METHODS OF ESTIMATING REPEATABILITY AND MOST PROBABLE PRODUCING ABILITY IN BEEF CATTLE

by

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INTRODUCTION

Selection is the most powerful tool that the animal breeder has for improving the genetic makeup of his animals. Yet, it is difficult to make maximum use of this tool because many factors affect the phenotypes of animals and complicate the effects of selection. If the breeder is to make maximum use of selection, he must be able to determine or estimate the magnitude of the environmental effects and account for them in his selection program.

The economic gain that a breeder receives is based largely on the productivity of the cow herd; primarily, the number of pounds of beef marketed. The feeder calf producer is, therefore, concerned with the weight and grade of feeder calves that he can produce. Weaning weight appears to be the most influential factor for economical gain and will be the basis of this study. The breeder is faced with the task of accurately evaluating the productivity of each cow within his herd and comparing her with her herd-mates to determine which cows to cull. Since most of the variation in performance from one time to another is due to environment, the procedure to standardize an animal's record must be based upon the effects of those peculiarities of environment. However, it should also be realized that whatever corrections are used in standardizing the records, they will not be exactly correct for every individual, even though they are correct for the average of the entire population. Therefore, researchers have studied various environmental deviations and have attempted to develop accurate adjustment factors for them. Environmental variations most commonly adjusted for are: age of dam, sex of calf, month and year of birth, location, and management practices. The use of such adjustment factors has been widespread. An evaluation of the effects of these adjustment factors on the progeny performance of beef cows was needed for this study.

Each of these standardized (adjusted) records may be considered an estimate of the true productivity of a cow, plus or minus an error for incomplete or inaccurate correction for factors which are not standard. If the adjustments made are correct for the average of a population, the errors are as likely to be negative as they are to be positive. Therefore, by averaging all of the records of an animal, one would expect the errors to cancel each other out so that the sum of n observations plus or minus n errors would approach zero. Thus, the larger the number of observations, the less the chance for error.

Lush (1949) developed a method of evaluating an animal's productivity based upon the number of records per animal and the repeatability of a trait called most probable producing ability (MPPA). This method can be used to estimate the producing ability of all cows in a herd and to compare them against herd-mates for culling purposes. Most probable producing ability can be calculated on any number of records, and the accuracy of prediction of a production trait, such as average daily gain or weaning weight, can be determined.

REVIEW OF LITERATURE

A large number of studies has been conducted to estimate the environmental and genetic factors that influence growth rate of beef calves from birth to weaning. Several investigations have been performed to determine the repeatability of growth rate, expressed as preweaning average daily gain or weight at 205 days of age. However, only limited reports can be found in the literature concerning the most probable producing ability (MPPA) of beef cows.

Adjustment Factors For Standardizing Beef Preweaning Performance Data

Sex of Calf. The sex of a calf has been found by several workers to significantly influence preweaning average daily gain or weight at 205 days of age. Usually, calf weights are adjusted to a steer basis. Bulls usually outgain steers, and steers usually outgain heifers. Marlowe *et al.* (1965) reported that creep fed bull calves grew 9.7 percent faster than creep fed steer calves and noncreep fed bulls grew 6.6 percent faster than noncreep fed steer calves. Similarly, steers grew approximately 6 percent faster than heifer calves regardless of whether or not they were creep fed. The study included 17,294 Angus and 11,663 Hereford preweaning records and was based on Virginia BCIA performance records for the years 1957 through 1962.

Age of Dam. The beef cow influences the weaning weight of her calf both by the genes she transmits and by the maternal environment she provides prior to weaning. Presumably, changes in size, weight and physiological function which accompany aging are expected to influence this environment and have a direct effect on weaning weight (Koch and Clark, 1955a).

Methods of adjusting for age of dam effects and biases have been worked out by Lush and Shrode (1950), Koch and Clark (1955a) and Hohenboken and Brinks (1969). For the Virginia BCIA data, Marlowe *et al*. (1965) reported calves from cows under seven years of age and over eleven years grew slower than calves from seven to eleven year old cows. Multiplicative adjustment factors used in the Virginia BCIA program are reported as shown in appendix I.

Age of Calf. Studies of cow-calf operations in Virginia have revealed that calf age is not very influential upon average daily gain to weaning as long as the calves studied are within the age range of 120 to 270 days. These results were observed by Marlowe *et al*. (1965). Similar results had been reported earlier by Marlowe *et al*. (1958) and Marlowe and Gaines (1958).

Creep Feeding. The study of field data indicates tremendous variation in gain exists when creep feeding is practiced. The magnitude of creep feeding effects on Virginia BCIA herds was reported by Marlowe (1962). Because of this variation, the Virginia BCIA program does not correct for creep feeding practices, but list creep fed and noncreep fed calves separately. Records used in this study, however, were adjusted for creep feeding practices by using the adjusting factors reported by Marlowe _et_ _al_. (1965). These adjustment factors are reported in appendix II.

