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Age, frequency and season of weighing, and reproduction as factors influencing growth curve parameters in Angus cows

Ronald Edwin Morrow

To the Graduate Council:

I am submitting herewith a dissertation written by Ronald Edwin Morrow entitled "Age, frequency and season of weighing, and reproduction as factors influencing growth curve parameters in Angus cows." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

J.B. McLaren, Major Professor

We have read this dissertation and recommend its acceptance:

W.T. Butts, R.R. Shrode, J. Philpot, D.O. Richardson

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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AGE, FREQUENCY AND SEASON OF WEIGHING, AND REPRODUCTION AS FACTORS INFLUENCING GROWTH CURVE PARAMETERS IN ANGUS COWS

A Dissertation

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Ronald Edwin Morrow

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ABSTRACT

The objectives of this study at the University of Tennessee were to estimate the effect of the following factors on growth curve parameters: (1) age, (2) season and frequency of weighing. (3) reproductive status at three age intervals and (4) condition of the cow at early age. The final objective was to evaluate the relationship of mature weight and general rate of maturing with performance of progeny.

The main body of data consisted of the growth curve parameters, mature weight (A) and rate of maturing (K), as determined by asymptotic regression of several series of weights on 102 mature Angus cows. The growth model described by Brody (1945) was used as the basis of the asymptotic regression. The study was divided into two phases. The first phase was designed to evaluate growth curve parameters derived from weights taken from birth to specified ages ranging from 1.5 years to 8.5 years of age plus one set of estimates derived using lifetime weights. The second phase was used to determine the influence of season of year on the parameters estimated from weights taken at various times of the year.

In Phase I the mean estimates of mature weight (A) were 539, 503, 465, 473, 481, 485, 484 and 482 kg for ages 1.5 through 8.5 years, respectively. The mean estimates of rate of maturing (K) were .061, .069, .073, .069, .065, .062, .061 and .061 for the same ages. The mean estimates of A and K using lifetime weights were 497 kg and .056, respectively. Correlations between estimates of A at the various ages were low until 4.5 years of age, at which time the correlation tended to stabilize. The same trend was shown between estimates of K. Early reproductive status

of each cow was coded as (1) if the cow calved at two and three years of age, (2) if the cow calved just at three or (3) if the cow calved at two and was open at three. The least-squares analyses of A and K showed a significant age-reproduction interaction. The-cow-within-reproduction component was highly significant, indicating significant independent variation with which to work in animal breeding projects.

In Phase II eight weight-age curves were calculated for each animal--one group of four sets of estimates using weights to five years of age and another group using lifetime weights. Within each group one set of parameters was estimated using all weights to the respective age. The other three sets were based on weights from birth to yearling plus one weight per year--summer, fall or winter. The symbols A and K are used with the following subscripts: 0 or 5 as a first digit to represent lifetime and five years of age, respectively; 0. 2. 3, or 4 as a second digit to represent all weights, summer weights, fall weights or winter weights, respectively. Mean estimates of mature weight were 496, 492, 492, 522, 483, 478, 487 and 508 kg for A_{00}, A_{02}, A_{03}, A_{04}, A_{50}, A_{52}, A_{53} and A_{54}, respectively. Mean estimates of rate of maturing were .0573, .0583, .0614, .0545, .0646, .0642, .0642 and .0602 for K_{00}, K_{02}, K_{03}, K_{04}, K_{50}, K_{52}, K_{53} and K_{54}, respectively. Correlations among the estimates of mature weights were all positive and larger than .7. Correlations among the rates of maturing were larger than .5 except for those involving the relationship of K_{00} and estimates of the parameters derived using weights up to five years of age. This study indicated that a single annual weight from one to five years of age is adequate for estimating growth curve parameters.

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CHAPTER I

INTRODUCTION

Asymptotic regression of periodic weights on age has been used by many workers to describe growth and development of cattle (Brody, 1945; Joandet, 1967; Joandet and Cartwright, 1969; Brown, Brown and Butts, 1972a, b, c). Useful genetic variation in estimates of rate of maturing and mature size from such operations has been observed (Joandet, 1967; Joandet and Cartwright, 1969; Brown and Brown, 1972; Brown *et al.*, 1972a, b, c). Relationships among rate of maturity, mature size and productive efficiency have been suggested by these authors. Effective application of this information in selection procedures requires additional knowledge of factors affecting the shape of weight-age curves and the ability to characterize animals at early ages. Two factors which have been shown to affect cow weight are age and lactation stress (Fitzhugh, Cartwright and Temple, 1967). Work by Joandet (1967) suggested that effects of parturition, lactation and the interactions of these two effects with season of year produced the greatest irregularities in the growth patterns of females.

The primary objective of this study was to estimate the effect of age on growth curve parameters. Secondary objectives were to evaluate the influence that the following additional factors have on growth curve parameters:

(1) Reproductive status at three age intervals,

(2) Season of weighing and number of weights per year,

(3) Condition of the cow at early ages.

The final objective was to determine the relationship of adjusted estimates of mature weight and rate of maturing with performance of progeny of the animals.

CHAPTER II

LITERATURE REVIEW

I. GROWTH CURVE MODELS

Fitting growth curves with various mathematical models has been one technique used to evaluate characteristics of the entire growth of plants and animals (Brody, 1945; Bertalanffy, 1957, 1960; Richards, 1959; Nelder, 1961; and Laird, 1965, 1966).

Models described by the above authors were studied by Brown (1970) who fitted each model to weights of 298 individual animals. He used the mean residual variation of various parameters from each model as an indication of gross differences in the fitting abilities of the respective models. The interpretability of the model and the degree of difficulty in estimation of the constants also was considered. The five most frequently used mathematical models for calculating growth curve parameters are discussed in the following sections. In each model A represents mature weight, K is general rate of maturing, B is a form parameter and Y_t is the weight at time t.

Von Bertalanffy Model

This model, $Y_t = A(1-Be^{-Kt})^3$, describes a sigmoid curve with limited flexibility. The term, Be^{-Kt}, represents the maturity yet to be achieved. The component $(1-Be^{-Kt})$ is the degree of maturity already attained by the individual. The ratio of these two measures represents a multiplicative correction factor for differences in stage of development at time, t.

This ratio approaches zero as the individual nears maturity and provides a correction in K for any differences in physiological maturity between two animals at a constant age. The point of inflection in this model cannot be interpreted as being meaningful in the biological sense because of the fixed nature of its location. The Bertalanffy model was used by Joandet (1967) in studying the efficiency of TDN utilization in beef cattle because of its consideration of anabolic and catabolic processes.

Brody Model

The form of the Brody model most often used, $Y_t = A(1-e^{-Kt})$, has only two parameters; therefore, calculations and interpretations are easier. This model does not have the same flexibility as the model, $Y_t = A(1-Be^{-Kt})$. The Brody model provides for a Y-intercept term (A-B) and gave the second best fit of the models tested by Brown (1970). The absence of a point of inflection did not create a large discrepancy between observed and predicted weights. Brown (1970) suggested that the lack of knowledge regarding the true biological points of inflection in cattle growth curves is one advantage of Brody's model because no emphasis can be misplaced on estimates of that point in the growth pattern. Taylor (1965), Taylor and Fitzhugh (1971) and Smith (1974) generated and used statistics from this model which also were used by Brown et al. (1972a, b, c). One of the measures generated from the Brody model is the degree of maturity for weight at a given time. The velocity of this term represents the absolute growth rate described by the above authors. The values of A and K in Brody's model were negatively correlated in the work by Brown (1970), but the correlation was much less than the negative correlation observed among the estimates of mature weight and rate of maturing derived by using the Von Bertalanffy model. The simplicity, ease of interpretation and goodness of fit make it a useful model for all but the most critical growth studies.

Gompertz Model

This model, $Y_t = Y_o \exp((L/\alpha)\ (1-e^{-\alpha t}))$, was used by Laird (1966) and differs from the other models in that it is a double exponential function. The asymptotic limit is $Y_o\ e\ L/\alpha$. The value of Y_o should represent birth weight. In the work by Brown (1970), the estimates were severely over-estimated. Fixation of Y_o at a known birth weight produced an equation which gave a better fit during the early growth period but decreased the overall goodness of fit. The magnitude of α reflects the same properties as K in other models. Laird (1966) found that the Gompertz equation adequately described the postnatal growth of many mammals and birds. Buffington et al. (1973) fitted the Gompertz growth model to weights of Wrolstad White turkeys. The equation presented parameters having a clear and unambiguous biological interpretation.

Logistic Model

The Logistic model, $Y_t = A/(1 + e^{-Kt})^M$, is a three-parameter form of the generalized model described by Nair (1954) and Nelder (1961). An estimate of mature weight, rate of maturing and a variable point of inflection can be derived from this model. The absence of B is reflected in larger K values and in decreased variability of M. In the von Bertalanffy and Brody models M is fixed, and B is allowed to vary. Weight at inflection is dependent upon the value of M. In the Logistic model, relative growth rate is completely related to K and M, whereas, in the other models it is dependent primarily on K. The length of maturing interval measured from the Logistic model was larger than for the other models studied by Brown (1970) due to the increased value of K and the smaller estimate of mature size.

In analyzing the growth of White Leghorn pullets from hatching to 18 weeks of age, Garber (1951) fitted the Logistic curve, the Gompertz curve and the Brody curve and determined the Logistic curve to be best for chickens in that stage of growth. The Gompertz and Brody equations tended to overestimate weight at young ages and underestimate the parameters at older ages.

Richards Model

The Richards model, $Y_t = A(1-Be^{-Kt})^M$, was the most sophisticated function fitted by Brown (1970) and was the most accurate predictive model but presented problems in interpretation. It differs from the Logistic model in that B is added, and it provides flexibility needed to fit weight changes during young ages. The greatest difficulty was the non-convergence of the iterative procedure for the least-squares estimates of A, B, K and M. In some instances, the component $(1-Be^{-Kt})$ became negative and presented an unrealistic situation.

Summary of Models

Of the five models discussed by Brown (1970), the use of the Logistic model produced the largest residual variation, but this value was not much larger than the residual mean squares of the Gompertz and von Bertalanffy models. All models differed most in their ability to describe the shape of the curve during the early period of growth. The Logistic and Gompertz models gave much higher overestimates of the young weights than did the other models. The Brody and Richards models yielded similar mean residual variations and had negligible differences in fitting qualities. Of the two models, Brody's model is preferred because of ease of interpretation and mechanical fitting when the purpose of the study is to describe growth in terms of mature weight and rate of maturing.

II. VARIATION IN GROWTH PARAMETERS

Several authors have discussed work based on growth curve analysis (Brown, 1970; Brown and Brown, 1972; Brown et al., 1972a, b, c; Rakes, Brown and Bryant, 1971) and have demonstrated genetic variation within and between breeds of cattle.

Rakes et al. (1971) studied the lifetime weight-age relationships for four breeds of dairy cattle using monthly weights from birth to end of life. A negative correlation of -.58 between mature weight and rate of maturing was observed. Brown, Fitzhugh and Cartwright (1971) reported also that estimates of mature weight were negatively correlated with rate of maturing (-.64), age at inflection of the growth curve (-.61) and growth rate at the point of inflection (-.23).

Brown et al. (1972a) fitted weight-age curves for 296 Angus females and 288 Hereford females. The Angus growth patterns were more variable than those of the Herefords. Estimates of heritability of mature weight (A) were similar for the two breeds, but estimates of heritability of rate of maturing (K) were twice as large in Angus as in Hereford. The genetic correlations between A and K indicated that selection for early maturity would lead to smaller mature weights. The phenotypic correlations between A and K indicated that heifers which were lighter prior to four months of age were early-maturing and became heavier than late-maturing animals from 4 to 24 months. The estimates of heritability of weights at 4-month intervals from 4 to 36 months were moderately high in Herefords and moderately low and variable in Angus.

