13 in Angus calves and female gain plus .072 kg/day and female gain times 1.09 in Herefords. The Angus sex disparity was larger than the Hereford difference. Schaeffer and Wilton (1973) found a sex difference in preweaning average daily gain of 11% (.90 for males and .81 for females) in Angus and 10% (.88 for males and .80 for females) in Herefords for calves from dams age 5 years and older. Kress and Webb (1972) found sex differences of 11% in Angus and 9% in Herefords preweaning average daily gain.

TABLE 18. PREWEANING AVERAGE DAILY GAIN LEAST SQUARES MEANS AND CORRECTION FACTORS FOR INDIVIDUAL SEXES

Breed and sex	No. of calves	Least squares mean (kg)		Correction factors	
				Add.	Mult.
Angus					
Males	1600	.870	.016		
Females	1688	.767	.016	.103	1.13
Hereford					
Males	1781	.853	.018		
Females	290	.781	.019	.072	1.09

Both additive and multiplicative correction factors reduced the sex mean square for Angus preweaning gains to a nonsignificant ($P > .10$) point (table 19). The multiplicative sex correction factor reduced the sex by herd interaction mean square in Angus calves' preweaning average daily gain by 25% and the corresponding F-value by 31%. The reduction was not significant ($P < .05$) and the interaction was still highly significant, however. Appendix figure 27 shows the results of regressing the mean difference between the sexes on the least squares Angus herd means. The regression is positive and significant ($b = 1.175$ kg/day difference/kg/day herd mean $P < .01$, $R^2 = .95$). (For every kg/day difference in herd mean there was a difference between the sexes of 1.175 kg/day in preweaning average daily gain). The results of this regression suggest that an additive sex correction factor would tend to over-adjust the females in the low mean herds and under-adjust the females in the high mean herds. Model III analysis showed that the herd by sex interaction made up less than 1% of the total variation, even though it was highly significant ($P < .01$). The multiplicative sex correction factor for Angus preweaning gain also reduced the sex by age of dam interaction by 1% and the corresponding F-value by 15%. The reduction was not significant ($P > .05$) and the interaction was still significant ($P < .05$) after the adjustment. Appendix figure 28 shows the Angus least squares means for individual ages of dam within each sex. The figures suggested only random

fluctuations that cumulatively were enough to cause the interaction to be statistically significant. Model III analysis of the individual sexes showed that the variance of the females was 89% as large as the male variance (Appendix table 44). After the multiplicative sex adjustment, the male variance was 88% as large as the adjusted female variance, so the scalar effects of the multiplicative adjustment simply reversed the disparity in the variances of the sexes. Therefore, in preweaning gain as in birth weight analysis, the multiplicative adjustment factor's ability to equalize the variances was not an advantage in this study of the preweaning gains of Angus calves.

The Hereford sex mean squares for preweaning average daily gains were reduced to nonsignificance ($P > .10$) by both the additive and the multiplicative adjustments (table 20). The sex by age of dam and the sex by herd interactions did not approach significance in the Hereford data neither before nor after the adjustments. There were insufficient numbers of female Herefords available for Model III analysis of preweaning average daily gain.

Overall, the multiplicative adjustment factor was preferred as the sex correction factor for Angus preweaning gain because of its ability to reduce the interactions involving sex. In the Hereford data, the interactions were unimportant and on the basis of all other considerations being equal, the additive factor at least did not increase the overall variation, and thus was the preferred correction factor for the Hereford data.

TABLE 19. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR PREWEANING AVERAGE DAILY GAIN IN ANGUS CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment	Mean square	F-ratio ^a
Sex (S)	1	None	-	-	4.7240**	665.35 (.000)
		S	Male	Add	.0000	.00 (.999)
		S	Male	Mult	.0001	.01 (.917)
Age of dam (A)	9	None	-	-	.2970**	41.83 (.000)
		A	6 yrs	Add	.0026	.36 (.953)
		A	5-10 yrs	Add	.0076	1.07 (.382)
		A	6 yrs	Mult	.0022	.28 (.980)
		A	5-10 yrs	Mult	.0090	1.17 (.309)
S x A	9	None	-	-	.0139*	1.96 (.040)
		S	Male	Mult	.0137+	1.67 (.090)
		A	6 yrs	Mult	.0109	1.38 (.190)
		A	5-10 yrs	Mult	.0100	1.30 (.230)
S x H	3	None	-	-	.3994**	56.25 (.000)
		S	Male	Mult	.3202**	39.05 (.000)
A x H	27	None	-	-	.0139**	1.96 (.002)
		A	6 yrs	Mult	.0167**	2.11 (.001)
		A	5-10 yrs	Mult	.0161**	2.09 (.001)
Remainder	3234	None	-	-	.0071	
		S	Male	Mult	.0082	
		A	6 yrs	Mult	.0079	
		A	5-10 yrs	Mult	.0077	

**P<.01, *P<.05, + P<.10, taken from individual analysis of variance tables.

^a Associated P-value in parenthesis.

TABLE 20. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR PREWEANING AVERAGE DAILY GAIN IN HEREFORD CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment	Mean square	F-ratio ^a
Sex (S)	1	None	-	-	.6741**	71.71 (.000)
		S	Male	Add	.0220	2.34 (.122)
		S	Male	Mult	.0218	2.25 (.130)
Age of dam (A)	9	None	-	-	.0427**	4.54 (.000)
		A	7 yrs	Add	.0019	.20 (.993)
		A	5-10 yrs	Add	.0074	.79 (.627)
		A	7 yrs	Mult	.0021	.20 (.993)
		A	5-10 yrs	Mult	.0072	.73 (.683)
S x A	9	None	-	-	.0078	.83 (.589)
		S	Male	Mult	.0078	.80 (.618)
		A	7 yrs	Mult	.0082	.80 (.618)
		A	5-10 yrs	Mult	.0075	.76 (.665)
S x H	3	None	-	-	.0027	.29 (.834)
		S	Male	Mult	.0003	.03 (.999)
A x H	27	None	-	-	.0085	.90 (.614)
		A	7 yrs	Mult	.0093	.90 (.614)
		A	5-10 yrs	Mult	.0092	.93 (.568)
Remainder	1991	None	-	-	.0094	
		S	Male	Mult	.0097	
		A	7 yrs	Mult	.0103	
		A	5-10 yrs	Mult	.0099	

**P<.01, *P<.05, taken from individual analysis of variance tables.

^a Associated P-value in parenthesis.

Table 21 shows the least squares means for the individual ages of dam for the preweaning average daily gains of Angus and Hereford calves and the adjustment factors for age of dam. The multiplicative adjustments to the set of dam ages 5 to 10 years show just the opposite trend here from the birth weight multiplicative factors. Here, the Angus 2 year old dams are lower than the Hereford 2 year olds, at 3 years they were nearly even and at 4 years the Hereford dams were lower. The expected results would have been Angus dams consistently lower in required adjustments for preweaning gain, due to their reportedly better milking ability. The 11+ year old dams of both breeds required a 2% adjustment. Schaeffer and Wilton (1973) considered all dams aged 5 years and older as one group. They found that non-creep fed Angus calves from 2, 3 and 4 year old dams required 12, 6 and 3% adjustments, respectively, while Hereford calves from the same respective ages of dam required 17, 10 and 4% adjustments.

Table 19 shows the effects on pertinent means squares from using both additive and multiplicative factors to adjust Angus preweaning gains to both a 6 year old dam basis and to the set of dams aged 5 to 10. All of the correction factors reduced the age of dam mean square significantly ($P < .05$) to nonsignificant ($P > .10$) status, with the multiplicative adjustment to a 6 year old dam basis reducing the mean square to the lowest ($P < .05$) point. The multiplicative adjustments to a 6 year old dam basis and to the set of dams aged 5 to 10

TABLE 21. PREWEANING AVERAGE DAILY GAIN LEAST SQUARES MEANS AND
CORRECTION FACTORS FOR INDIVIDUAL AGES OF DAM

CORRECTION FACTORS FOR INDIVIDUAL LACTS OF DAM						
Age of dam	No. of calves	Least squares mean (kg)	Correction factors			
			Add.	Mult.	Add.	Mult.
Hereford						
			6 years		5-10 years	
2	200	.777±.023	.07	1.09	.06	1.07
3	337	.791±.020	.05	1.07	.04	1.05
4	351	.804±.020	.04	1.05	.03	1.03
5	272	.815±.020	.03	1.04		
6	248	.841±.020	.00	1.01		
7	208	.846±.022	-	-		
8	136	.826±.023	.02	1.02		
9	120	.833±.023	.01	1.02		
10	85	.822±.025	.02	1.03		
11	114	.812±.023	.04	1.04	.02	1.02
Angus						
2	571	.738±.016	.11	1.15	.10	1.13
3	520	.801±.016	.05	1.06	.04	1.04
4	445	.823±.016	.03	1.03	.01	1.01
5	348	.839±.017	.01	1.01		
6	318	.851±.017	-	-		
7	232	.840±.017	.01	1.01		
8	219	.836±.017	.01	1.02		
9	168	.830±.017	.02	1.02		
10	129	.820±.018	.03	1.04		
11	338	.818±.016	.03	1.04	.02	1.02

reduced the sex by age of dam interaction effect by 30 and 39%, respectively. The reductions were not significant ($P > .05$) but they were enough to move the interaction effect from being a significant ($P < .05$) source of variation to highly significant ($P < .01$). The corresponding F-ratios of the interaction were reduced by 30 and 34%, respectively. The sex by age of dam effect, as previously discussed under sex adjustments, is displayed graphically in Appendix figure 28. The same respective multiplicative adjustments increased the age of dam by herd interaction mean square in Angus preweaning average daily gain by 20 and 16%. Neither increase was significant ($P > .05$) and the level of significance of the interaction ($P < .01$) was not affected. The corresponding F-ratios of the interaction were increased by 8 and 7%, respectively. The age of dam by herd effect in Angus calves' preweaning gains is displayed graphically in figure 12. Visual appraisal suggested the cumulative effects of random fluctuations as the cause of the interaction's significance. Adjusting to a 6 year old dam basis and to the set of dams aged 5 to 10 years increased the error mean square for Angus preweaning gain analysis by 11 and 8%, respectively. Bartlett's test, done on data from Model III analysis of individual ages of dam (Appendix table 42) showed that the variances of the respective Angus dam ages were heterogeneous ($P < .01$). The range in variances was .0027 (.0048 to .0075, standard deviation = .0010) before adjustments, .0030 (.0051 to .0081, standard deviation = .0012)

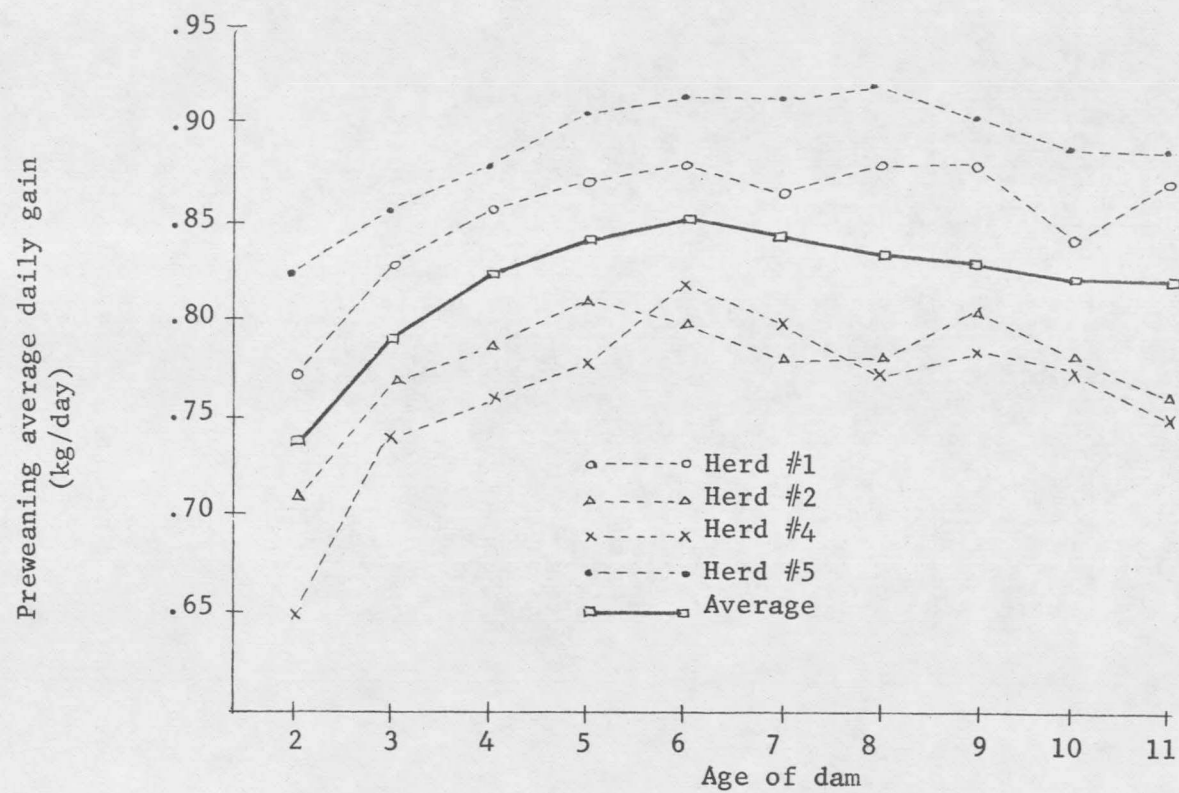


Figure 12. Angus preweaning average daily gain least squares means for each herd and age of dam.

after adjusting to a 6 year old dam basis, and .0048 (.0066 to .0114, standard deviation =.0011) after adjusting to the set of dam ages 5 to 10 years. Thus, the scalar effects of the multiplicative adjustments were unable to correct for the heterogeneity of individual ages of dam variances in Angus preweaning gain.

The multiplicative age of dam correction factors all reduced the age of dam effect on Hereford preweaning average daily gain to approximately the same nonsignificant ($P > .10$) point (table 20). Individual age of dam variances obtained from Model III analysis of Hereford bull calves were heterogeneous. Heterogeneity was determined by Bartlett's test at the $P < .01$ level (Appendix table 42). The range in the individual variances was .0040 (.0063 to .0103, standard deviation =.0016) before adjustments, .0046 units (.0068 to .0114, standard deviation =.0019) after adjusting to a 6 year old dam basis, and .0043 units (.0066 to .0109, standard deviation =.0018) after adjusting to the set of dams aged 5 to 10. The scalar effects of the multiplicative adjustments were unable to equalize the variances in preweaning average daily gains within age of dam subclasses.

Figure 13 shows the overall and individual herd least squares means for the individual ages of Hereford dams. Age of dam by sex and age of dam by herd interaction effects on Hereford preweaning average daily gain were nonsignificant ($P > .10$) before and after multiplicative age of dam adjustments were made.

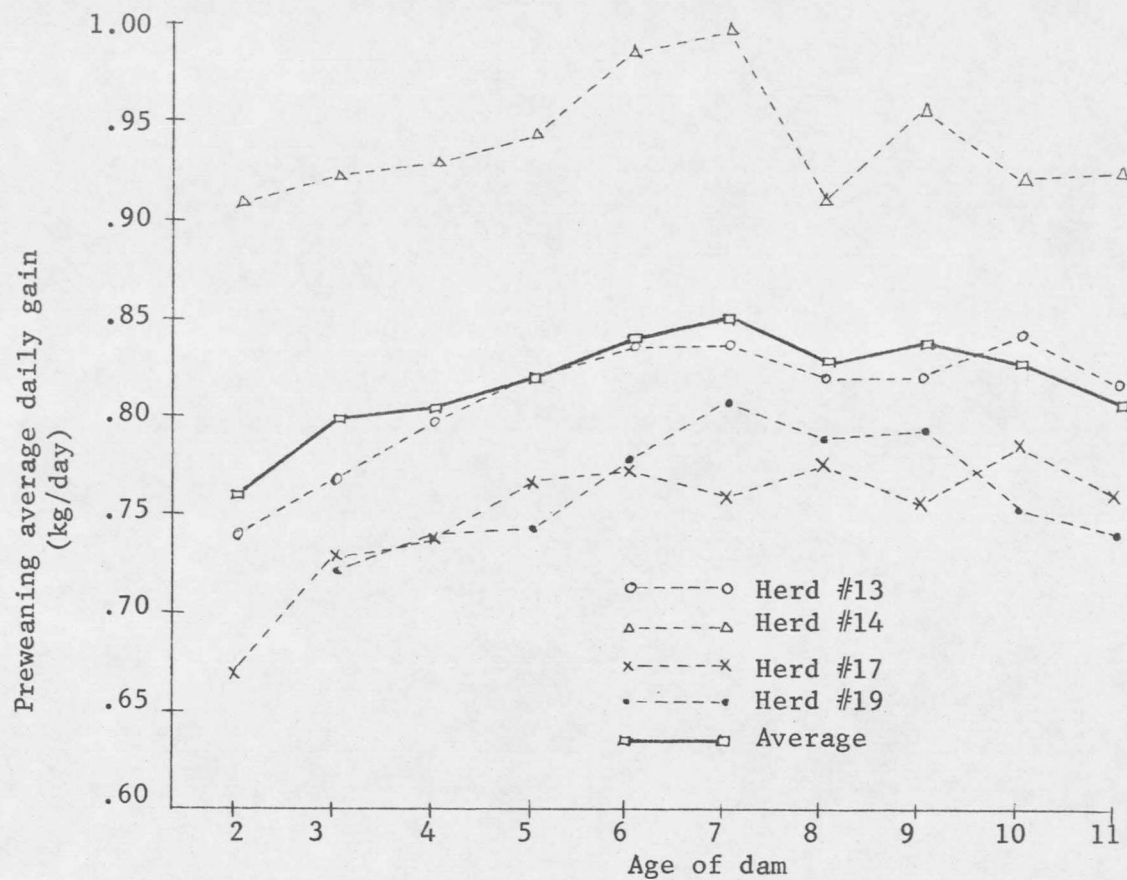


Figure 13. Hereford preweaning average daily gain least squares means for each herd and age of dam.