Month of Birth. The effects of month or season of birth are often confounded with location. Therefore, season effects for Virginia BCIA records should be based upon data collected in the state of Virginia. Marlowe _et_ _al_. (1965) observed that calves born during February through March gained about 4 percent faster than January and June calves, 12 percent faster than July through October calves and 6 percent faster than November and December calves.

Other workers have reported seasonal effects, but in each case season was confounded with either age of calf or age of dam (Koch and Clark, 1955a; Nelms and Bogart, 1956; and Swiger _et_ _al_., 1962). Rollins and Guilbert (1954) reported that calves born during August through November 15 gained 0.24 pounds per day less from birth to 4 months of age than calves born from March through May. Mid-November through February calves were intermediate in growth. Jamison (1966) concluded that seasonal effects were of the magnitude that required adjustment.

Additive adjustment factors for Virginia BCIA preweaning average daily gain of Angus calves are reported in appendix III.

Methods of Estimating Repeatability

An estimate of repeatability is a description of a particular population under certain environmental conditions. Thus, the values of repeatability are usable for those situations where environmental conditions are similar. If, however, repeatability is approximately the same for different environmental conditions, the estimates can be used with confidence under a wide variety of conditions.

Repeatability can be measured in several ways for a trait such as weaning weight. Several of the methods used are: correlation between the consecutive offspring performance records of a dam; the regression of offspring record on the dam's record; and by intraclass correlation. The intraclass correlation method is most commonly used when the trait considered is measured through the offspring. Such is the case with weaning weight.

A tendency for repeatability based on the likeness of adjacent records to be higher than the repeatability of nonadjacent records or randomly chosen records has been observed by Koger and Knox (1947), Gregory _et al_. (1950), Koch and Clark (1955a) and Cunningham and Henderson (1965).

Koger and Knox (1947) calculated correlation and regression coefficients of one year's calf record with the next and found almost identical coefficients of 0.49 and 0.50, respectively. The correlation coefficient between first and second records was higher (0.66). The authors averaged all subsequent records (total of five) and correlated them with both the first record and the average of the first two records and obtained correlation coefficients ranging from 0.51 to 0.59. Regression coefficients declined from 0.76 to 0.32 with the inclusion of additional records.

Taylor et al. (1960) reported a correlation coefficient of 0.27 between first and second records and 0.31 between first and the average of all subsequent records for Hereford cattle located at the Blacksburg station. Corresponding regression coefficients were 0.31 and 0.26, and the intraclass correlation coefficient was 0.26. The authors also reported correlation coefficients of 0.52 for Angus and 0.51 for Herefords between the first and the average of all subsequent records on data from the Front Royal station. Corresponding regression coefficients were 0.38 and 0.55 and the intraclass correlation coefficients were 0.42 for Angus and 0.39 for Herefords.

Hohenboken and Brinks (1969) stated that Angus cows often allow calves other than their own to nurse, thus making a calf's weaning weight less a reflection of the dam's maternal ability and would obscure permanent differences among cows, thus lowering the estimated repeatability value.

A summary of repeatability estimates found in the literature is shown in appendix IV.

Most Probable Producing Ability

The calculation of most probable producing ability (MPPA) is accomplished by the formula given by Lush (1949):

$$\text{MPPA} = \text{HA} + \frac{nr}{1+(n-1)r} \cdot \sum \left(\frac{\text{IA} - \text{HA}}{n} \right)$$

where: n = Number of records for a particular cow

r = Repeatability between records of an individual cow

HA = Contemporary herd-year average

IA = Average of all calves by an individual cow

Each record is corrected for known environmental variations.

Thus, the fraction $\frac{nr}{1+(n-1)r}$ indicates how much we trust the cow's own average as an indication of her real producing ability (Lush, 1949). He also stated that much of the effect of averaging is obtained when n is as low as two or three, although each additional record increases the accuracy of prediction, especially if r is very small.

The accuracy of estimating MPPA is, therefore, dependent upon n and r. Thus, by increasing n or by more accurate measurement of r, one can improve the efficiency of selection by the use of MPPA. It also follows that early culling can be done if r values are large.

The magnitude of the repeatability estimate is a deciding factor on the number of records required before culling levels can be set. For weaning weight, it appears that estimates are high enough that culling may be done after a dam's first record, particularly if her record is substantially below the herd average. These conclusions were reached by Koger and Knox (1947), Koch (1951), Botkin and Whatley (1953) and Lueker *et al*. (1963).