Large gains at young ages were characteristic of early-maturing females in the study reported by Brown et al. (1972b). Early-maturing females of both the Angus and Hereford breeds were characterized by lighter body weights prior to four months of age, larger gains to about two years of age and smaller mature weights than late-maturing females. Heifers with large gains after 16 months were generally late-maturing and grew to large mature weights. The authors concluded that selection for large gains or large weights would not effect the same changes in the growth pattern of all individuals. Selection for rate of maturing would be even more complex since the rate of approach to mature weight can be increased or decreased by changing mature weight or by changing growth rate. The correlations showed that immature weight and gain are useful indicators of mature weight and rate of maturing.

Brown et al. (1972c) reported Hereford females to be 84 pounds heavier at maturity than Angus females and were slower to reach maturity. The mean rate of maturing was .0437 for the Herefords and .0566 for the Angus. Heritability of mature weight was low for both groups. The heritability of K was large in the Angus and low in the Hereford. Analyses of variance of A and K showed that year of birth had a highly significant effect on A and K in both breeds, and sire effects on K were significant.

Sire variation in A was not significant in Angus heifers, but it was in Herefords. Season of birth did not contribute to differences in mature weight or rate of maturing. Sire, calving year and season of birth accounted for a major portion of the variation in K in Angus cattle but not in Herefords. Variation in A was largely unexplained in both breeds.

Fitzhugh and Taylor (1971) reported positive correlations between degree of maturity and body weight at the same age, which indicated that the genetically heavier animals at a given age tended to be more nearly mature. These correlations decreased in magnitude and became negative as the age interval increased. All correlations between degree of maturity and mature weight were negative, thus indicating that animals which were more nearly mature at age t were lighter at birth. Heritabilities of degree of maturity were slightly lower than the corresponding heritabilities of body weight. Selection for increased degree of maturity at any age would tend to increase both absolute and relative growth rate at early ages and decrease them at later ages.

Direct analysis of age at a constant degree of maturity was used by Taylor and Fitzhugh (1971) to investigate the relationship between time required to reach mature size. This approach required no assumptions with respect to the form of the growth curve. The heritabilities of time required to mature ranged from .22 at birth to .42 at 18 months of age. Animals which were classified as early-maturing at any age tended to be early-maturing at all ages, and animals genetically heavier at maturity tended to take a longer time to reach their mature body weight. The age at which an individual reached a given degree of maturity tended to be proportional to about the .3 power of its mature weight. The heritability of .37 for time taken to reach maturity was reduced to .35 when mature weight was held constant. This indicated that within breed selection for time taken to mature should be reasonably effective even with mature weight held constant.

Various combinations of growth curve parameters were used by Brown and Brown (1972) to assess the differential energy costs associated with different growth patterns. By using equations presented by the National Research Council (NRC), daily requirements for maintenance and growth from birth to maturity were calculated. Two animals of nearly equal mature weight but having different rates of maturity were compared. Cost of maintenance for the earlier-maturing cow was greater at all ages up to five years of age. The cost to reach a given weight was greater for the slower-maturing cow at all weights. The annual cost of maintenance of the two cows after maturity was similar. The comparison of two animals of different mature weight provided a contrast of maintenance as well as development. At all ages, up to five years, the early-maturing cow had greater cost of development; but, at all weights, the slow-maturing cow had greater cumulative costs. The authors suggested that profitable production was possible at all mature weights, but at all mature weights, there can be combinations of maturing rate and production level that are unprofitable. These results agree with Guilbert and Gregory (1952) who stated that the shape of the growth curve rather than magnitude of growth is related to efficiency since the shape reflects rate of increase both in size and maturity.

III. BIOLOGICAL FACTORS INFLUENCING ESTIMATES OF GROWTH CURVE PARAMETERS

In order for estimates of growth curve parameters to be useful in selection and in breeding programs, the estimates must be derived at young ages and must be indicative of the genetic growth of the animals. Three primary factors that have been suggested to influence the shape of the growth curve are age, reproduction (lactation stress) and condition. The interactions of these main factors are important in determining the point in the life of an animal where these estimates best indicate the genetic potential for growth. Ellis (1963) and Maddox (1964) found that significant sources of variation in cow weight included breed, previous parity, year, weighing date, age, calving month, sex of calf and weaning weight of calf. They suggested that these factors probably influenced condition of the animal rather than skeletal size. Fitzhugh (1965) reported that age and previous parity had a significant influence on cow weight at parturition and at weaning.

Age

Several workers have reported various ages at which cows have attained their mature weight. Nelson (1967) reported cows attained their mature weight at six to seven years of age. Work by Brinks et al. (1962a), Knox and Koger (1945) and Marlowe, Freund and Graham (1962) indicated Angus and Hereford cows reached maturity at six to eight years of age. Brown, Gifford and Honea (1956a, b) reported mature weight was reached at 5 to 5.5 years of age in Angus and Hereford cows and that 88% of their mature weight was attained by three years of age. Joandet and Cartwright

(1969) observed that some animals required as long as twelve years to reach mature weight, but that in most cases mature weight was reached between five and nine years of age. These authors stated that five to six years of consecutive postnatal monthly weights were required to establish estimates of asymptotic weight. Fitzhugh et al. (1967) reported that age accounted for a significant portion of the variation in cow weight. Brown and Franks (1964) observed no definite trend with respect to increased weight or body measurements associated with age increases from 31 to 42 months of age.

Brown (1970) used von Bertalanffy's model to estimate growth curve parameters from birth to the age of seven months. No meaningful information was gained by analysis of these parameters. Richard's model was used to analyze weights from birth to first breeding (600 pounds), and the estimates of asymptotic weights were similar to those resulting from the analysis of all weights from birth to maturity. Brown et al. (1972a) reported that a minimum age of 60 to 42 months were required to accurately estimate weight-age parameters for males and females, respectively.

To answer the question "How early could an individual reach terminal age and still contribute data suitable for use?", Joandet (1967) used the Gompertz equation with several series of weights. Age was decreased from final weight to 24 months of age by deleting weights for one year at a time, and growth parameters were estimated each time weights were deleted. The terminal age ranged from six to eight years, and when only weights prior to five years of age were used, estimates of the parameters were unsatisfactory, as defined by coefficients of determination. Estimates of asymptotic weight decreased and coefficients of determination increased as the maximum age at which weights were used was decreased.

Reproduction

Many researchers (Brown and Franks, 1964; Vaccaro and Dillard, 1966; Fitzhugh et al., 1967; Joandet and Cartwright, 1969; Schake and Riggs, 1972) have discussed the stress of parturition and lactation on the growth of animals and have worked with the weight changes in the reproductive cycle of beef cows.

Weights and body measurements taken at three years of age on daughter-dam pairs of Hereford and Angus cows were studied by Franks and Brown (1963). Dry cows were about 100 pounds heavier than wet cows in both daughter and dam analyses. Measurements of height and depth were not significantly different for the two groups. Marlowe (1962) reported pregnant Angus cows were 86 pounds heavier and pregnant Hereford cows 101 pounds heavier than cows nursing calves. Fitzhugh et al. (1967) found that cows parous the previous year were lighter than nonparous cows for both parturition weight and weight at weaning. Repeatability estimates for both weights generally exceeded .45. Cows which had not raised calves the previous year were heavier than cows which raised calves, but both groups were lighter than nonparous cows. It was suggested that the extra weight, accumulated during the period in which the parous cows were not lactating, was maintained through at least one subsequent lactation period.

Nelson (1967) observed that when cow weights were adjusted to a constant age, cows that had raised a calf to weaning the previous year were lighter than cows that had not weaned a calf. Similar findings were reported by Ellis (1963), Maddox (1964) and Fitzhugh (1965). Cows calving first at two years of age tended to be heavier at maturity than cows calving initially at three years of age. The effect of fecundity on post-parturition weight was significant at the .05 probability level. Bereskin and Touchberry (1967) stated that weight may be biased upward as much as 15% due to pregnancy alone beyond five months of gestation.

Non-significant weight differences of 40-45 kg between 4.5-year-old cows bred to calve initially at three years of age over those calving first at two years were reported by Bernard and Lelande (1967). Eckles and Swett (1918) were cited by Nelson (1967) as finding that calving dairy heifers initially at 20-24 months of age versus 28-34 months adversely affected their weight at six years of age. In the work by Bernard and Lelande (1967), at every age except birth, heifers that later calved at two were heavier than heifers calving at three.

Brinks et al. (1962a) stated that Hereford cows which were younger than five years of age tended to gain weight during lactation. Cows that were 6-10 years of age lost weight. However, Joandet (1967) observed that parturition status did not contribute to the total variance of asymptotic weight.

Condition

Cundiff et al. (1971) and Brungardt (1972) indicated that selection of breeding cattle based on weight per day of age calculated on a time-constant basis resulted in favoring fatter cattle as cattle which reached a certain stage of physiological maturity at a younger age. This selection had a pronounced effect on the shape of the growth curve. Work by Eller (1972) indicated that weight alone was not a sufficient measure of size and that selection for conventional yearling weight alone would favor fatter animals. He further concluded that this selection procedure would produce animals of several skeletal sizes and body shapes.

Brown and Shrode (1971) indicated the dam's condition score at weaning and the change in the dam's condition from April until weaning were important in multiple regression models predicting lifetime ADG in bulls and final fat thickness in heifers. Estimates of fatness, whether condition scores or ultrasonic fat thickness, received negative weightings in the equations. In addition, there was evidence that, at a given age, the amount of fat deposition reflected differences in growth curves which were related to lifetime growth rate.

Koger and Knox (1951) reasoned that gains made after three years of age tended to represent fat deposition rather than actual skeletal growth. Growth curves of two animals, one late-maturing and one early-maturing to asymptotic weights, were shown by Smith (1974). Adjusting weight of the early-maturing animal to the same condition as the late-maturing animal resulted in the same condition-constant mature weight. Smith (1974) suggested that in the case of animals with the same mature size, early-maturing animals would not only be heavier at all early ages but would also be fatter. If early-maturing heifers are in better condition at early ages, this additional fat may physiologically increase their tendency to fatten at later ages.

IV. RELATIONSHIPS BETWEEN PERFORMANCE AND GROWTH CURVE PARAMETERS

In recent years cow size has been a controversial subject among cattlemen. Although many popular articles have been written on the influence of cow size, research results have been inconclusive.

Taylor and Craig (1965) stated that rapid growth is positively correlated with larger mature size. Taylor (1965) suggested that cattle of larger mature size should gain more rapidly over a time-constant interval. Neville et al. (1962) found a non-significant regression of post-weaning ADG of calf on weight of calf's dam. The average 240-day weight of calf increased seven pounds for each 100-pound increase in dam weight (Neville et al., 1962). Ellis (1963) and Tanner (1964) observed that the average pounds of calf produced per unit of cow weight decreased as average cow weight increased.

Relationships between cow weight and calf performance were low according to Sawyer et al. (1963), but the correlation and regression coefficients indicated that heavier cows tended to produce calves that gained more rapidly and that were heavier from birth to 18 months of age. The correlations between the 5.5 year weight of dam and the ADG of calf was .26. Correlations among cow weights and calf weights reported by Brinks et al. (1962a) were low but suggested that heavier cows tended to produce heavier calves at birth and weaning. Spring weight of cow was more highly correlated with calf birth weight, 180-day gain, weaning weight and weaning score than was fall cow weight. It was suggested that since the spring weight contained nearly a full-term calf weight in addition to cow weight that the correlations with birth weight would be expected to be higher.

Genetic correlations of mature spring and fall weights with preceding weights and gains were reported by Brinks et al. (1964). The correlations were fairly high and indicated that selection for fast gaining cattle with heavy weights early in life would result in increased mature cow weights.

These authors reported the heritability of mature spring weight was .52 and of mature fall weight was .57. Singh et al. (1970) observed that cow weight at parturition significantly influenced birth weight but did not significantly influence preweaning ADG or weaning weight. The heavier cows produced heavier calves at weaning. Correlations of cow weight with the number of productive years the cow remained in the herd and with the calves produced per year were small and non-significant. This indicated that no relationship existed between cow size and reproductive performance. However, birth weight significantly influenced preweaning ADG and weaning weight.

