

A PROPOSED GROWTH ANALYSIS IN BEEF CATTLE

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INTRODUCTION

Growth is one of the more important factors of efficient beef production. Rapid gains produce marketable beef at an earlier age on less feed which minimizes production costs. However, if rapid gains made early in life are genetically related to mature size, then some of the increased efficiency of production may be cancelled by increased maintenance cost of the breeding herd. The ideal beef animal is possibly one that makes maximum gains to a market weight of approximately 1,000 pounds with an adequate fat cover to maintain quality standards, yet has a minimal mature size that would be efficient to maintain under range conditions.

The purpose of this study was to develop a measure of the change in rate of growth or the point of inflection of the growth curve for individual bull and steer calves utilizing weights from birth to one year of age. Then the relationship of this measure to commonly used indices of growth will be studied hoping that this measure will aid in selection of animals having the most economical growth curve. The possibility of defining and fitting an individual growth curve allows for a method of evaluating an individual's growth potential from a combined consideration of all measured weights over various environmental conditions.

REVIEW OF LITERATURE

Growth is characteristically measured as a mass or weight change with respect to a time interval. It is a complex entity that is greatly affected by environmental conditions. Numerous definitions of growth have been formulated. Pomeroy (1955) defined growth, by quoting Schloss (1911), as "correlated increase in mass of the body in definite intervals of time in a way characteristic of the species." Brody (1945) defined growth as a relatively irreversible time change in the measured dimension. Maynard (1947) distinguished between "true growth" and fat deposition in adipose tissues. True growth represents the mass increase of muscle, bone and organs and is often difficult to distinguish from fattening. Considering these definitions, growth is an abstract entity.

Growth may be evaluated by plotting weight against age and establishing a growth curve (Pomeroy, 1955). The growth curve produced is roughly a sigmoid-shaped curve that is very similar for all farm mammals. The characteristic sigmoid shape is produced by two opposing forces, a growth accelerating force and a growth retarding force. At younger ages the growth accelerating force is dominant in producing rapid gains relative to the weight already attained. At older ages the growth retarding force becomes the dominant factor. The point of inflection in the growth curve corresponds to the age

when the growth curve comes under the influence of the growth retarding force rather than the accelerating force. The point of inflection occurs when the growth curve changes from an increasing function to a decreasing function. It is the point at which growth rate is at a maximum. Generally, the point of inflection is believed to coincide with puberty, which occurs in farm mammals after approximately 30 percent of the mature weight is attained (Brody, 1945). A growth curve is ultimately limited by the individual's genetic constitution for mature size. Suboptimal environmental conditions can affect mature size causing it to be less than genetically possible; whereas, optimum conditions can cause mature size to be greater than the genetic potential.

Hafez (1963) presented an evaluation of growth and factors affecting it as shown in Figure 1. Numerous studies have given evidence in support of the fact that growth is a complex variable greatly affected by extraneous conditions (Dickinson, 1960; Moore et al., 1961; Winchester, 1964; Marlowe and Gaines, 1958; Gilbert and Gregory, 1952; Lasley et al., 1961; Parish et al., 1962).

Swiger et al. (1962a) presented a list of important traits to consider in economical production of desirable beef. The traits listed were:

- (1) pre-weaning growth rate
- (2) post-weaning growth rate
- (3) efficiency of feed use
- (4) carcass composition and quality
- (5) reproductive ability.

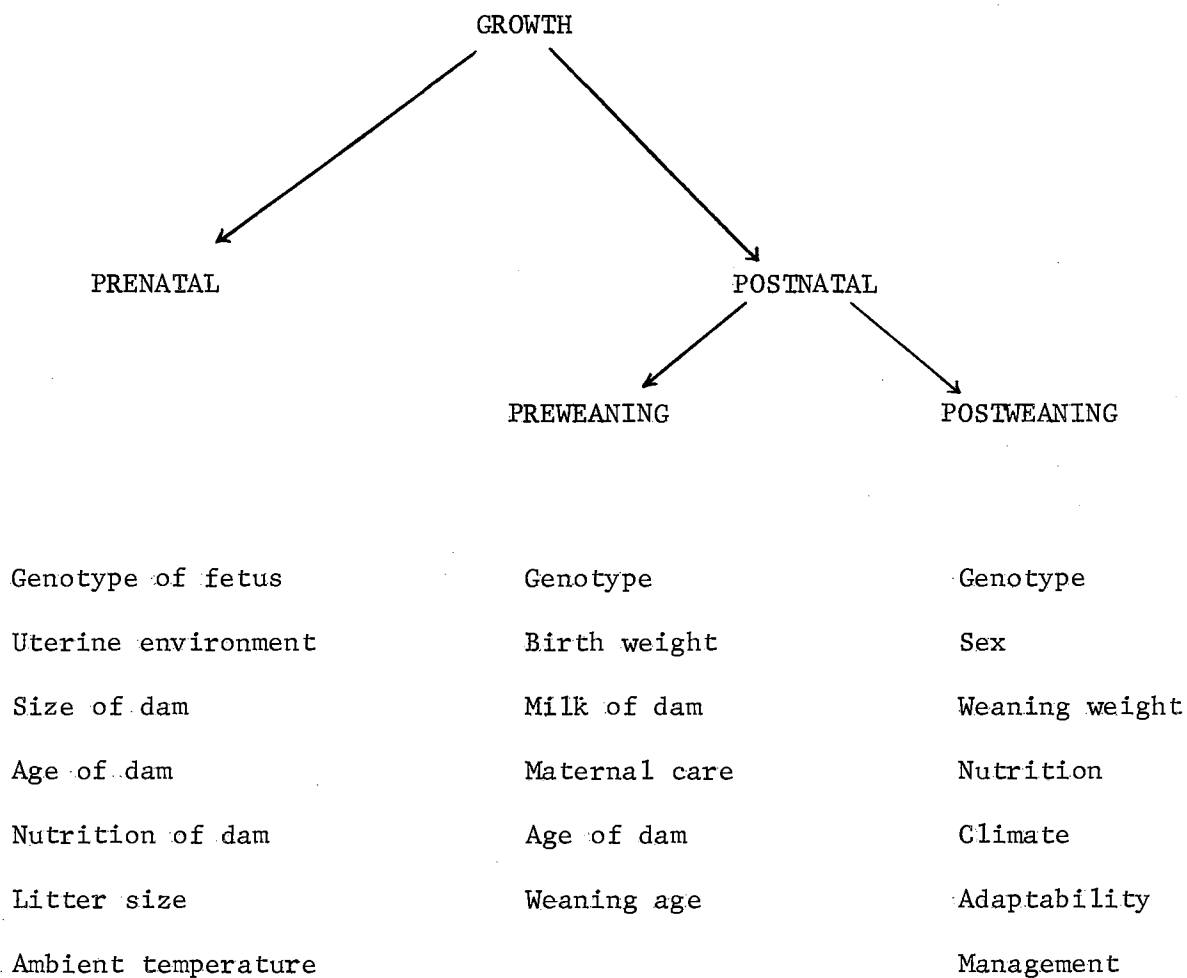


Figure 1. Summary of factors affecting prenatal, preweaning and postweaning growth in farm mammals from Hafez (1963).

Warwick (1958) stated that "an important objective of beef cattle breeding research is to estimate the genetic interrelationship of important traits in order that selection indices permitting maximum progress may be constructed." Considering these statements, it appears that not only could an estimate of an individual's growth curve and the point of inflection allow for subsequent size selection at an earlier date, but it could also yield a measure of economic importance, since the point of inflection represents the period of maximum gain.

An evaluation of economically important traits and their relationship to growth rate and subsequent size in feeding studies is required in order to determine the genetic control a breeder has over growth performance. Heritability estimates for specific traits relate the amount of genetic control available; whereas, the genic correlation between traits relates the amount of common gene control.

Birth Weight

Birth weight is a manifestation of the individual's growth potential (prenatal) and the environment provided by the dam (intra-uterine). Dickerson (1960) and Koch and Clark (1955a) stated that maternal effect is a factor to consider in evaluating birth weight. Dickerson (1960) stated that age of dam and the number of previous parities affect birth weight. Consideration of heritability estimates for birth weight reveals the relative importance of genetic and environmental causal components.

Numerous workers have reported heritability estimates for birth weight. Swiger (1961) reported an estimate of 0.22 in a study of 750 purebred Hereford calves in Ohio. Knapp and Clark (1950) and Koch and Clark (1955c) used data from the U.S. Range Livestock Experiment Station, Miles City, Montana, to obtain respective estimates of 0.53 and 0.44. Lasley et al. (1961) used data from Hereford calves raised by the San Carlos Apache Indian Tribe, San Carlos, Arizona, to obtain an estimate of 0.67. Warwick (1958) reported the mean estimate from the literature to be 0.41. Considering these estimates, it appears that birth weight, as a manifestation of prenatal growth, is largely under genetic control.

Lasley et al. (1961) obtained a genetic correlation of $0.93 \pm .07$ between intra-uterine and post-uterine growth using records of 414 Hereford calves. A genetic correlation of $0.99 \pm .01$ was obtained for birth weight and weaning weight. These correlations indicate that the genes responsible for prenatal growth are also responsible for postnatal growth to weaning.

Brinks et al. (1962a), in a study involving 1,029 bulls at the Miles City Station, obtained a genetic correlation of 0.75 between birth weight and final weight at the end of a 196-day postweaning feedlot period. Brinks et al. (1964) observed similar genetic correlations of 0.61 and 0.68 between birth weight and mature spring and mature fall weight, respectively, in Hereford females. Brinks et al. (1962a) obtained genetic correlations of birth weight with 180-day gain (preweaning gain), 180-day weaning weight, and 196-day gain (postweaning gain) of 0.11, 0.21 and 0.71. Similarly, Brinks et al. (1964) obtained genetic correlations of birth weight with

gain (birth to weaning), weaning weight, and gain (weaning to 12 months) in Hereford females of 0.46, 0.60 and 0.07.

Collectively, these studies indicate that birth weight can be genetically controlled by the breeder and that it is related to subsequent size under similar environmental conditions.

Preweaning Growth Rate

Preweaning growth rate, measured as average daily gain from birth to weaning, has considerable economic value. Weaning weight is a relative measure of preweaning growth rate in that it represents the sum of birth weight and gain to weaning age. However, it is well documented that weaning weight is affected by such variables as: age of dam, sex, season of birth and type of management (Cundiff, 1965). Swiger et al. (1962b) found that age of dam had a curvilinear effect on gain from 130 to 200 days of age. Work by Rollins and Guilbert (1954) demonstrated the importance of milking ability on suckling gain. Therefore, several environmental factors are associated with measures of weaning weight or preweaning growth rate. The results of Brinks et al. (1964) demonstrate the relationship between preweaning growth rate (gain) and weaning weight. Heritability estimates for preweaning gain and weaning weight were 0.40 ± 0.06 and 0.43 ± 0.06 , respectively. A genetic correlation of 0.99 was obtained between these two traits. Comparisons of genetic correlations of these two traits with others in the study showed close similarity yielding further evidence. Koch and Clark (1955b) reported heritability estimates of 0.11 and 0.07 for weaning weight and gain

from birth to weaning, respectively, which again reveals the close similarity (magnitude) of estimates. Numerous workers have presented heritability estimates of weaning weight that range from 0.11 to 0.43 (Pahnish et al., 1961; Lasley et al., 1961; Koch and Clark, 1955b; Knapp and Clark, 1950; Swiger et al., 1963). Warwick (1958) obtained a mean estimate of 0.30 from 26 reference sources. Therefore, it appears that the breeder has less genetic control over weaning weight than birth weight. Biologically, it is understandable in that maternal influence (milking ability) has a larger influence on weaning weight. The maternal effect is environmental relative to the calf and, therefore, causes a larger portion of the weaning weight variance to be due to environmental conditions.