Taylor *et al*. (1960) observed that culling could be done prior to weaning (120 days) about as effectively as at weaning. Hoover *et al*. (1956) reached the same conclusion when they calculated intraclass correlation coefficients of 0.29 and 0.32 for calf weights at 112 and 210 days of age, respectively. The regression coefficients for the two ages were 0.35 and 0.34, respectively.

Lush (1949) stated that the use of lifetime averages makes selection more efficient because it reduces the amount of variation due to temporary circumstances. Thus, heritability increases with n, but the selection differential is slightly decreased with the use of averages. The net result of the large increase in heritability and slight reduction in the selection differential which can be attained with the same percentage of culling is that progress per generation when selecting on an average of n records is $\sqrt{\frac{n}{1+(n-1)r}}$ times as great as selection on one record. The magnitude of repeatability and the effect of the number of records as was reported by Lush (1949) are shown in appendix V.

OBJECTIVES

The objectives of this study were to:

(1) study the three preweaning traits, preweaning average daily gain (ADG), 205-day weight and index value and to determine the magnitude of correlation that exists between these traits. ADG was calculated using additive and multiplicative adjustment factors.

(2) determine the repeatability of adjusted 205-day weight.

(3) determine the most accurate method of estimating most probable producing ability of beef cows based on the trait adjusted 205-day weight.

It is hoped that the method and factors that are considered the most accurate will be utilized in the Virginia Beef Cattle Improvement Association (BCIA) for use by the members in selecting or culling breeding females in their herds.

SOURCE OF DATA

Four large Angus herds that were enrolled in the Virginia BCIA performance testing program were selected for this study. The criteria for selecting these four herds included the number of years enrolled in the Beef Cattle Improvement Association (11 to 16 years), the number of calves weaned per year (minimum of 30), the number of sires used in the breeding herd each year, and most importantly, that the management of the breeding herd was fairly constant throughout the period of time selected for this study.

The initial study included 9,515 preweaning calf performance records with the largest herd (Herd 1034) accounting for 3,863 calf records. The other three herds had approximately equal numbers of calf records. Herd 1007 accounted for 1,840 calf records, Herd 1014 for 1,932 records and Herd 1051 for 1,880 records.

METHODS AND PROCEDURES

Three preweaning traits were initially included in this study. They were preweaning average daily gain, 205-day weaning weight and index value.

Weaning weight at 205 days of age was adjusted by the additive adjustment factors of Marlowe et al. (1965) for age of dam, sex of calf, month of birth of calf, age of calf and management practice followed in regard to creep feeding.

Actual average daily gain, average daily gain adjusted additively for age of dam, sex of calf, month of birth of calf, age of calf and creep feeding practice; average daily gain adjusted multiplicatively for age of dam; and average daily gain adjusted multiplicatively for both age of dam and sex of calf were studied. These multiplicative adjustment factors were calculated by Marlowe (1962) and are reported in appendix I.

Index value was also calculated by the method of Kincaid and cited by Marlowe et al. (1958), whereby:

Index Value=(40 x adjusted daily gain - 18)+(5 x type score)

Means, standard deviations and correlations between all of the traits studied were calculated by the Least-squares and Maximum Likelihood General Purpose Program of Harvey (1968). The effects of herds and years upon the means, variances and correlations were studied. The data were analyzed with herd effects absorbed, year effects absorbed, and with no equations absorbed, both within herds and pooled over herds.

Following the preliminary analysis described above, adjusted 205-day weight was selected for further study.

Determination of Repeatability. Since repeatability is determined from repeated observations of an individual dam, all dams with only a single record were removed from the data. This resulted in a reduction of the number of calf records by approximately one-third.

To calculate a realistic estimate of repeatability, all records were checked to insure that the first BCIA record listed for each dam was actually her first calf record. In the early years of performance testing of beef cattle in Virginia, many cows were included which had produced calves previously. Therefore, these dams and any dam that had reached four years of age before producing her first calf record were removed from the data. This reduced the number of records to 3,834 and the number of dams represented to 841.

Correlation of Adjacent Records. Harvey's (1968) program was used to calculate the correlation coefficients among the first nine records of all dams. Also, the average of the first two records and the first three records were correlated with subsequent records. Correlation coefficients between adjacent records were calculated, as well as between non-adjacent records.

Intraclass Correlation. Koch and Clark (1955a) stated that by separating the data into subclasses of calves born in the same year and out of cows of a given age, the analysis within subclass removes the average effects that years and age of dam have on traits. This is the procedure used to calculate repeatability in this study by intraclass correlation. Therefore, the 841 dams were divided into classes by their year of birth and by the year in which they produced their first calf performance record. The classes were then further divided into subclasses by the total number of calf records per dam. The subclasses included dams with two, three, four, five and six records. All dams that had failed to calve two or more years consecutively were removed from the data. This reduced the number of dams to 630.