Kress, Hauser and Chapman (1969) suggested that calves from large cows are heavier at weaning and have the genetic potential to be larger at maturity. Their data indicated heifers that were heavier at 15 months of age tended to calve at an earlier age and that larger cows should be more efficient. Correlations of .16 and .21 between actual cow weight and weaning weight and cow weight and 205-day weaning weight, respectively, were reported by Urick et al. (1971). A negative correlation of -.56 between cow weight and calf weight per 45.4 kg of cow weight indicated an inverse relationship of calf and cow weights. The coefficient of linear regression indicated a 1.93 kg increase in 205-day weight for each unit (45.4 kg) increase in actual cow weight. Knox (1957) found that the calf-weaning weight per unit of weight of the dam was 13% greater for large cows. Cartwright et al. (1964) reported a curvilinear regression of calf weight on weight of dam. Nelson and Cartwright (1967) reported that the relationship between calf pre-weaning ADG and dam weight was more curvilinear in Herefords than in Angus.

In a study to evaluate the relationship of dam's weight and weight changes to calf's growth rate in Hereford cattle, Vaccaro and Dillard (1966) observed a consistent loss in weight during the first 60 days of lactation and a consistent gain thereafter to re-establish normal weight. Each kilogram of increase in dam's weight resulted in an increase of about .025 kg in birth weight of calves. The correlations between dam weight and birth weight of calf averaged .32. Dam weight was not significantly associated with calf pre-weaning gain. Younger dams producing the faster gaining calves showed smaller loss in weight during the first part of lactation and higher gains during the last part. The older cows which had the faster gaining calves tended to have larger weight losses during the first 60 days of lactation but gained weight thereafter.

Lifetime records of 164 ewes were analyzed by Nichols and Whiteman (1967). The regressions of lifetime production measures on ewe body weight were small, indicating that the total production of larger ewes was only slightly more than that of smaller ewes. When average lifetime weight was adjusted to a constant condition score, the correlations between weight and production increased.

Mature weight in Angus and Herefore cattle was positively correlated with immature body weights at all ages in the data of Brown et al., 1972b. The genetic correlations of immature body weight with mature weight in Herefords were large at all ages but were less than .10 in Angus prior to 16 months of age. It was suggested by these authors that selection of Angus and Hereford replacement heifers on the basis of yearling body weight would not result in responses in mature weight. The phenotypic correlations between rate of gain and mature weight indicated that the fastest gaining animals prior to eight months attained smaller mature weights, and that rapid gains after eight months were indicative of heavier mature weights.

Correlations were reported by Brown et al. (1972c) between growth parameters and weights of Angus and Hereford cattle. In Angus cattle, the correlation between K and actual weight increased from -.31 at four months to .48 at 12 months and then decreased to -.24 at 36 months. Correlations between A and actual weight increased from .19 at eight months to .84 at 36 months. The correlation between A and actual weight at four months was .27.

Genetic correlations between monthly gain and rate of maturing also were reported by Brown et al. (1972c). They suggested that prior to 16 months of age, genes influencing rate of gain have a similar effect on maturing rate. Negative correlations were observed between rate of maturing and rate of gain at older ages. These negative relationships suggested that heifers which gained rapidly after 16-20 months of age were not genetically superior with respect to early maturity. However, phenotypic correlations indicated that large early gains were synonymous with early maturity.

Heavier animals at any age tended to have higher absolute growth rates at all intervals according to Smith (1974) except that animals which were heavy at early ages tended to grow more slowly from 550 days to three and one-third years of age. Animals which were heavy at weaning and at 396 days tended to exhibit a reduction in relative growth rate and in absolute maturing rate after 396 days.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE AND DESCRIPTION OF DATA

Data used in this study were collected at the University of Tennessee Plateau Experiment Station, Crossville, Tennessee, between the years of 1959 and 1973. The original data consisted of weights collected quarterly on 102 mature Angus cows present in the cow herd in 1972. Routine management records were kept, and all animals represented in the study were under the same type of management during the 15-year period. The breeding seasons were 90 days in length with cows being bred during April, May and June. Most calves were born during January, February and March. Heifers were bred to calve as two year olds and, approximately 63% of the animals used in this study calved at two and again at three years of age. Another 27% calved first at three years of age and 10% calved as two year olds and were open as three year olds. Culling of cows was based primarily on age and not on performance. In addition to birth weight, pre-weaning weights were collected at approximately 120 days of age. Weaning data were collected in early October at a mean age of approximately 240 days. All animals were scored with respect to condition at pre-weaning and at weaning. The quarterly weights taken on the animals were as follows: Spring, late April, Summer, early July; Fall, late October; and Winter, late December or early January. Replacement heifers were selected on the basis of weaning weight and type score. The heifers were wintered on a silage ration designed to produce about one pound per day increase in body weight.

II. DESCRIPTION OF COMPONENTS OF REPRODUCTION AND CALCULATION OF CALVING INFORMATION

Much discussion has been devoted to the cause-and-effect relationship between reproduction and growth. The literature contains considerable information on the effect of reproduction (lactation and age of first calving) on cow weight. In this study reproductive status at three ages were analyzed. The first factor was early reproductive status; the second factor was reproductive status at four and five years of age; and the third was a coded variable indicating reproductive performance after five years of age. The average calving date and calving interval in each group also were calculated.

Early Reproductive Status (EREPRO)

Early reproductive status refers to the lactation status of cows at two and three years of age. The variable EREPRO consists of three categories. The first group was made up of cows which calved at both two and three years of age. Cows which were open as two year olds and calved at three years of age made up the second group and the third group within EREPRO was made up of animals which calved as two year olds but were open as three year olds.

Reproductive Status at Four and Five Years of Age (FFREPRO)

After the highly significant effect of EREPRO on growth parameters was observed in Phase I of the study, the other reproductive status groups were added to the analyses. FFREPRO was coded as three groups. The first group was made up of animals which calved at both four and five years of age and contained approximately 83% of the animals. The cows which were open as four year olds and calved as five year olds made up the second group and contained 12% of the animals. The third group contained the cows which calved as four year olds and were open at five years of age.

Late Reproductive Status (LREPRO)

Late reproductive status indicated the reproductive performance of cows after they were five years of age. The first group, which was made up of approximately 89% of the animals, contained the cows which calved each year. The other 11% made up the second group, which was composed of cows which were open one year after they were five years of age.

Birth Weight (BW)

An average progeny birth weight was calculated for each cow. Birth weight of female calves was adjusted to a male basis by adding six pounds to the birth weight of a female (Butts, 1966).

III. ASYMPTOTIC REGRESSION MODEL

Growth parameters, mature weight (A) and general rate of maturing (K), were estimated by asymptotic regression of various series of weights on age as described by Brown et al. (1972a, b, c). The basic model ($Y_t = A(1-Be^{-Kt})$) was the one that was used by Brody (1945) and was discussed in detail in Section I of Chapter I.

A computer program written by Viola Gibbons and Dr. W. L. Sanders at the University of Tennessee and based on the equations discussed by

Snedecor and Cochran (1967) was used to perform the asymptotic regressions in this study.

Beginning with the general equation in which the weight of an animal is represented by the equation

$$W = A + Be^{-Kt} \qquad (1)$$

and rewriting it in the form of

$$Y = p^t = e^{t \ln p} \text{ since} \qquad (2)$$

$$\ln y = t \ln p,$$

then equation (1) can be written as

$$W = A + B_{(p)}^{t}. \qquad (3)$$

Taylor's theorem, where

$$F(\alpha, B, o) \doteq f(a_1, b_1, c_1) + (\alpha - a_1) fa +$$

$$(B - b_1) fb + (r - c_1) fc$$

and the derivatives of equation (3)

$$dw/dA = 1,\ dw/dB = (p)^t \text{ and } dw/dp = B^{t(p)t-1}$$

can be used to derive the following equation:

$$W \doteq A + B_1(p_1)^t + (A - A_1)\ 1 + (B - B_1)\ p^t +$$

$$(p - p_1)\ B\ t\ (p)^{t-1} = A + B_p^{\ t} + (p - p_1)\ (p)^{t-1}.$$

Letting $X_1 = p^t$, $X_2 = t(p)^{t-1}$ and $C = (p - p_1)B_1$,

$$W = A + BX_1 + (p - p_1)\ BX_2 \text{ or}$$

$$W = A + BX_1 + CX_2 \qquad (4)$$

The first step in the program is to guess p and generate X_1 and X_2. An iterative procedure is begun by making a second guess of p based on the division of C by B and adding it to the previous p. The procedure is repeated until $K_n - K_{n-1} < 10^{-b}$ and multiple regression analysis is performed to determine A, B and C, as shown in equation (4).

IV. ESTIMATION AND STATISTICAL ANALYSIS OF GROWTH CURVE PARAMETERS

Evaluations of factors affecting growth curve parameters were made in two separate phases in this study. The first phase was based on evaluation of the effect of age; the second phase consisted of evaluation of the effect of season of weighing.

Phase I

In the first phase, the growth curve parameters, mature weight (A) and maturing rate (K), were estimated using all available weights from birth of the animal to the specified age. The ages used were at yearly intervals from 1.5 years through 8.5 years. The weights beyond the specified ages were deleted. Lifetime estimates of A and K were derived by performing an asymptotic regression on all available weights for each cow, regardless of age. The lifetime age ranged from five to 13 years. Since the spring weights of the animals contained certain bias due to parturition status of the cow, the ages designated were at the half-year age. This prevented the last weights used in the asymptotic regression from being biased due to parturition status. The parameters were estimated using approximately the same number of weights within each age group.

Raw means and simple correlations among the estimates of mature weight and rate of maturing at the various ages were used to study the relative agreement of the parameters. The model used to evaluate the estimates of A and K included the following factors: age, early reproduction status as two and three year olds, interaction of age and reproductive status and cow-within-reproduction. The least squares constants for these factors were used to adjust the means of age-reproduction subclasses and to calculate the least-squares means for each age group.

Bartlett's test of homogeneity of variances as described by Snedecor and Cochran (1967) was used to test the variances of the age-reproduction subclasses. It was found that with the estimates derived using weights to 1.5 years and the estimates for EREPRO group 2 at two years of age in the test that the variances were not homogeneous. Elimination of the estimates at one year of age significantly decreased the heterogeneity. For this reason the estimates at 1.5 years of age and the animals in the second EREPRO group at 2.5 years of age were deleted.

Phase II

After analysis of the estimates derived in Phase I, the question of how many weights per year and at what time(s) during the year animals should be weighed to best delineate their growth pattern was considered. In an attempt to answer this question, the weights on the same animals used in Phase I were used in a series of eight asymptotic regressions per cow. Two groups were designated--five years and lifetime. In the first group (Five years) weights beyond five years of age were deleted and in the second group (Lifetime) all available weights for each cow in the designated season(s) were used, regardless of age. Then four estimates per age group were calculated using (1) all quarterly weights collected during the year (2) only summer weights (3) only fall weights and (4) only winter weights. In each case, all the weights that were collected from birth to one year of age were used, followed by one of the series of weights described above.

The basic model used in the analysis of A and K contained the following factors: age, season, early reproduction and cow-within-reproduction plus various interaction terms. The parameters were correlated with the progeny performance variables, and various regression analyses were performed to evaluate the use of growth parameters to predict progeny performance. Estimates of the parameters derived from winter weights were used to study the effects of later (FFREPRO and LREPRO) status on growth parameters and its value for predicting progeny performance when condition of the offspring was held constant.

CHAPTER IV

RESULTS AND DISCUSSION

I. PHASE I - EFFECTS OF AGE

Means of the estimated mature weights (A) at the various ages are presented in Table 1. The digit after the letter indicates the age at which the growth parameters were estimated. The symbol A_{LT} represents mature weight calculated by asymptotic regression using all weights available for individual cows. Table 1 shows that the highest and most variable estimates of A were obtained when only weights taken prior to 1.5 years of age were used in the weight-age curves, followed closely by those estimates using only weights prior to 2.5 years of age. The lowest mean estimate of mature weight was A_3, the age at which all cows had completed at least one lactation. The magnitude of the variation in estimates of mature weight decreased significantly from A_2 to A_3 and continued to decline as age increased. The lifetime mean estimate was higher than estimates at other mature ages.