In both the Angus and the Hereford data, adjusting to the set of dam ages, 5 to 10 years, was preferable. Adjusting to the set of ages had approximately the same effect as adjusting to the single age, but adjusting to the set of ages involved more data, which could have allowed more chance phenomena to enter and confuse the data. In addition, the simple inconvenience of adjusting more records was considered.

Overall, there was no clear cut decision as to additive versus multiplicative age of dam correction factors in Angus preweaning average daily gain. The multiplicative factor reduced the sex by age of dam effect, increased the age of dam by herd interaction effect and appeared to have no effect on the within age of dam subclass variation. Neither of the interactions were significant sources of variation in Hereford preweaning average daily gain. The multiplicative factor appeared to increase the within age of dam subclass variation, and so would not be the preferred factor if all other factors were equal.

Schaeffer and Wilton (1974b) analyzed the preweaning averaged daily gain of 64,000 Angus and Hereford calves and concluded that the additive correction factors were preferable for both sex and age of dam adjustments.

Weaning weight. Model II analyses of variance for weaning weight are presented in table 22. The main effects (herd, year within herd, sex and age of dam) were all highly significant ($P < .01$) sources of variation in both breeds. Herd by sex interaction effects were a highly significant ($P < .01$) source of variation in both breeds. Herd by age of dam interactions were highly significant ($P < .01$) in Angus and significant ($P < .05$) in Herefords. Sex by age of dam was a highly significant ($P < .01$) source of variation in Angus, but only approached significance ($P < .10$) in Herefords. The partial regressions of weaning weight on age in days at weaning were analyzed at the level which was significant in Model I analysis. The cubic level was highly significant ($P < .01$) in Model II analysis in Angus. The cubic regression equation was: $\hat{Y} = 207 \text{ kg} + (.728 \text{ kg/day}) (X \text{ days} - 217 \text{ days}) + (-.00196 \text{ kg/day}^2) (X \text{ days} - 217 \text{ days})^2 + (-.000024 \text{ kg/day}^3) (X \text{ days} - 217 \text{ days})^3$.

Hereford weaning weights were regressed on the weaning age of the linear level only in Model II and found to be highly significant ($P < .01$) with a partial regression coefficient of .731 kg/day.

Least squares means and standard errors for Angus weaning weights were 220 ± 3 kg for males and 194 ± 3 kg for females. The mean weaning age was 217 (standard deviation = 25) days. Hereford least squares means and standard errors for weaning weights were 216 ± 3 kg for males and 198 ± 3 kg for females. Hereford calves were weaned at an average of 211 (standard deviation = 24) days.

TABLE 22. LEAST SQUARES ANALYSES OF VARIANCE FOR WEANING WEIGHT -
MODEL II

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	5	102286**	8	141491**
Year/herd	40	17033**	70	14745**
Sex (S)	1	567284**	1	184245**
Age of dam (A)	9	30731**	9	50103**
H x S	5	14656**	7	3913**
H x A ^a	45	871**	66	687*
S x A	9	1149**	9	845+
Regression on age at weaning				
Linear-	1	533963	1	136047**
Quadratic-	1	17072		
Cubic-	1	5106**		
Remainder	5784	403	5830	466

^a Hereford results for this interaction were determined by a separate analysis in which sex by age of dam was omitted.

+ P<.10.

* P<.05.

**P<.01.

Table 23 presents the least squares means for the individual sexes along with the number of animals in each subclass and the correction factors calculated from the means. The Hereford multiplicative adjustment agreed with the industry recommended adjustment of 10% while the Angus adjustment was higher at 13%.

Sellers et al. (1970) found the difference between bull and heifer weaning weights to be greater for Hereford than for Angus. They reported differences of 15 and 10%, respectively, in their Hereford and Angus data. Cundiff et al. (1966a) reported a 13% difference overall between sexes in the weaning weights of Angus and Herefords analyzed together. Minyard and Dinkel (1965a) and Kress and Burfening (1972) reported sex differences in Hereford weaning weights of 8 and 9%, respectively.

In Angus weaning weights the least squares analysis of variance mean square for sex effects was reduced ($P < .05$) to a nonsignificant ($P < .10$) status by both additive and multiplicative calculated adjustment factors (table 24). The industry correction to a steer basis reduced the sex mean square to 3% of its unadjusted value, although the reduction was not sufficient to remove the sex effect from the highly significant ($P < .01$) region. The calculated and industry recommended multiplicative sex adjustments reduced the sex by herd interaction mean square by 17 and 22%, respectively, of the unadjusted value. The corresponding F-ratios were reduced by 26 and 21%,

respectively. The reductions were nonsignificant ($P > .05$) and the interaction effects were not changed from the highly significant ($P < .01$) region. Figure 14 shows the herd by sex interaction represented as the differences between the sexes regressed on the least squares means of the individual herds. The regression ($b = .66$ kg difference/kg herd mean, $R^2 = .61$, $P < .06$) suggests the need for a multiplicative sex adjustment to correct for this interaction. Model III analysis of the relative values of the sources of variation (table 31) showed that the herd by sex interaction actually made up less than 1% of the total variation. The relatively low importance of this interaction could be the reason that the multiplicative factors did not have a greater influence.

TABLE 23. WEANING WEIGHT LEAST SQUARES MEANS AND CORRECTION FACTORS FOR INDIVIDUAL SEXES

Breed and Sex	No. of calves	Least squares mean	Correction factors		
			Additive	Mult.	Mult. ^a
Angus					
Males	2968	220.0±2.8			.95
Females	2934	194.4±2.8	25.6	1.13	1.05
Hereford					
Males	3900	216.4±2.5			.95
Females	2050	197.6±2.6	18.8	1.10	1.05

^a Industry recommended factors.

TABLE 24. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR WEANING WEIGHT IN ANGUS CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment ^a	Mean square	F-ratio ^b
Sex (S)	1	None	-	-	567284**	1407.65 (.000)
		S	Bull	Add	18	.04 (.836)
		S	Bull	Mult	65	.14 (.710)
		S	Steer	Mult(I)	19595**	49.23 (.000)
Age of dam (A)	9	None	-	-	30731**	76.26 (.000)
		A	7 yrs	Add	543	1.35 (.205)
		A	5-9 yrs	Add	374	.93 (.498)
		A	5-10 yrs	Add	510	1.27 (.247)
		A	7 yrs	Mult	144	.33 (.965)
		A	5-9 yrs	Mult	420	.98 (.455)
		A	5-10 yrs	Mult	542	1.26 (.253)
		A	5-10 yrs	Mult(I)	6879**	15.42 (.000)
S x H	5	None	-	-	14656**	36.37 (.000)
		S	Bull	Mult	12207**	27.07 (.000)
		S	Steer	Mult(I)	11403**	28.65 (.000)
A x H	45	None	-	-	871**	2.16 (.000)
		A	7 yrs	Mult	938**	2.15 (.000)
		A	5-9 yrs	Mult	919**	2.14 (.000)
		A	5-10 yrs	Mult	920***	2.14 (.000)
		A	5-10 yrs	Mult(I)	950**	2.13 (.000)

TABLE 24. (CONTINUED)

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment ^a	Mean square	F-ratio ^b
S x A	9	None	-	-	1149**	2.85 (.003)
		S	Bull	Mult	914*	2.03 (.032)
		S	Steer	Mult(I)	846*	2.13 (.024)
		A	7 yrs	Mult	904*	2.07 (.028)
		A	5-9 yrs	Mult	882*	2.05 (.030)
		A	5-10 yrs	Mult	885*	2.06 (.029)
		A	5-10 yrs	Mult(I)	830+	1.86 (.053)
Remainder	5784	None	-	-	403	
		S	Bull	Mult	451	
		S	Steer	Mult(I)	398	
		A	7 yrs	Mult	437	
		A	5-9 yrs	Mult	430	
		A	5-10 yrs	Mult	430	
		A	5-10 yrs	Mult(I)	446	

^a (I) denotes industry recommended factors.

^b Associated P-value in parenthesis.

**P<.01, *P<.05, +P<.10, taken from individual analysis of variance tables.

TABLE 25. EFFECTS ON MEAN SQUARES OF ADDITIVE AND MULTIPLICATIVE SEX AND AGE OF DAM
ADJUSTMENTS FOR WEANING WEIGHT IN HEREFORD CALVES

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment ^a	Mean square	F-ratio ^b
Sex (S)	1	None	-	-	185887**	400.62 (.000)
		S	Bull	Add	661	1.42 (.231)
		S	Bull	Mult	20	.04 (.836)
		S	Steer	Mult(I)	745	1.67 (.193)
Age of dam (A)	9	None	-	-	37338**	80.47 (.000)
		A	7 yrs	Add	5	.01 (.999)
		A	5-10 yrs	Add	350	.75 (.665)
		A	7 yrs	Mult	121	.24 (.988)
		A	5-10 yrs	Mult	425	.84 (.580)
		A	5-10 yrs	Mult(I)	1986*	3.85 (.000)
S x H	7	None	-	-	3783**	8.15 (.000)
		S	Bull	Mult	2852**	5.77 (.000)
		S	Steer	Mult(I)	2563**	5.73 (.000)
A x H	66	None	-	-	687**	1.48 (.007)
		A	7 yrs	Mult	852**	1.67 (.001)
		A	5-10 yrs	Mult	841**	1.67 (.001)
		A	5-10 yrs	Mult(I)	848**	1.64 (.001)
S x A	9	None	-	-	845+	1.82 (.059)
		S	Bull	Mult	926+	1.87 (.051)
		S	Steer	Mult(I)	847*	1.89 (.048)
		A	5-10 yrs	Mult	798	1.58 (.115)
		A	5-10 yrs	Mult(I)	789	1.53 (.130)

TABLE 25. (CONTINUED)

Trait	df	Trait adjusted	Adjustment basis	Type of adjustment ^a	Mean square	F-ratio ^b
Remainder	5830	None	-	-	464	
		S	Bull	Mult	494	
		S	Steer	Mult(I)	447	
		A	7 yrs	Mult	509	
		A	5-10 yrs	Mult	505	
		A	5-10 yrs	Mult(I)	516	

+ P<.10.

* P<.05.

**P<.01.

^a (I) denotes industry recommended factors.^b Associated P-value in parenthesis.

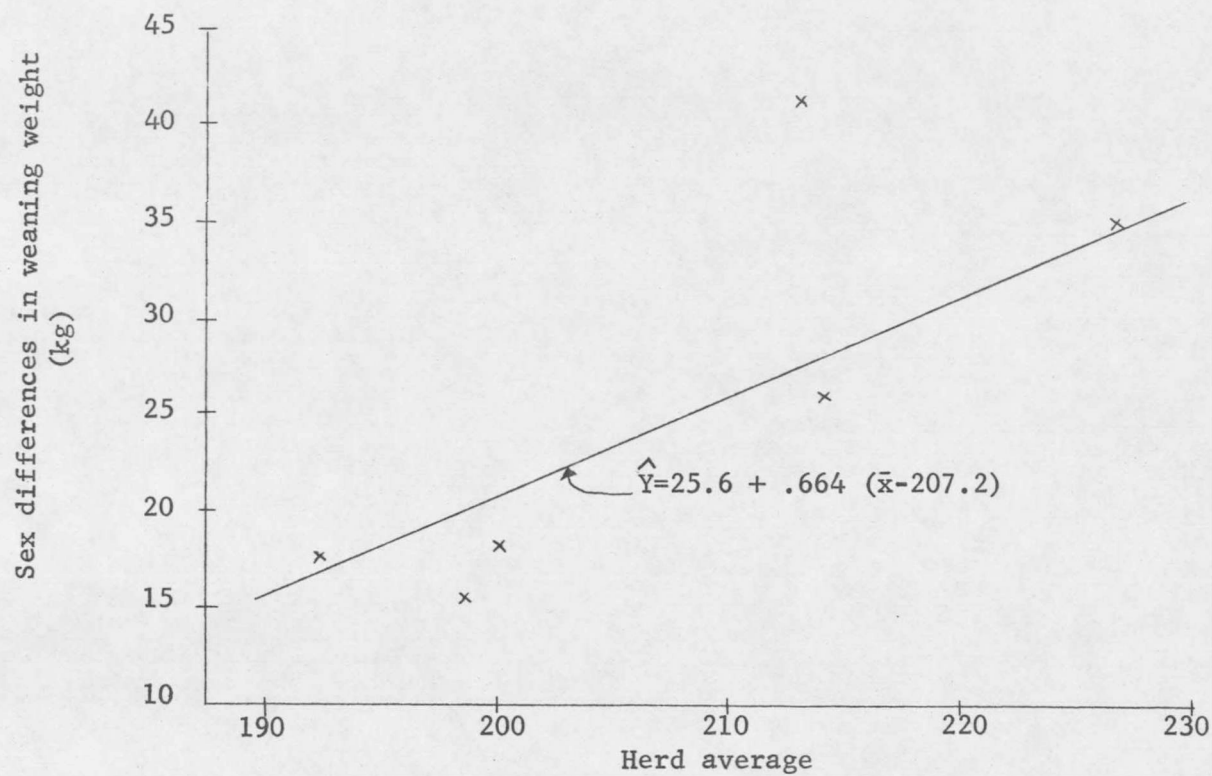


Figure 14. Regression of sex differential in weaning weight of each Angus herd on the least squares herd mean.

The calculated and industry sex multiplicative sex adjustments reduced the sex by age of dam interaction mean square by 20 and 26%, respectively. The corresponding F-ratios were reduced by 29 and 25%, respectively. The reductions were nonsignificant ($P > .05$). Figure 15 shows the sex by age of dam interaction effects on Angus weaning weights as the individual age of dam subclass means for each sex. The curve suggests a slight increase in the difference between the sexes as age of dam increased.

Model III analysis of the individual sexes showed (Appendix table 41) that the ratio of male to female error variance components of Angus weaning weights was 1.08 before adjustment, .84 after multiplicative adjustments with the calculated factors, and .88 after multiplicative sex adjustments with the industry factors. Cundiff et al. (1966) gave the multiplicative factor's ability to equalize the variances of the sexes as a major reason for their selecting it over the additive factors. Clearly, that was not the case with the Angus weaning weight data in this study.

Sex effects in the Hereford weaning weight data were reduced to a nonsignificant ($P > .10$) level by all three adjustments used (additive, calculated multiplicative, and industry recommended multiplicative), (table 25). The calculated multiplicative adjustment reduced the mean square for the sex by herd interaction by 25% and the industry

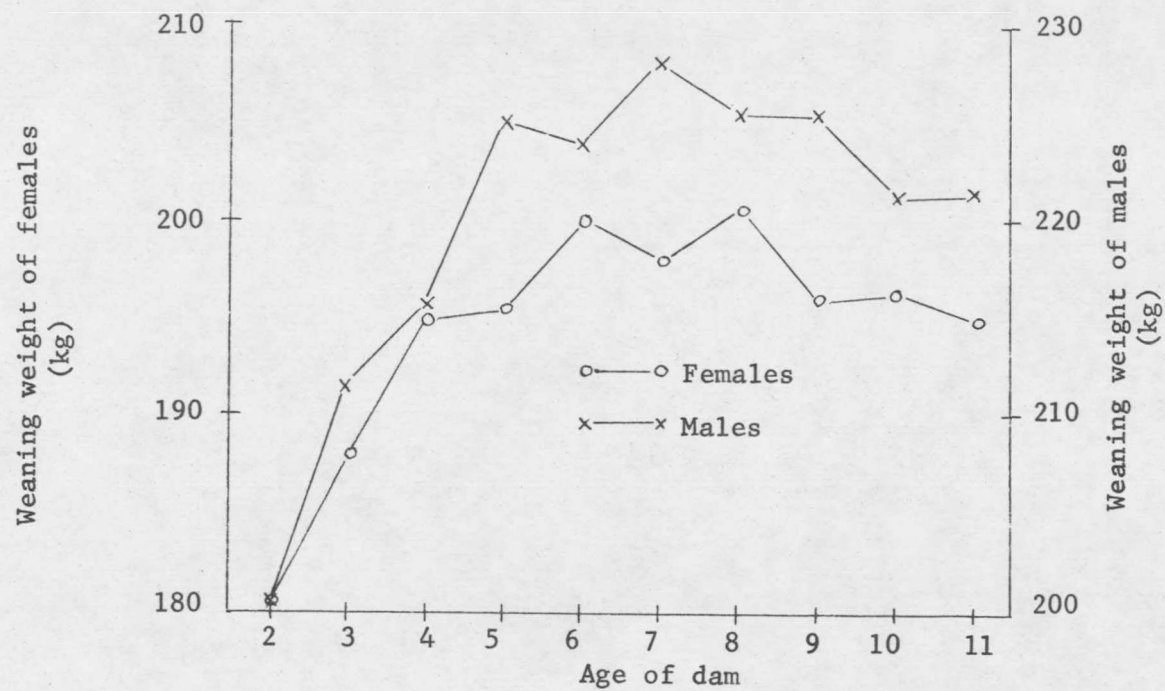


Figure 15. Angus male and female weaning weight least squares means for each age of dam.

factor reduced it by 32%. Neither reduction was significant ($P > .05$) and the effect was not moved from the highly significant ($P < .01$) region.