Within each herd the variance components attributable to within and between cows were utilized to calculate repeatability of adjusted 205-day weaning weight. The method used to calculate repeatability by using the pooled subclass variance components was that of intraclass correlation:

$$r = \frac{V_B}{V_B + V_W}$$

where: r is the intraclass correlation coefficient, which is a measure of repeatability

V_B is the between dam variance component

V_W is the within dam variance component

A separate intraclass correlation coefficient was calculated for each of the four herds, then the sums of squares and degrees of freedom were pooled over herds for the 160 subclasses and the between and within dam variance components calculated to determine the intraclass correlation coefficient for all herds.

The nested analysis of variance method was utilized to calculate the variance components (Barr and Goodnight, 1970). The sums of squares, degrees of freedom, expected mean squares and variance components are listed in appendix VI. The variance component usually referred to as the error term was the within dam variance component. The between dam variance component was obtained by subtracting the expected mean square for error from the expected mean square for between dams and dividing the remaining quantity by the k value, the number of offspring per dam. The k values were calculated by the nested analysis of variance program of Barr and Goodnight (1970).

Regression of Second Record on First. Repeatability of 205-day weight was also calculated by regressing the second calf performance record of a dam on her first calf performance record by the use of Harvey's (1968) program. This method is appropriate for calculating repeatability when the groups of records are made at different times.

Searle (1962) stated that if selection on the first records has determined which animals were able to make a second record, the variances of the two sets of records will not be equal. Also, changes in environmental conditions during the time in which the two records are measured may also disturb the equality of variances. Therefore, this method of estimating repeatability was not used in further calculations.

Most Probable Producing Ability. The most probable producing ability (MPPA) of a cow was calculated by the general formula of Lush (1949), whereby each dam is evaluated by the deviation of her offspring performance record from that of the herd average for each particular year. Each deviation is then weighed by the number of calf records (n) and by the repeatability (r) of the particular trait. Thus, the quantity $\frac{nr}{1+(n-1)r}$ is the amount of weight placed on a dam's offspring performance record.

Lush's (1949) method is appropriate for predicting MPPA when records are standardized for environmental factors, such as adjusted 205-day weaning weight.

Repeatability used for the calculation of all MPPAs was determined by pooling the sums of squares and degrees of freedom for the 160 subclasses (described earlier in this thesis) and calculating a pooled intraclass correlation coefficient for all herds.

Two methods of calculating most probable producing ability were evaluated. They were the herd-year method and the sire-year method.

Herd-Year Method. The herd-year method used was essentially the same as that described by Lush (1949) and was calculated by the following formula:

$$Y_n = \mu + \frac{nr}{1+(n-1)r} \cdot \sum_{i=1}^{n} \left(X_i - \bar{X}_{h_i}\right) / n$$

where: μ = approximate mean of all Angus calves in all herds of 430 pounds.

n = total number of offspring records.

r = repeatability of adjusted 205-day weaning weight.

Y_n = Most probable producing ability based on n records.

X_i = dam's progeny performance for the i^{th} record.

$\bar{X}_{h_i}$ = herd average of all calves in the i^{th} year.

Actually, three MPPAs were calculated, designated as MPPA1, MPPA2 and MPPA3. MPPA1 was calculated on the basis of the deviation of the dam's first record from the herd-year average, weighed by the number of records (one) and repeatability (0.31) and added to the overall (approximate) mean of 430 pounds. Thus, the year effects were accounted for in this calculation technique.

MPPA2 was calculated based upon the deviation of the average of the first and second records from the average of the herd for the years in which those records were made.

Similarly, MPPA3 for each dam utilized the first three progeny records. The deviations from the herd-year averages were determined, and the sum of the deviations were then weighed for the number of records (three) and the repeatability estimate.

Sire-Year Method. The sire-year method was used to calculate MPPAs for the first three records of each dam included in this study, if the sire was known for the dam's first three calves. Those dams bred to an unidentified sire for any one of the first three progeny records were discarded from the data. Also, if a dam failed to produce a calf in two or more consecutive years, she was not utilized in this procedure. This reduced the number of dams to 630 with 182 of these dams having six or more calf performance records.

The sire-year method of calculating MPPAs was identical to the herd-year method described above except that $\bar{X}_{s_i}$ was substituted for $\bar{X}_{h_i}$ in the formula, where $\bar{X}_{s_i}$ was the average of all calves by a particular sire in the i^{th} year.

The sire-year method of calculating MPPA accounts for the variation in calf records both due to sires and to year. Therefore, the dam's progeny performance records were evaluated as deviations from the average of all calves bred to a particular sire in a particular year. MPPAs were also calculated for each of the first three records by the sire-year method.

Contemporary Herd-Year Average. MPPAs were also calculated for both herd-year and sire-year methods substituting the contemporary herd-year average for μ in the equations.