Means of the estimates of rate of maturing (K) are presented in Table 2. The highest mean value for K was K_3, the age at which the estimated mean mature weight was the lowest. The K_3 estimates were the least variable and the K_1 estimates were the most variable, followed closely by K_2. In contrast to mature weight, mean rate of maturing decreased when weights after 3.5 years of age were included in calculation of the estimates. The lifetime estimates had the lowest mean K value and exhibited theleast variation. Coefficients of variation indicated that

TABLE 1. MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF MATURE WEIGHT (A) ESTIMATED AT VARIOUS AGES

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_{LT}
N	102	102	102	102	102	87	75	49	102
Mean	539	503	465	473	481	485	484	482	497
S.D.	161	150	77	68	59	51	45	38	41
C. V.	30	30	17	14	12	11	9	8	8

TABLE 2. MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF MATURING RATE (K) ESTIMATED AT VARIOUS AGES

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_{LT}
N	102	102	102	102	102	87	75	49	102
Mean	.061	.069	.073	.069	.065	.062	.061	.061	.056
S.D.	.024	.023	.016	.018	.016	.015	.014	.013	.012
C. V.	38	33	22	26	25	24	22	22	21

the estimates of K were more variable than the estimates of A. The coefficients of correlations among the estimates of A at the various ages are shown in Table 3. In tables 3 and 4, simple correlations are presented above the diagonal, and residual correlations adjusted for early reproductive status are shown below the diagonal. The correlations between A_1 and the estimates of A at mature ages were negative. Correlations among pairs of K values at various ages are shown in Table 4. These correlations tended to be smaller than the correlations among estimates of mature weight. The largest correlations were observed between estimates at adjacent ages. There was a tendency toward stabilization of the relationship among estimates of K at four years of age, and the same trend was observed with respect to estimates of mature weight calculated from all weights prior to and including four years of age. The correlations between A and K at the various ages are given in Table 5 and 6. Table 5 contains the simple correlations; Table 6 the residual correlations. These correlations were generally negative and the correlations of the greatest magnitude were observed between estimates of A and K within the same age. Although the magnitude of the negative correlation decreased as age increased, there was a significant negative correlation between A and K at the mature ages. Sanders (1974) has indicated a quadratic relationship between A and K. This would mean that the correlations between A and K would not necessarily indicate biological meaning, especially at younger ages.

Analyses of variance of A and K are shown in Table 7. Preliminary analyses indicated variation in age effects, and the data indicated differences in early reproductive performance. In order to reduce the environmental variation, reproductive status and the reproduction-age interaction were added to the model. Cow effect was nested within

TABLE 3. CORRELATIONS[1] AMONG MATURE WEIGHTS[2] (A) ESTIMATED AT VARIOUS AGES

	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_{LT}
A_2		.67	.44	.34	.32	.34	.37	.27
A_3	.48		.72	.59	.56	.53	.51	.50
A_4	.30	.72		.92	.85	.79	.62	.74
A_5	.40	.66	.92		.97	.88	.77	.84
A_6	.43	.70	.81	.95		.94	.88	.91
A_7	.38	.62	.74	.87	.94		.98	.95
A_8	.39	.58	.68	.80	.88	.97		.96
A_{LT}	.43	.57	.68	.83	.90	.95	.96	

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

[2]Coefficients above the diagonal represent simple correlations among unadjusted values. Coefficients below the diagonal are residual correlations after adjustment for variation in reproductive status prior to 4 years of age.

TABLE 4. CORRELATIONS[1] AMONG MATURING RATES[2] (K) ESTIMATED AT VARIOUS AGES

	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_{LT}
K_2		.75	.35	.23	.09	-.01	-.30	-.21
K_3	.58		.64	.43	.25	.08	-.20	-.18
K_4	.46	.69		.89	.73	.59	.28	.34
K_5	.45	.62	.88		.94	.79	.53	.56
K_6	.40	.60	.81	.94		.91	.76	.76
K_7	.22	.43	.68	.80	.89		.95	.84
K_8	.07	.19	.48	.55	.66	.86		.91
K_{LT}	.19	.19	.56	.65	.72	.79	.84	

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

[2]Coefficients above the diagonal represent simple correlations among unadjusted values. Coefficients below the diagonal are residual correlations after adjustment for variation in reproductive status prior to 4 years of age.

TABLE 5. CORRELATIONS[1] AMONG MATURE WEIGHTS (A) AND RATES OF MATURING (K) ESTIMATED AT VARIOUS AGES

	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_{LT}
K_2	-.85	-.58	-.39	-.33	-.30	-.37	-.26	-.19
K_3	-.65	-.82	-.69	-.59	-.55	-.54	-.44	-.45
K_4	-.23	-.32	-.75	-.74	-.68	-.61	-.38	-.55
K_5	-.06	-.11	-.57	-.72	-.70	-.63	-.44	-.56
K_6	.07	.05	-.39	-.58	-.64	-.11	-.51	-.55
K_7	.16	.21	-.23	-.38	-.47	-.56	-.48	-.51
K_8	.30	.37	.04	-.05	-.17	-.39	-.46	-.43
K_{LT}	.31	.41	-.01	-.16	-.25	-.25	-.30	-.41

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

TABLE 6. RESIDUAL CORRELATIONS[1] AMONG MATURE WEIGHTS (A) AND RATES OF MATURING (K) ESTIMATED AT VARIOUS AGES AND ADJUSTED FOR REPRODUCTION

	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_{LT}
K_2	-.74	-.34	-.21	-.23	-.37	-.29	-.20	-.28
K_3	-.43	-.74	-.64	-.58	-.68	-.61	-.50	-.54
K_4	-.16	-.33	-.72	-.68	-.52	-.49	-.38	-.48
K_5	-.06	-.17	-.56	-.69	-.57	-.53	-.39	-.45
K_6	-.13	-.15	-.49	-.57	-.60	-.59	-.45	-.50
K_7	-.03	.04	-.36	-.41	-.44	-.57	-.48	-.45
K_8	-.03	.14	-.27	-.28	-.32	-.50	-.53	-.45
K_{LT}	-.03	.26	-.19	-.20	-.22	-.32	-.31	-.38

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

TABLE 7. MEAN SQUARES OF MATURE WEIGHT (A) AND RATE OF MATURING (K)

Source of Variation	df	Mean Squares A	K
Age	6	10852	.000738
Repro	2	710391	.001411
Age x Repro	12	339524**	.002595**
Cow/Repro	97	73795*	.000772**
Residual	485	70032	.000134

*P < .05

**P < .01

reproductive classifications because of the confounding of individual cow effect and early reproductive status. The cow-within-reproduction component, shown in Table 7, represents independent variation ($P < .01$) with which to work in genetic studies. The main effects, age and reproduction, were not significant ($P < .05$), but the age-reproduction interaction was significant at the .05 level of probability for A and at the .01 level for K. Least-squares means of the age-reproduction subclasses were calculated and are presented in Table 8. Definite and consistent patterns with respect to the effects of age and early reproductive status on the weight-age parameters were observed. The same pattern observed in the preliminary analyses existed with respect to A_2 and K_3 in reproductive groups 1 and 3 but in the group 2 the estimates of A_3 decreased considerably and that of K_3 increased. The means of the parameters appeared to stabilize at 4.5 years of age and no large changes were observed until 8.5 years of age where sampling error due to the reduction of the numbers of observations could be responsible for part of this change. Changes in the magnitude of the estimates of A and K within groups and across ages showed a greater reduction in A_2 and a larger increase in K_2 when compared to previous estimates derived at these ages. The lowest estimate of A and highest estimate of K for group 1 was at 3.5 years of age, which would be after two lactations. For group 2 the estimates of A decreased and estimates of K increased until 8.5 years of age. No consistent pattern was observed with respect to trends of the estimates for reproductive group 3. The highest estimate of A was at 5.5 years and indicated that effects other than age and early reproductive status may have affected the magnitude of the estimates.

TABLE 8. LEAST-SQUARES MEANS OF MATURE WEIGHT (A) AND RATE OF MATURING (K) FOR AGE-REPRODUCTION SUBCLASSES

Repro'		Age 2	3	4	5	6	7	8
1	A	457	449	459	470	483	493	444
	K	.076	.078	.073	.068	.061	.056	.082
2	A	---	535	503	500	493	493	577
	K	---	.057	.066	.065	.067	.066	.056
3	A	468	450	516	536	528	519	513
	K	.078	.079	.060	.055	.057	.058	.060

'Repro 1 - Calved as 2 and 3 year old
2 - Open as 2, calved as 3 year old
3 - Calved as 2, open as 3 year old

Growth curves plotted using least-squares means of the various age groups are shown in Figure 1. Figure 2 shows the actual growth of an individual cow and the fitted growth curves using estimates derived at three and six years of age.

II. PHASE II - EFFECTS OF SEASON

Since most mature beef cows are not weighed at frequent and regular intervals, it is important to know how many weights per year will be required to accurately describe the growth of the animal. In addition, seasonal variation in weights of the same animal are known to exist; therefore, it is feasible that weight taken in a certain season of the year might better indicate the actual genetic growth of the animal. In order to study the effect of season of weighing on the estimates of the growth curve parameters, the following results are presented, and inferences will be made as to the best frequency and seasons of weighing.

Analysis of Growth Parameters Derived from Various Seasonal Weights

Means and standard deviations of the estimates of mature weight (A) and the rate of maturing (K) for the various age-season groups are presented in Tables 9 and 10, respectively. The first subscript following the letter A or K represents the age category--0 for lifetime and 5 for five years of age. The second subscript indicates the season or time of year the weights were collected--2 for summer weights, 3 for fall weights, 4 for winter weights and 0 for all quarterly weights. The highest estimates of mature weights resulted when winter weights taken during the entire lifetime of each animal were used (04). This was expected since the cows in this herd gained weight and condition after weaning (McLaren

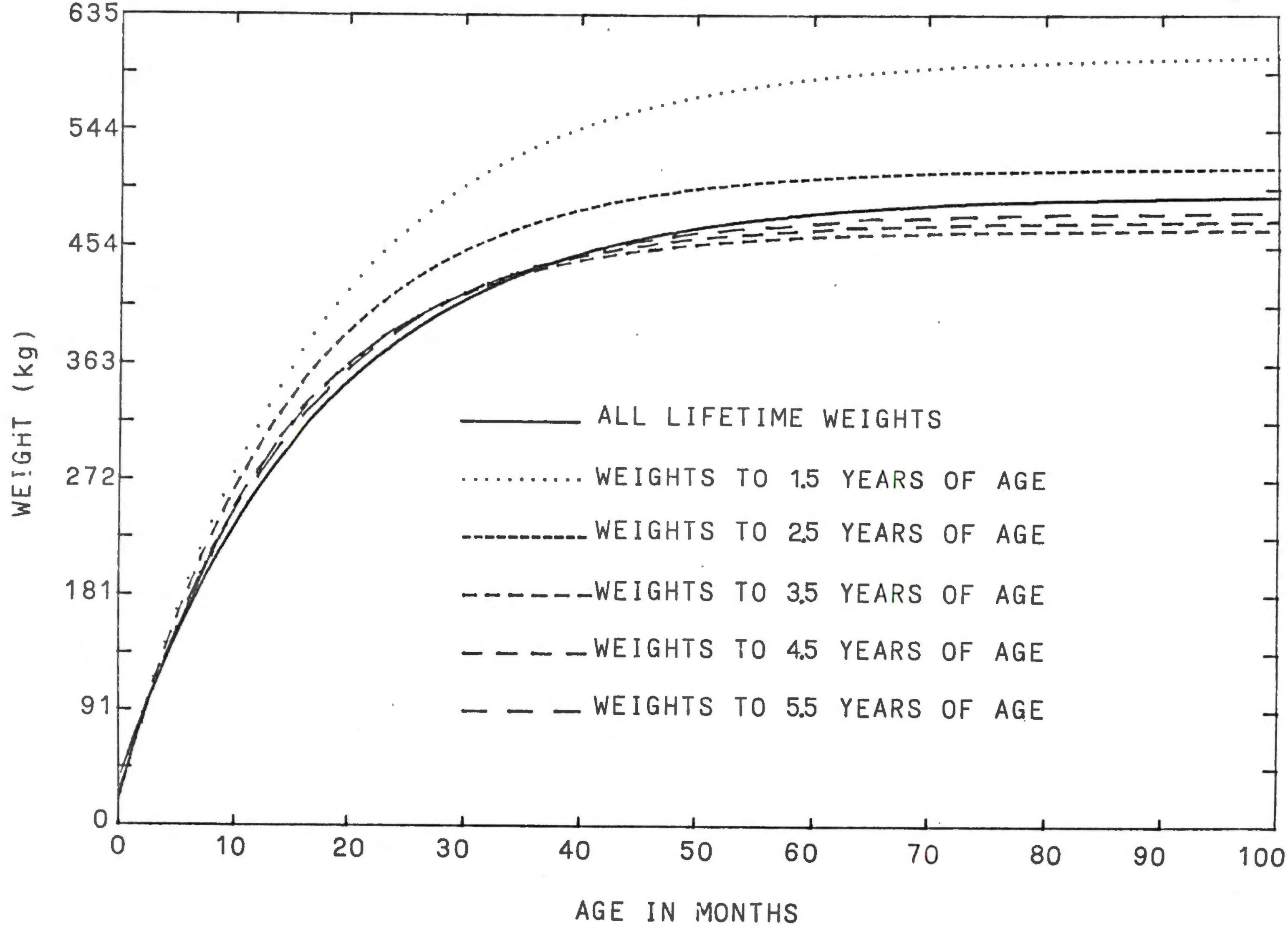

Figure 1. Growth curves plotted using least-squares means of various age groups.