Brinks et al. (1964), in a study of Hereford females from the Miles City Station, found genetic correlations of 0.52 and 0.41 between gain (birth to weaning) and mature spring and mature fall weight, respectively. The genetic correlations of weaning weight with mature spring and fall weight were 0.59 and 0.51, respectively. Brinks et al. (1962a), using records of 1,029 Hereford bulls, obtained a genetic correlation of 0.54 between gain to 180 days of age and final weight after a 196-day feedlot period. These results indicate that as the animal grows from birth more environmental factors are associated with subsequent gains and weights to weaning age. The dam not only exerts influence by the genes she transmits, but also by the environment she provides to weaning age (Koch and Clark, 1955a). However, the genetic correlations between gain (birth to weaning) and weaning weight with mature size do indicate that larger weaning weights and gains (birth to weaning) may be genetically

associated with mature size.

Postweaning Growth Rate

Postweaning growth rate is another growth performance measure that is related to ultimate size attained. Any subsequent weight reached by an animal is the sum of his initial weight plus the gain (growth rate) to the measured weight. Postweaning growth rate is perhaps the most economically important character to the cattle feeder and, as such, has received considerable attention. Many studies of feedlot performance have indicated that faster gaining animals make more efficient use of feedstuffs (Rollins et al., 1962; Lickley et al., 1960; Pepito, 1961; Pierce et al., 1954; Koch et al., 1963; Brown and Gifford, 1962).

Heritability estimates of postweaning growth rate are higher than preweaning growth rate. Warwick (1958) presented an average estimate of 0.45. Consideration of the general standardized environment of feedlot tests and the independence of the calf from his dam allows for less environmental conditions to contribute variation in postweaning growth rate. This would cause higher heritabilities.

The genetic interrelationship of postweaning growth rate or gain to other growth performance measures has been established by various workers. Brinks et al. (1962a) observed genetic correlations of 0.71, -.08, 0.06, and 0.76 between 196-day feedlot gain and birth weight, 180-day preweaning gain, 180-day weaning weight and final feedlot weight, respectively, in Hereford bulls. Brinks et al. (1964), using Hereford female performance records, established

genetic correlations of 0.07, -.23, -.20 and 0.35 between gain (weaning to 12 months) and birth weight, gain (birth to weaning), weaning weight and mature fall weight, respectively. Swiger et al. (1962a) obtained a genetic correlation of 0.47 between average daily gain in the feedlot and weaning weight. A genetic correlation of -.32 was obtained between weaning weight and days from weaning to 1,000 pounds.

It is established that a measure of postweaning growth rate is genetically related to subsequent size. Faster gaining animals require less time to reach standard market weights, and this may be indicative of the relative mature size of the animal. Therefore, knowledge of the relative mature size could indicate the relative growth performance at various ages for individual calves under standard environmental conditions.

Yearling Weight

Since yearling weight is a manifestation of any previous weight plus gain over a given time interval, one can logically assume that gaining ability is manifested in all weights taken from birth to maturity. The environmental conditions affecting any particular weight may inhibit accurate size selection.

Heritability estimates for yearling weight of 0.74, 0.86, 0.41 ± 0.06 , 0.48, 0.77, 0.84 and 0.43 have been reported by Swiger (1961), Knapp and Clark (1950), Brinks et al. (1964), Brinks et al. (1962), Shelby et al. (1960), Shelby et al. (1955), and Koch and Clark (1955b), respectively. These estimates indicate that mass

selection would be effective in improving yearling weight. The standardized feedlot environment and conditions associated with measures of yearling weight cause less of the total variation to be due to environmental sources. Since it has been established that growth rate measures are genetically related to subsequent size, selection for yearling weight could improve growth performance.

Mature Size

Mature size is attained when the structural growth potential ceases to exist. Seasonal and environmental conditions can greatly affect the relative size measures of aged animals. Therefore, mature size is a relative weight. Mature size is most often measured as an average of several seasonal weights.

Heritability estimates for mature size, measured as an average of fall and spring weights, of 0.57 ± 0.11 and 0.73 were reported by Brinks *et al.* (1964) and Brinks *et al.* (1962b). An estimate of 0.72 ± 0.22 was obtained by Lickley *et al.* (1960) when an average of the August weights at ages of 4, 5 and 6 years were used to estimate mature size. These estimates yield evidence that mass selection for mature size can be effective.

High genetic relationships between postweaning growth rate and mature size have been established by Brinks *et al.* (1964) and Lickley *et al.* (1960). Gregory (1965) stated that it is logical to assume that genetically larger cattle produce calves with above average growth impulse. This implies that size selection should be effective in promoting related growth performance.

General Considerations

The feasibility of shortening the postweaning feeding test from size selection has been reviewed by several workers (Swiger and Hazel, 1961; Swiger et al., 1961; Swiger et al., 1963; Knapp and Clark, 1947; Urick et al., 1957; Ruby et al., 1948; Alexander and Bogart, 1961). Collectively, they indicate that a high genetic relationship existed between successive weights and gains at various ages and periods. Environmental factors notably affected weights at younger ages to a greater extent than weights at older ages obtained from feeding tests. Therefore, selection for growth performance (weight) at younger ages is not considered as efficient as selection at heavier weights and older ages.

Fitting of individual growth curves has generally been done by fitting smooth curves of various models to a complete set of observed weights at corresponding ages from birth to maturity. Brody (1945) essentially fitted two successive exponential curves to observed weights from conception to the "observed" point of inflection, puberty, and weights from puberty to maturity. An increasing exponential was fitted in the first phase and a decreasing exponential in the second phase. The exponential equation used was: $W = Ae^{\beta t}$. W represents any weight at time t and A and β are parameters.

Pearl (1927) and Nair (1954) represented various procedures for fitting a logistic curve to describe a population's or an individual organism's growth. The general equation is:

$$W = \frac{k}{1 + me^t}$$

where:

W = weight

m = parameter

k = limiting size

t = time.

However, the logistic curve does not lend itself to biological application for estimating the point of inflection due to its symmetry.

It makes the point of inflection occur at one-half the limiting size.

Pearl (1927) reported on the use of an asymmetrical logistic curve to describe individual growth. The equation of the curve is:

$$W = \frac{k}{1 + me^{a_0 t} + a_1 t^2 + a_2 t^3}$$

where:

W = weight

a_0 = parameter

k = limiting size

a_1 = parameter

m = parameter

a_2 = parameter.

t = time

The logistic equations require that k, the limiting or mature size, be known in order to estimate the parameters of the equations. The mathematical evaluation of the point of inflection is found by taking the second derivative of the equation with respect to t and setting it equal to zero and solving for t.

Figure 2 demonstrates the typical asymmetrical growth curve and point of inflection as presented by Pearl (1927).

Most methods of fitting logistic curves require that observations be spread over the entire range and that they be equally spaced on the time scale.

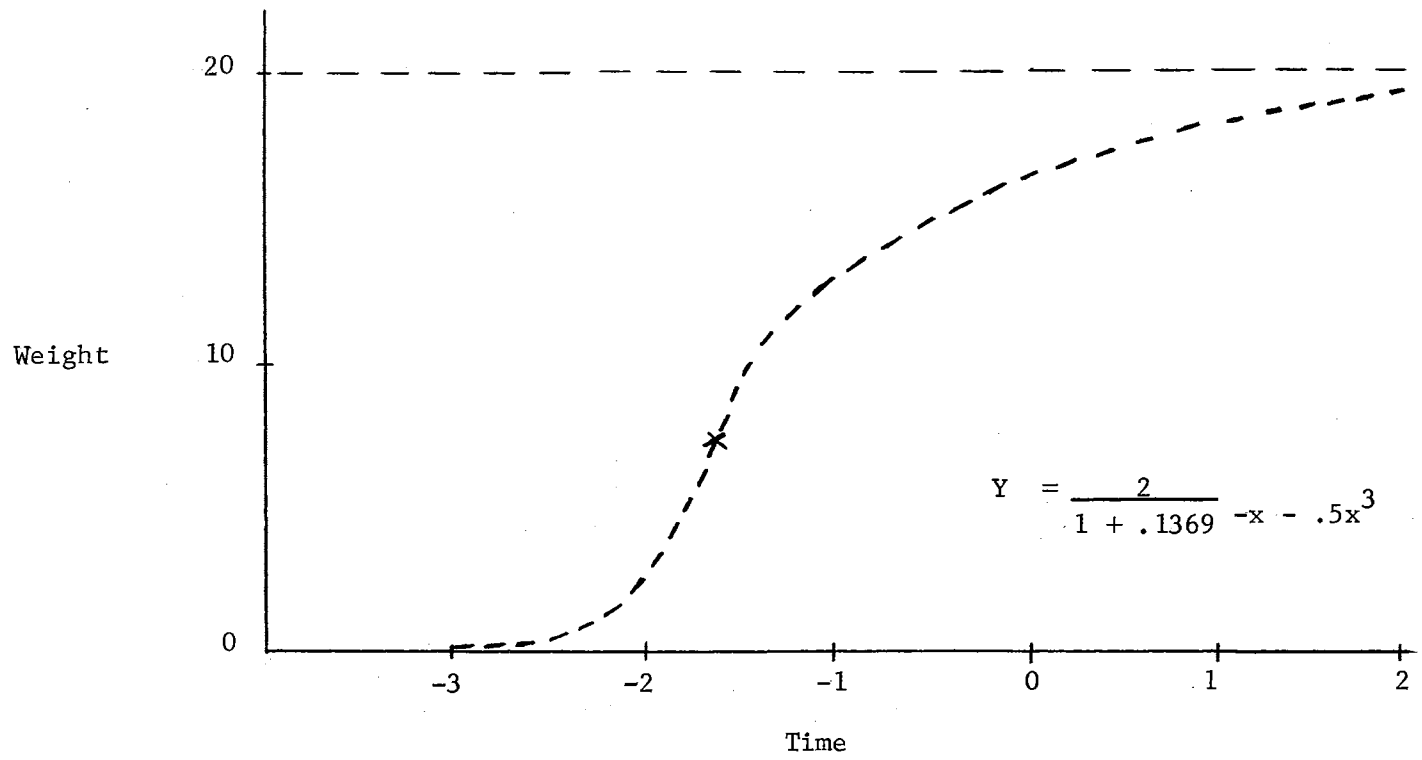


Figure 2. Typical asymmetrical growth curve after Pearl (1927).

MATERIALS AND METHODS

Data

The data used in this study were successive liveweight measures from birth through a 168-day postweaning feeding test of approximately 870 bull and steer calves tested at the Fort Reno Livestock Research Station, El Reno, Oklahoma. The station is operated jointly by the Oklahoma State University and the Animal Husbandry Research Division, A.R.S., U.S.D.A. Data were collected over a five-year period from 1960 through 1964 from Angus, Hereford and some crossbred beef calves of these two breeds. Individual performance records of each calf were classified by year, sex, breed, sire, dam and age of dam (months). All calves were spring dropped.

Liveweight measures and corresponding ages of each calf were recorded at varying time intervals. The first measure was birth weight and the second, weaning weight. All calves were generally placed on feeding test immediately at weaning and successive 28-day weights taken during a 168-day feeding period. Most calves were weighed on 14-day intervals during the last 28-day period in order to obtain an average 154-day feedlot weight. Therefore, either eight or nine corresponding weights and ages from birth through a 168-day feeding period were available on each calf.