Evaluation of the Herd-Year and Sire-Year Methods. All possible correlation coefficients between the MPPAs for the first three records by both the herd-year method and sire-year method for adjusted 205-day weaning weights, based on the first six records of each dam, were calculated. Correlations between the first, second and third MPPAs and the average of all subsequent records (maximum of six records) were calculated by both methods. All correlation coefficients were calculated on a within herd basis and also pooled over all four herds by Harvey's (1968) program.

t-test for Rho Equal Zero. The correlation coefficients obtained by both herd-year and sire-year methods with subsequent record averages were tested by the method of Snedecor (1956) to determine if the correlation coefficients were significantly different from zero by the formula:

$$t = \frac{r}{\sqrt{\frac{1 - r^2}{n - 2}}}$$

where: r = correlation coefficient between the MPPA and a single record or an average of all records.

n = number of pairs being tested.

t = t value for n-2 degrees of freedom.

$HO : r = 0$

The correlation coefficients for MPPA1 by both herd-year and sire-year methods with the average of the second through the sixth records were tested on a within herd basis and then pooled over all herds to test the hypothesis that the coefficients were not significantly different from zero. The correlation coefficients between MPPA2 and the average of the third through sixth records, and MPPA3 with the average of the fourth through sixth records were tested on a within herd basis and then pooled over all herds to test the hypothesis that the correlation coefficients were not significantly different from zero.

t-test for Non-Independent Correlation Coefficients. Since there is a dependency between the herd-year and sire-year methods of calculating MPPAs (both methods are based on the same records)), the t-test for significance of difference between two non-independent correlation coefficients as described by Williams (1959) was used. That is:

$$t = \frac{(r_1-r_2)\sqrt{(n-3)(1+r_3)}}{\sqrt{2\ (2r_1r_2r_3 + 1-r_1^2-r_2^2-r_3^2)}}$$

where: $r_{x_1x_2} = r_1$; $r_{x_1x_3} = r_2$; $r_{x_2x_3} = r_3$

n = number of pairs being tested

t_{n-3} = degrees of freedom

HO : $r_1 = r_2$

The hypothesis that the correlation between the two methods of calculating most probable producing ability are equal is tested by this formula. If the values are not different enough to be significant, then little will be gained by the additional work required to calculate sire-year MPPAs. The t-test was performed on both a within herd and overall herd basis.

RESULTS AND DISCUSSION

Traits Studied. The traits chosen for this study were average daily gain (ADG), weaning weight at 205 days of age and weaning index. These measurements were adjusted for various environmental factors as discussed under methods and procedures, first, by the five additive adjustment factors of Marlowe *et al.* (1965) (reported in appendixes II and III) and, secondly, by the multiplicative adjustment factors reported in appendix I for both age of dam only and for age of dam and sex of calf.

Means and standard deviations of the traits studied are presented in table I. The data were analyzed by Harvey's (1968) program, first without herd or year effects included, and later with each of these effects included.

As shown in table I, the means of the traits studied varied only slightly with the inclusion of herd or year in the model. The variances, however, were reduced by including these effects. There was only a very slight reduction in the standard deviations of the traits when years were included, but a rather sizeable reduction was observed when herds were included in the model.

Herd effects accounted for a reduction of five pounds in the standard deviation of actual 205-day weaning weight and for three and one-half pounds reduction for adjusted 205-day

TABLE I. MEANS AND STANDARD DEVIATIONS OF TRAITS STUDIED.

	Code	Mean	Standard Deviation
Weaning weight at 205 days, unadjusted	1	388.3	76.71
	2	388.3	81.75
	3	387.9	81.07
Weaning weight at 205 days, adjusted additively	1	425.7	50.29
	2	425.7	53.74
	3	425.6	53.29
ADG, unadjusted	1	1.67	0.27
	2	1.67	0.29
	3	1.67	0.29
ADG, adjusted additively	1	1.77	0.24
	2	1.77	0.26
	3	1.77	0.26
ADG, adjusted for age of dam only	1	1.71	0.25
	2	1.71	0.28
	3	1.71	0.28
ADG, adjusted for age of dam and sex of calf	1	1.74	0.26
	2	1.74	0.28
	3	1.74	0.28
Index value	1	114.0	13.52
	2	114.0	14.05
	3	114.0	13.75

Code: 1 = Herd effects absorbed.
2 = No equations absorbed.
3 = Year effects absorbed.

weaning weight. Year effects reduced the standard deviations less than one pound.