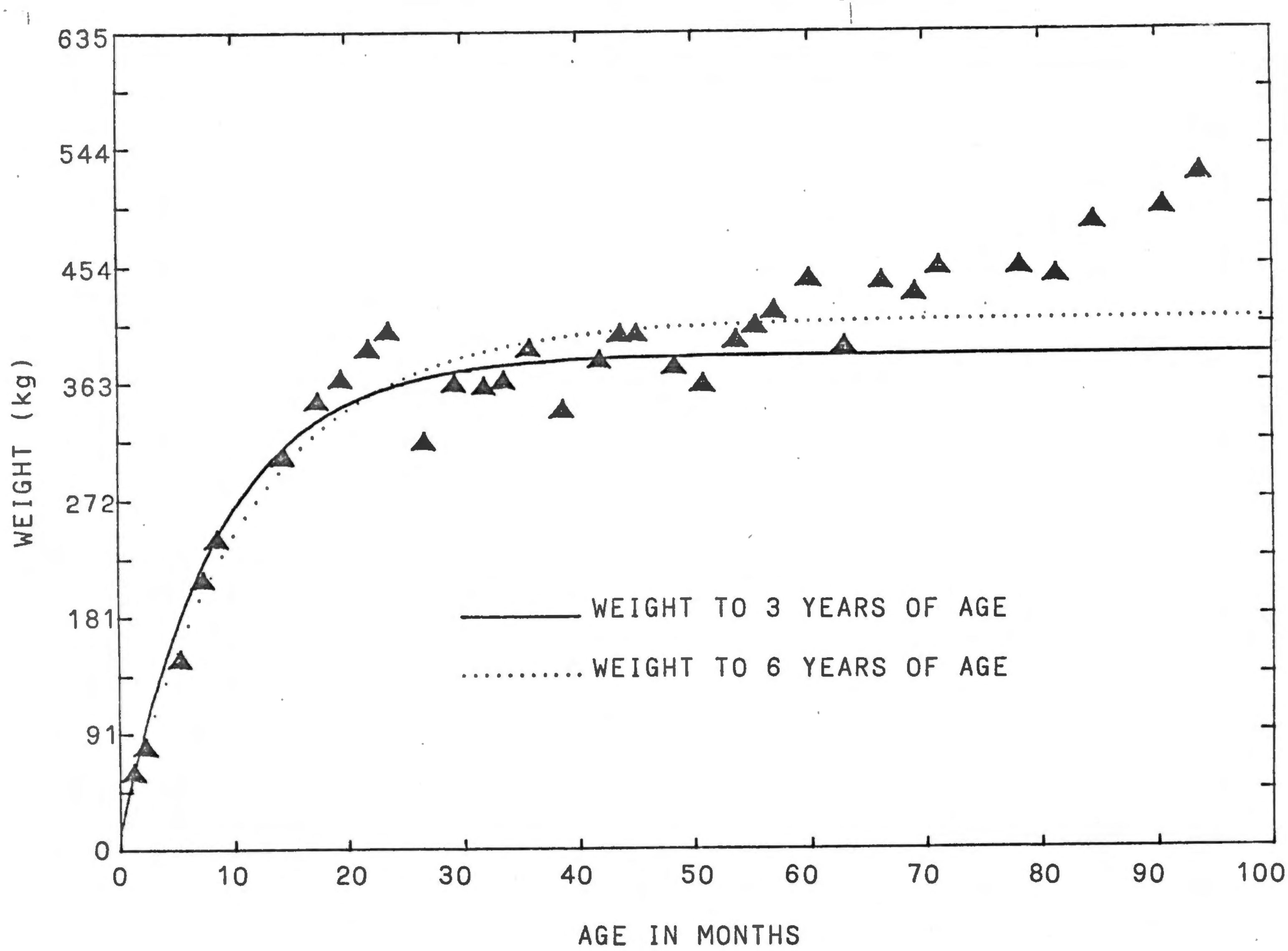

Figure 2. Fitted growth curves from weights to three years of age and from weights to six years of age for Angus 154. Actual growth curve of the animal is shown.

TABLE 9. MEANS AND STANDARD DEVIATIONS OF MATURE WEIGHT (A) ESTIMATED FOR THE AGE-SEASON SUBCLASSES

	Source of estimates of A							
	A00	A02	A03	A04	A50	A52	A53	A54
$\bar{A}$ (Kg)	496	492	492	522	483	478	487	508
S.D.	40.9	42.5	41.9	45.8	55.3	53.3	52.0	61.7

TABLE 10. MEANS AND STANDARD DEVIATIONS OF MATURING RATE (K) ESTIMATED FOR THE AGE-SEASON SUBCLASSES

	Source of estimates of K							
	K00	K02	K03	K04	K50	K52	K53	K54
$\bar{K}$	.0572	.0584	.0614	.0545	.0646	.0642	.0642	.0602
S.D.	.0113	.0102	.0100	.0096	.0149	.0129	.0125	.0133

and Odom, 1970) and as age increased, the cows increased in condition. The second highest mean was obtained when only winter weights prior to five years of age were used. This latter group (54) had the highest standard deviation with respect to A and K and all estimates from 5-year groups had higher standard deviations than the lifetime estimates which indicated that the difference in mature weight tended to decrease as age increased. The mean of each estimate of A derived from lifetime weight was higher than that of the corresponding season group using only weights to five years of age. The opposite trends with respect to estimates of K are shown in Table 10. Highest estimates of rate of maturing were obtained when weights to five-years of age were used, and the use of winter weights resulted in lower estimates of K than weights taken in the other three seasons. The lowest estimate of K was K_{04}, the group with the highest A value. The reversal in magnitude of the mean of A and K suggested a negative correlation between mature weight and rate of maturing. The lower means and standard deviations for estimates derived from lifetime weights indicate that rate of maturing decreased as age increased and that the influence of factors resulting in differences in maturing rate at younger ages tended to decrease as age increased.

Correlations among estimates of A and K from the various combinations of weights are presented in Table 11. Correlations among mature weights are shown above and those among K values are shown below the diagonal. All of the correlations among estimates of A were highly significant, and the lowest correlations were between A_{54} and the estimates from lifetime weights. Correlations among the various estimates of K were all significant with the exception of the correlations between K_{54} and K_{00}. In general,

TABLE 11. CORRELATIONS[1] AMONG MATURE WEIGHTS[2] AND AMONG MATURING RATES[3] ESTIMATED FOR AGE-SEASON SUBCLASSES

	00	02	03	04	50	52	53	54
00		.94	.95	.93	.84	.82	.84	.74
02	.80		.89	.84	.82	.87	.81	.71
03	.78	.83		.91	.85	.81	.89	.76
04	.81	.77	.84		.82	.78	.83	.83
50	.54	.68	.77	.73		.94	.96	.90
52	.41	.72	.70	.62	.88		.92	.83
53	.46	.66	.79	.69	.93	.89		.86
54	.23	.46	.54	.60	.83	.79	.81	

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

[2]Coefficients above the diagonal are simple correlations among estimates of A.

[3]Coefficients below the diagonal are simple correlations among estimates of K.

these correlations were lower than the correlations among the A estimates. The highest correlation between a pair of estimates of A was between K_{53} and K_{50} (r = .96). The correlation of .93 between K_{53} and K_{50} was the highest between any pair of estimates of K. These correlations indicate that annual weights taken after weaning resulted in more repeatable estimates of growth curve parameters than annual weights taken at other seasons of the year especially when only weights prior to five years of age were used.

Correlations among the estimates of A and K are presented in Table 12. These correlations are all negative except that between K_{00} and A_{54} (r = .05). Correlations between K_{00} and the estimates calculated from weights taken on animals at ages up to five years were smaller than the other correlations. The diagonal of the correlation matrix contains the correlations between A and K estimates within the same age-season group. The coefficient of correlation between the parameters from the five-year-old estimates are slightly larger than the correlation of .62 reported by Brown et al. (1972a) for Angus cattle, and the correlation between A and K from the lifetime estimates were smaller.

The analyses of variance of A and K are shown in Table 13. The effect of age, season, early reproductive status, various interactions among these main effects and the cow-within-reproduction component were included in the model. The classification of early reproductive status was the same as used in Phase I and is described on page 21. Age at which estimates were calculated did not significantly affect the value of A, but this effect was significant at the .05 level of probability with respect to variation in K. Lifetime estimates of K were lower than the

TABLE 12. CORRELATIONS[1] AMONG MATURE WEIGHTS (A) AND MATURING RATES (K) ESTIMATED FOR THE AGE-SEASON SUBCLASS

	K00	K02	K03	K04	K50	K52	K53	K54
A00	-.41	-.49	-.53	-.49	-.57	-.55	-.54	-.48
A02	-.33	-.56	-.48	-.41	-.54	-.60	-.52	-.46
A03	-.32	-.44	-.57	-.45	-.55	-.54	-.59	-.49
A04	-.25	-.35	-.42	-.50	-.50	-.48	-.50	-.55
A50	-.14	-.36	-.42	-.37	-.72	-.70	-.70	-.71
A52	-.09	-.36	-.36	-.30	-.63	-.74	-.63	-.62
A53	-.15	-.35	-.44	-.36	-.66	-.67	-.72	-.65
A54	.05	-.20	-.25	-.27	-.55	-.55	-.54	-.75

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$), and those greater than 0.25 are significant ($P < .01$).

TABLE 13. MEAN SQUARES OF MATURE WEIGHT (A) AND MATURING RATE (K) ESTIMATED USING SEASONAL WEIGHTS

Source	Mean Squares		
	df	A	K
Age	1	79603	.000843*
Season	3	80190**	.000556**
Reproduction	2	512254**	.003953**
Cow/Reproduction	99	73164	.000769
Age X Season	3	3155*	.000052
Age X Reproduction	2	60443**	.001602
Reproduction X Season	6	6526**	.000107**
Age X Repro X Season	6	3568**	.000053**
Age X Cow/Repro	99	5649**	.000143**
Season X Cow/Repro	297	2601*	.000047
Age X Season X Cow/Repro	297	1169	.000024

*P < .05

**P < .01

"5-year-old" estimates. Season and reproduction exerted a highly significant effect on both parameters, and the age X reproduction interaction and the reproduction X season interaction were both significant influences. The age X season interaction was significant for A but not for K. The least-squares means of the age X reproduction interaction subclasses are presented in Table 14. The means indicate the variation at five years that was due to early reproduction differences tended to decrease using lifetime weights.