Methods of Fitting Growth Curves

Many measures have been used in evaluating growth. Such variables as average daily gain, weight per day of age, age adjusted weaning weight and age adjusted yearling weight have been utilized. A common characteristic of any growth evaluating variable is that the variable is a function of liveweight with respect to a time dimension. A consummate growth analysis is ultimately attained by observing corresponding liveweights and ages from birth to maturity.

Some methods of fitting growth curves have been reviewed, but the data available do not lend themselves to any previously proposed method due to unequal time intervals between weights and the limited range of weights with respect to mature size.

Two methods of fitting growth curves were proposed in this study. The first method utilized a least squares procedure presented by Hartley (1965) that allows for use of a logistic curve. The asymmetrical logistic curve described by Pearl (1927) was chosen as a suitable model due to its biological significance toward asymmetrical growth response. The procedure of fitting the asymmetrical logistic curve is involved and requires extensive mathematical evaluations and extrapolations. The asymmetric logistic curve equation is:

$$Y = \frac{k}{1 + ce^{a_1x + a_2x^2 + a_3x^3}}$$

where:

Y = weight

x = age in days

k = mature size (parameter)

c = constant (parameter)

a_1 = parameter

a_2 = parameter

a_3 = parameter.

This equation has five parameters that must be estimated.

The original equation can be modified by taking the reciprocal of each side

$$\frac{1}{Y} = \frac{1+c e^{a_1x + a_2x^2 + a_3x^3}}{k}$$

and transposing $1/k$ to the left hand side.

$$\frac{1}{Y} - \frac{1}{k} = \frac{c}{k} e^{a_1x + a_2x^2 + a_3x^3}$$

By taking the natural logarithm of the equation a linear function is obtained:

$$\ln \left[\frac{1}{Y} - \frac{1}{k} \right] = \ln(c/k) + a_1x + a_2x^2 + a_3x^3.$$

This equation can be considered as a linear model of the form:

$$W = \beta_0 + \beta_1X + \beta_2X^2 + \beta_3X^3$$

where:

$$W = \ln(1/Y - 1/k)$$

$$\beta_0 = \ln(c/k)$$

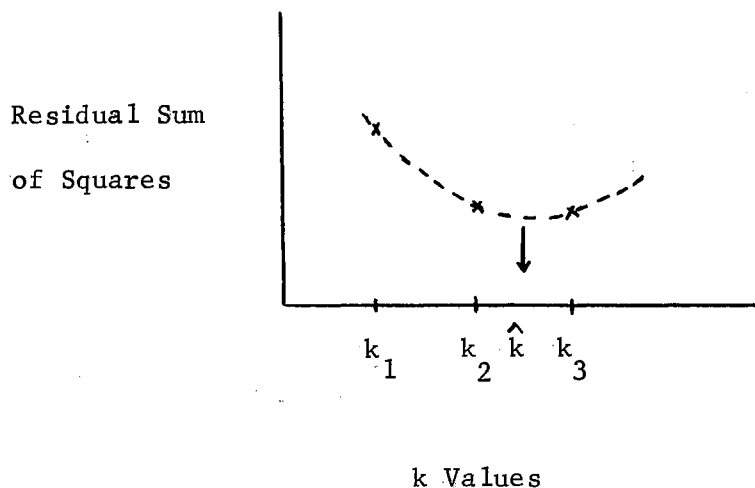
$$\beta_1 = a_1$$

$$\beta_2 = a_2$$

$$\beta_3 = a_3.$$

To utilize this model, k must be known or estimated for each calf. The least squares procedure presented by Hartley (1965) allows

for an estimation of k . Three values of k are chosen that cover the range of mature size. Each k is then used in the linear model and by regression analysis the reduction and residual sums of squares due to regression are obtained. After all three selected values of k are used in the model, the residual sums of squares are compared and fitted to a parabola to estimate a \hat{k} , that will yield a minimal residual. An assumption is made that these quantities do graph into a parabola. The graphic representation is:



The estimated k , \hat{k} , was obtained from the formula:

$$\hat{k} = \frac{\Delta(Q_1 - Q_3)}{2(Q_1 - 2Q_2 + Q_3)}$$

where:

Δ = interval between selected k values

Q_1 = residual sum of squares for lowest k chosen

Q_2 = residual sum of squares for the second k chosen ($k_1 + \Delta$).

Q_3 = residual sum of squares for the third k chosen ($k_2 + \Delta$).

After having estimated k , the estimated \hat{k} is substituted into the logistic curve linear model and estimates of the regression coefficients ($\beta_0, \beta_1, \beta_2, \beta_3$) obtained. One is able to estimate c from the relationship:

$$\beta_0 = \ln(c/k)$$

since k is equal to \hat{k} . The other β 's are direct measures equivalent to the a_i 's, $i = 1, 3$, in the original equation.

Having estimated the asymmetric logistic growth curve for each calf, the point of inflection has to be obtained by an iterative computer program that compares the second derivative of the asymmetrical logistic curve equation for varying ages. The point of inflection is that age at which the second derivative changes sign. No direct measure can be obtained by solving due to the mathematics involved. This procedure of defining the growth curve, estimating k , and the point of inflection requires extensive extrapolations of the original data and some assumptions.

The second method utilized was one of fitting four average age and liveweight measures to a polynomial model. The model assumed was:

$$Y_{ij} = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \beta_3 x_i^3 + e_{ij}$$

where:

Y_{ij} = liveweight at i^{th} age and j^{th} observation

X_i = age in days

e_{ij} = random error assumed normally distributed with mean zero and variance, σ_e^2 .

In an attempt to eliminate weighing errors associated with any single observed weight, four selected average weights and ages were computed as observations for fitting the model. These four measures were:

- (1) birth weight
- (2) average weight and age of second and third original observations
- (3) average weight and age of fourth, fifth and sixth original observations
- (4) average weight and age of seventh, eighth and ninth original observations.

Since four sets of observations were fitted to a linear model with four parameters, no error term for residual sum of squares is available. The fitted curve passes directly through the four selected observations. This procedure was employed hoping that weigh-period errors would be minimized in fitting the polynomial growth curve model. This particular model allows for a least squares fit to a curve that has a second derivative that is easily obtained. The mathematical evaluation of the point of inflection (second derivative) is obtained by taking successive derivatives with respect to X, age. The first derivative of the general model equation is:

$$f' = \beta_1 + 2\beta_2 X + 3\beta_3 X^2.$$

The second derivative is obtained by taking the derivative of the f' equation with respect to X. The second derivative is thusly:

$$f'' = 2\beta_2 + 6\beta_3 X.$$

Setting the second derivative equal to zero and solving for x will yield a measure of the point of inflection. It is mathematically evaluated as:

$$x = -1/3 \beta_2/\beta_3.$$

The second method of fitting the growth curve allows for a direct measure of the point of inflection; however, the model used does not allow for application of the curve beyond the limits of the data. This particular model fits a cubic curve to the data; and outside the limits of the data, the curve has no biological significance. A graphic representation of fitting this growth-curve model is presented in Figure 3.

Variables

Six variables were selected for analysis in this study. They were birth weight, adjusted weaning weight, adjusted yearling weight, the point of inflection and predicted yearling weight from the estimated growth curve (using the second procedure) and yearling condition score.

Birth Weight

Birth weight was directly obtained from the original data. Additive correction factors after Koch and Clark (1955a) were utilized to correct birth weight for the effect of age of dam. Factors of 4, 2 and 0 pounds were designated for calves produced by cows with respective ages of less than 3, 4 and 5 or more years.

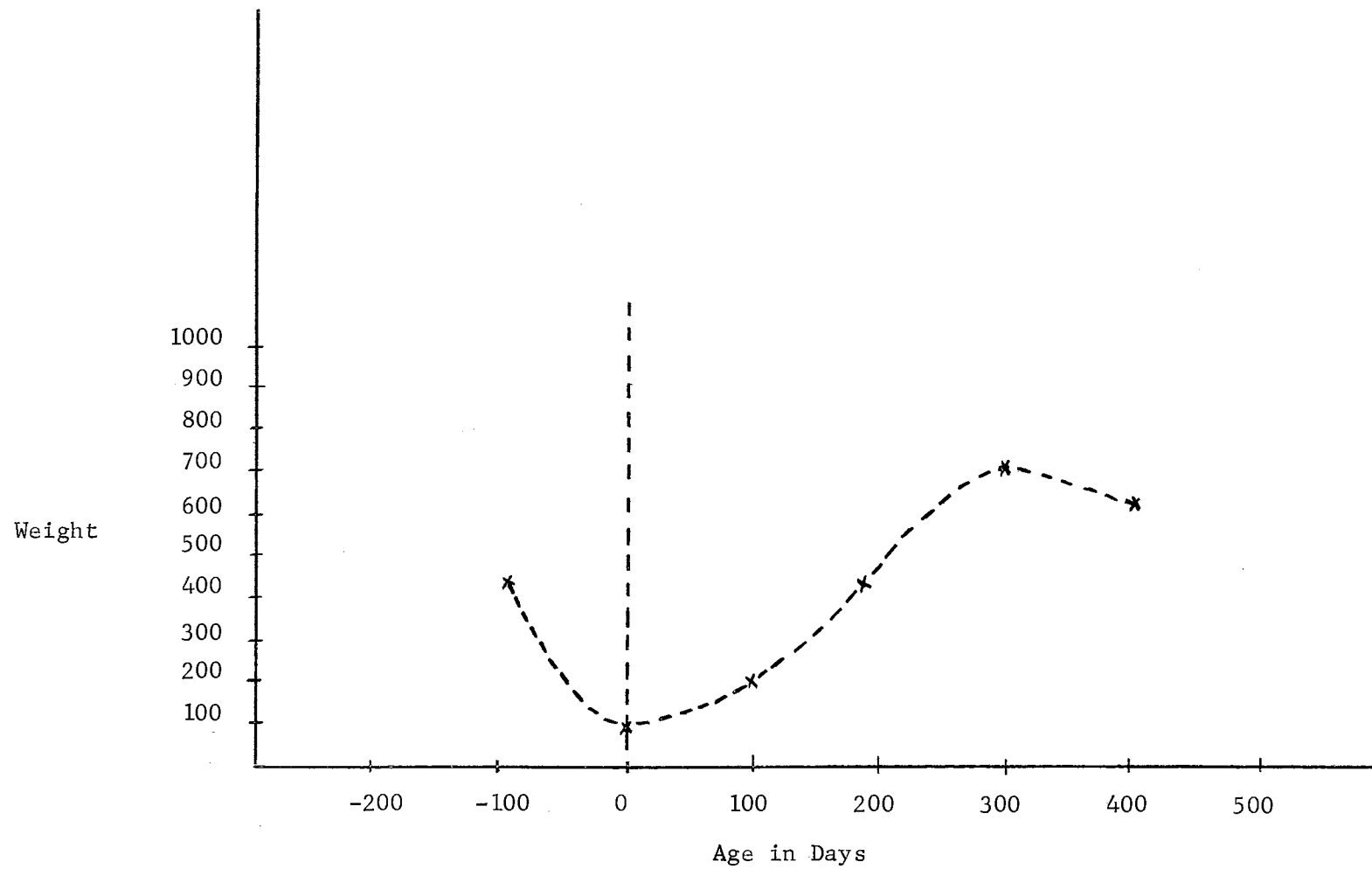


Figure 3. A growth curve as fitted by the linear polynomial model.

Adjusted Weaning Weight

Actual weaning weight was taken as the second of the successive liveweight measures in the original data. Adjustment of this weight to a standard 205 days was done by the following formula:

$$\text{205-day weight} = \left(\frac{\text{actual wt.} - \text{birth wt.}}{\text{age in days}} \times 205 \text{ days} \right) + \text{birth weight.}$$

The resulting 205-day weaning weight was adjusted for the effect of age of dam by multiplicative factors as adopted by the U.S.D.A. Federal Extension Service Beef Cattle Record Committee. These factors are presented in Table I.