Of the four methods used to calculate average daily gain, average daily gain adjusted by the five additive adjustment factors had the largest means and lowest standard deviations. When average daily gain was adjusted multiplicatively for age of dam only, it yielded means 0.05 pound less than the mean values for additive adjustment, but the standard deviations were approximately 0.02 of a pound higher. Average daily gain adjusted multiplicatively for age of dam and sex of calf were approximately 0.03 pound lower than the additively adjusted means and averaged 0.02 pound higher in their standard deviations.

A study of the means and standard deviations of average daily gain reveals that use of the five additive adjustment factors is the best method of accurately determining average daily gain. However, adjustment for age of dam accounts for a large portion of the variation attributable to this trait, and adjustment for both age of dam and sex of calf approach the level of accuracy of the five additive adjustment factors.

The index value was influenced by both herd and year effects with herd effects being more critical in reducing the amount of variability.

The correlation coefficients among the traits studied are shown in table II. As anticipated, the correlation between average daily gain adjusted additively was slightly

TABLE II. CORRELATIONS OF TRAITS STUDIED.

	Code	Weaning wt., adjusted additively	ADG unadjusted	ADG adjusted additively	ADG adjusted for age of dam only	ADG adjusted for age of dam and sex of calf	Index value
Weaning weight, unadjusted	1	.70	.60	.68	.56	.53	.58
	2	.71	.61	.68	.57	.55	.57
	3	.71	.61	.69	.57	.55	.60
Weaning weight, adjusted additively	1		.85	.97	.89	.88	.85
	2		.86	.98	.84	.89	.85
	3		.87	.98	.89	.89	.87
ADG, unadjusted	1			.86	.95	.93	.74
	2			.88	.96	.94	.76
	3			.88	.96	.94	.77
ADG, adjusted additively	1				.90	.91	.87
	2				.91	.92	.87
	3				.92	.92	.89
ADG, adjusted for age of dam only	1					.98	.77
	2					.98	.79
	3					.98	.80
ADG, adjusted for age of dam and sex of calf	1						.78
	2						.80
	3						.80

Code: 1 = Herd effects absorbed.
2 = No equations absorbed.
3 = Year effects absorbed.

higher with average daily gain adjusted multiplicatively for age of dam and sex of calf than for average daily gain adjusted only for age of dam, but the differences were only very slight.

Since all of the traits presented in table II were related to some degree, the trait adjusted 205-day weight was selected for further study as being the most useful measurement for the cattle industry.

Year Effects. The means and standard errors of herds within years and the pooled estimates of year effects over all the herds are reported in table III.

Herd 1007 year means ranged from 429 pounds in 1954 to 501.1 pounds in 1964 with an overall mean of 466.9 pounds for the 15 years, which is the highest of the four herds reported in this study.

Herd 1014 year means ranged from 405.5 pounds in 1963 to 487.4 pounds in 1966 with an overall mean of 431.2 pounds.

Herd 1034 ranged in year means from 394.2 pounds in 1960 to 426.3 pounds in 1956 with an overall mean of 411.4 pounds, which is the lowest of the four herds.

The range of Herd 1051 from 421.5 pounds in 1964 to 485.5 pounds in 1957 may not be a valid estimate of year effects since the standard error of 485.5 pounds was 32.8. The overall year mean was 444.0 pounds.

The trends exhibited by the within herd-year means and overall pooled means of table III indicate that year effects

TABLE III. HERD-YEAR MEANS AND STANDARD ERRORS OF ADJUSTED 205-DAY WEIGHTS.

	Herd			
	1007	1014	1034	1051
Year	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.
53		426.8±15.4		
54	429.0±19.7	439.3±14.1		
55	438.7±10.9	406.2±12.6	416.0± 6.3	
56	463.9± 7.1	423.6± 9.5	426.3± 5.3	
57	461.5± 6.2	414.6± 8.6	418.8± 5.3	485.5±32.8
58	492.9± 6.1	431.9± 8.5	411.8± 5.4	446.0±10.1
59	460.1± 5.5	421.3± 9.1	408.3± 4.6	457.3±10.1
60	453.6± 5.2	417.6± 7.6	394.2± 4.4	475.5± 9.9
61	454.4± 4.8	427.3± 6.7	426.1± 2.9	444.2± 8.3
62	465.2± 5.1	414.3± 9.0	410.9± 3.3	438.1± 8.5
63	499.2± 6.7	405.5± 7.0	410.6± 3.7	423.5± 5.5
64	501.1± 6.0	425.1± 7.9	398.0± 3.6	421.5± 6.6
65	482.6± 4.9	422.9± 9.2	407.2± 3.5	429.5± 5.9
66	449.2± 5.6	487.4± 8.0	402.1± 3.3	438.1± 5.7
67	465.2± 5.6	480.2± 8.5	415.8± 3.2	442.7± 6.3
68	487.5± 6.5	455.1±11.4	413.5± 3.8	427.5±10.4
Mu	466.9± 2.1	431.2± 2.5	411.4± 1.2	444.0± 3.5

were not uniform for the four herds. This may be partially explained by the influence in geographical locations of the herds as well as management differences.