The F-ratio for the sex by herd interaction was reduced by 29% by the calculated sex correction factor and by 30% by the industry recommended factor. Figure 16 shows the sex by herd interaction in Hereford weaning weights as the mean difference between the sexes regressed on the least squares herd means. The significant, positive regression ($b = .26$ kg difference/kg herd mean, $R^2 = .56$, $P < .05$) would indicate the need for a multiplicative sex correction factor if this interaction were considered important enough to require correction. Model IIIa analysis of the relative importance of the sources of variation (table 39) showed that the herd by sex interaction made up less than 1% of the total variance in Hereford weaning weights.

The sex by age of dam interaction effect mean square for Hereford weaning weights was increased 10% and the corresponding F-ratio was increased 3% by the calculated multiplicative sex correction factor. The increase was not a significant amount ($P > .05$) although the interaction was moved from the region of approaching significance ($P < .10$) to the significant ($P < .05$) region. The sex by age of dam interaction mean square was not affected by the industry recommended multiplicative sex correction factors although the sex by age of dam F-ratio was increased by 4%. Appendix figure 29 shows the individual least squares means of the age of dam subclasses within each sex.

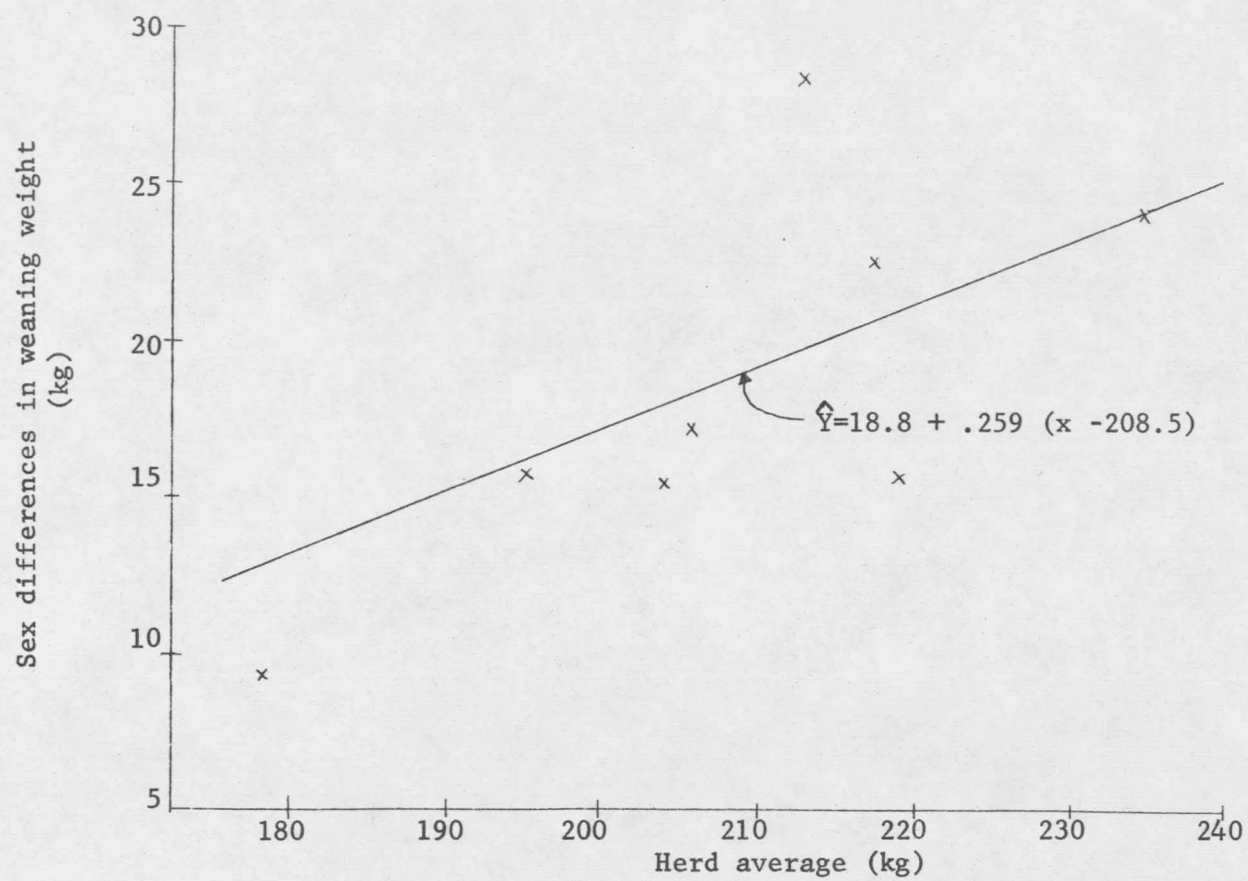


Figure 16. Regression of sex differential in weaning weight of each Hereford herd on the least squares herd mean.

The source of the interaction effect appeared to be in the 9 and 10 year old dams, which showed a sharper decline for the females than for the males. This fluctuation was considered to be a random chance phenomenon and no further special consideration was given to it in this study. Model IIIa analysis showed that the sex by herd interaction effect made up less than 1% of the total variance in Hereford weaning weights (table 39).

Model IIIa analysis of the individual sexes (Appendix table 41) showed that the ratio of male to female error mean squares from the least squares analyses of variance was 1.26 before adjustment, 1.04 after the calculated multiplicative sex adjustment, and 1.03 after the industry recommended multiplicative sex adjustment. The Hereford sex adjustment results here agree with Cundiff et al. (1966) who found that the scalar effects of the multiplicative sex adjustments were able to equate the variances of the sexes.

The multiplicative sex correction factors were selected as the preferred method of adjusting for sex effects on weaning weight in this study. The multiplicative factor was able to reduce the sex by herd and sex by age of dam interaction effect in Herefords. Also, the scalar effects of the multiplicative factor decreased the heterogeneity of variance between the sexes in the Hereford weaning weight data.

Sellers et al. (1970) and Linton et al. (1968) both chose multiplicative sex correction factors because of their ability to reduce the heterogeneity of variances between the sexes. Minyard and Dinkel (1965a) found that multiplicative sex correction factors were better at reducing the sex effects than the additive factors were.

Table 26 shows the least squares means for the individual age of dam subclasses and the correction factors calculated from these means. The multiplicative age of dam correction factors to the set of dams aged 5 to 10 are consistently lower in the Angus than in the Herefords. The Angus adjustments were 11, 6, 3 and 1% for dams aged 2, 3, 4 and 11. The Hereford adjustments were 13, 8, 4 and 4% for the same respective dam ages. This may be a reflection of the Angus dams' reportedly better milking ability. The Hereford factors are closer to the industry recommended factors of 15, 10, 5 and 5% for the same respective ages of dam. The Herefords' better agreement may be due to the industry recommended factors being based on a majority of Hereford records.

Cardellino and Frahm (1971) reported within herd multiplicative age of dam correction factors of 1.15, 1.08, 1.02 and 1.00 for 2, 3, 4 and 5 to 9 year old Angus dams, respectively, and 1.23, 1.09, 1.01 and 1.00 for Hereford dams of the same respective ages. Kress and Burfening (1972) found Angus age of dam differences in weaning weight of 13, 8, 5 and -1% for 2, 3, 4 and 11+ ages of dam when compared to

dams aged 5 to 10 and Hereford differences of 10, 8, 2 and -6% for the same respective ages. Sellers et al. (1970) found age of dam by breed interaction effects on weaning weight, but considered them unimportant. Their reported overall multiplicative age of dam correction factors for Angus and Herefords were 1.12, 1.07, 1.03, 1.00 and 1.05 for bull calves of cows aged 34 mos, 34 to 45 mos, 4 to 5 years, 6 to 12 years and 13+ years, respectively. Steers and heifer correction factors for the same respective ages of cows were 1.11, 1.06, 1.02, 1.00 and 1.02, and 1.09, 1.06, 1.02, 1.00 and 1.04, respectively.

The Angus age of dam adjustments were calculated to a 5 to 9 year old basis in addition to the 5 to 10 year old basis. The Newman-Keuls analysis had shown the set of Angus dams aged 5 to 9 years to be the homogenous mature set.

All of the calculated age of dam adjustment factors reduced the age of dam effect to well within the nonsignificant ($P > .05$) level in Angus weaning weight analysis (table 24). The industry recommended factors reduced the unadjusted age of dam mean square to 22% of its unadjusted value. The reduction was significant ($P < .05$) although the interaction effect was not removed for the highly significant ($P < .01$) region.

TABLE 26. WEANING WEIGHT LEAST SQUARES MEANS AND CORRECTION FACTORS FOR INDIVIDUAL AGES OF DAM

Age of dam	No. of calves	Least squares mean (kg)	Correction factors						
			Add	Mult	Add	Mult	Add	Mult	Mult ^a
			7 yrs		5-10 yrs		5-9 yrs		5-10 yrs
Angus									
2	898	190.2±2.8	23.1	1.12	21.3	1.11	21.8	1.11	1.15
3	820	200.1±2.8	13.2	1.07	11.3	1.06	11.8	1.06	1.10
4	718	205.3±2.8	8.2	1.04	5.9	1.03	6.4	1.03	1.05
5	666	210.0±2.9	3.2	1.02					
6	605	212.1±2.9	1.4	1.01					
7	493	213.3±2.9							
8	464	213.0±2.9	.5	1.00					
9	323	210.8±3.0	2.7	1.01					
10	264	219.1±3.1	4.1	1.02			2.7	1.01	
11+	651	208.3±3.0	5.0	1.02	3.2	1.01	3.6	1.02	1.05
Hereford									
			7 yrs		5-10 yrs		5-10 yrs		
2	833	187.5±2.7	26.3	1.14	24.9	1.13		1.15	
3	1005	197.1±2.6	16.8	1.08	15.4	1.08		1.10	
4	891	205.2±2.7	8.6	1.04	7.3	1.04		1.05	
5	782	211.3±2.6	2.3	1.01					
6	676	212.5±2.7	1.4	1.01					
7	567	213.7±2.7							
8	377	213.8±2.8							
9	292	213.7±2.9							
10	221	210.4±2.9	3.2	1.02					
11+	306	204.8±2.9	9.1	1.04	7.7	1.04		1.05	

^a Industry recommended factors.

The already highly significant ($P < .01$) age of dam by herd interaction mean square was increased by all of the multiplicative adjustment factors. Adjusting the Angus weaning weights to a 7 year old dam basis increased the age of dam by herd interaction mean square by 7%, adjusting to either set of dam ages (5 to 9 years and 5 to 10 years) caused a 6% increase and the industry recommended factors caused a 9% increase. The corresponding F-ratios were all reduced by 1% or less. None of the increases were significant ($P > .05$) and the interaction effect was not moved from the highly significant ($P < .01$) region. Figure 17 shows the age of dam by herd interaction as the least squares means of the individual ages of dam for each herd. The interaction effect appears to be most noticeable in the three youngest and the three oldest ages of dam. The mean weaning weights of calves from the younger dams appears to have increased at a faster rate in the higher average herds and the mean weights from the older dams decreased at a faster rate in the same high average herds. This could be a chance occurrence or possibly an amplification of the overall trend, amplified by the larger average numbers. One interesting speculation to explain the drop in the older dams is that the younger dams represent the dams selected under the new selection program and the older dams are holdovers from the "unimproved" herd. A second speculation is suggested by the overall shape of the curves. The trend appears to be that the dams from the higher average herds were pushed

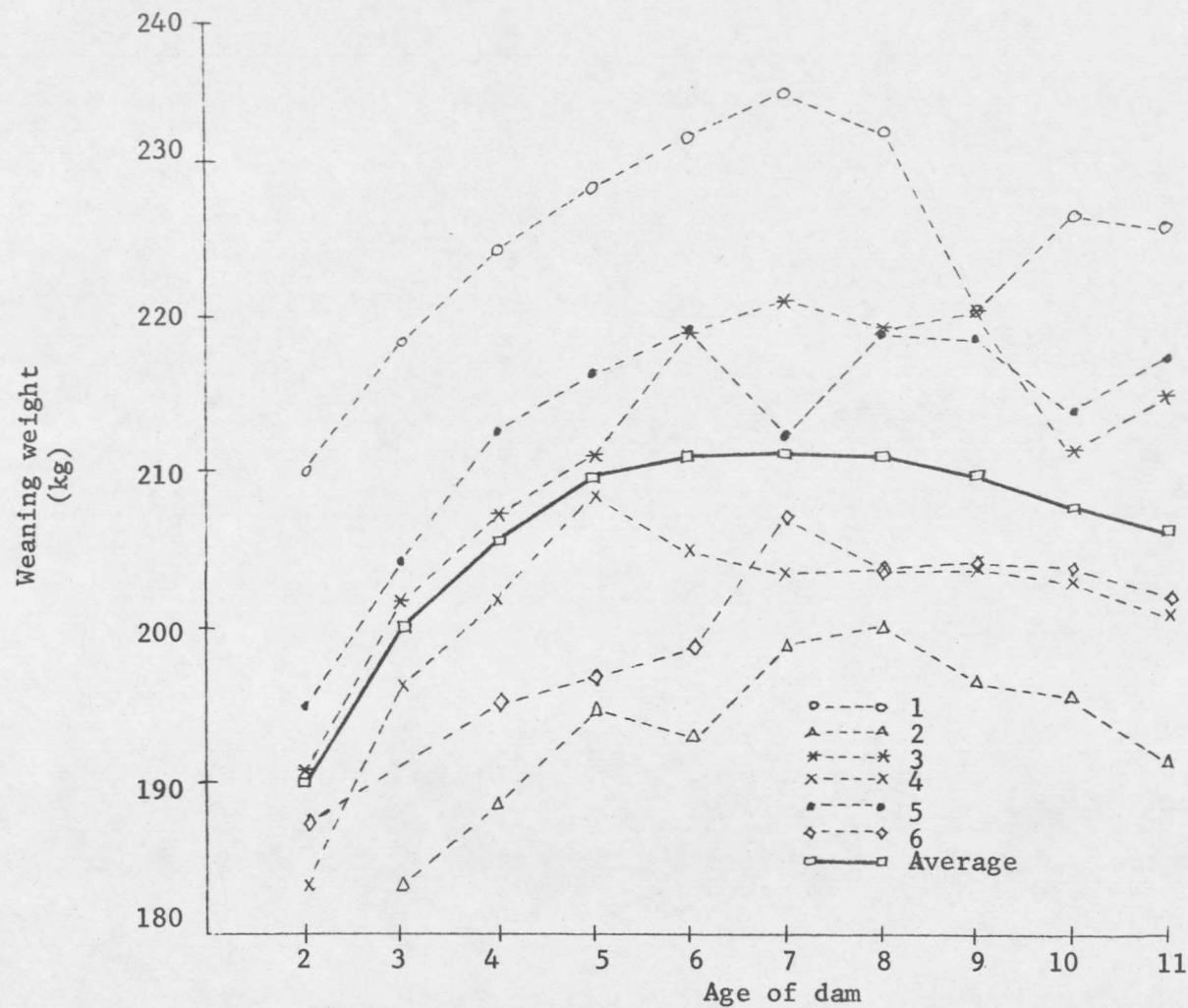


Figure 17. Angus weaning weight least squares means for each herd and age of dam.

faster to their optimum capacity but were not able to maintain such a high level of production past their seventh or eighth years. This is pure speculation, however, and no conclusions can be drawn from these data concerning the herd by age of dam interaction in Angus weaning weights.

The multiplicative age of dam adjustment factors reduced the sex by age of dam interaction out of the highly significant ($P < .01$) region in all cases. The multiplicative adjustment to a 7 year old dam basis reduced the sex by age of dam interaction mean square by 21%, the adjustment to either of the sets of ages of dam (5 to 9 and 5 to 10 years) reduced the mean square by 23% and the industry recommended adjustments reduced it by 28%. The respective F-ratio reductions were 27, 28, 28 and 35%. The industry adjustment reduced the interaction effect to the region of approaching significant ($P < .10$) while all the others reduced the effect to the significant ($P < .05$) region.

The error mean square for Angus weaning weights were increased by 8% by the multiplicative adjustment to a 7 year old basis, by 7% by the two adjustments to the sets of ages, and by 11% by the industry recommended factors.