Figure 3 shows growth curves plotted using the means of the seasonal groups at five years of age. Figures 4 and 5 show the actual growth of an individual animal and the fitted growth curve using seasonal estimates.

Estimates of Growth Parameters and Performance of Progeny

Coefficients of correlation between the growth parameters and progeny performance traits--weaning weight (WWT), weaning average daily gain (WNADG), weaning adjusted average daily gain (WNAADG), and weaning condition score (WNCOND) are presented in Table 15. The coefficients of correlation between the various estimates of mature weight and performance traits were generally negative and non-significant. Positive non-significant correlations were observed between A_{04} and A_{54} and the traits involving progeny weight. The magnitude of the coefficients of correlation within each season were similar for the two age groups and indicated that more variation existed between seasons than between age groups within a season.

Coefficients of correlation between estimates of maturing rate and performance traits were all positive. Significant correlations were observed between WWT and K_{00}, K_{02}, K_{03}, K_{50}, and K_{52}. Significant

TABLE 14. LEAST-SQUARES MEANS OF MATURE WEIGHT (A) AND RATE OF MATURING (K) FOR AGE-REPRODUCTION SUBCLASSES IN PHASE II

Repro*		Age 0	Age 5
1	A	493	465
	K	.058	.065
2	A	513	516
	K	.059	.064
3	A	488	500
	K	.064	.058

*Repro 1 - Calved as 2 and 3 year old
2 - Open as 2, calved as 3 year old
3 - Calved as 2 year old, open as 3 year old

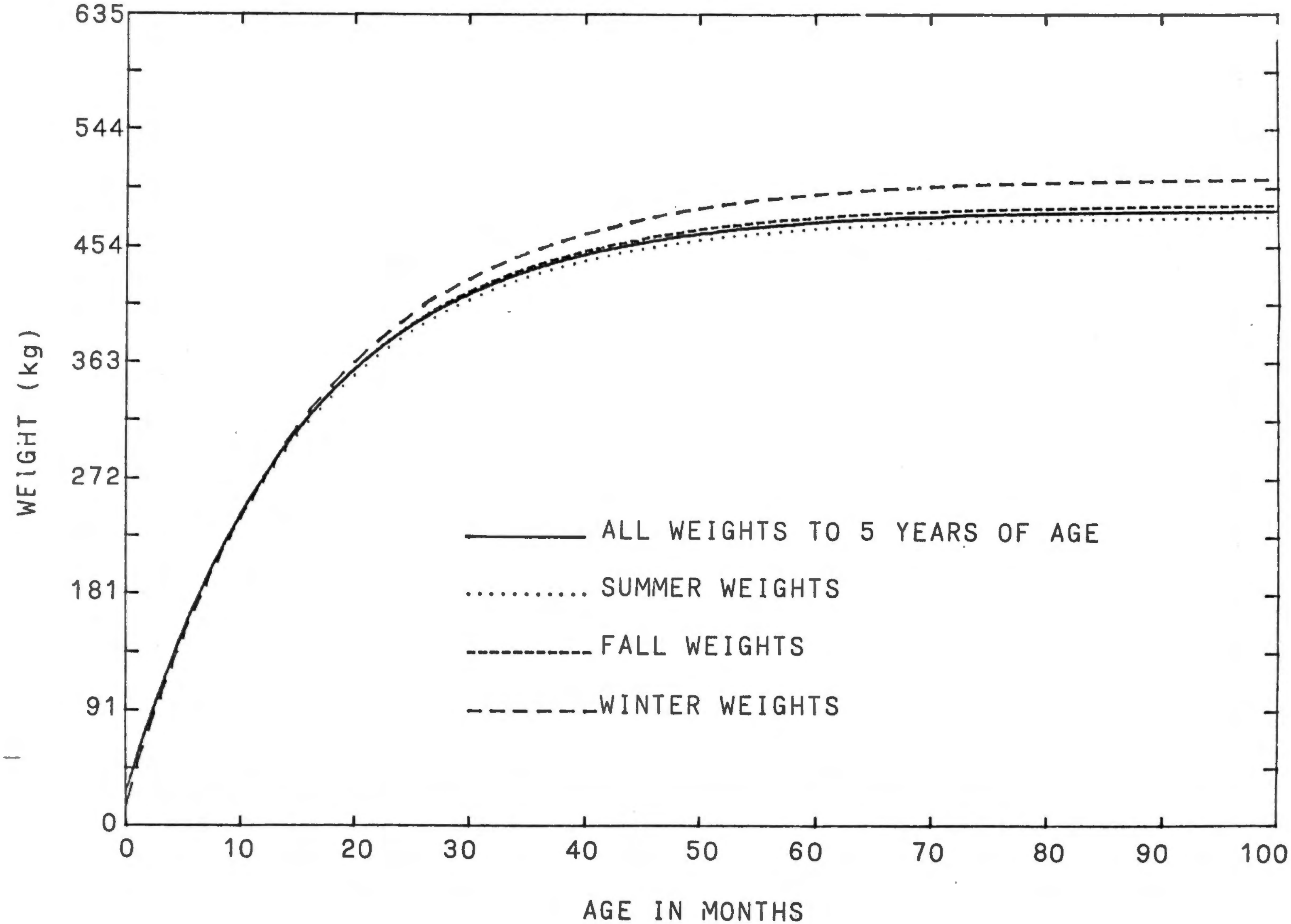

Figure 3. Growth curves plotted using means of seasonal groups at five years of age.

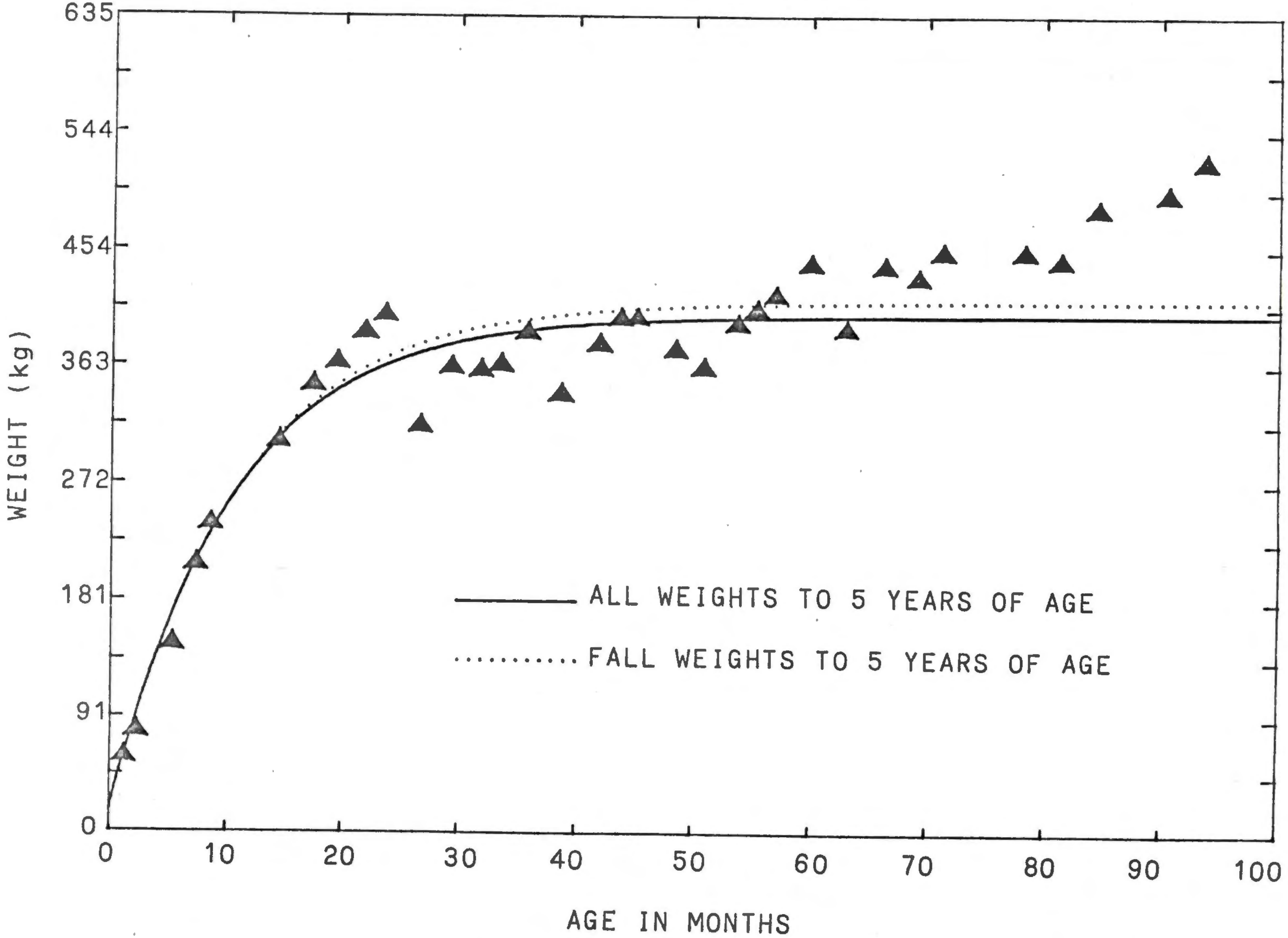

Figure 4. Fitted growth curves from all weights to five years of age from and fall weights to five years of age for Angus 154. Actual growth curve of the animal is shown.

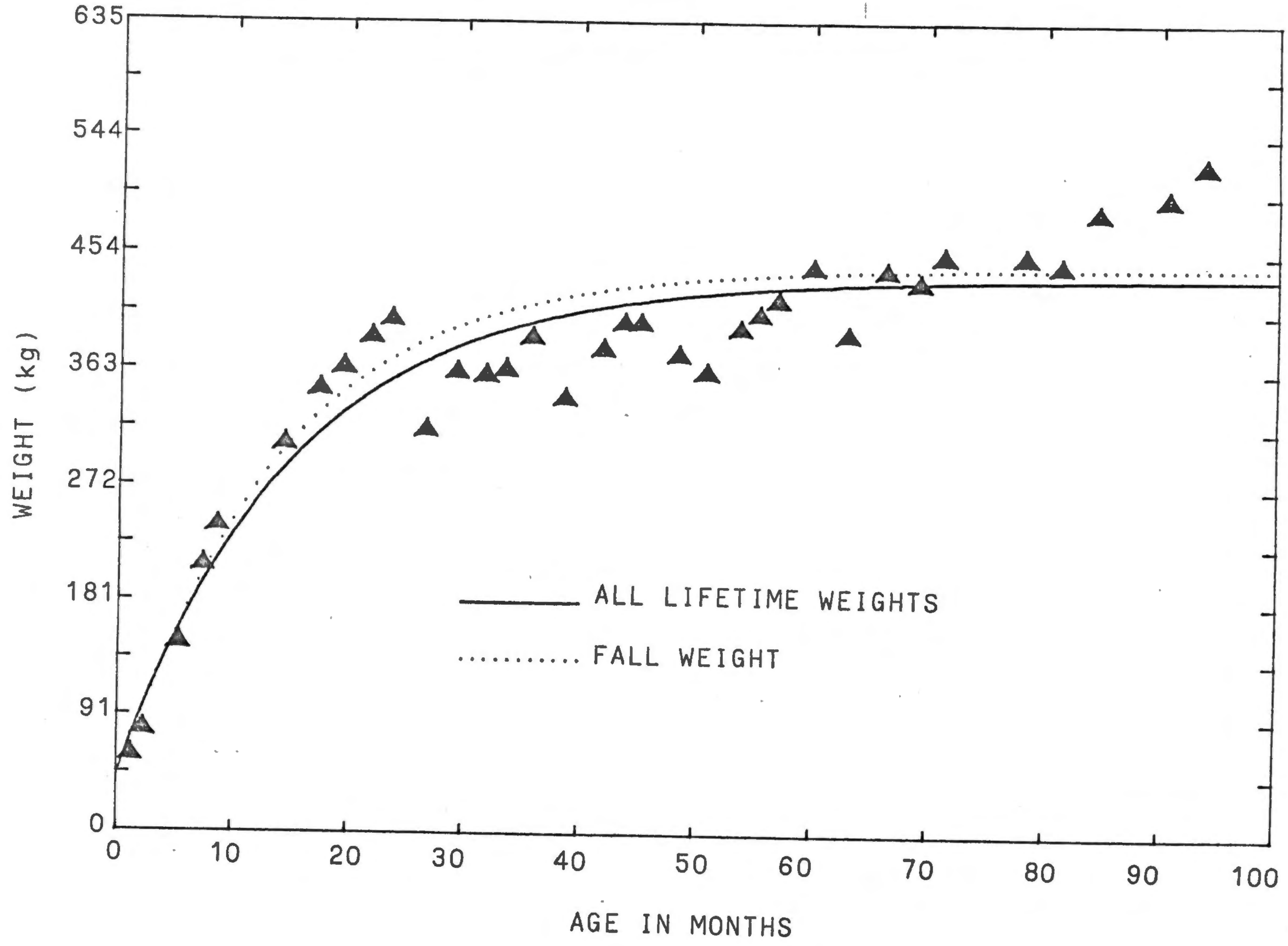

Figure 5. Fitted growth curves from all lifetime weights and from fall weights after one year of age on Angus 154. Actual growth curve of the animal is shown.