Table I

Multiplicative Adjustment Factors for Age of Dam Effects
on 205-Day Weaning Weight

Age of Dam (Years)	Factor
2	1.15
3	1.10
4	1.05
5-10	1.00
11-over	1.05

Adjusted Yearling Weight

Adjusted yearling weight is a constructed variable that was calculated by the formula:

$$\text{adjusted yearling weight} = \text{postweaning average daily gain} \times 160 \text{ days} + \text{205-day weaning weight adjusted for age of dam.}$$

Postweaning average daily gain was obtained by the formula:

$$\text{postweaning average} = \frac{\text{final feedlot wt.} - \text{actual weaning wt.}}{\text{daily gain} \quad \text{number of days between weights}}$$

This measure of yearling weight (365 days of age) is considered adjusted for the effects of age of calf and age of dam through use of the 205-day adjusted weaning weight value.

Yearling Condition Score

Yearling condition score was measured by visual appraisal of the calves upon completion of the 168-day feeding period. A committee of three judges scored each calf on the relative amount of finish. A numerical scale of 15 points was used where 8 represented an estimated "Good" quality score and one point intervals represented each one-third of a grade. The score for each calf was an average score from the three judges. This variable was selected for analysis in an attempt to estimate the relative amount of fat associated with the yearling weight and to see if condition was related to the point of inflection.

Point of Inflection

The point of inflection in days is the variable associated with the respective estimated growth curve as fitted to the original data. It was hoped that it would represent the age of maximum gains and to be genetically related to subsequent size. This variable is classified by year, breed, sex, sire, dam, age of dam, and age of calf. Considering the two proposed methods of defining the growth curve, two estimates might have been obtained.

Predicted Yearling Weight

Predicted yearling weight is a calculated value that was obtained by estimating the liveweight at 365 days of age using the fitted growth curve. It is a relative measure to the model fitted and should be comparable to the adjusted yearling weight directly calculated.

General Observations

Birth weight, adjusted weaning weight and adjusted yearling weight are adjusted for the effects of age of calf and age of dam. Yearling condition score, the point of inflection and predicted yearling weight are not adjusted for these effects. Adjustment procedures utilizing the regression models:

$$a) Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

$$b) Y = \beta_0 + \beta_1 X_1 + \beta_{11} X_1^2 + \beta_3 X_2 + \beta_4 X_2^2$$

where

Y = observed variable

X_1 = age of dam (months)

X_2 = age in days

$\beta_i, i = 0, 4$ = parameters

were employed to account for linear and quadratic adjustments if needed. Following the necessary adjustments, the data were classified by year, breed, sex and sire. Through use of an hierarchical classification, the among-sire component within year, sex and breed

was obtainable for estimation of genetic variances and covariances.

Statistical Analyses

All statistical analyses were carried out by use of a 1410 IBM computer located at the Oklahoma State University Computing Center. Fortran IV was the programming language employed. Proposed statistical analyses included estimation of the heritabilities of the six variables by use of the half-sib intra-class correlation method and determination of genetic and environmental correlations between variables.

Fundamental application of the analysis of variance was employed for estimation of genetic and environmental variances and covariances. A standard library program for computing an hierarchical classification analysis of variance was available at the Oklahoma State University Computing Center. A complete analysis of variance was obtained through use of the program. All expected mean square variance component coefficients were listed with the tabular analysis of variance obtained.

Estimation of genetic and environmental variances and covariances requires estimation of observational components of variance, among-sire and within-sire components, from the analysis of variance and equating these observational components to causal components. The among-sire component is related to the genetic causal component from a consideration that each sire mean of a group of half-sibs represents one-half the breeding value of that sire. The genetic variance is considered to be the variance of breeding values.

Therefore, the among-sire component represents one-fourth the additive genetic variance. The within-sire component represents the environmental variance and three-fourths the genetic variance from a consideration of the additive nature of sums of squares in the analysis of variance. The total variance, phenotypic, is the sum of the genetic and environmental variance according to the model:

$$P = G + E$$

assuming there is no correlation between genotype and environment. Computing the analysis of variance for each trait allows for estimation of the genetic and environment variances.

If two variables were added and an analysis of variance computed on the resulting sum, a means of estimating the genetic and environmental covariance is available. The variance of a sum of two variables is the sum of the two individual variances plus twice the covariance. Therefore, the among-sire component as estimated is equal to one-fourth the genetic variance of one trait and one-fourth the genetic variance of the second trait plus one-half the genetic covariance between the traits. Having an estimate of one-fourth the genetic variance of each trait from a previous analysis of variance, the genetic covariance can be evaluated. A similar consideration of the within-sire components allows for estimation of the environmental covariance.

Considering traits i , j , $i + j$, the among-sire components (S_i, S_j, S_{ij}) and within-sire components (W_i, W_j, W_{ij}) , the mathematical evaluation of the respective genetic and environmental

variances and covariances are:

$$\begin{aligned} \frac{1}{4} V_{Gi} &= S_i & V_{Ei} &= W_i - 3S_i \\ \frac{1}{4} V_{Gj} &= S_j & V_{Ej} &= W_j - 3S_j \\ \frac{1}{4} V_{Gij} &= \frac{1}{2}(S_{ij} - S_i - S_j) & V_{Eij} &= \frac{1}{2}(W_{ij} - W_i - W_j) - 3/4(V_{Gij}) \end{aligned}$$

where

V_G = genetic variance of a trait

V_{Gij} = genetic covariance

E = environmental variance

E_{ij} = environmental covariance

The actual mathematical formulae for each specific parameter to be estimated are:

$$\begin{aligned} \text{heritability} &= 4 \left(\frac{S_i}{S_i + W_i} \right) \\ \text{genetic correlation} &= \frac{\frac{1}{4} V_{Gij}}{\left(\frac{1}{4} V_{Gi} \cdot \frac{1}{4} V_{Gj} \right)^{\frac{1}{2}}} \\ \text{environmental correlation} &= \frac{V_{Eij}}{\left(V_{Ei} \cdot V_{Ej} \right)^{\frac{1}{2}}} \end{aligned}$$

Phenotypic correlations are obtainable from the additive relationship assumed. The phenotypic covariance is the sum of the genetic covariance and the environmental covariance. The respective variance is obtained in an identical fashion by adding the genetic and environmental variance. The formula for the phenotypic correlation coefficient is symbolically:

$$r_p = \frac{V_{Gij} + V_{Eij}}{\left[(V_{Gi} + V_{Ei}) (V_{Gj} + V_{Ej}) \right]^{\frac{1}{2}}}$$

The genetic interrelationships with certain variables as they affect the variation in a single variable can be established by use of a path coefficient analysis. The path coefficient, a standard partial regression coefficient, relates the relative importance of an individual independent variable in determining the variation in a dependent variable. Multiple regression theory presented by Snedecor (1946) employs use of a correlation coefficient matrix in establishing the normal equations. The partial regression coefficients obtained by solving the normal equations are actually standard partial regression coefficients or path coefficients. The normal equations following matrix notation using the general linear hypothesis model of full rank would be:

$$X'X\beta = X'Y$$

where

$$X'X = \begin{pmatrix} 1 & r_{12} & \dots & r_{1n} \\ r_{21} & 1 & r_{23} & \dots & r_{2n} \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ r_{n1} & \dots & \dots & \dots & 1 \end{pmatrix}, \quad n = \text{number of independent variables}$$

$$X'Y = \begin{pmatrix} r_{1y} \\ r_{2y} \\ \cdot \\ \cdot \\ \cdot \\ r_{ny} \end{pmatrix}, \quad \text{vector of correlation coefficients of } y \text{ with every independent variable}$$

$$\beta = \begin{pmatrix} b_0 \\ b_1 \\ \cdot \\ \cdot \\ b_n \end{pmatrix}$$

, vector of estimates of path coefficients.

Solutions of the normal equations are obtained by inversion of $X'X$ and multiplying the inverse, $X'X^{-1}$, times $X'Y$. Solutions may also be obtained by use of the Forward Doolittle procedure as presented by Steel and Torrie (1960). The Forward Doolittle procedure was used in this study.

RESULTS AND DISCUSSION

Standard Measures

Analyses of birth weight, adjusted weaning weight, adjusted yearling weight and yearling condition score are independent of the model of growth curve fitted. Relative measures of the point of inflection and predicted yearling weight depend upon the respective growth curve fitted to the data. Therefore, analyses among these four traits are equally applicable to the respective measures obtained from individual growth curves.

Birth weight, adjusted weaning weight and adjusted yearling weight are standard measures that have been adjusted for the effects of age of calf and age of dam. Yearling condition score measures are not adjusted and, therefore, must be before valid analyses can be computed. Regression analyses computed by using linear and quadratic models indicated that linear corrections for age of dam and age of calf were sufficient. Measures of age of dam in months and weaning age of calf were regressed on yearling condition score. Graphic plots of the linear and quadratic models are presented in Figures 4 and 5. It is noticed that the effects of age of dam do not appear to be of importance. The range of yearling condition score from both the linear and quadratic models is approximately one-half of a grade. Comparisons of linear and quadratic plots using

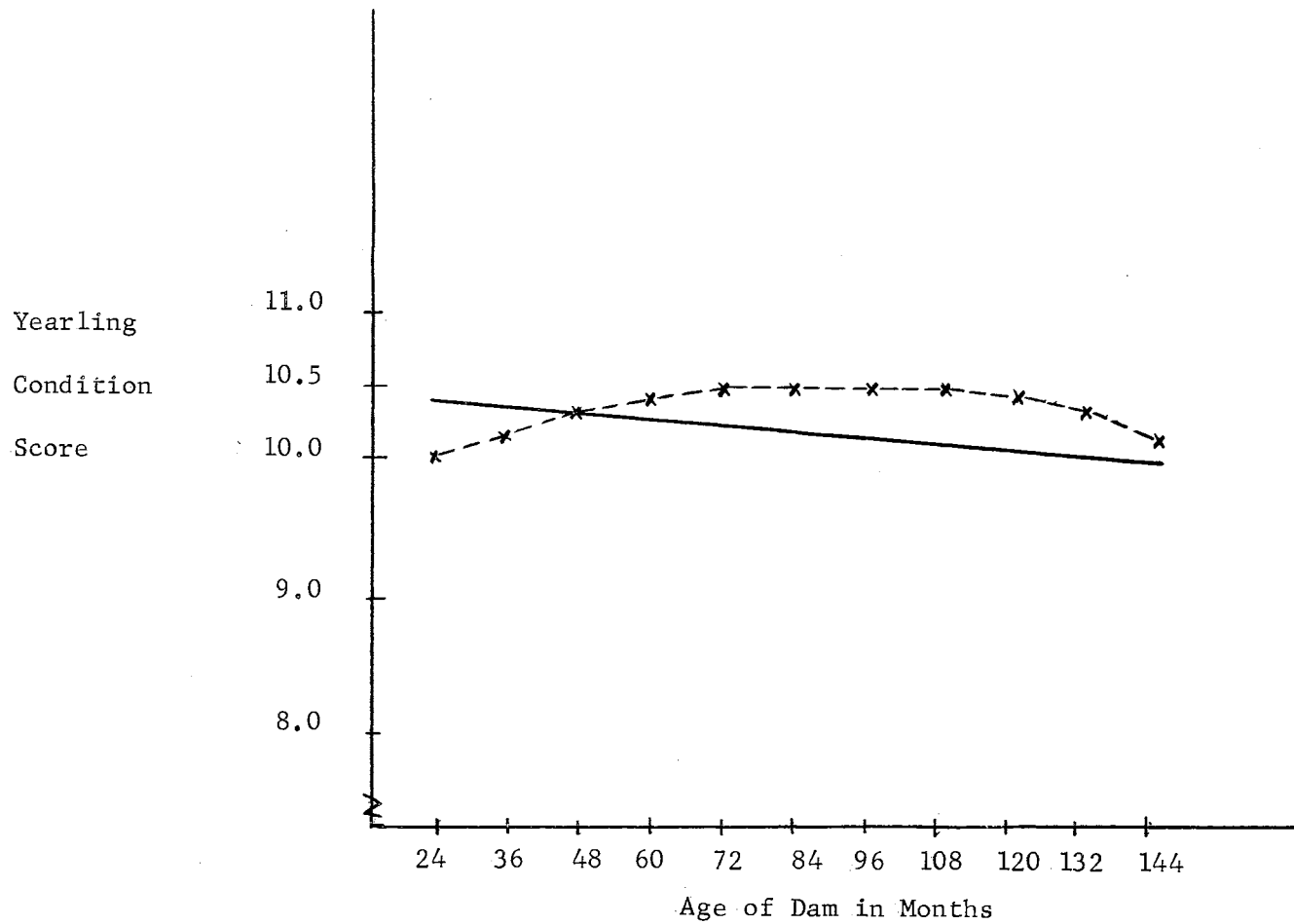


Figure 4. Linear and quadratic regressions of age of dam on yearling condition score.