Model III analysis of individual ages of dam (Appendix table 42) effects on Angus weaning weights showed that the range of the age of dam subclass variances was 124 units (255 to 379, standard deviation = 51) before adjustments, 118 units (276 to 394, standard deviation = 54)

after adjusting to a 7 year old dam basis, 116 units (270 to 386, standard deviation = 53) after adjusting to the set of dams aged 5 to 10 years, and 137 (281 to 418, standard deviation = 61) after the industry recommended multiplicative adjustments. Thus the scalar effects of the multiplicative correction factors did little to equalize the individual age of dam subclass variances.

The age of dam effects in Hereford weaning weights were reduced to a nonsignificant ($P > .10$) level by all the calculated additive and multiplicative factors (table 25). The industry recommended multiplicative factors reduced the age of dam mean square by 95% which reduced the level of significance to the significant ($P < .05$) region.

The multiplicative age of dam correction factors all increased the age of dam by herd interaction effects on Hereford weaning weight. The adjustment of the 7 year old dam basis increased the interaction effect by 24%, the adjustment to the set of dams aged 5 to 10 by the calculated factors increased the interaction mean square by 22% and the adjustment to the set by the industry recommended factors increased the interaction mean square by 23%. None of the increases was a significant ($P < .05$) amount and the significance level of the age of dam by herd interaction was unchanged at $P < .01$. The respective F-ratios were increased by 13, 13 and 11%. The age of dam by herd interaction, illustrated graphically in figure 18 does not appear to follow the

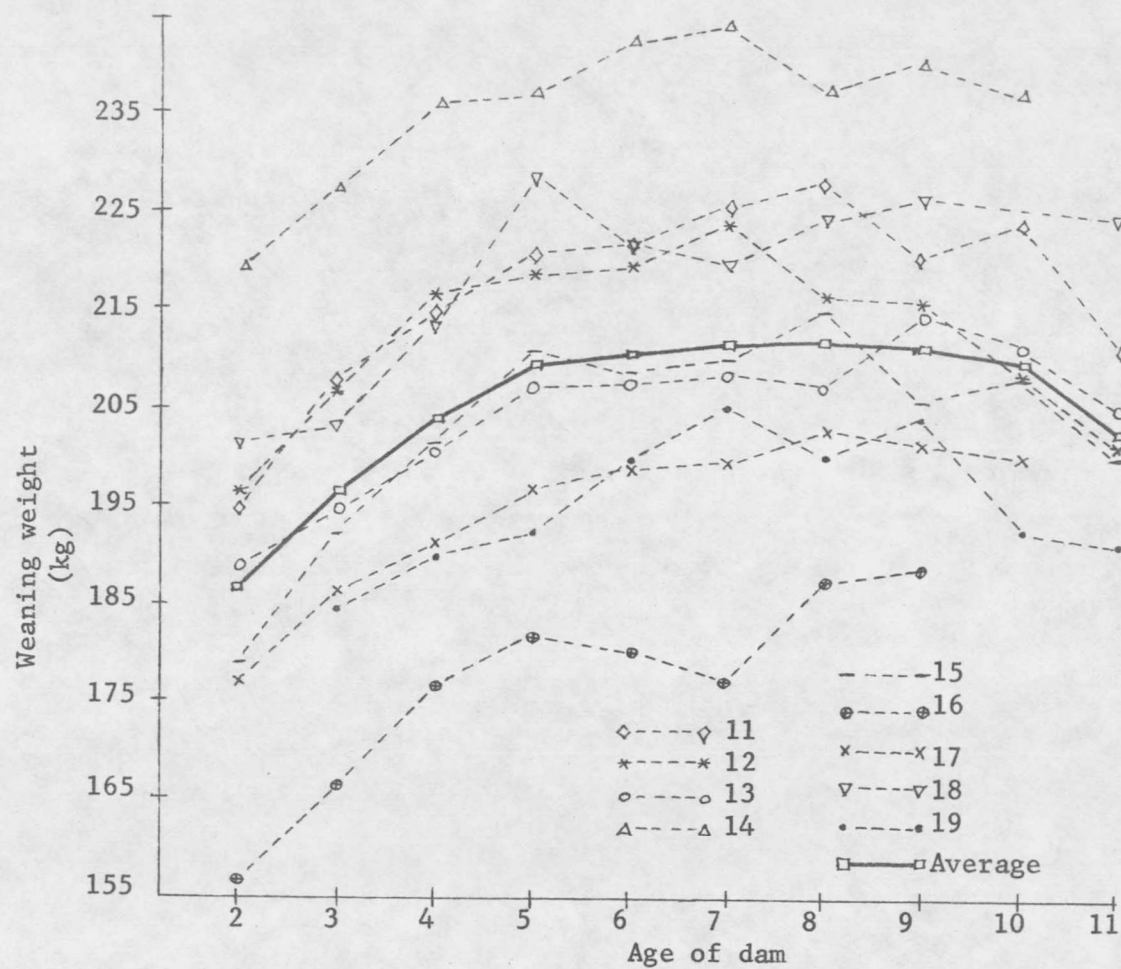


Figure 18. Hereford weaning weight least squares means for each herd and age of dam.

trends suggested in the Angus age of dam by herd interaction. The Hereford age of dam by herd interaction effect on weaning weight appears to have been caused by random fluctuations which cumulatively were probably enough to raise the effect to a highly significant ($P < .01$) level. Model IIIa analysis of relative variances showed that the age of dam by herd interaction was less than 1% of the overall variation in Hereford weaning weights (table 39).

The multiplicative age of dam adjustment factors had little effect on the sex by age of dam interaction effect on Hereford weaning weights (table 25). Adjustments to the 5 to 10 year old set of dam ages reduced the sex by age of dam interaction mean square by 6 and 7% when the calculated and industry recommended factors, respectively, were used. The respective F-ratios were reduced by 13 and 16%. The interaction effect was approaching significance ($P < .10$) both before and after the adjustments. Model IIIa analysis showed that the age of dam by sex interaction effects were less than 1% of the total Hereford weaning weight variation (table 39).

The error mean square of the least squares analysis of variance for Hereford weaning weights was increased by 10% by the multiplicative adjustment to a 7 year old dam basis, by 9% by the calculated adjustment to the set of dams aged 5 to 10 years, and 11% by the industry recommended adjustment to the same set.

Model IIIa analysis of individual variances of age of dam subclasses (table 32), showed that the range of variances was 60 units (404 to 464, standard deviation = 25) for the unadjusted data, 120 units (428 to 548, standard deviation = 56) for the data adjusted to a 7 year old dam basis, 113 units, (428 to 541, standard deviation = 54) for the data adjusted by calculated factors to the set of dams aged 5 to 10 years and 132 units (428 to 560, standard deviation = 61) in the data adjusted to the 5 to 10 year old set by the industry recommended factors. In this study of Hereford weaning weights, the multiplicative adjustment factors appear to have increased the heterogeneity in the individual age of dam variances. (Heterogeneity, $P < .01$, had been determined by Barlett's test).

Overall, the additive correction factor was the preferred method of adjusting age of dam effects on Hereford weaning weights. The multiplicative factor had little effect on the sex by age of dam interaction but it increased the effect of the age of dam by herd interaction and increased the within age of dam subclass variance. The decision was not so clear cut in the Angus data. The multiplicative factor appeared to have little effect on the age of dam by herd interaction or on the within age of dam subclass variance, although it did decrease the sex by age of dam variance.

Cundiff et al. (1966b) preferred additive age of dam correction factors for their combined Angus-Hereford study because they noted that the multiplicative factors tended to cause further divergence of

the subclass variances. Linton et al. (1968) chose additive factors for the same reasons. However, when Linton et al. (1968) dropped the class for dams aged 13 and over, they found the multiplicative factors were "more successful in equalizing the variability."

Table 27 shows the results on mean squares of adjusting for both age of dam and sex effects by all combinations of additive and multiplicative means. Comparison of the Angus source mean squares to their respective error mean squares showed that the multiplicative age of dam and additive sex adjustments were best at reducing the age of dam by herd and the age of dam by sex interactions. The additive age of dam - multiplicative sex adjustment was best at reducing the sex by herd interaction in Angus weaning weights. The same comparisons in the Hereford weaning weight data showed that the F-ratio was at its lowest value for the age of dam by herd interaction when the additive age of dam - additive sex adjustment was made. The sex by age of dam interaction F-ratio was lowest when the multiplicative age of dam - additive sex adjustments were used and the sex by herd interaction F-ratio was lowest when the additive age of dam - additive sex adjustment was used.

TABLE 27. MEAN SQUARES OF PERTINENT TRAITS BEFORE AND AFTER COMBINED AGE OF DAM AND SEX ADJUSTMENTS OF WEANING WEIGHTS BY BOTH ADDITIVE (A) AND MULTIPLICATIVE (M) MEANS

Age of dam adjustment ^a	Sex adjustment ^a	Age of dam(A)	Sex(S)	Mean squares		A x S ^b	Error
Angus							
None	None	30731**	56612**	871**	14656**	1149**	403
A	A	374	18	871**	14656**	1149**	403
A	M	439	90	1010**	12199**	1318**	451
M	A	420	510	919**	15857**	882*	430
M	M	472	105	1062**	13238**	1008*	482
M(I)	M(I)	6910**	22154**	964**	12883**	878*	442
Hereford							
None	None	37338**	185887**	687**	3783**	845+	464
A	A	350	24	687**	3783**	845+	464
A	M	359	270	741**	2868**	926*	492
M	A	410	255	839**	4143**	798+	505
M	M	428	128	900**	3099**	947*	536
M(I)	M(I)	1986*	864	848**	2807**	892+	493

^a (I) = Industry recommended factors.

^b A x S analysis in Herefords was done in a model in which A x Herd was excluded.

**P<.01, *P<.05, +P<.10, taken from individual analysis of variance tables.

A major difference between the Angus and Hereford results of weaning weight analysis was the value of the industry recommended multiplicative correction factors. They appeared to do a much better job of correcting the data in the Hereford data. This is probably due to the industry factors being based primarily on Hereford data. The factors' inability to adequately correct the Angus data may be an indication of a basic, inherent difference between the two breeds in the relative values of the production traits within the individual sexes and ages of dam. A valid, significant difference would indicate the need for separate adjustment factors for the separate breeds.

Postweaning average daily gain. Analysis of postweaning average daily gain was complicated by management effects. The heifer calves in this data were generally put on pasture after weaning while the bull calves were placed in a feedlot. This effect is shown in the least squares analysis of variance (table 27) of postweaning average daily gain. The sex effects mean squares are by far the largest source of variation in the table. Model III analysis of Angus postweaning average daily gain showed that sex effects were 75% of the total variation (table 31).

Herd and year within herd were also highly significant ($P < .01$) sources of variation in the postweaning average daily gain of both breeds. Age of dam was a significant ($P < .05$) source of variation in

TABLE 28. LEAST SQUARES ANALYSIS OF VARIANCE FOR POSTWEANING GAIN -
MODEL II

Source	Angus		Hereford	
	df	Mean square	df	Mean square
Herd (H)	4	2.9357*	8	2.7147**
Year/herd	31	.7718**	62	.7155**
Sex (S)	1	161.3766**	1	80.7586**
Age of dam (A)	9	.0385*	9	.0177
H x S	4	2.5541**	6	2.9996**
H x A ^a	36	.0424**	71	.0282**
S x A	9	.0654**	9	.0086
Remainder	3591	.0168	4661	.0191

^a The Hereford herd by age of dam effect was analyzed in a model in which the sex by age of dam interaction was not included.

* P<.05.

**P<.01.

Angus but was nonsignificant ($P>.10$) in Herefords. Figure 19 shows the least squares means of the individual ages of Angus dams. There is some suggestion of compensatory growth in the youngest and the oldest age of dam classes. Herd by sex interactions were a highly significant ($P<.01$) source of variation for both breeds. The interaction is probably due to the differing management systems postweaning in the different herds.

Sex by age of dam was a significant interaction in Angus postweaning average daily gains. Figure 20 shows the mean Angus postweaning average daily gain of each sex for the individual ages of dam. The curves suggest that there was compensatory growth in female calves from the younger dams. Sex by age of dam interaction effects were nonsignificant ($P>.10$) in Herefords.

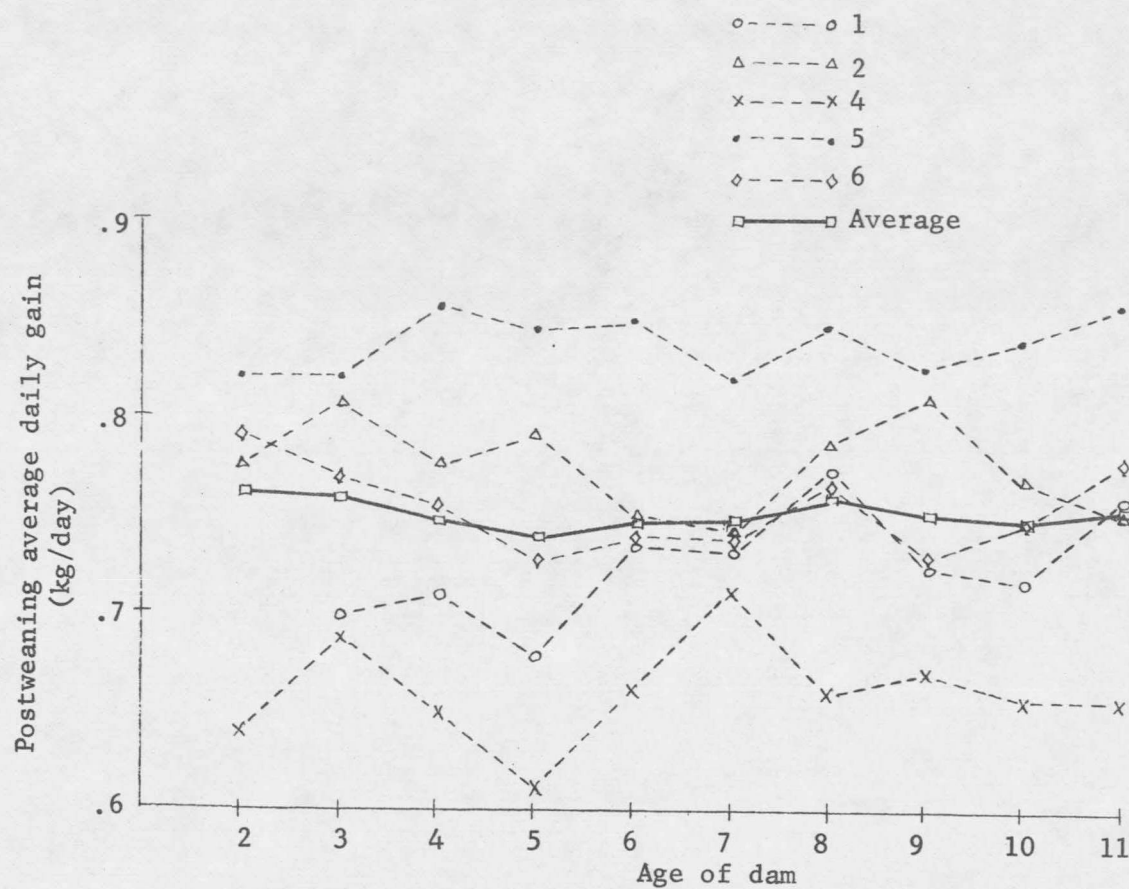


Figure 19. Angus postweaning average daily gain least squares means for each herd and age of dam.

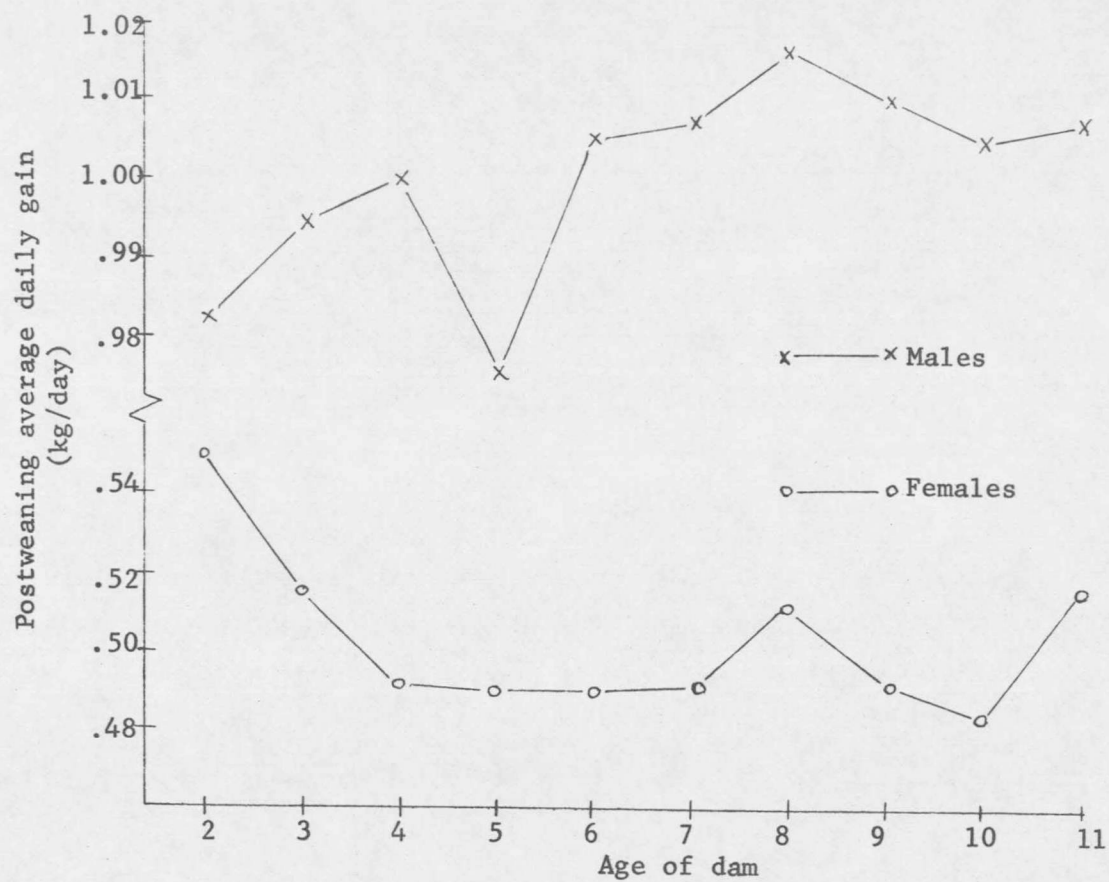


Figure 20. Angus male and female postweaning average daily gain least squares means for each age of dam.