TABLE 15. CORRELATIONS[1] BETWEEN PROGENY PERFORMANCE TRAITS AND DAM GROWTH CURVE PARAMETERS

Source[2] of A and K	WWT	WNADG	WWAADG	WWCOND
A00	-.09	-.07	-.09	-.20
A02	-.10	-.02	-.03	-.19
A03	-.02	-.03	-.07	-.18
A04	.10	.05	.05	-.10
A50	-.04	-.06	-.09	-.20
A52	-.03	-.02	-.03	-.21
A53	-.00	-.02	-.07	-.18
A54	.13	.03	.02	-.10
K00	.31	.17	.21	.06
K02	.30	.07	.12	.03
K03	.25	.11	.16	.10
K04	.19	.07	.08	.01
K50	.25	.18	.21	.16
K52	.20	.07	.10	.11
K53	.19	.11	.15	.13
K54	.09	.10	.11	.10

[1]Coefficients of correlation greater than 0.20 are significant ($P < .05$) and those greater than 0.25 are significant ($P < .01$).

[2]The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

correlations were also observed between WNAADG and K_{00} and K_{50}. These correlations indicate a trend for faster-maturing cows to wean heavier calves and for heavier cows to wean lighter calves. This trend was more pronounced when mature weight was estimated using weights other than those taken in winter. The fact that the correlations between the variables measuring rate of gain of the calf and those measuring rate of maturing of the cow were not significant while those between WWT and estimates of K were significant ($P < .05$) which could be interpreted as an indication that faster-maturing cows either calved earlier and weaned older calves or had calves that were heavier at birth. The negative correlation between A and K and the fact that heavier cows have heavier calves at birth suggests that faster-maturing cows calved earlier than the slower-maturing cows.

To facilitate evaluation of the relationship between growth parameters and progeny performance, simple regression analyses were performed using the performance traits as dependent variables and the growth parameters as independent variables. The regression coefficients and the coefficients of determination (R^2) obtained when performance traits were predicted using estimates of mature weights were not significant. Regression coefficients from equations predicting weight and gain were generally negative except for A_{04} and A_{54}. All regression coefficients from equations predicting weaning condition were negative but were significant only when A_{00}, A_{50}, and A_{52} were used. Less than 1% of the variation in calf gains was explained by the various estimates of A, and these estimates explained from 1% to 4.5% of the variation in WNCOND, indicating that mature weight was a better predictor of calf weaning condition than of calf weight or rate of gain.

Regression coefficients and R^2 values with rate of maturing used to predict the dependent variables are presented in Table 16. Similar trends were observed with respect to the predictive values of the various growth parameters as were observed in the correlation coefficients between the parameters and performance traits. That is, only the regressions of WWT on K_{00}, K_{02}, K_{03}, K_{50} and K_{52} were significant. The R^2 values were variable and ranged from .8% to 9.9% for K_{54} and K_{00}, respectively. Again, the significant predictive value of the growth parameters observed for WWT was not observed in equations predicting ADG or weaning condition. The regression of adjusted ADG on K_{00} and K_{50} was significant at the .05 level of probability and indicated that using all weights to estimate growth parameters would be more meaningful in predicting performance of progeny.

Partial regression coefficients resulting from various models combining estimates of K and A used to predict progeny performance when weaning condition and/or birth weight of the calf were held constant are presented in Tables 17-21. Weaning condition was the first variable entered in the regression equation and was followed by the linear, quadratic and cubic forms of K and A, respectively. Birth weight was added to the model in order to remove the effect of variation in that variable when studying the effect of A and K on weaning weight and adjusted 205-day weight, as shown in Tables 18 and 21. Rate of maturing was entered in the model before mature weight because of the higher R^2 value for K in the linear models.

The regression analyses of weaning weight on the independent variables are shown in Table 17. In each model, weaning conditions score of

TABLE 16. COEFFICIENT OF REGRESSION AND R^2 VALUES BASED ON REGRESSION OF PROGENY PERFORMANCE TRAITS ON RATE OF MATURING

Independent Variables	Dependent Variables							
	WWT		WNADG		WNAADG		WNCOND	
	b	R^2	b	R^2	b	R^2	b	R^2
K_{00}	1230**	.099	2.10	.027	2.72*	.097	3.03	.004
K_{02}	1321**	.092	.93	.004	1.66	.029	1.34	.001
K_{03}	1114*	.063	1.62	.013	2.37	.057	5.44	.010
K_{04}	865	.035	1.06	.005	1.16	.013	.39	.000
K_{50}	744*	.063	1.78	.034	2.00*	.090	5.91	.027
K_{52}	691*	.040	.81	.005	1.10	.020	4.73	.013
K_{53}	684	.037	1.26	.012	1.75	.048	5.74	.018
K_{54}	302	.008	1.12	.010	1.18	.025	4.15	.010

*P < .05

**P < .01

TABLE 17. PARTIAL REGRESSION COEFFICIENTS AND R^2 VALUES FROM EQUATIONS PREDICTING WEANING WEIGHT

Source[1] of A and K	Intercept	Independent Variables							
		WN COND	K	K^2	K^3	A	A^2	A^3	R^2
00	- 358	42.9**	3628**	44154	- 386351	.9	-.0008	.0000002	.352
02	-1181	44.8**	-11006**	248308	-1541354	3.7*	-.0035	.0000011	.377
03	-8379	42.5**	- 6322	156084	- 980556	23.3**	-.0213	.0000011	.378
04	-3194	43.8**	-14340*	-182236	793772	7.5	-.0065	.0000019	.387
50	-1640	42.4**	6796*	- 67048	252278	4.1**	-.0037	.0000012	.361
52	-1401	44.2**	- 911	53389	- 343501	3.7	-.0033	.0000010	.343
53	-5503	43.1**	17092	-219219	984465	13.9**	-.0126	.0000038*	.369
54	-1157	40.9**	10165	-112643	434556	2.4	-.0022	.0000007	.375

*P < .05

**P < .01

[1]The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

TABLE 18. PARTIAL REGRESSION COEFFICIENTS AND R^2 VALUES FROM EQUATIONS PREDICTING WEANING WEIGHT WITH BIRTH WEIGHT INCLUDED

Source[1] of		Independent Variable								
A and K	Intercept	BW	WN COND	K	K^2	K^3	A	A^2	A^3	R^2
00	779	2.88**	37.77**	- 6965**	154380	- 922245	- 2.14	.0020	-.00000056	.455
02	- 72	2.92**	40.06**	-20758**	404665	-2359219	.74	-.0007	.0000002	.485
03	-7354	2.72**	37.56**	- 6825**	134190	- 715392	20.40*	-.0187	.0000057*	.466
04	-3867	2.78**	38.66**	- 2373*	89456	- 646313	9.80**	-.0085	.0000024	.480
50	- 950	2.53**	38.57**	6142*	- 65888	273969	1.92**	-.0018	.0000006	.441
52	-1173	2.66**	40.27**	3995	- 27209	67734	2.50**	-.0022	.0000007	.433
53	-4888	2.54**	39.71**	19155	-262478	1240181	11.92*	-.0108	.000033	.448
54	-1448	2.48**	37.91**	12013	-156066	705778	2.91**	-.0026	.000008	.452

*P < .05

**P < .01

[1]The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

TABLE 19. PARTIAL REGRESSION COEFFICIENTS AND R^2 VALUES FROM EQUATIONS PREDICTING WEANING AVERAGE DAILY GAIN (WNADG)

Source[1] of A and K	Intercept	Independent Variables							
		WNCOND	K	K^2	K^3	A	A^2	A^3	R^2
00	4.7	.1484**	18.1	- 184	563	-.0145	.000014	0	.333
02	.28	.1554**	-70.1	1325	-7878	.0039	-.0000041	0	.324
03	-10.7	.1471**	-59.1	1076	-6112	.033	-.00003	0	.323
04	-8.88	.1512**	133.0	-2227	12295	.017	-.000014	0	.340
50	-3.89	.1914**	44.4	-583	2582	.0088*	-.0000081	0	.350
52	-6.68	.1531**	45.1	-607	2712	.0170	-.000016	0	.321
53	-8.85	.1515**	45.5	-618	2832	.0226	-.000021	0	.323
54	.32	.1469**	33.7	-461	2183	-.0018*	.0000013	0	.331

*P < .05

**P < .01

[1] The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

TABLE 20. PARTIAL REGRESSION COEFFICIENTS AND R^2 VALUES FROM EQUATIONS PREDICTING ADJUSTED AVERAGE DAILY GAINS (WNAADG)

Source[1] of A and K	Intercept	Independent Variables						
		WNCOND	K	K^2	K^3	A	A^2	R^2
00	2.18	.144**	- 7.1*	260	- 1876	-.006	.000007	.338
02	- .68	.153**	-93.1	1727	-10058	.008	-.000007	.331
03	-19.50	.140**	-63.2	1145	- 6427	.058	-.000052	.325
04	-14.10	.147**	88.6	-1381	7112	.033	-.000028	.338
50	- 4.86	.148**	44.4	- 564	2417	.011*	-.000010	.346
52	- 6.97	.152**	51.2	- 674	2966	.017*	-.000016	.315
53	-12.65	.146**	55.4	- 748	3391	.033	-.000030	.315
54	- 1.71	.146**	57.1	- 817	3910	.003*	-.000003	.326

*P < .05

**P < .01

[1]The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

TABLE 21. PARTIAL REGRESSION COEFFICIENTS AND R^2 VALUES FROM EQUATIONS PREDICTING ADJUSTED 205-DAY WEIGHT WITH BIRTH WEIGHT INCLUDED

Source[1] of A and K	Intercept	Independent Variables								
		BW	WNCOND	K	K^2	K^3	A	A^2	A^3	R
00	893.6	1.81**	28.67**	- 5758*	119416	- 715251	- 2.37	.0025	-.0000008	.425
02	332.2	1.83**	30.70**	-21961	400225	-2306828	.28	-.0003	.0000001	.426
03	-3498.6	1.75**	28.13**	-12571	218560	-1186475	10.37	-.0094	.0000028	.413
04	-2803.2	1.72**	29.37**	10245	-153252	764651	6.79	-.0057	.0000016	.422
50	- 632.0	1.65**	29.87**	7696	98250	424029	1.33	-.0012	.0000004	.423
52	-1171.8	1.77**	30.60**	10925	-147396	661279	2.69	-.0025	.0000008	.407
53	-2226.2	1.70**	29.72**	11113	-154296	717052	5.62	-.0051	.0000016	.402
54	- 449.6	1.71**	29.81**	12549	-185721	912169	.68	-.0006	.0000002	.416

*P < .05

**P < .01

[1]The first digit indicates age to which weights used to derive A and K were collected - 0 = lifetime weights, 5 - only weights prior to 5 years of age used. The second digit represents the season in which weights were taken - 0 = all quarterly weights, 2 - summer weights, 3 - fall weights and 4 - winter weights.

the calf made a highly significant contribution to variation in weaning weight. The linear term of the K polynomial was significant at the .01 level of probability in the models including K_{00} and K_{02} and significant at the .05 level of probability when K_{03}, K_{04} and K_{50} were included. The reverse trend was observed for the models with respect to mature weight in that the linear term of A_{00} was not significant. A_{02} was significant at the .05 level of probability, and A_{03}, A_{04}, A_{50}, A_{52}, A_{53} and A_{54} were highly significant ($P < .01$) after WNCOND and maturing rate were fitted. The R^2 values ranged from 34.3% to 38.7%. In Table 18, the same models were used with the exception of adding birth weight at the beginning of each model to predict weaning weight. Birth weight was highly significant in each case and added approximately 9% to the R^2 values. WNCOND alone accounted for 24% of the variation in WWT.