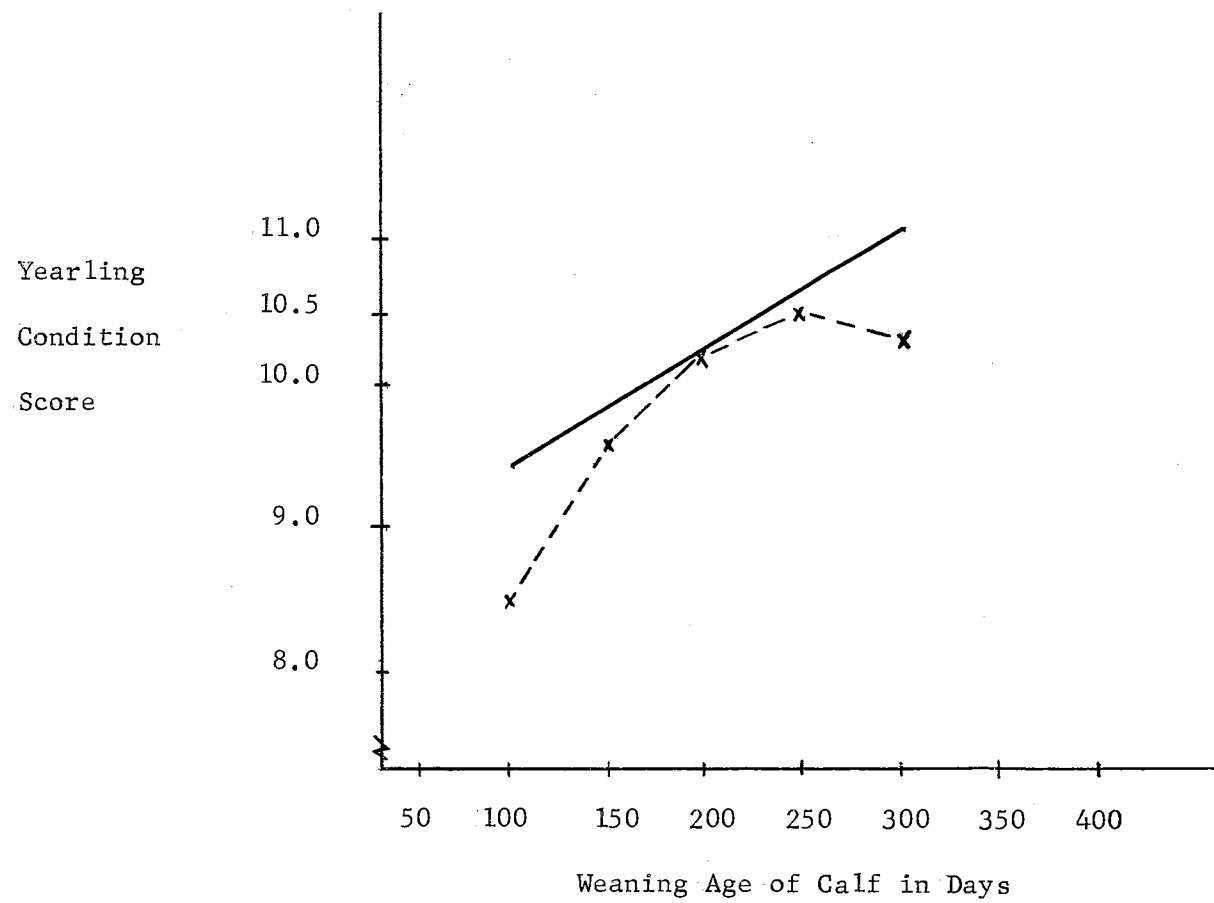


Figure 5. Linear and quadratic regressions of weaning age of calf on yearling condition score.

weaning age of calf reveal that within the weaning age range (150 days to 250 days), a linear adjustment should be sufficient. The original models utilized were multiple and, therefore, the age of calf regression values are conditional upon the age-of-dam effects. On this basis, linear corrections for age of dam and age of calf were considered appropriate.

The specific adjustment formula was: adjusted yearling condition score = actual yearling condition score - β_1 \times age of dam - β_2 \times age of calf. The β_i , $i = 1, 2$, values were determined in fitting the original models.

Table II contains means, standard deviations and coefficients of variation for birth weight, adjusted weaning weight, adjusted yearling weight and yearling condition score.

Table II

Means, Standard Deviations and Coefficients of Variation for Birth Weight, Weaning Weight, Yearling Weight and Yearling Condition Score

Trait	Mean	S.D.	C.V. (%)
Birth Weight	70.8 lbs.	11.2	15.6
Weaning Weight	465.5 lbs.	52.15	11.2
Yearling Weight	873.5 lbs.	79.46	9.1
Yearling Score	10.3	1.19	11.5

Heritability estimates obtained by the half-sib intra-class correlation method are presented in Table III. These estimates are in general agreement with reported estimates.

Table III

Heritability Estimates for Birth Weight, Adjusted Weaning Weight, Adjusted Yearling Weight and Yearling Condition Score

Trait	Estimate
Birth Weight	.27 ± .10 ^a
Adjusted Weaning Weight	.36 ± .12
Adjusted Yearling Weight	.34 ± .11
Yearling Condition Score	.29 ± .10

^aStandard error (Falconer, 1960)

The heritability estimate of 0.27 for birth weight agrees closely with the estimate of 0.22 presented by Swiger (1961). However, the estimates of Knapp and Clark (1950), Koch and Clark (1955c) and Lasley *et al.* (1961) are all of greater magnitude. The mean estimate of birth weight heritability reported by Warwick (1958) was 0.41.

Adjusted weaning weight heritability was estimated to be 0.36. This agrees closely with the literature. Warwick (1958) reported a mean estimate from 26 reference sources to be 0.30.

A heritability estimate of 0.34 was obtained for adjusted yearling weight. This estimate is somewhat lower than estimates reported in the literature. Estimates ranging from 0.86 to 0.41 have been reported by Swiger (1961), Knapp and Clark (1950), Brinks *et al.* (1964), Brinks *et al.* (1962), Shelby *et al.* (1960), Shelby *et al.* (1955) and Koch and Clark (1955b).

No reported estimates of yearling condition score heritability were obtained. However, the estimate of 0.29 from this study does

indicate that yearling condition score can be improved by mass selection.

Genetic and environmental correlations obtained in this study between birth weight, adjusted weaning weight, adjusted yearling weight and yearling condition score are presented in Table IV.

Table IV

Genetic and Environmental Correlations Between Birth Weight, Adjusted Weaning Weight, Adjusted Yearling Weight and Yearling Condition Score^a

	WW	YW	YC
BW	(G) .573	.431	.714
	(E) .278	.378	-1.325
WW		.844	-.119
		.793	.407
YW			-.001
			.456

^a BW = birth weight, WW = weaning weight, YW = yearling weight, YC = yearling condition score

The genetic correlation of 0.57 between birth weight and adjusted weaning weight is lower than the correlation of 0.99 found by Lasley et al. (1961). Brinks et al. (1962a) obtained a genetic correlation of 0.21 between birth weight and 180-day weaning weight. Similarly, Brinks et al. (1964) observed a genetic correlation of 0.60 between birth weight and weaning weight in Hereford females. These estimates indicate that birth weight is genetically related to weaning weight.

The correlation of birth weight and adjusted yearling weight was 0.43. This estimate is very similar to the correlation between

birth weight and adjusted weaning weight. Results presented by Brinks et al. (1962a), using 1,029 Hereford bull calves, revealed a genetic correlation of 0.75 between birth weight and final weight after a postweaning feeding test of 196 days.

The genetic correlation between adjusted weaning weight and adjusted yearling weight was 0.84. Brinks et al. (1964) observed similar correlations of 0.59 and 0.51 between weaning weight and mature spring and fall weights in Hereford females. A correlation of 0.54 between gain (birth to weaning) and final feedlot weight after a 196-day feeding test was observed in Hereford bulls by Brinks et al. (1962a).

Collectively, these correlations indicate that subsequent size is related to earlier liveweight measures. A path coefficient analysis assuming adjusted yearling weight as the dependent variable reveals that adjusted weaning weight is more important in determining the variation in adjusted yearling weight than birth weight. This is expected in light of the variables measured and the formula used in computing adjusted yearling weight. A path coefficient diagram is presented in Figure 6.

Genetic correlations of yearling condition score with birth weight, adjusted weaning weight and adjusted yearling weight yield inconsistent results. Essentially no correlation was found between yearling condition score and adjusted yearling weight. A small negative correlation of -0.12 was obtained between yearling condition score and adjusted weaning weight. However, a large correlation of 0.71 was obtained between yearling condition score and birth weight.

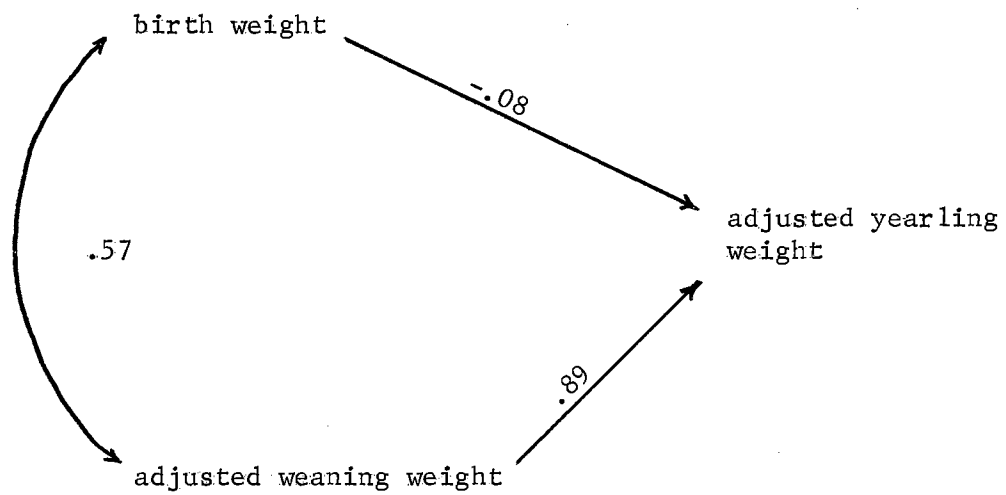


Figure 6. Path coefficient diagram for genetic relationships among birth weight, adjusted weaning weight and adjusted yearling weight.