Herd by age of dam interactions were a highly significant ($P < .01$) source of variation in both breeds. Figures 19 and 20 show the least squares means for the individual ages of dam for each herd of Angus and Hereford, respectively. The curves suggest random fluctuations that cumulatively were probably sufficient to cause the interactions to be significant ($P < .01$).

The least squares means and standard errors for males and females, respectively, for postweaning average daily gains were $1.00 \pm .02$ and $.50 \pm .02$ kg/day in Angus and $1.09 \pm .03$ and $.60 \pm .03$ kg/day in Herefords.

The Angus bull calves were kept on postweaning test for a mean (and standard deviation) of 170 (3) days and the Angus heifer calves for 178 (3) days. Their respective final test weights were 386.6 ± 4.6 and 288.3 ± 4.6 kg (least squares means and standard errors). The mean (and standard deviation for) test length for Hereford bulls was 156 (3) days and for heifers 164 (3) days. The least squares means and standard errors of final test weights were 394.4 ± 5.4 and 301.9 ± 5.5 kg for Hereford bulls and heifers, respectively.

The least squares analysis of variance results for final test weight is presented in table 29. All main effects (herd, year within herd, sex, and age of dam) were highly significant.

The graph for age of dam effects (figure 21) on final test weights of Angus calves resembles somewhat the age of dam curves for the weaning and preweaning traits. Because the curve was not evident in age of dam analysis of postweaning average daily gain, (figures 19 and 20), the age of dam effect on final test weight was probably residual effects carried over from weaning weight. Whatever compensatory gains there were in postweaning gain, they were not enough to negate the age of dam effects on final test weight.

Sex by herd interaction effects were highly significant ($P < .01$) in both breeds. This effect is probably due to the difference in postweaning management systems. Herd by age of dam interactions were highly significant ($P < .01$) in Angus and significant ($P < .05$) in Herefords. Figure 22 suggests random fluctuations as the cause of this interaction effect on Angus final test weights. The sex by age of dam interaction was nonsignificant ($P > .10$) in both breeds.

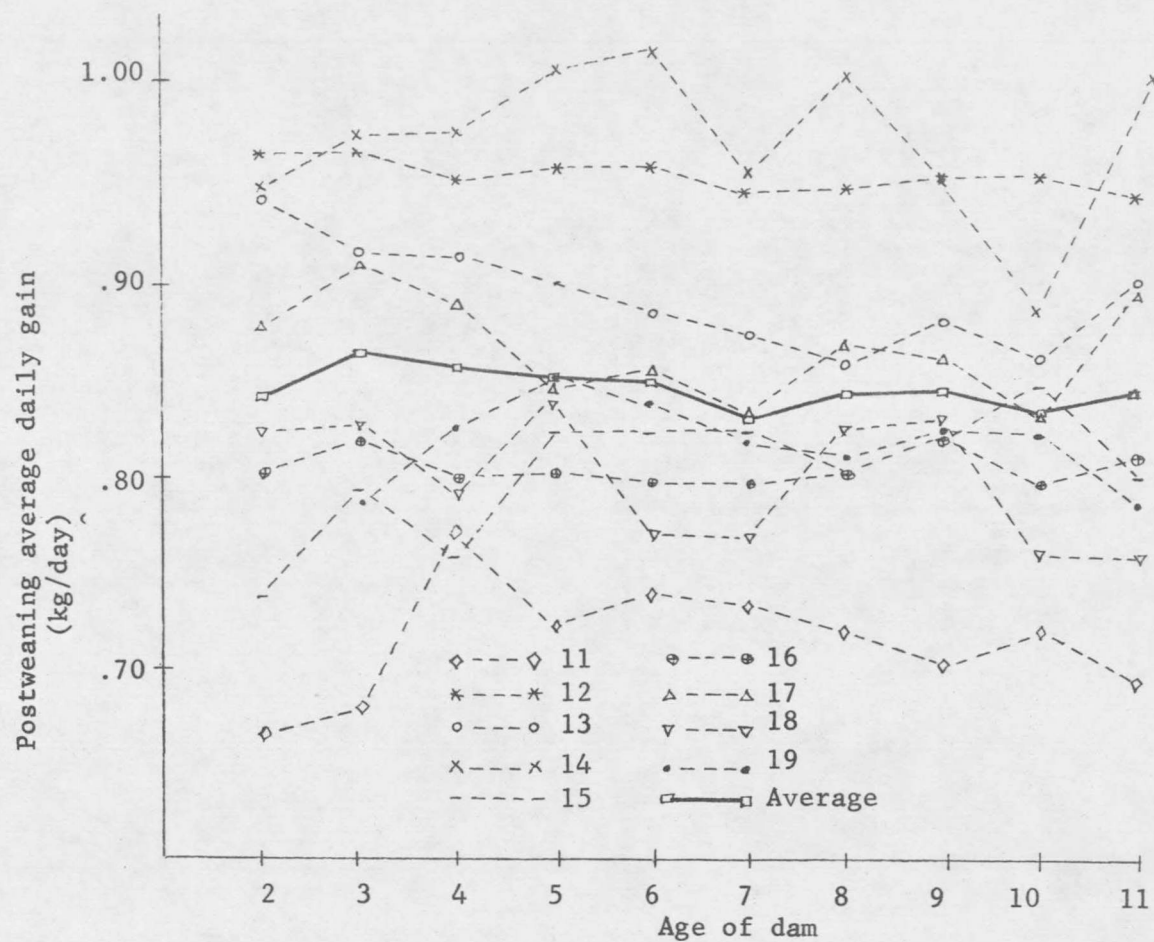


Figure 21. Hereford postweaning average daily gain least squares means for each herd and age of dam.

TABLE 29. LEAST SQUARES ANALYSIS OF VARIANCE FOR FINAL TEST WEIGHT -
MODEL II

Source	Angus		Hereford	
	df	Mean squares	df	Mean squares
Herd (H)	4	191743**	8	274122**
Year/herd	31	34459**	62	37843*
Sex (S)	1	6364792**	1	2836185**
Age of dam (A)	9	15759**	9	62306**
H x S	4	70886**	6	71509**
H x A ^a	36	2648**	71	1719*
S x A	9	2028+	9	604
Remainder	3591	1180	4661	1212

^a The Hereford herd by age of dam effect was analyzed in a model in which the sex by age of dam interaction was not included.

+ P<.10.

* P<.05.

**P<.01.

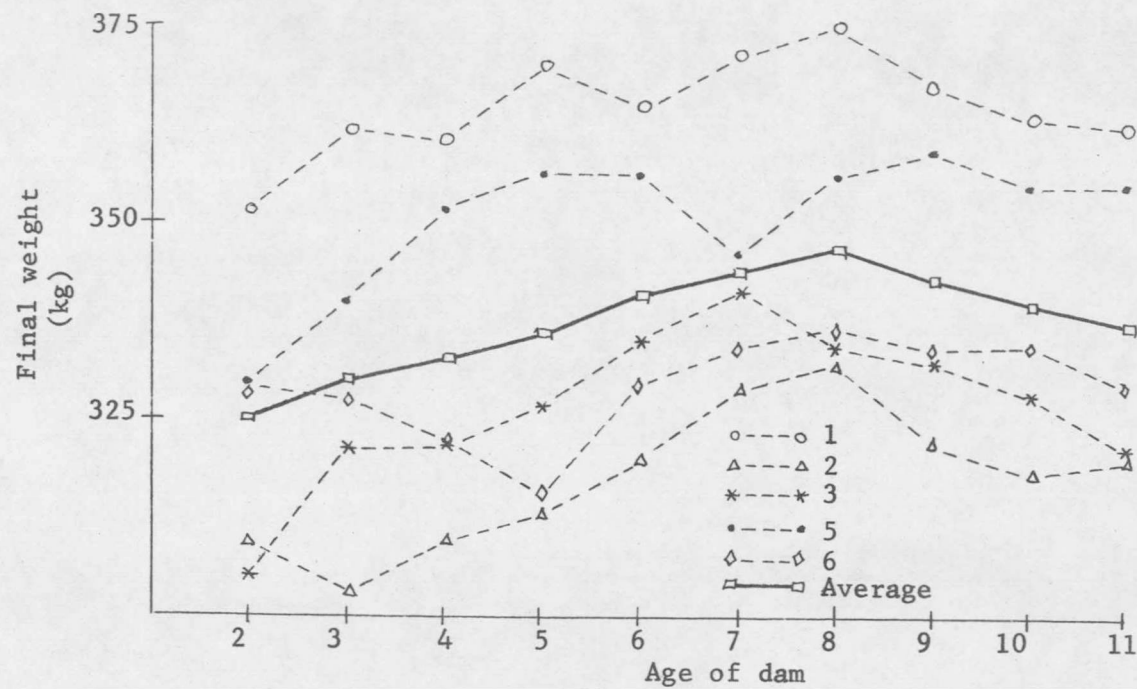


Figure 22. Angus final test weight least squares means for each herd and age of dam.

Model III Analysis

A single model was used for Model III analysis of Angus birth weight, preweaning gain, weaning weight, postweaning gain and final test weight (table 30). The model included the usual sex, age of dam and herd as fixed main effects, plus years within herd and sires with-
in years within-herds as random effects. Herd by sex was the only interaction included. All five traits were regressed on age at weaning at the linear, quadratic and cubic levels. All main effects, fixed and random, were highly significant ($P < .01$) for all traits with one exception. Age of dam was highly significant ($P < .01$) for all traits except postweaning gain, where the effect was nonsignificant ($P > .10$). The herd by sex interaction was significant for all traits ($P < .05$ for birth weight and $P < .01$ for the others).

The original objective was to analyze Model III Angus data with all interactions in the model. Preliminary analysis showed, however, that there were problems of confounding in the data. Many sire/year/herd subcells contained only one record. The decision was made to reduce the model by dropping some interactions rather than edit the data to keep as many records as possible in the analysis.

The partial cubic regression of birth weight on weaning age was not significant ($P > .10$). Because all calves within a year-herd sub-unit were weaned on a common date, the weaning age can be considered as a function of day of year born. The partial cubic

TABLE 30. LEAST SQUARES ANALYSIS OF VARIANCE FOR MODEL III - ANGUS

Source	df	Mean squares				
		Birth weight	Preweaning gain	Weaning weight	Postweaning gain	Final test weight
Herd (H)	3	582.1**	.8759**	53237**	3.586**	210890**
Year/herd	25	103.0**	.1872**	10099**	.589**	36448**
Sire/year/herd	131	19.7**	.0135**	690**	.027**	1866**
Sex (S)	1	1174.2**	2.4142**	131611**	54.450**	2371695**
Age of dam	9	77.4**	.0772**	4878**	.002	5396**
H x S	3	25.1*	.0572**	2246**	.573**	14567**
Regression on weaning age						
-linear	1	9.2	.0166	431	.013	2557
-quadratic	1	13.4	.0172	1293	.017	4472
-cubic	1	18.7	.0203+	1840*	.020	5507*
Remainder	1937	8.8	.0062	330	.014	876

**P<.01.

* P<.05.

+ P<.10.

regression of weaning age on preweaning gain approached significance ($P < .10$). Weaning and final test weight regressed on weaning age were both significant ($P < .05$) while postweaning gain on weaning age was not ($P > .10$) a significant regression. The cubic regression equation for weaning weight on weaning age was: $\hat{Y} = 210 \text{ kg} + (-1.65 \text{ kg/day}) (X \text{ days} - 218 \text{ days}) + (.0133 \text{ kg/day}^2) (X \text{ days} - 219 \text{ days})^2 + (-.000024 \text{ kg/day}^3) (X \text{ days} - 219 \text{ days})^3$. For Angus postweaning average daily gain regression on weaning age the equation was: $\hat{Y} = .761 \text{ kg/day} + (-.0091 \text{ kg/day/day}) (X \text{ days} - 219 \text{ days}) + (.000049 \text{ kg/day/day}) (X \text{ days} - 219 \text{ days})^2 + (-.00000008 \text{ kg/day/day}^3) (X \text{ days} - 219 \text{ days})^3$.

Table 31 shows the estimates of the proportions of the total variation attributed to each source of variation. Estimates were made by estimating the components of variance for each source of variation.

The heritabilities and correlations of the Angus traits are presented in tables 32, 33 and 34 for the combined analysis of both sexes, males only and females only, respectively. The combined estimate of heritability of birth weight of $.39 \pm .07$ agrees with the weighted averages of both Preston and Willis (1974) (avg. = .38) and Petty and Cartwright (1966) (avg. = .44). The combined estimate of heritability of preweaning average daily gain was $.29 \pm .06$. Preston and Willis reported a preferred value of .27 and Petty and Cartwright found a weighted average of .31 for heritability of preweaning gain.

TABLE 31. COMPONENTS OF VARIANCE AND THEIR RELATIVE PROPORTIONS IN LEAST SQUARES ANALYSIS OF VARIANCE - MODEL III - ANGUS

Source	Variance and percentage of total variance									
	Birth weight		Preweaning ADG		Weaning weight		Postweaning ADG		Final weight	
	Var.	%	Var.	%	Var.	%	Var.	%	Var.	%
	comp.	total	comp.	total	comp.	total	comp.	total	comp.	total
Herd (H)	1.25	8.4	.0019	11.5	116	12.8	.0078	5.8	459	7.1
Sire	.97	6.5	.0006	3.6	32	3.5	.0011	.8	87	1.4
Year	1.21	8.1	.0027	16.4	145	16.0	.0087	6.5	534	8.3
Sex (S)	2.17	14.6	.0045	27.3	245	27.1	.1014	75.4	4416	68.6
Age of dam	.48	3.2	.0005	3.0	31	3.4	-		31	.5
H x S	.04	.3	.0001	.6	5	.6	.0015	1.1	38	.6
Error	<u>8.77</u>	<u>58.9</u>	<u>.0062</u>	<u>37.6</u>	<u>330</u>	<u>36.5</u>	<u>.0140</u>	<u>10.4</u>	<u>876</u>	<u>13.6</u>
Total	14.89	100.0	.0165	100.0	904	99.9	.1345	100.0	6441	100.1

TABLE 32. ESTIMATES OF HERITABILITY AND GENETIC (G), ENVIRONMENTAL (E) AND PHENOTYPIC (P)^a CORRELATIONS FOR PRODUCTION TRAITS OBTAINED BY PATERNAL HALF-SIB ANALYSIS^b OF ANGUS CALVES - BOTH SEXES

		Preweaning gain	Weaning weight	Postweaning gain	Final test weight	Heritability estimate
Birth weight	G	.42±.15	.53±.14	.43±.17	.70±.12	.39±.07
	E	.19	.34	.20	.26	
	P	.26	.40	.26	.39	
Preweaning gain	G		.96±.01	.16±.21	.71±.10	.29±.06
	E		.99	.26	.69	
	P		.98	.24	.70	
Weaning weight	G			.10±.22	.73±.10	.27±.06
	E			.31	.72	
	P			.26	.72	
Postweaning gain	G				.71±.11	.20±.06
	E				.83	
	P				.80	
Final weight						.25±.06

^a Phenotypic correlation greater than .06 are significant ($P < .05$).

^b k value for sires = 11.32.

TABLE 33. ESTIMATES OF HERITABILITY AND GENETIC (G), ENVIRONMENTAL (E) AND PHENOTYPIC (P)^a CORRELATIONS FOR PRODUCTION TRAITS OBTAINED BY PATERNAL HALF-SIB ANALYSIS^b OF ANGUS HEIFER CALVES

		Preweaning gain	Weaning weight	Postweaning gain	Final test weight	Heritability estimate
Birth weight	G	.41±.31	.61±.26	.00±.29	.54±.27	.33±.10
	E	.34	.45	.36	.46	
	P	.35	.47	.25	.47	
Preweaning gain	G		.94±.04	-.11±.38	.55±.30	.15±.09
	E		.99	.18	.74	
	P		.98	.12	.71	
Weaning weight	G			-.18±.38	.62±.27	.15±.08
	E			.25	.77	
	P			.16	.75	
Postweaning gain	G				.48±.27	.27±.09
	E				.79	
	P				.72	
Final weight						.16±.09

^a Phenotypic correlations greater than .06 are significant ($P < .05$).