An analysis of variance table for year effects pooled over all four herds is presented in table IV. Year effects were significant at the $P < .0005$ level.

Correlation of Records. The first nine records of each dam were recorded and correlated with each other. The data were sorted into classes of dams by the total number of records. Those dams with nine records were analyzed by Harvey's (1968) program to obtain the correlation coefficient between the eighth and ninth records. Next, all dams with eight or nine total records were analyzed to determine the correlation coefficient between the seventh and eighth record. This procedure was followed with all classes to utilize the maximum number of records. These results are reported in table V.

Several trends are indicated by these correlations. First, the correlation of adjacent records are, in general, higher than the correlation of non-adjacent records. The greater the distance observed between any two records, the lower the correlation tends to become. These results are in agreement with those of Koger and Knox (1947), Gregory et al. (1950), Koch and Clark (1955a) and Cunningham and Henderson (1965). Secondly, as the number of records increased, there was a slight tendency for the correlation between adjacent

TABLE IV. ANALYSIS OF VARIANCE FOR YEARS POOLED OVER ALL HERDS.

Source	d.f.	Sum of Squares	Mean Squares	F
Total	3688	13,055,279		
Total Reduction	16	1,965,728	122,858	40.681
MU -YM[b]	1	726,693	726,693	240.624
Year	15	125,088	8,339	2.761[a]
Remainder	3672	11,089,551	3,020	

[a] Significance ($P < .0005$).

[b] d.f., S.S. and M.S. due to mean.

TABLE V. CORRELATIONS OF RECORDS 1 THROUGH 9 FOR ADJUSTED 205-DAY WEANING WEIGHT.

	Record							
Record	2	3	4	5	6	7	8	9
1	.39	.31	.28	.26	.14	.17	.16	.27
2		.37	.28	.32	.29	.20	.29	.31
3			.38	.24	.21	.22	.24	.39
4				.43	.32	.26	.32	.48
5					.42	.25	.17	.26
6						.44	.41	.29
7							.66	.55
8								.57

records to increase. This would be anticipated as a cow matures, but the magnitude of these correlations was not very great. The average correlation coefficient of the diagonals was 0.48.

Regression of Second Record on First. Repeatability has been estimated by the correlation of adjacent records, which was 0.48 in this study, and by the regression of the second record on the first (Searle, 1962). Regression of the second record on the first yielded a regression coefficient of 0.51.

Intraclass Correlation. Repeatability was also estimated by the intraclass correlation method. The intraclass correlation coefficients were calculated for each herd and the sums of squares and degrees of freedom pooled over all herds for a repeatability estimate for the Angus breed.

All four herds had similar numbers of calves represented per dam with k values of 3.9, 3.7, 3.7 and 3.6 for Herds 1007, 1014, 1034 and 1051, respectively.

The variance components attributed to the between and within dam components varied widely among the herds. In one instance, Herd 1014 had a negative between dam variance component making it impossible to calculate a valid repeatability estimate for that particular herd. The intraclass correlation coefficients for the other herds were 0.34, 0.35 and 0.14 for Herds 1007, 1034 and 1051, respectively. These repeatability values are in agreement with the work of Gregory _et al_. (1950), Koch and Clark (1955b), Hoover _et al_. (1956), Taylor _et al_. (1960), Rollins and Wagnon (1956) and Hohenboken and Brinks (1969). These values were lower than those of Koger and Knox (1947), Botkin and Whatley (1953), Leuker _et al_. (1963), Minyard and Dinkel (1965) and Jamison (1966). The individual herd sums of squares, degrees of freedom and variance components are reported in tables VI, VII, VIII, and IX.

The sums of squares and degrees of freedom for each of the 160 subclasses of the four herds were pooled, yielding a between dam variance component of 862 and a within dam variance component of 1908. These data are reported in table X. Intraclass correlation coefficient of 0.31 was calculated from these data. This estimate of repeatability is in agreement with those estimates of Berg (1961), Hoover _et al_. (1956), Gregory _et al_. (1950), Koch and Clark (1955b), Hohenboken and Brinks (1969) and Taylor _et al_. (1960). This value was used in calculating the MPPAs discussed below.

Most Probable Producing Ability. Most probable producing ability (MPPA) was calculated by two methods on a within and a pooled overall herd basis. The two methods of calculating MPPA are described in the methods and procedures section. The main difference between the two methods is that in the herd-year method, a cow's progeny performance record is expressed as a deviation from the herd-year mean;

TABLE VI. REPEATABILITY ESTIMATE FOR HERD 1007.