It is noted that the environmental correlation between birth weight and yearling condition score is greater than 1.00. This could lend evidence toward doubting the validity of the observed genetic correlation of 0.71. A path coefficient analysis assuming adjusted yearling weight as the dependent variable and birth weight, adjusted weaning weight and yearling condition score as independent variables is presented in Figure 7.

The magnitude of path coefficients indicates that birth weight is the most important variable controlling variation in adjusted yearling weight. The results obtained in Figure 7 are contradictory to the results obtained in the previous path coefficient analysis presented in Figure 6. The magnitude of the path coefficients in Figure 7 is extremely large and can lend evidence to doubt the validity of the results obtained.

Fitting Growth Curves

Polynomial Model

Initial results of fitting the polynomial model were not consistent with sample results. In many cases (256), the individual growth curve fitted by the polynomial model did not yield conceivable measures of the point of inflection. Brody (1945) stated that the point of inflection should occur around 180 days of age in cattle. Biological observations indicate that the period of maximum gain occurs prior to one year of age. The polynomial fit was directed to pass through the four average observations. If these observations plotted into an exponential or another form (linear), the scale of

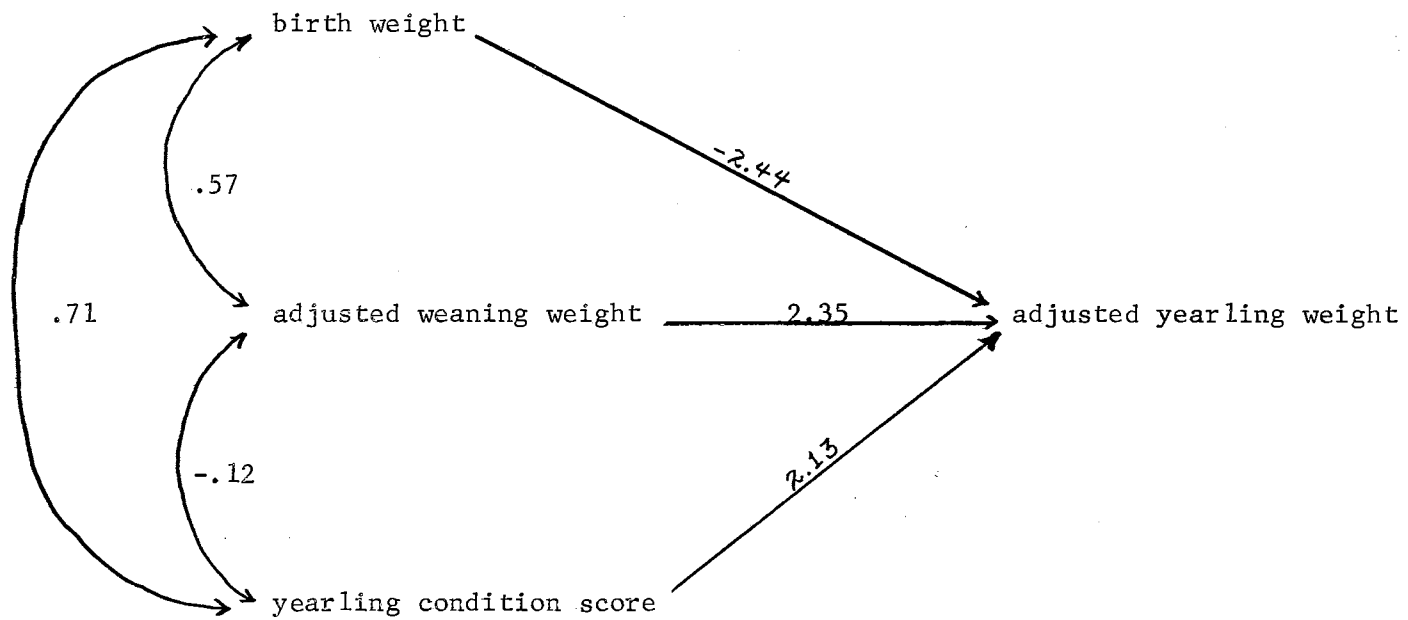


Figure 7. Path coefficient diagram for the genetic relationships among birth weight, adjusted weaning weight, yearling condition score and adjusted yearling weight.

the polynomial curve was essentially altered since all four points must be on the fitted polynomial. Since the scale of the fit was evidently altered, then the relative measures of the point of inflection are to be expected.

Adjustments to insure a relative fit with a point of inflection within the limits of the data were employed. The technique employed relied upon the aspect of all four sample points dictating the fit. In order to insure a relative measure of the point of inflection within the range of the data, adjusted measures of the second and third average weights at corresponding average ages were devised. The polynomial curve will properly fit the four average points if the second average weight is less than the predicted linear weight at the same average age and the third average weight is greater than the predicted linear weight at the third average. Graphically, the relative linear weight measures and proposed adjustments are presented in Figure 8.

The original fit follows an exponential. Therefore, if the third weight is greater than the linear predicted weight, a cubic polynomial can adequately fit the four observed data points. Singular weighing errors could quite possibly cause these average points to be in error. The actual procedure utilized was to figure the average daily gain from the first to the third average weight and the average daily gain from the second to the fourth weight measures. The respective linear predicted weights at the relative average ages were then computed. The original average second weight was compared to the linear predicted; and if the linear predicted was

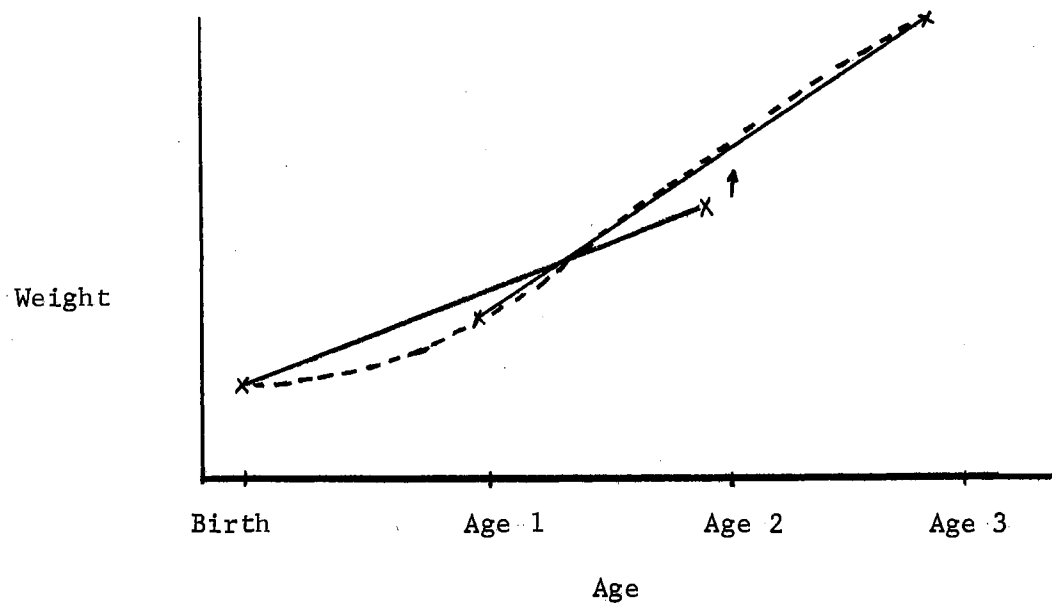


Figure 8. Graphic diagram of adjustments to insure relative polynomial fit.

greater than the average observed weight, no correction was made. If the linear predicted was less than or equal to the observed average weight, the linear predicted weight less one pound was used to fit the polynomial. A similar positive one pound adjustment was used on the third-period linear weight, if the observed weight was less than the linear predicted value. Therefore, this procedure allowed for replacing the observed average weights with a predicted weight that allowed for a cubic fit. It is realized that such a procedure dictates the point of inflection to occur between the second and third weights. Since liveweight measures were recorded to the nearest five pounds, this correction does not appear as extremely critical in view of the weighing errors that could have occurred.

Measures of the observed average weight deviation from the linear predicted weight when adjustments were made were obtained.

These deviations were generally of a small magnitude (less than 20 pounds).

After the necessary adjustments were employed on the 256 inconsistent cases, the relative measures of the point of inflection and predicted yearling weight were obtained for each calf.

Adjustment of Data

Measures of the point of inflection and predicted yearling weight from the polynomial model are not adjusted for the effects of age of calf and age of dam. Additive adjustments were obtained from multiple regression models previously mentioned.

Any quantity, $\beta_i x_i$, is an additive component in a general regression model for predicting a dependent variable. The actual additive adjustments for the linear and quadratic effects of calf weaning age and age of dam were calculated by multiplying the appropriate regression coefficient times the important concomitant independent variable. Graphic plots were used to determine the relative adjustments for weaning age of calf and age of dam needed. The adjusted variable value is the actual observed variable value minus the respective components deemed important.

Linear and quadratic plots of the effects of weaning age of calf and age of dam on these variables are presented in Figures 9, 10, 11 and 12. A linear correction for weaning age of calf was considered sufficient for the point of inflection from observations of Figures 9 and 10. Age-of-dam adjustments were considered unimportant in view of the range in the point of inflection predicted in Figure

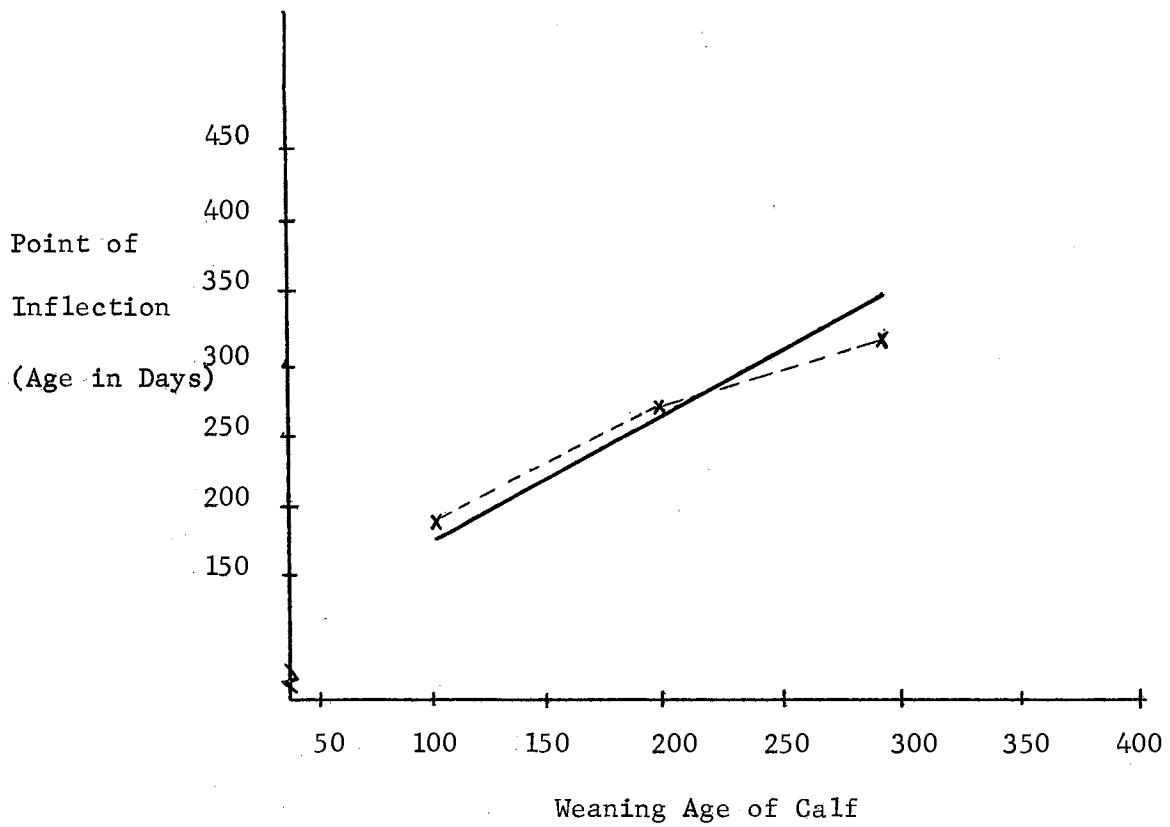


Figure 9. Linear and quadratic regressions of weaning age of calf on the point of inflection.