^b k-value for sires = 7.18.

TABLE 34. ESTIMATES OF HERITABILITY AND GENETIC (G), ENVIRONMENTAL (E) AND PHENOTYPIC (P)^a CORRELATIONS FOR PRODUCTION TRAITS OBTAINED BY PATERNAL HALF-SIB ANALYSIS^b OF ANGUS BULL CALVES

		Preweaning gain	Weaning weight	Postweaning gain	Final test weight	Heritability estimate
Birth weight	G	.38±.21	.44±.20	.54±.21	.68±.18	.52±.10
	E	.10	.31	.17	.22	
	P	.21	.35	.29	.37	
Preweaning gain	G		.96±.02	.19±.28	.65±.16	.32±.09
	E		.99	.37	.73	
	P		.98	.32	.70	
Weaning weight	G			.18±.30	.67±.16	.28±.09
	E			.41	.76	
	P			.35	.74	
Postweaning weight	G				.83±.10	.23±.09
	E				.84	
	P				.83	
Final weight						.24±.09

^a Phenotypic correlations greater than .06 are significant ($P \leq .05$).

^b k-value for sires = 7.03.

Combined sex analysis of weaning weight heritability gave an estimate of $.27 \pm .06$ which also agrees with the literature estimates. Petty and Cartwright reported a weighted mean of .28 and Preston and Willis reported .30. The individual sex estimates of the heritability of weaning weight, however, do not agree with the literature in that the males in this study were estimated at a higher level than the females ($.28 \pm .09$ vs. $.15 \pm .08$, the difference was not significant, ($P > .10$).

The heritabilities of the postweaning traits found here were lower than the majority of the literature reports. Estimates were $.27 \pm .09$ and $.16 \pm .09$ for postweaning gain and final weight, respectively, in heifers and $.23 \pm .09$ and $.24 \pm .09$ for the same respective traits in bull calves. Preston and Willis reported preferred values of .52 for feedlot gain and .77 for final test weight. Petty and Cartwright found heritability estimates of .52 for feedlot gain, .30 for pasture gain and .58 for final feedlot weight. Lower estimates were reported by Dickerson et al. (1974) who reported heritability estimates of .26 and .48 for postweaning gain and final test weight, respectively, in an Angus, Hereford and Shorthorn mixed study. Francoise et al. (1973) estimated heritability of yearling weight of .06 and .29 in Angus bulls and heifers, respectively.

One possible explanation could be that the animals in this study were showing the effects of selection. As bulls were selected by common criteria, the between sire variance component decreased and thus decreased the heritability estimates. The genetic and phenotypic correlations generally agreed with the literature estimates. There did not appear to be any noticeable differences in the correlations involving the postweaning traits, even though their heritability estimates were lower. This could indicate that the same values for genetic correlations can be used to calculate correlated response in spite of the selection influence on the heritability.

A single model was used for Model III analysis of variance of the five production traits in Hereford bull calves (table 35). The results agreed in general with the Model III Angus analysis. All main effects were highly significant ($P < .01$) for all traits except the age of dam effect which, as in Angus, was non-significant ($P > .10$) for postweaning gain but highly significant ($P < .01$) for the other four traits. (The herd effect in Hereford bulls was significant at a lower level ($P < .05$) for postweaning gain). Herd by age of dam interactions were nonsignificant ($P > .10$) for all traits. The linear partial regressions of production traits on age at weaning in days were highly significant ($P < .01$) for the traits preweaning gain and birth, weaning and final test weights but non-significant ($P > .10$) for postweaning gain. The regression coefficients

TABLE 35. LEAST SQUARES ANALYSIS OF VARIANCE FOR MODEL III - HEREFORD BULL CALVES

Source	df	Mean squares				
		Birth weight	Preweaning gain	Weaning weight	Postweaning gain	Final test weight
Herd (H)	2	1819.4**	1.6360**	92708**	3.378*	401520**
Year/herd	25	37.0*	.1767**	9504**	.690**	40036**
Sire/year/herd	148	22.1**	.0147**	738**	.029**	2032**
Age of dam (A)	9	54.6**	.0508**	2918**	.012	4028**
H x A	18	.2	.0078	319	.017	726
Regression on weaning age -linear	1	224.1**	.2560**	211897**	.012	239071**
Remainder	1175	10.6	.0082	404	.019	866

* $P < .05$.

** $P < .01$.

TABLE 36. COMPONENTS OF VARIANCE AND THEIR RELATIVE PROPORTIONS IN LEAST SQUARES ANALYSIS OF VARIANCE - MODEL III - HEREFORD BULL CALVES

Source	Variance and percentage of total variance									
	<u>Birth weight</u>		<u>Prewaning ADG</u>		<u>Weaning weight</u>		<u>Postweaning ADG</u>		<u>Final weight</u>	
	Var.	%	Var.	%	Var.	%	Var.	%	Var.	%
	comp.	total	comp.	total	comp.	total	comp.	total	comp.	total
Herd (H)	3.81	22.6	.0005	3.7	57	7.9	.0862	71.5	2978	61.7
Year/herd	.21	1.2	.0034	25.2	183	25.3	.0136	11.3	780	16.1
Sire/year/herd	1.61	9.6	.0009	6.7	48	6.6	.0014	1.2	166	3.4
Age of Dam (A)	.61	3.6	.0005	3.7	31	4.3	.0000	.0	40	.8
H x A	.00	.0	.0000	.0	0	.0	.0000	.0	0	.0
Remainder	<u>10.61</u>	<u>63.0</u>	<u>.0082</u>	<u>60.7</u>	<u>404</u>	<u>55.9</u>	<u>.0193</u>	<u>16.0</u>	<u>866</u>	<u>17.9</u>
Total	16.85	100.0	.0135	100.0	723	100.0	.1205	100.0	4830	99.9

were $-.022$ kg/day for birth weight, $-.0007$ kg/day for preweaning gain, $.68$ kg/day for weaning weight and $.72$ kg/day for final test weight. Table 36 presents the components of variation for each trait and their relative proportion of the total variation.

The genetic parameters obtained from Model III analysis of Hereford bull calves are presented in table 37. The estimate of heritability of birth weight of $.62 \pm .10$ is higher than the literature average estimates (see table 1), although it is in general agreement with the Hereford bull estimates of $.53$ by Knapp and Nordskog (1946), $.59$ by Shelby et al. (1957) and $.72$ by Shelby, et al. (1955). The estimates of heritability for preweaning gain and weaning weight, $.23 \pm .08$ and $.33 \pm .09$, respectively, are in general agreement with the literature. The postweaning gain estimate of heritability of $.16 \pm .07$ is lower than the literature estimates in general, although it is in agreement with the Angus estimate of this study and the Hereford bull estimates of $.11$ by Francoise et al. (1973). The final test weight estimate of $.40 \pm .09$ is also lower than the majority of the literature estimates but it is higher than the Angus estimate of this study. Koch et al. (1973) estimated heritability of final weight in Hereford bulls at $.29$ and Cundiff et al. (1975) estimated 452 day weight in Angus and Herefords mixed at $.40$ within breed and $.27$ within herd.

TABLE 37. HERITABILITY ESTIMATES AND GENETIC (G), ENVIRONMENTAL (E) AND PHENOTYPIC (P)^a
CORRELATIONS AMONG PATERNAL HALF-SIBS^b IN HEREFORD BULL CALVES

		Preweaning gain	Weaning weight	Postweaning gain	Final test weight	Heritability estimate
Birth weight	G	.17±.19	.37±.17	.74±.21	.60±.13	.62±.10
	E	.22	.31	.01	.13	
	P	.19	.33	.24	.36	
Preweaning gain	G		.97±.01	.55±.28	.73±.12	.32±.08
	E		.99	.00	.53	
	P		.98	.13	.60	
Weaning weight	G			.65±.27	.84±.09	.33±.09
	E			.00	.51	
	P			.15	.63	
Postweaning gain	G				.77±.12	.16±.07
	E				.78	
	P				.74	
Final test weight						.40±.09

^a Phenotypic correlations greater than .06 are significant (P<.05).

^b k-values for sires = 6.91.

Genetic correlations between postweaning gain and birth weight, pre-weaning gain, and weaning weight are lower than the Angus bull estimates, otherwise the correlations are in general agreement with the Angus estimates and the literature in general (see tables 34 and 36). There were a total of 85 Hereford sires in this Model III analysis. Sires used more than one year were counted as separate sires. The total number of sire/year/herd df was 148.

Model IIIa was an analysis of both sexes of Hereford calves under Model III type analysis, but weaning weight was the only trait.

Table 38 shows the least square analysis of variance table for the Model IIIa analysis of Hereford weaning weights. All sources of variation were highly significant ($P < .01$). Herd, sex and age of dam were fixed effects and year within herd and sire within year within herd were random effects. The interactions fitted were herd by sex and sex by age of dam. The partial regression of weaning weight on age at weaning was highly significant ($P < .01$) at the linear level with a regression coefficient of .729 kg/day. Individual sex analysis produced highly significant ($P < .01$) partial regression coefficients of .716 kg/day for females and .750 kg/day for males.

The individual components of variance and their relative importance are shown in table 39. Each main effect made up at least 3% of the overall variation. Each of the interactions, however, made up less than 1% of the total variation. Herd by sex and sex by age of

dam interactions were therefore both highly significant ($P < .01$) statistically, but neither was of practical importance to this study.

The estimates of heritability from Model IIIa analysis of weaning weight (table 40) were $.23 \pm .03$ for the combined-sex analysis, $.28 \pm .05$ for males only and $.23 \pm .06$ for females only. These estimates are slightly lower than the preferred value of .27 by Preston and Willis (1974) and the weighted average of .31 by Petty and Cartwright (1966). They are, however, in general agreement in value and relative sex rankings with the Angus data of this study. The bull calf values agree especially well.

TABLE 38. LEAST SQUARES ANALYSIS OF VARIANCE FOR MODEL IIIa - HEREFORD
WEANING WEIGHTS

Source	df	Mean square
Herd (H)	8	141756**
Year/herd	71	14344*
Sire/year/herd	388	854**
Sex (S)	1	170951**
Age of dam (A)	9	14326**
H x S	7	3336**
S x A	9	1105**
Regrssion on weaning age -linear	1	1057936**
Remainder	5504	440

** $P < .01$.

TABLE 39. COMPONENTS OF VARIANCE AND THEIR RELATIVE PROPORTION OF THE TOTAL VARIATION - MODEL IIIa - HEREFORD WEANING WEIGHTS - BOTH SEXES

Source	Variance component	Percent total
Herd (H) =	225	22.0
Sire =	36	3.1
Year =	185	15.9
Sex (S) =	197	17.0
Age of dam =	36	3.1
H x S =	7	.6
S x A =	4	.3
Remainder =	<u>440</u>	<u>37.9</u>
Total	1160	99.9

TABLE 40. PATERNAL HALF-SIB ESTIMATES OF HERITABILITY OF WEANING WEIGHT BY MALE ONLY, FEMALE ONLY, AND COMBINED SEX ANALYSIS OF HEREFORD CALVES - MODEL IIIa

Analysis	No. of calves	Heritability estimate
Males only	3934	.28±.05
Females only	2065	.23±.06
Combined sexes	5999	.23±.03

SUMMARY

Field records of 6200 purebred calves from 6 Angus herds and 7700 purebred calves from 9 Hereford herds were analyzed by least squares analysis. Herd, year, year within herd, sire within year within herd, sex, age of dam, and interactions among these factors along with regressions on day of birth and age at weaning were analyzed in various combinations as independent variables in three basic least squares models. Response variables were birth weight, preweaning average daily gain, weaning weight, postweaning average daily gain and final postweaning test weight.

The objectives of this study were: to analyze time trends in order to estimate past response to genetic selection; to calculate and evaluate sex and age of dam correction factors used to reduce environmental effects; and to estimate genetic parameters in order to predict future responses to selection.

The time trend analysis showed that birth and weaning weights did increase significantly in the time period (1959 to 1973) of the study. It is assumed that the weaning weight increase was a direct response and the birth weight increase a correlated response to selection. Both breeds showed a nonsignificant increase in postweaning average daily gain and no discernible response in final test weight.

Correction factor analyses showed few clear cut decisions between additive and multiplicative factors. The decision criteria were effects on main sources of variation, interaction sources and within sex and

age of dam subclass variation. The multiplicative sex correction factors were preferred in birth and weaning weight adjustments in both breeds and in preweaning average daily gain adjustment in Angus.

Additive sex correction factors were preferred in Hereford preweaning average daily gain adjustments. Multiplicative age of dam correction factors were preferred in both breeds for birth weight adjustments.

Additive age of dam correction factors were preferred in Hereford preweaning average daily gain and weaning weight. No decision between additive and multiplicative age of dam correction factors was reached in Angus preweaning average daily gain and weaning weight.

The relative sex and age of dam adjustment factors were consistently different for the two breeds. The sex difference was consistently larger in the Angus traits as compared to the Hereford differences. The industry recommended multiplicative factors were shown to be inadequate in equalizing the sex and age of dam effects in the Angus data, but were better at correcting the Hereford data. The industry recommends the same factors for both Angus and Hereford adjustments, although the industry recommendation may have been based primarily on Hereford records. In this study, correction factors were not applicable across breeds.

As an example, the sex differences (bull vs. heifer) in weaning weight were 13% in the Angus data and 10% in the Hereford data. The industry recommendation is a 10% adjustment. The Angus adjustments to the 5 to 10 year old dam basis required 11, 6, 3 and 1% adjustments

for 2, 3, 4 and 11+ year old subclasses, respectively. Hereford adjustments for the same respective set of dam ages for weaning weight were 13, 8, 4 and 4%. The industry recommended adjustments for the same respective ages of dam were 15, 10, 5 and 5%.

The common practice of adjusting age of dam effects to the set of dams aged 5 to 10 years was found to be wholly adequate when compared to adjusting to a single age of dam or to adjusting to a different set.

The estimates of heritability in the Angus data were .39, .29, .27, .20 and .25 for birth weight, preweaning average daily gain, weaning weight, postweaning average daily gain and final test weight, respectively, from combined sex analyses. Angus estimates from bull only analyses were .52, .32, .28, .23 and .24 for the same respective traits and from heifer only analyses the estimates were .33, .15, .15, .27 and .16. Hereford bull heritability estimates for the same respective traits were .62, .32, .33, .16 and .40. Hereford heritability estimates for weaning weight only (Model IIIa, with more data) were .28 for males, .23 for females, and .23 for the combined analysis of sexes.

The estimates of heritability for birth weight, preweaning average daily gain and weaning weight were in general agreement with the literature estimates. Individual sex analysis showed estimated heritabilities for bull calves to be higher than for females in Angus, which was not in agreement with the majority of the literature estimates.

Heritability estimates for postweaning average daily gain and final weight were lower than most previously published estimates. The suggestion was made that the lower heritability estimates were an effect of selection.

The correlation estimates were in general agreement with the literature estimates, including correlations involving those traits whose heritability estimates were lower.

The genetic correlations are important in estimating correlated response to selection. The majority of cattle producers try to increase gains and weaning and final weights but don't wish to increase birth weight. Bull analysis of both breeds showed postweaning average daily gain and final test weight to have genetic correlations with birth weight in excess of .50. Preweaning average daily gain and weaning weight had genetic correlations to birth weight of less than .50, indicating the bull selection at weaning would be better at controlling birth weight than selection for a postweaning trait.

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APPENDIX

APPENDIX TABLE 41. ERROR MEAN SQUARES OF MODEL III ANALYSIS OF
VARIANCE OF SEPARATE SEXES^a

Trait	Analysis				
	Angus		Hereford-III	Hereford-IIIA	
	Males	Females	Males	Males	Females
No. calves	1101	1012	1379	3934	2065
Birth weight					
Normal	8.92	8.53	10.61		
After adjustment	8.92	10.04	10.61		
Preweaning gain					
Normal	.0065	.0058	.0082		
After adjustment	.0065	.0074	.0082		
Weaning weight					
Normal	347	321	404	463	367
After adjustment	347	410	404	463	444
After industry adjustment	313	354	365	418	405
Postweaning gain					
Normal	.0149	.0064	.0193		
Final weight					
Normal	970	585	866		

^aObtained from analyzing each sex separately.