Partial regression coefficients from the equations predicting average daily gain (WNADG) are presented in Table 19. As shown for weaning weight, the effect of weaning condition (WNCOND) was highly significant in each model. The effect of rate of maturing on WNADG was not significant. The effects of mature weight were significant in the models using A_{50} and A_{54}. The R^2 values ranged from 32.1% to 35.0%. The addition of birth weight to the model increased the R^2 by an average of 3%.

In Table 20 are presented the partial regression coefficients and R^2 values for adjusted average daily gain (WNAADG). As observed for the other variables, WNCOND is highly significant in all models. Significance of rate of maturing was observed only for K_{00}. Mature weight was significant for all estimates based on 5-year weights with the exception of A_{53}. The R^2 values averaged 32.9%.

In order to more adequately appraise the significance of A and K observed for actual weaning weight and the scattered significance observed for the ADG variables, adjusted 205-day weight was calculated for each calf. Since K was highly significant in most models with WWT as the dependent variable, it was hypothesized that early-maturing cows calved earlier in the season and, therefore, weaned heavier calves. The regression models used to predict adjusted 205-day weight are shown in Table 21. Again, both birth weight and weaning condition are highly significant in all models. The linear portion of K_{00} was significant at the .05 level but no other significance for the growth parameters was observed, indicating that the early-maturing cows calved earlier in the season. This could be attributed to the fact that they either were heavier at younger ages, went into the breeding herd and were bred earlier than the late-maturing heifers or their calving interval was shorter.

Analysis of Estimates Derived Using Fall Weights

At this point the decision was made to choose the best sets of estimates based upon fit and biological meaning in order to more closely study the factors influencing the estimates of mature weight and maturing rate. The estimates derived using fall weights to five years of age and at lifetime were chosen for further investigation. These groups had the highest correlations with the group using all weights, which is the group assumed to best fit the actual growth of the animal. Since most beef producers would routinely weigh cows when weaning calves and might not at other times of the year, this group would be most logical.

The two sets of estimates calculated from fall weights were used as dependent variables in regression analyses presented in Tables 22 and 23.

Partial regression coefficients and R^2 values with cow preweaning condition (CPWCON), scored at about 120 days of age, as the independent variable showed no significance. The R^2 was less than 1% for prediction of mature weight and over 2% for rate of maturing estimated at both five years of age and at lifetime.

Partial regression coefficients and R^2 values with cow weaning condition (CWNCON) as the independent variable are shown in Table 22. The linear, quadratic and cubic forms of CWNCON for A_{03} and A_{53} were highly significant and had an R^2 of over 9%. The influence of CWNCON on K_{03} was cubic and on K_{53} was linear, quadratic and cubic with an R^2 of 7.5%. The least-squares means of the estimates by reproduction group for EREPRO, FFREPRO and LREPRO are presented in Table 23. The analyses of variance and R^2 values are presented in Table 24. Early reproduction status was highly significant for A_{53} and significant for A_{03} and K_{53}. Four- and five-year-old reproductive status was highly significant for both estimates of maturing rate and significant for mature weight estimated on animals five years of age. Late reproductive status had a highly significant effect on K_{03}. These results indicate that as the age of the animal increased, the influence of reproductive stress at earlier ages decreased. The R^2 values were higher for the estimates on animals five years of age.

The appendix contains Tables 25 and 26. Table 25 shows the means and other statistics of the variables used in this study. Table 26 presents the least-squares means of A and K estimates from Phase I and includes ages 1-8.

TABLE 22. REGRESSION OF COW WEANING CONDITION ON GROWTH CURVE PARAMETERS

Dependent Variables	Intercept	Independent Variables			R^2
		CWNCON	$CWNCON^2$	$CWNCON^3$	
A_{03}	-9024	3105**	-315**	10.6**	.097
A_{53}	-12407	4083**	-409**	13.5**	.093
K_{03}	.5528	-.1451	.0142	-.0005**	.017
K_{53}	1.3686	-.3817*	.0369*	-.0012*	.075

*P < .05

**P < .01

TABLE 23. LEAST-SQUARES MEANS OF A AND K FOR THE REPRODUCTION GROUPS

Variable	Subgroup	n	A_{03}	A_{53}	K_{03}	K_{53}
EREPRO	1	60	496	483	.0532	.0596
	2	34	520	523	.0525	.0531
	3	8	504	498	.0555	.0578
FFREPRO	1	85	502	487	.0584	.0664
	2	12	522	531	.0491	.0496
	3	5	512	510	.0558	.0591
LREPRO	1	91	503	512	.0564	.0553
	2	11	528	509	.0500	.0474

TABLE 24. MEAN SQUARES OF GROWTH CURVE PARAMETERS ESTIMATED FROM FALL WEIGHTS

Source	df	Mean Squares			
		A_{03}	A_{53}	K_{03}	K_{53}
E Repro	2	33919*	90707**	.0000465	.0005303*
FF Repro	2	9554	45790*	.0006162**	.0013515**
L Repro	1	12568	3373	.0008270**	.0000071
Residual	96	7912	10934	.0000828	.0001257
R^2		.13	.25	.21	.29

*P < .05

**P < .01

CHAPTER V

SUMMARY

The objectives of this study were to estimate the effect of the following factors on growth curve parameters: (1) age, (2) season of weighing and number of weights per year, (3) reproductive status at three age intervals and (4) condition of the cow at early ages. The final objective was to evaluate the relationship of mature weight and general rate of maturing with performance of progeny.

The main body of data consisted of the growth curve parameters, mature weight (A) and rate of maturing (K), as determined by asymptotic regression of several series of weights of 102 mature Angus cows. The growth model described by Brody (1945) was used as the basis of the asymptotic regression. The study was divided into two phases. The firsst phase was designed to evaluate growth curve parameters derived from weights taken from birth to specified ages ranging from 1.5 years to 8.5 years of age plus one set of estimates derived using lifetime weights. The second phase was used to determine the influence of season of year on the parameters estimated from weights taken at various times of the year.

In Phase I the mean estimates of mature weight (A) were 539, 503, 465, 473, 481, 485, 484 and 482 kg for ages 1.5 through 8.5 years, respectively. The mean estimates of rate of maturing (K) were .061, .069, .073, .069, .065, .062, .061 and .061 for the same ages. The mean estimates of A and K using lifetime weights were 497 kg and .056, respectively. Correlations between estimates of A at the various ages were low until 4.5

years of age, at which age the correlation tended to stabilize. The same trend was shown between estimates of K. Early reproductive status of each cow was coded as (1) if the cow calved at two and three years of age, (2) if the cow calved just at three years of age or (3) if the cow calved at two years of age and was open at three years of age. The analyses of A and K showed a significant age-reproduction interaction. The cow-within-reproduction component was highly significant, indicating significant independent variation with which to work in animal breeding projects.

In Phase II eight weight-age curves were constructed for each animal--one group of four sets of estimates using weights of animals at ages up to five years and another group using lifetime weights. Within each group one set of parameters was estimated using all weights to the respective age. The other three sets were based on weights from birth to yearling plus one weight per year--summer, fall or winter. The symbols A and K are used with the following subscripts: 0 or 5 as a first digit to represent lifetime and five years of age; 0, 2, 3, or 4 as a second digit to represent all weights, summer weights, fall weights or winter weights, respectively. Mean estimates of mature weight were 496, 492, 492, 522, 483, 478, 487 and 508 kg for A_{00}, A_{02}, A_{03}, A_{04}, A_{50}, A_{52}, A_{53} and A_{54}, respectively. Mean estimates of rate of maturing were .0573, .0583, .0614, .0545, .0646, .0642, .0642 and .0602 for K_{00}, K_{02}, K_{03}, K_{04}, K_{50}, K_{52}, K_{53} and K_{54}, respectively. Correlations among the estimates of mature weights were all positive and larger than .7. Correlations among the rates of maturing were larger than .5 except for those involving the relationship of K_{00} and estimates of the parameters derived using weights up to five years of age. This study indicated that a single annual weight from one to five years of age is adequate for estimating growth curve parameters.

In the analyses of variance of A and K in Phase II, season and reproduction exerted a highly significant effect on both parameters. The age x reproduction interaction and reproduction x season interaction were both significant. Correlations between growth parameters and progeny performance traits were generally low with negative correlations between mature weight and performance. In the regression analyses less than 1% of the variation in calf gain was explained by the various estimates of A, but up to 10% of the variation was accounted for by the estimates of K. The multiple regression equations indicated that earlier-maturing cows tended to wean heavier calves, primarily because of earlier calving dates.

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LITERATURE CITED

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APPENDIX

TABLE 25. MEANS, STANDARD DEVIATIONS, COEFFICIENTS OF VARIATION AND RANGE OF PERFORMANCE VARIABLES

Variable	Mean ± S. D.	Range	C. V. (%)
Number of calves	6 ± 2.3	2 - 12	38.6
Weaning weight	476 ± 45	340 - 570	9.3
Adjusted 205-day weight	464 ± 31	355 - 528	6.7
Weaning ADG	1.81 ± .14	1.36 - 2.11	8.0
Weaning Adjusted ADG	1.95 ± .15	1.44 - 277	7.5
Birth weight	64 ± 5	50 - 75	8.1
Calf weaning condition	8.9 ± .5	7.6 - 10.3	6.1
Calving date	55.1 ± 16.7	1 - 127	30.3
Calving interval (days)	363.2 ± 14.3	308 - 414	3.9
Cow preweaning condition	9.2 ± 1.0	7.0 - 11.5	11.5
Cow weaning condition	10.3 ± 1.0	7.5 - 13.0	9.7

TABLE 26. LEAST-SQUARES MEANS OF MATURING WEIGHT (A) AND RATE OF MATURING (K) FOR AGE-REPRODUCTION SUBCLASSES, AGES 1-8

		Age							
Repro*		1	2	3	4	5	6	7	8
1	A	616	447	439	499	460	490	497	468
	K	.0580	.080	.081	.076	.070	.062	.058	.0475
2	A	611	653	533	502	492	487	486	592
	K	.058	.048	.060	.068	.069	.070	.070	.056
3	A	475	492	474	539	560	533	542	536
	K	.080	.077	.077	.058	.054	.055	.057	.058

*Repro 1 - Calved as 2 and 3 year old
2 - Open as 2, calved as 3 year old
3 - Calved as 2 year old, open as 3 year old

VITA

Ronald Edwin Morrow was born in Prairie Grove, Arkansas, on August 30, 1946, and is the son of Mr. and Mrs. Ivan Morrow. He attended elementary and secondary school at Siloam Springs, Arkansas. After graduation from high school with honors he attended Arkansas Polytechnic College in 1964-1966 and received his B.S. in Animal Science from the University of Arkansas in 1968. He then served two years in the U.S. Army, part of which was served in the Republic of Vietnam. Upon completion of his military service he entered graduate school at the University of Arkansas and received his M.S. in Animal Breeding in 1971. In January 1972, he began work on his Ph.D. at the University of Tennessee.

He is married and has two children, ages five years and three months.