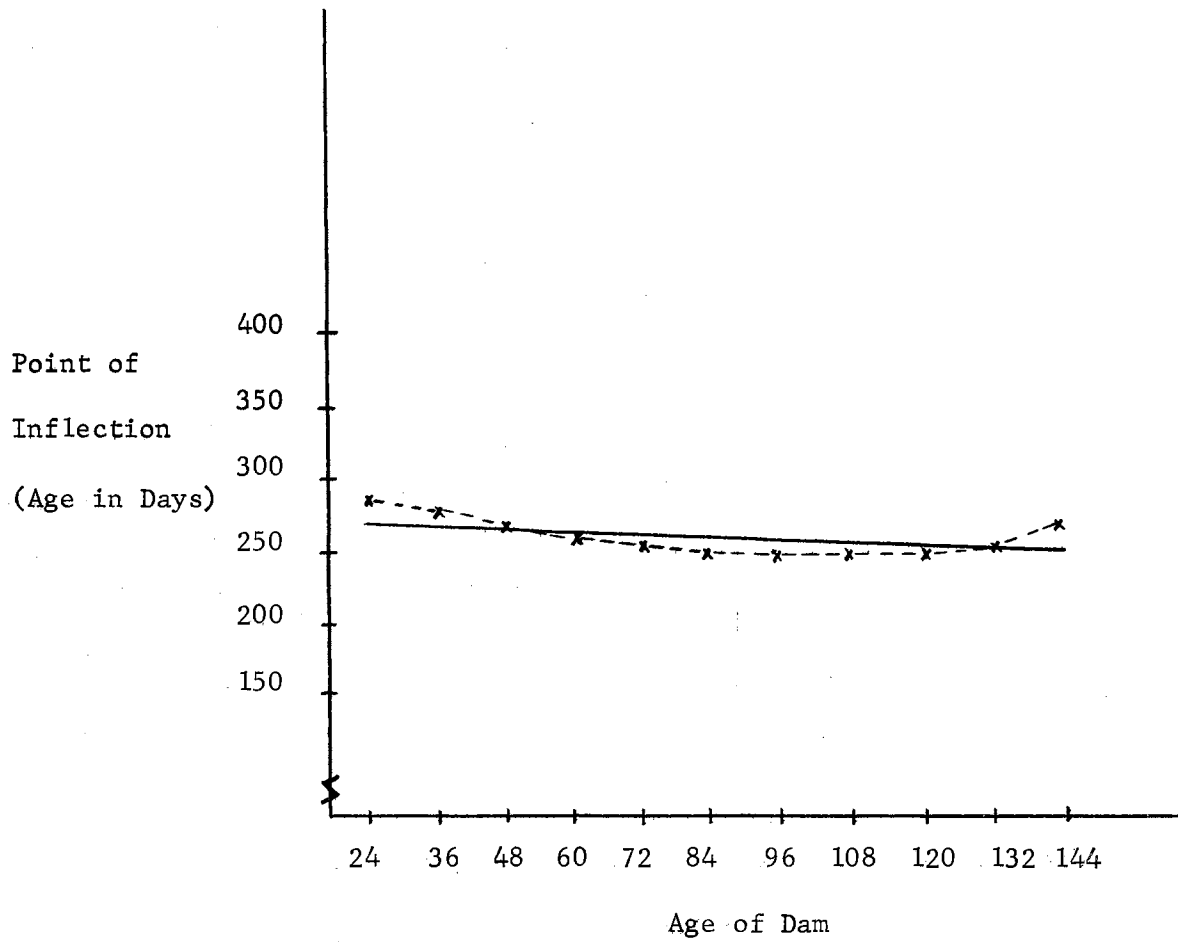


Figure 10. Linear and quadratic regressions of age of dam (months) on the point of inflection.

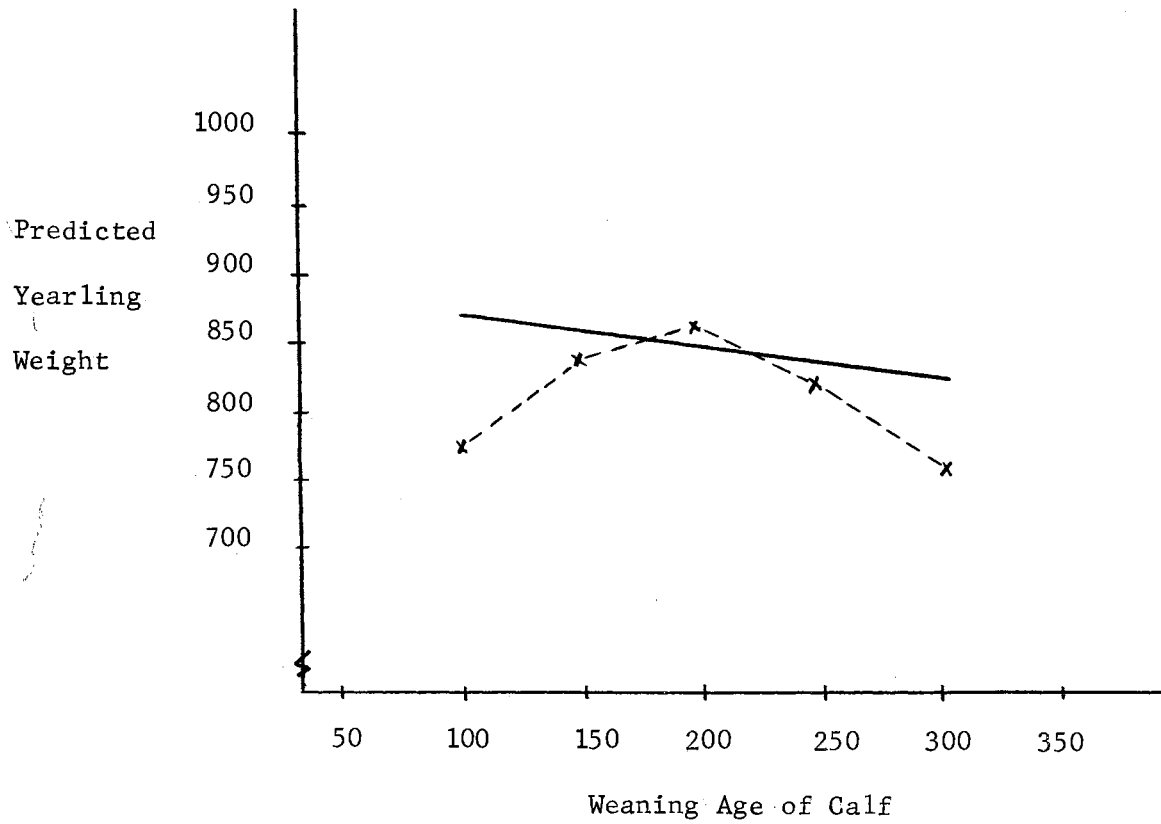


Figure 11. Linear and quadratic regressions of weaning age of calf on predicted yearling weight.

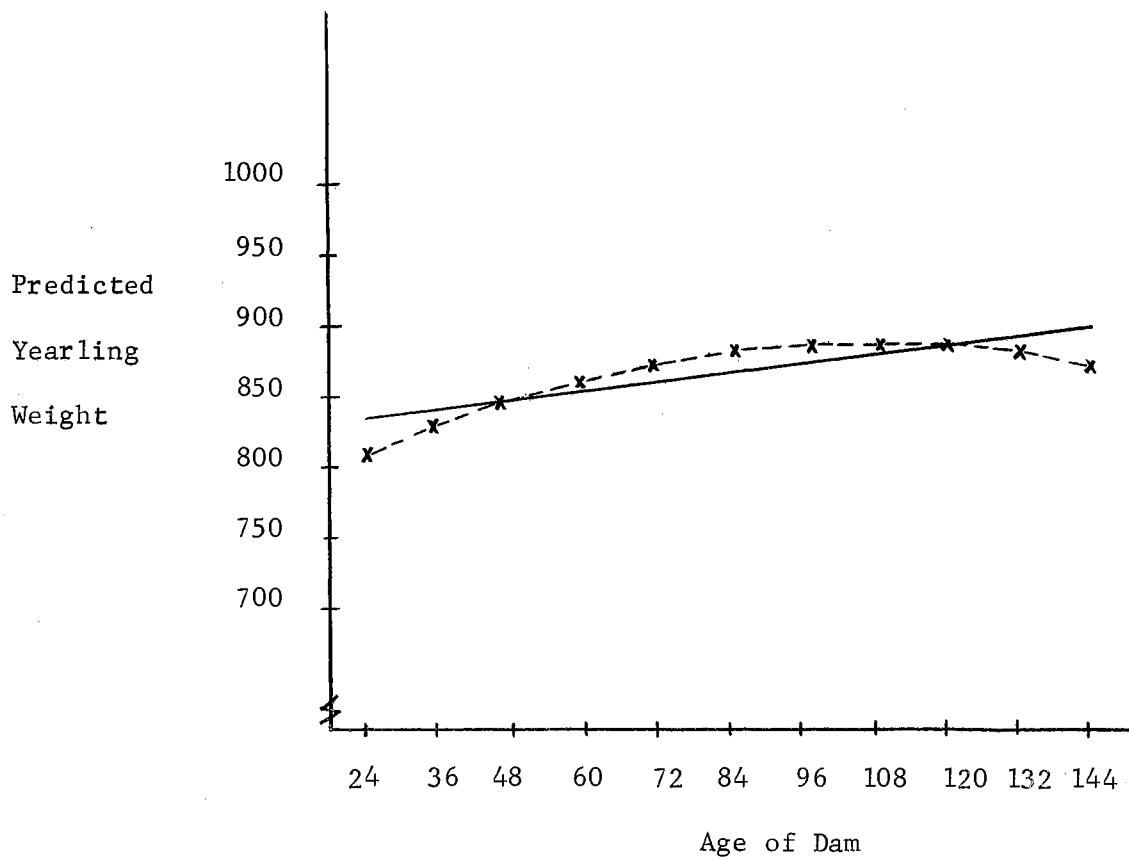


Figure 12. Linear and quadratic regressions of age of dam (months) on predicted yearling weight.

10. Observation of Figure 9 within the range of weaning age (150 to 250 days) indicates that a linear adjustment is sufficient.

Adjustments for predicted yearling weight involved use of both linear and quadratic components for weaning age of calf and age of dam. Figures 11 and 12 illustrate the graphic plots of the linear and quadratic effects of weaning age of calf and age of dam on predicted yearling weight.

Statistical Analysis

Following the appropriate adjustments to the point of inflection and predicted yearling weight as measures from the polynomial model growth curve, statistical analyses in accord to the standard measures of birth weight, adjusted weaning weight, adjusted yearling weight and yearling condition score were obtained.