APPENDIX TABLE 42. ERROR MEAN SQUARES OF MODEL III AND MODEL IIIa
ANALYSIS OF VARIANCE OBTAINED FROM SEPARATE
ANALYSIS OF AGE OF DAM SUBCLASSES BEFORE AND AFTER
MULTIPLICATIVE AGE OF DAM ADJUSTMENTS

	Age of dam				
	2	3	4	5-10	11
	Model III Angus				
No. calves	314	337	295	952	215
Birth weight					
Normal	7.01	8.17	7.96	9.24	8.75
6 years	8.30	9.05	8.15	9.24	8.86
5-10 years	8.10	8.41	7.99	9.24	8.86
Preweaning avg. daily gain					
Normal	.0055	.0054	.0048	.0059	.0075
6 years	.0072	.0060	.0051	.0059	.0081
5-10 years	.0070	.0058	.0049	.0059	.0078
Weaning weight					
Normal	312	260	255	326	379
7 years	392	298	276	326	394
5-10 years	384	292	270	326	386
5-10 years ^a	412	315	281	326	418
	Model III Hereford				
	221	224	702	61	
No. calves	171	221	224	702	61
Birth weight					
Normal	9.04	7.19	10.06	12.07	12.87
6 years	11.42	7.92	11.06	12.07	12.87
5-10 years	10.97	7.72	11.06	12.07	11.82
Preweaning avg. daily gain					
Normal	.0068	.0103	.0087	.0077	.0063
6 years	.0081	.0114	.0095	.0077	.0068
5-10 years	.0078	.0109	.0092	.0077	.0066

APPENDIX TABLE 42. (CONTINUED)

	Age of dam				
	2	3	4	5-10	11
	<u>Model III Hereford</u>				
No. calves	171	221	224	702	61
Weaning weight					
Normal	323	434	418	405	351
7 years	420	506	452	405	380
5-10 years	412	506	452	405	380
5-10 years ^a	427	525	461	405	387
	<u>Model IIIa Hereford</u>				
No. calves	820	1015	905	2946	313
Weaning weight					
Normal	422	464	404	428	456
7 years	548	541	437	428	493
5-10 years	539	541	437	428	493
5-10 years ^a	558	561	445	428	503

^aIndustry recommended factors.

APPENDIX TABLE 43. LEAST SQUARES ANALYSIS OF VARIANCE FOR INDIVIDUAL SEXES - MODEL III -
ANGUS

Source	df	Mean squares				
		Birth weight	Preweaning gain	Weaning weight	Postweaning gain	Final test weight
Males						
Herd	3	334.7**	.7762**	44953**	2.171	193147**
Year/herd	23	50.2**	.1240**	6582**	5.454**	39643**
Sire/year/herd	108	17.7**	.0199**	592**	.029**	1795**
Age of dam	9	39.4**	.0469**	2893**	.005	2420**
Regression of weaning age -linear	1	13.0	.2283**	143176**	.261**	207321**
Remainder	956	8.9	.0065	347	.015	970
Females						
Herd	3	230.1	.2211	15364	2.400*	60893**
Year/herd	20	79.1**	.1095**	6176**	.199**	15307**
Sire/year/herd	97	14.5**	.0082**	448**	.012**	858**
Age of dam	9	33.4**	.2446**	1464**	.006	1422*
Regression of weaning age -linear	1	24.5	.2440**	43196**	.033*	42798**
Remainder	879	8.5	.0058	321	.006	585

**P<.01.

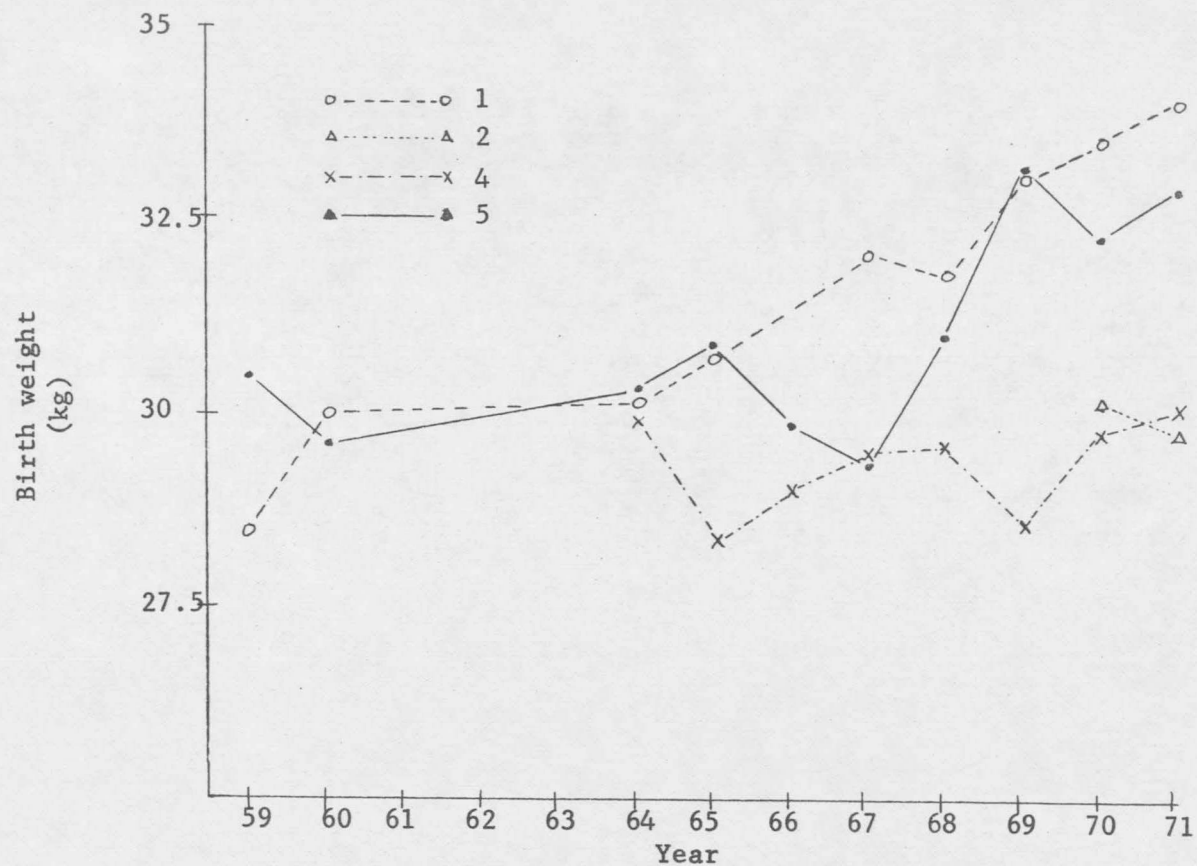
*P<.05.

APPENDIX TABLE 44. LEAST SQUARES ANALYSIS OF VARIANCE FOR WEANING
WEIGHT WITHIN EACH SEX - MODEL IIIa - HEREFORD

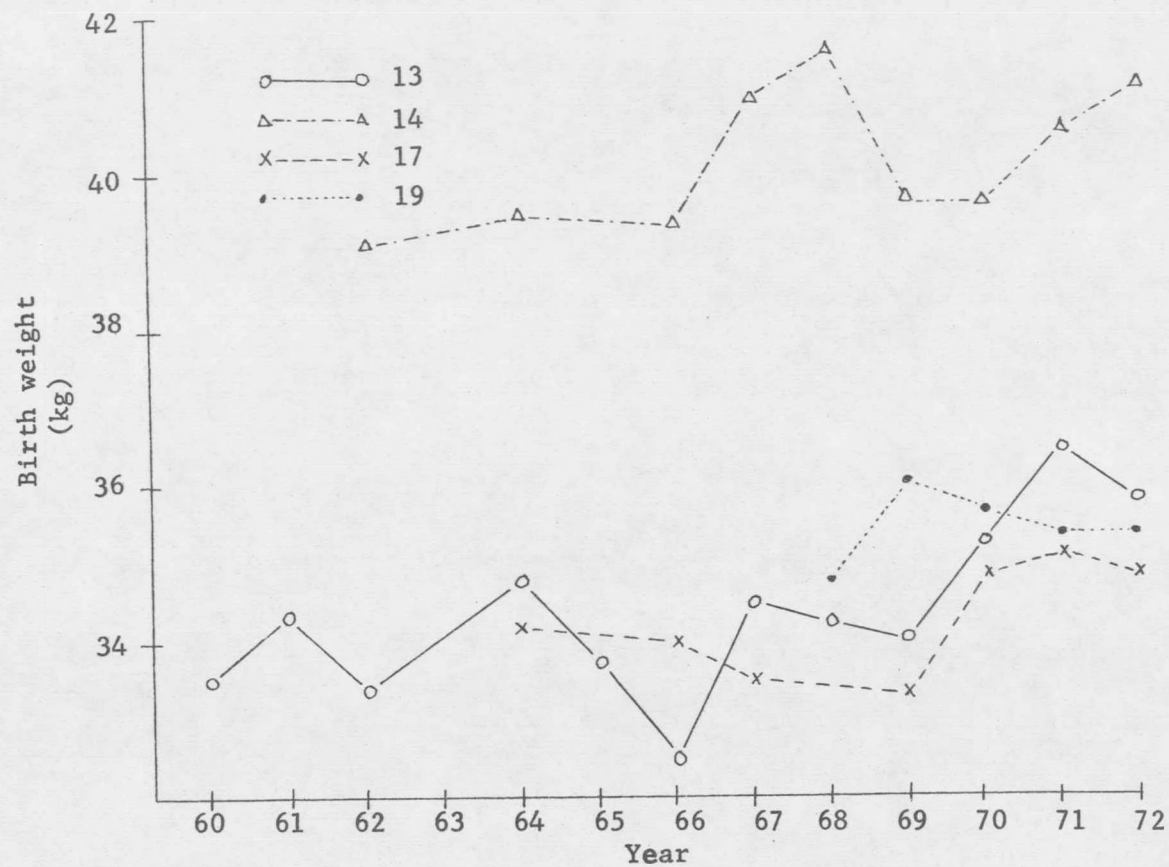
Source	df	Mean square
Males		
Herd	8	107550**
Year/herd	69	11112**
Sire/year/herd	356	844**
Age of dam	9	11543**
Regression of weaning age		
-linear	1	715553**
Remainder	3490	463
Females		
Herd	7	56939**
Year/herd	37	8193**
Sire/year/herd	180	609**
Age of dam	9	5569**
Regression of weaning age		
-linear	1	309529**
Remainder	1830	367

**P<.01.

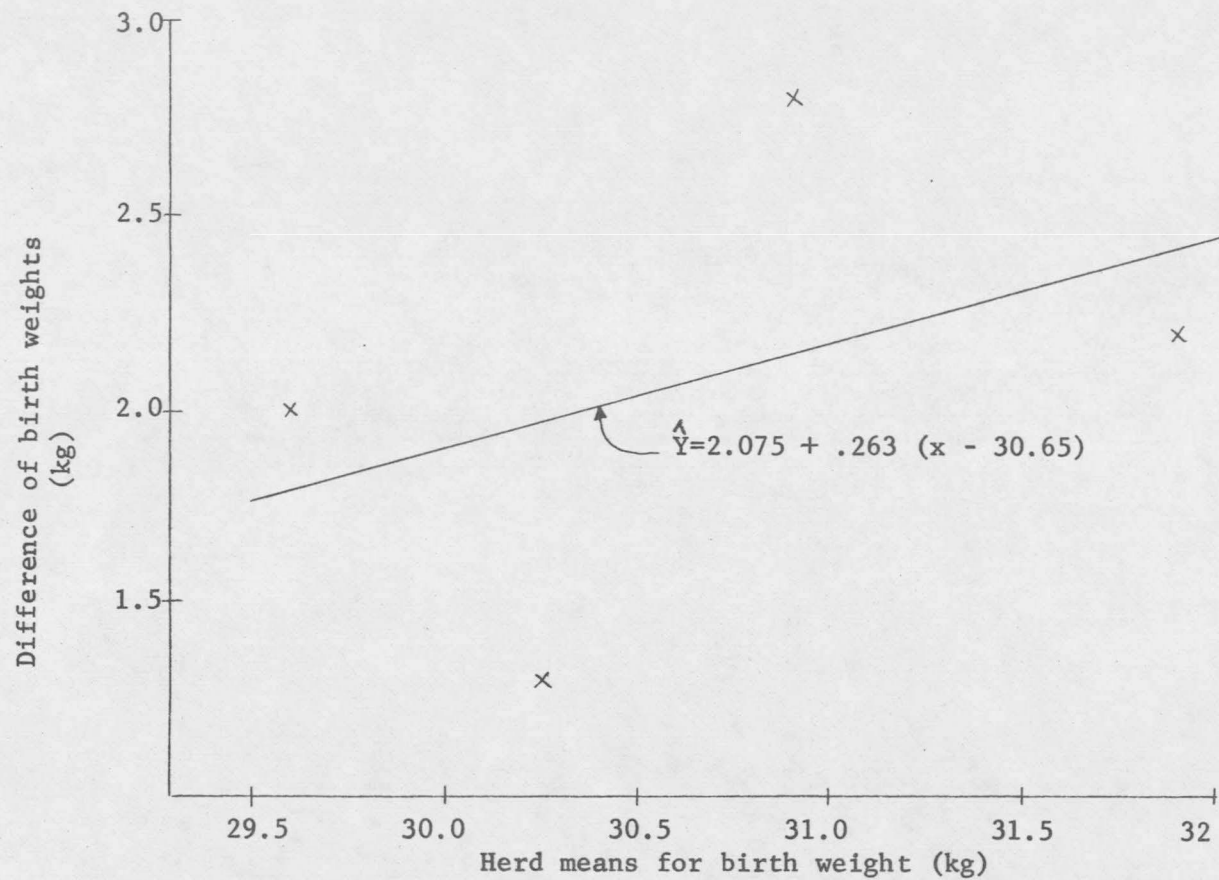
*P<.05.



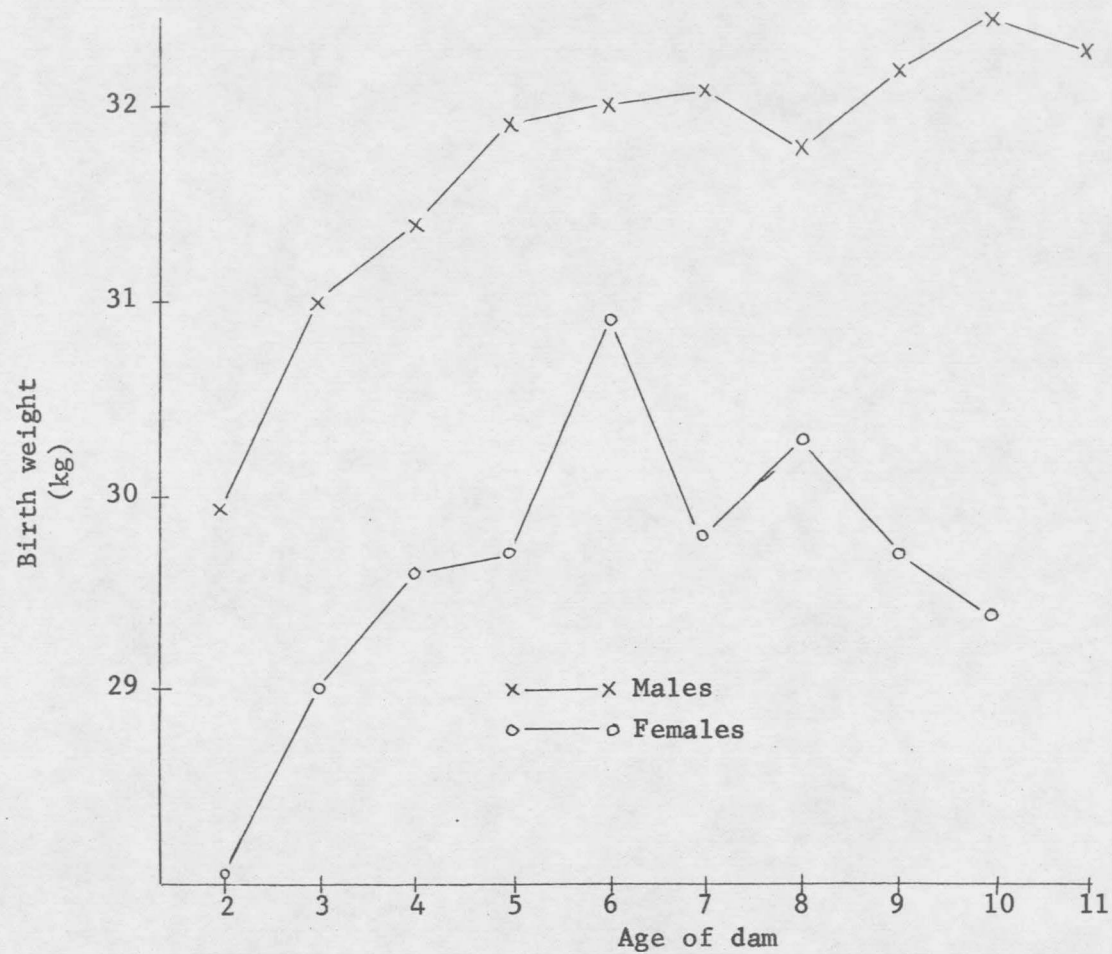
Appendix figure 23. Least squares means for birth weight by herd and year for Angus calves.