Table V contains the means, standard deviations and coefficients of variation for the point of inflection and predicted yearling weight.

Table V

Means, Standard Deviations and Coefficients of Variation for the Point of Inflection and Predicted Yearling Weight

Trait	Mean	S.D.	C.V. (%)
Point of Inflection	253.7 (days)	29.9	11.8
Predicted Yearling Weight	840.8 (lbs.)	74.5	8.8

A heritability estimate of 0.00 ± 0.01 was obtained for the point of inflection; whereas, an estimate of 0.27 ± 0.10 was found

for predicted yearling weight. Adjusted yearling weight heritability was estimated to be 0.34. This estimate generally agrees with the 0.27 estimate for predicted yearling weight. However, heritability estimates for yearling weight ranging from 0.06 to 0.86 have been reported by Swiger (1961), Knapp and Clark (1950), Brinks *et al.* (1962), Shelby *et al.* (1960), Shelby *et al.* (1955), and Koch and Clark (1955b). These observed estimates are generally lower than those reported in the literature.

The heritability estimate of 0.00 obtained for the point of inflection was actually 0.0045. This estimate indicates there is essentially no genetic control available in selecting for this particular measure of the point of inflection.

Genetic and environmental correlations between the point of inflection, predicted yearling weight and the other standard variables are given in Table VI.

Table VI

Genetic and Environmental Correlations Between the Point of Inflection, Predicted Yearling Weight and Other Standard Measures^a

	BW	WW	AYWT	YC
PYWT (G)	.48	.75	.90	-.29
(E)	.38	.76	.98	.55
POF (G)	-2.07	-1.31	-1.38	.51
(E)	.04	-.17	.03	-.06

^a BW = birth weight, WW = weaning weight, AYWT = adjusted yearling weight, YC = yearling condition, PYWT = predicted yearling weight and POF = point of inflection.

The genetic correlations of predicted yearling weight with birth weight, weaning weight and yearling condition score of 0.48, 0.75 and -.29, respectively, compare generally with the genetic correlations of 0.43, 0.84 and -.00 obtained when adjusted yearling weight was correlated to the respective measures. The genetic correlation of 0.90 between predicted yearling weight and adjusted yearling weight is automatic in nature but does reveal the relative association of the predicted measure to the adjusted yearling weight. The polynomial model estimation of predicted yearling weight is relatively accurate.

The correlations between the point of inflection and the standard measures generally yield inconsistent results. Apparently, the lack of genetic variation in the point of inflection measure is manifested in these correlations.

The genetic correlation observed between the point of inflection and predicted yearling weight, as estimated by the polynomial model, was -2.70. The environmental correlation was 0.05.

No path coefficient analysis was attempted in light of the observed genetic correlations.

Logistic Model

Sample results obtained from fitting the asymmetrical logistic curve revealed that an invalid assumption had been made in the least squares procedure for estimating k , the limiting size. An assumption was made that the individual residual sum of squares obtained from fitting the logistic with three selected k values would plot into a

parabola. The procedure presented by Hartley (1965) relied upon this assumption in order to estimate a limiting size, \hat{k} , for fitting a logistic from which a relative measure of the point of inflection could be obtained. The original data were limiting in range and relative measures of a limiting or mature size. The use of an asymmetrical logistic curve depended upon a known value of k or the limiting size. Therefore, a valid procedure for estimating k was not obtained from Hartley's procedure.

Figure 13 represents a graphic plot of the residual sum of squares for various sample calf data over a range of selected k values. Instead of plotting into a parabola, the residual sum of squares plots into a decreasing exponential. Larger k values yield smaller residual sums of squares.

Evidently the larger selected k values allow for a scale alteration. The relative scale of the logistic fit is expanded, and the limited range of observations actually forms a "closer" fit in respect to least squares theory.

Use of the logistic curve requires that the mature or limiting size be known. Since no true measure was available from the original data, an estimate of mature size could have been used to allow for use of the logistic curve. The procedure employed to estimate mature size from the original data was not valid; therefore, the logistic curve was not applicable. The original data were collected relatively early in respect to maturity. Therefore, obtaining a measure or estimate of mature size was critical in using the logistic curve to define the growth response.

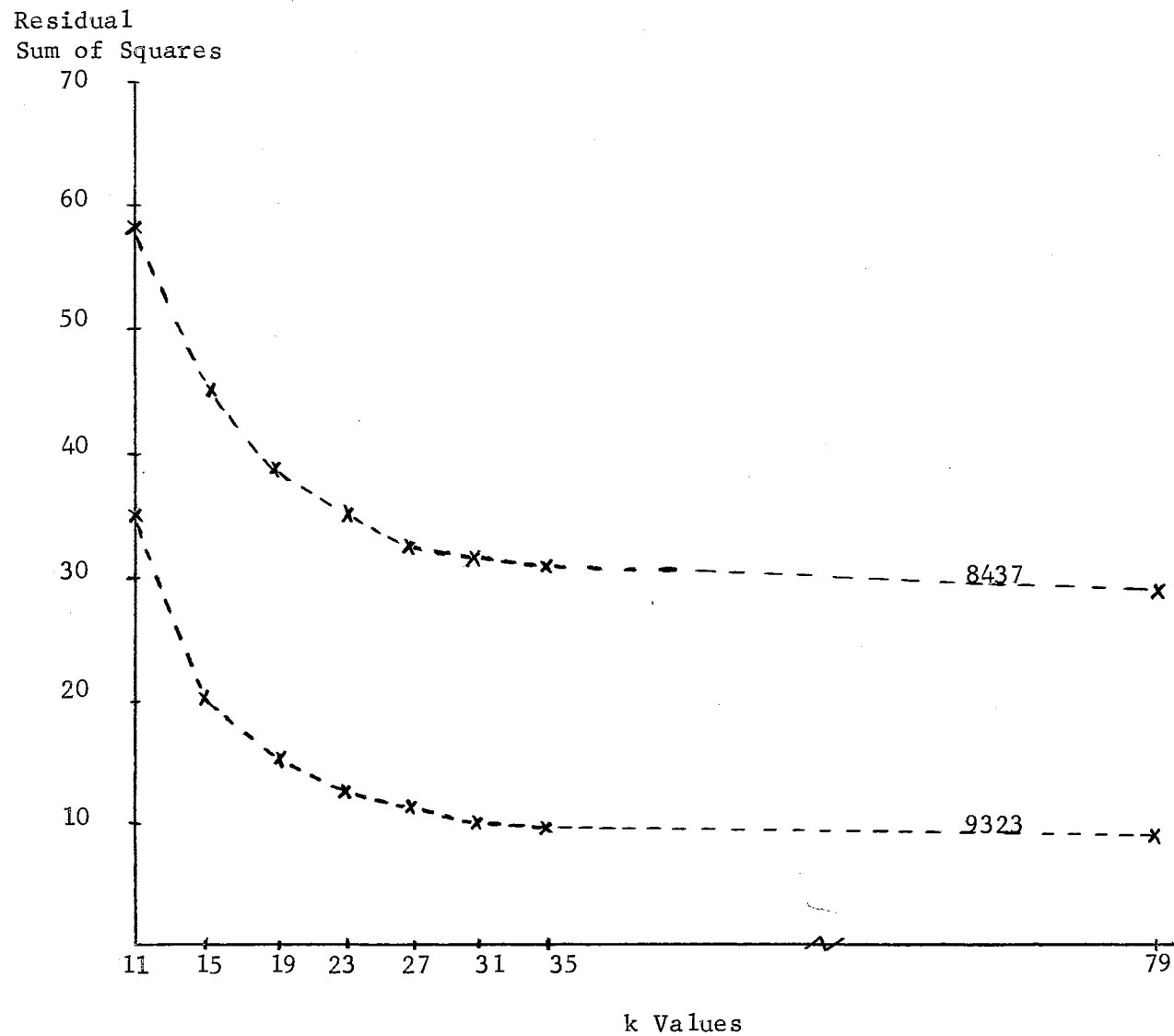


Figure 13. Graphic plot of the residual sum of squares over a range of k values.

General Discussion

The proposed measure of the point of inflection was not obtained in this study due to failure to fit a suitable growth curve. Allowing that any growth analysis is intricate and complex, the failure to develop a suitable model did not allow for an avenue of measuring the point of inflection. Although a measure was obtained from use of the linear polynomial model, its application is certainly limited in the biological application of the fitted curve. This relative measure of the point of inflection is definitely dependent upon the shape of the original observation points. Since adjustments were made to insure a "proper" fit, the overall application of this method and procedure of defining the growth curve and measuring the point of inflection has no practical value. No genetic variation was found for the point of inflection measure. Proposed genetic relationships with other standard measures yielded inconsistent results. Therefore, the proposed growth curve analysis was not obtained due to failure to correctly define a growth curve and measure the point of inflection.

Since the original data were limited in range, the application of the logistic model was dependent upon Hartley's least squares procedure for estimating k or the limiting size. An invalid assumption in this procedure did not allow for a suitable estimation of k ; hence, the asymmetrical logistic model is not applicable to the observed data. If complete data were available from birth to maturity, the asymmetrical logistic model could have biological application. Such data would not be dependent upon an estimation of k , and it is

possible that a valid measure of the point of inflection could be obtained.

Results obtained for the standard measures of birth weight, adjusted weaning weight, adjusted yearling weight and yearling condition score are valid and comparable to reported results. All heritability estimates are consistent with reported findings and are applicable. Relative genetic correlations between these measures are of an automatic nature, but they do relate that size selection at heavier weights and older ages is more efficient than selection on weights and ages at earlier dates.

SUMMARY

Growth performance measures of corresponding liveweights and ages from birth through a 168-day postweaning feeding test of 869 beef calves (bulls and steers) were utilized to define individual growth curves and measure the point of inflection or age of maximum gain for each calf. Additional measures of birth weight, adjusted weaning weight, adjusted yearling weight, yearling condition score and a predicted yearling weight from the growth curve were also analyzed to obtain estimates of the heritability for each trait and genetic and environmental correlations between these traits.

Two methods were proposed to define and fit an individual growth curve to the original data. One method involved use of a linear polynomial model using weight as the dependent variable and age measures as the independent variables. The second method required use of a model derived from the equation of an asymmetrical logistic curve. This model required that a mature or limiting size be known in order to fit an individual growth curve. A procedure was employed to estimate the mature size for each calf from a consideration of the original data.

Results obtained from sample analyses revealed that the procedure for estimating an individual's mature size was invalid. Therefore, the second method proposed to fit a growth curve was not applicable.

Results observed from fitting the linear polynomial model were available, but application of this growth curve had no biological significance beyond the limits of the original data. However, relative measures of the point of inflection and predicted yearling weight were available.

Heritability estimates of 0.27, 0.36, 0.34, 0.00, 0.27 and 0.29 were obtained for measures of birth weight, adjusted weaning weight, adjusted yearling weight, the point of inflection, predicted yearling weight and yearling condition score, respectively.

Estimates of genetic and environmental correlations between the point of inflection and the other measures were inconsistent. However, genetic correlations between measures independent of the fitted growth curve were acceptable. The magnitude of these correlations indicated that size selection at heavier weights and older ages is more efficient than earlier weights and ages. Environmental correlations between weight measures at older ages and heavier weights are higher than environmental correlations between earlier weights and ages. Therefore, size selection at heavier weights and older ages would be more efficient since environmental conditions are correlated to a greater extent.

The proposed objective of defining a growth curve to estimate the point of inflection was not accomplished. It was hoped that the point of inflection would be genetically related to subsequent size so earlier size selection could be accomplished in beef cattle.

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