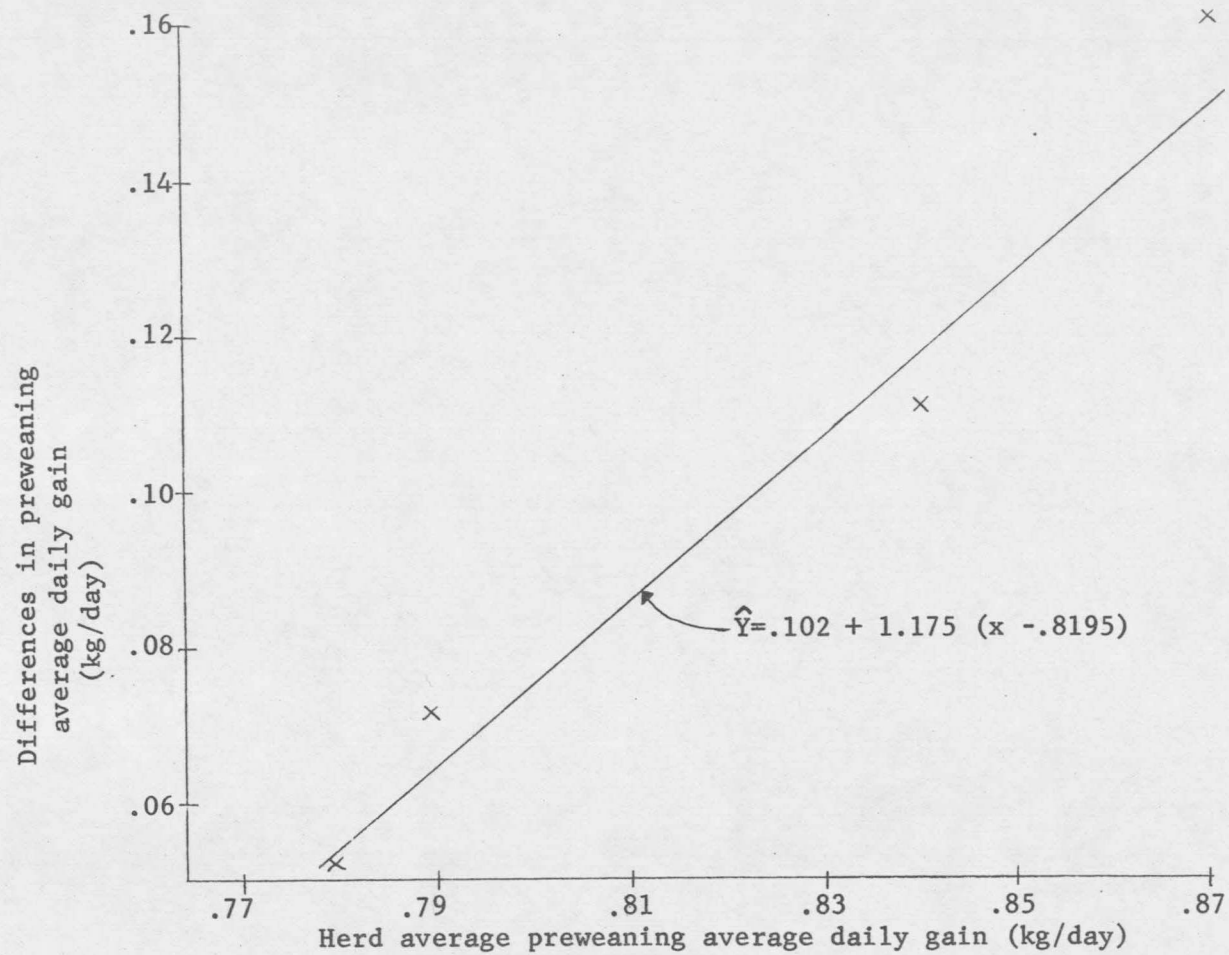
Appednix figure 24. Least squares means for birth weight by herd and year for male Hereford calves.



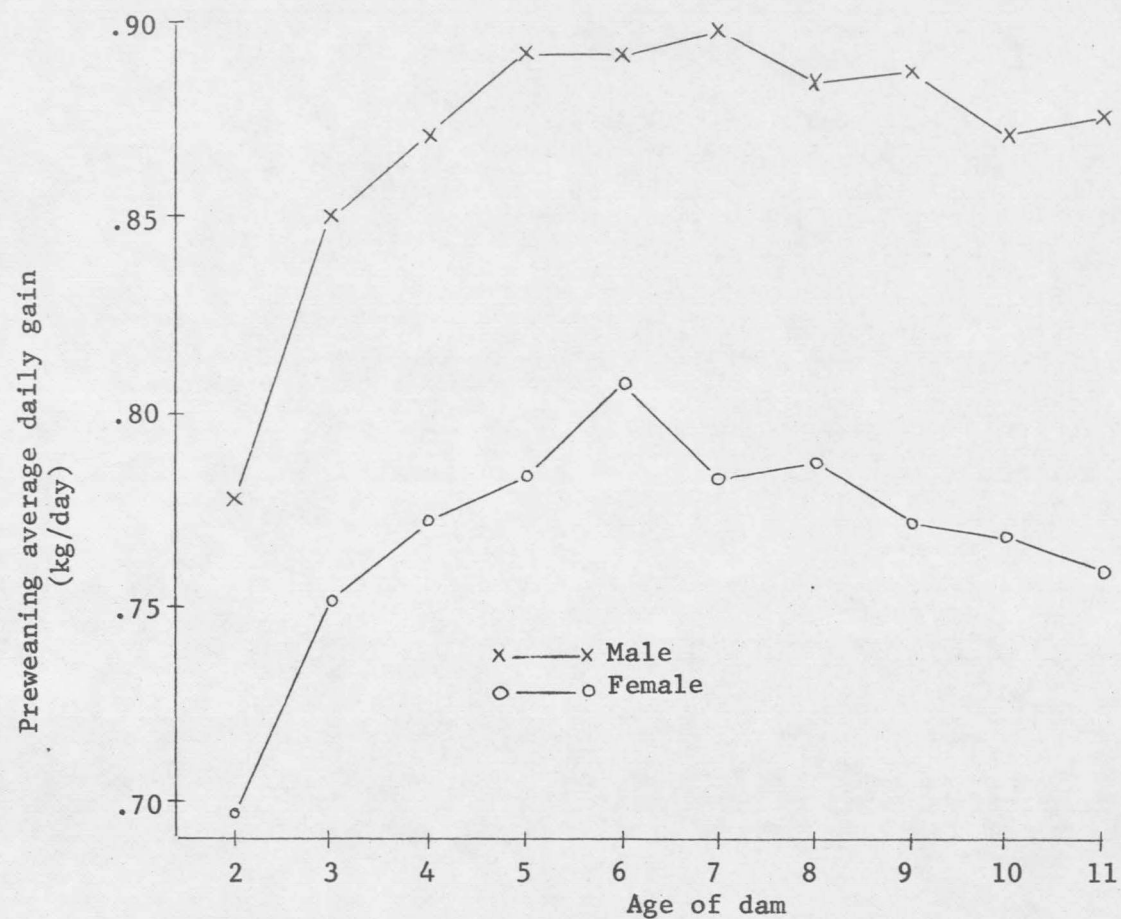
Appendix figure 25. Regression of the difference in the least square means for birth weight of male and female Angus calves on the least square herd means for birth weight.



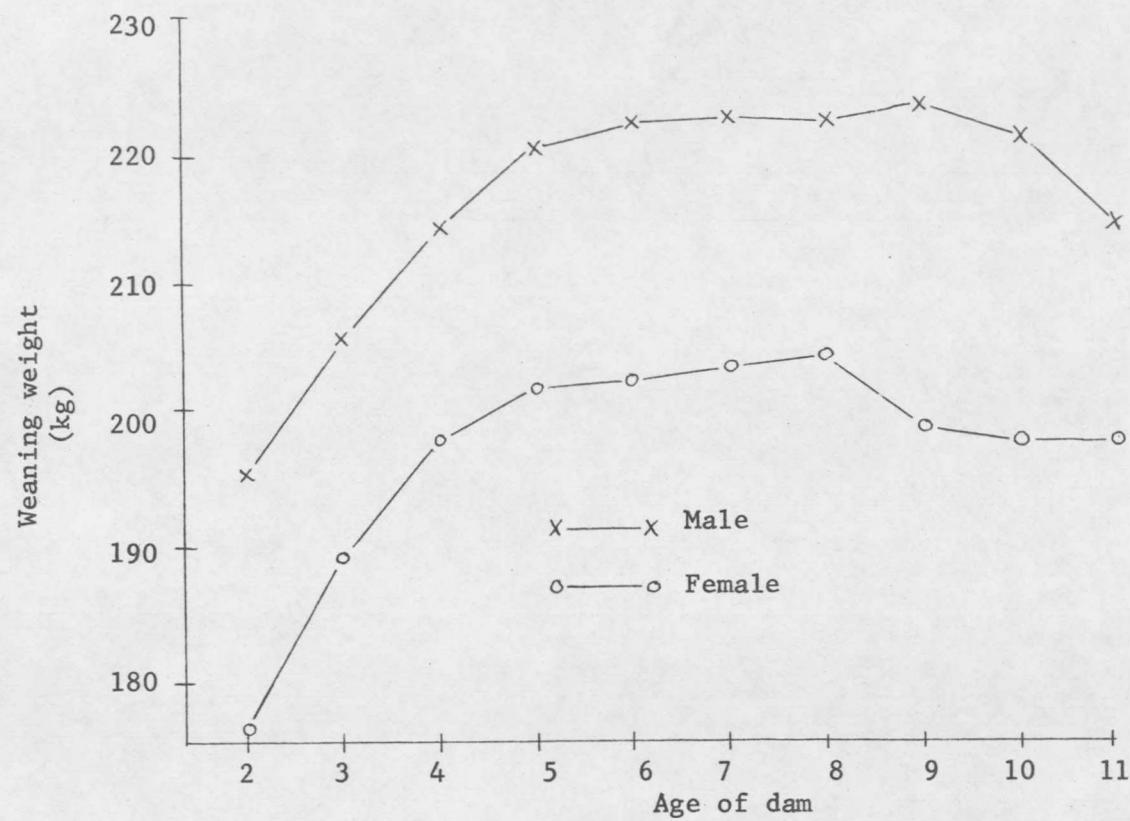
Appendix figure 26. Least square mean birth weights of Angus male and female calves by age of dam.



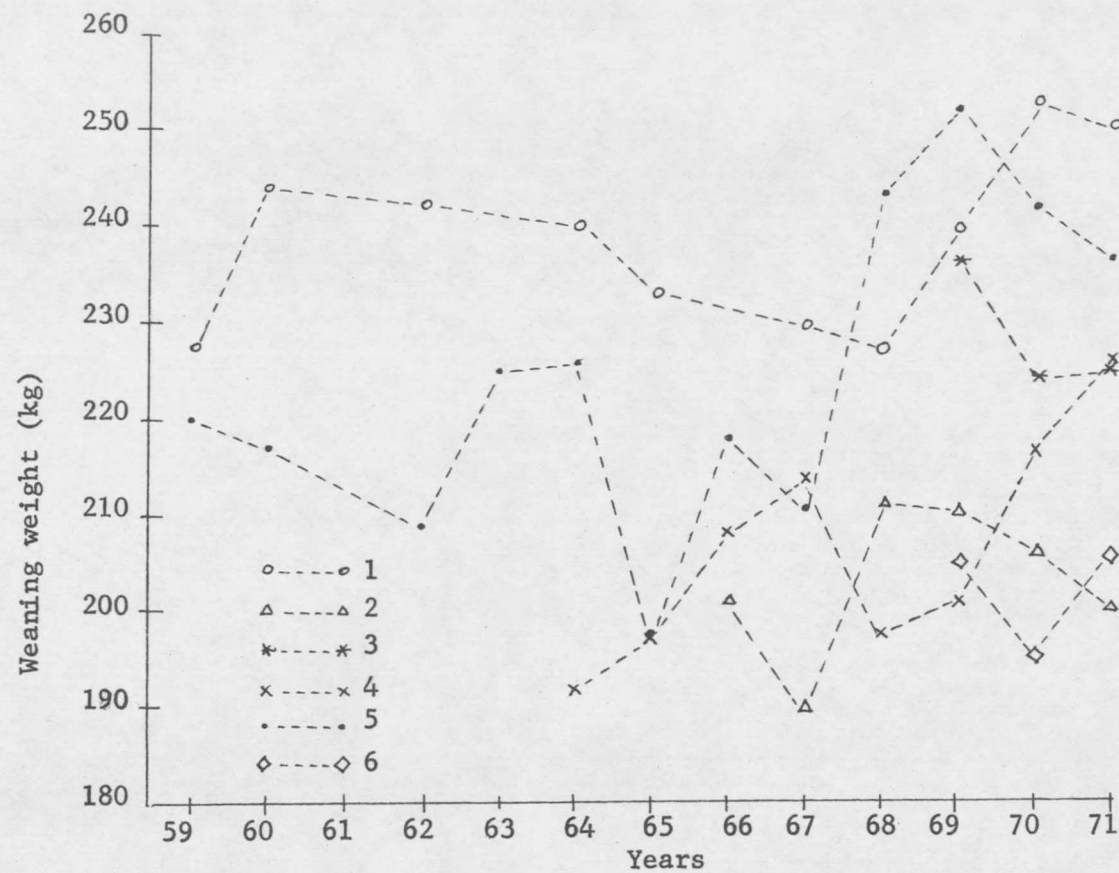
Appendix figure 27. Regression of the differences in the least square means for preweaning average daily gain of male and female Angus calves on the least square herd means.



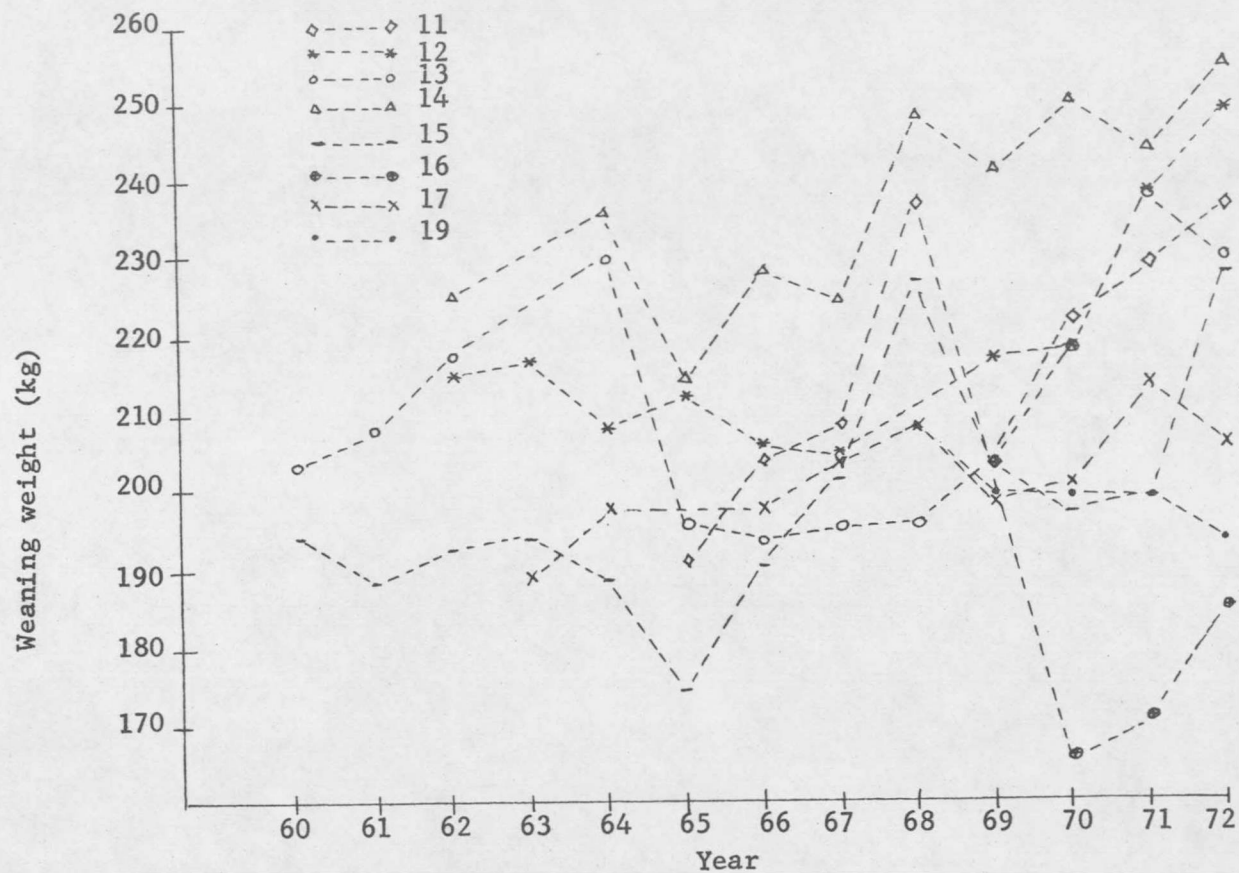
Appendix figure 28. Least square mean preweaning average daily gains for male and female Angus calves by age of dam.



Appendix figure 29. Least square mean weaning weights for male and female Hereford calves by age of dam.



Appendix figure 30. Least squares means for weaning weight for herd by year in Angus calves.



Appendix figure 31. Least square means for weaning weight for herd by year in Hereford calves.

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