Source	d.f.	Sum of Squares	Mean Square	Variance Component
Total	225	684,397		
Between Dams	89	285,052	3,203	548
Within Dams	136	399,345	1,074	1,074

k = 3.9

Number of subclasses = 34

Repeatability = 0.34

TABLE VII. REPEATABILITY ESTIMATE FOR HERD 1014.

Source	d.f.	Sum of Squares	Mean Square	Variance Component
Total	485	1,701,197		
Between Dams	120	367,141	3,060	negative
Within Dams	365	1,334,056	3,655	3,655

k = 3.7

Number of subclasses = 41

Repeatability = 0

TABLE VIII. REPEATABILITY ESTIMATE FOR HERD 1034.

Source	d.f.	Sum of Squares	Mean Square	Variance Component
Total	1594	3,256,788		
Between Dams	356	1,208,145	3,394	906
Within Dams	1238	2,048,643	1,655	1,655

k = 3.7

Number of subclasses = 63

Repeatability = 0.35

TABLE IX. REPEATABILITY ESTIMATE FOR HERD 1051.

Source	d.f.	Sum of Squares	Mean Square	Variance Component
Total	336	687,116		
Between Dams	64	181,858	1,089	300
Within Dams	272	505,257	1,858	1,858

k = 3.6

Number of subclasses = 22

Repeatability = 0.14

TABLE X. POOLED REPEATABILITY ESTIMATES FOR ALL HERDS.

Source	d.f.	Sum of Squares	Mean Square	Variance Component
Total	2876	6,329,498		
Between Dams	629	2,042,197	3,247	862
Within Dams	2247	4,287,301	1,408	1,980

k = 3.8

Number of subclasses = 160

Pooled repeatability = 0.31

whereas, with the sire-year method, a cow's progeny performance record is expressed as a deviation from the sire-year mean. In other words, the sire-year mean is the average of all progeny performance records of calves born to a particular sire in a given year.

Three MPPAs were calculated for each dam by both the herd-year and sire-year methods and correlated with subsequent records (maximum of six records). These results are reported in tables XI, XII, XIII.

The merit of any prediction equation is the degree to which a predicted value is related to an actual value. Therefore, the correlation coefficient between the MPPA value and the average of subsequent records appears to be the most accurate measure of the validity of the prediction equations. Therefore, the correlations between MPPA1 (based on the first record), MPPA2 (based on average of first two records) and MPPA3 (based on first three records) and the average of all subsequent records (maximum of six) was used to compare the effectiveness of the two methods of calculating most probable producing ability of a cow.

The results obtained when the MPPA equations were calculated substituting the contemporary herd-year average for μ were low and inconsistent. The pooled correlation coefficients between MPPA1, MPPA2 and MPPA3 and the average of subsequent records for the herd-year method were 0.15, 0.10 and 0.10, respectively. The respective pooled sire-

TABLE XI. CORRELATIONS OF HERD-YEAR MOST PROBABLE PRODUCING ABILITIES WITH RECORDS

		Average of Records							Single Record				
MPPA	Herd	2&3	3&4	4&5	5&6	2-6	3-6	4-6	2	3	4	5	6
	1007	.43	.46	.27	.38	.43	.36	.35	.34	.36	.34	.25	.51
1[a]	1014	.14	-.08	-.41	-.21	-.24	-.26	-.25	.19	.05	-.06	-.00	-.25
	1034	.33	.36	.24	.29	.30	.27	.21	.23	.28	.25	.27	.10
	1051	.22	-.05	-.02	.31	.31	.24	.31	.25	.11	.22	.09	.54
	1007		.56	.31	.43		.45	.40		.44	.38	.27	.56
2[b]	1014		-.03	-.08	-.13		-.12	-.14		.06	-.03	-.08	-.12
	1034		.38	.28	.28		.36	.32		.32	.26	.25	.22
	1051		.19	.31	.30		.33	.31		.22	.08	.28	.41
	1007			.35	.51			.50			.43	.27	.63
3[c]	1014			-.13	-.10			-.15			-.09	-.07	-.12
	1034			.20	.16			.21			.17	.12	.16
	1051			.31	.33			.40			.15	.26	.42

[a] Based on first record.

[b] Based on first 2 records.

[c] Based on first 3 records.

TABLE XII. CORRELATIONS OF SIRE-YEAR MOST PROBABLE PRODUCING ABILITIES WITH RECORDS

		Average of Records							Single Record				
MPPA	Herd	2&3	3&4	4&5	5&6	2-6	3-6	4-6	2	3	4	5	6
1[a]	1007	.42	.44	.25	.18	.27	.21	.21	.37	.33	.33	.20	.30
	1014	.14	-.12	-.03	-.01	-.03	-.04	-.05	.19	.05	-.12	.04	-.07
	1034	.30	.34	.28	.19	.31	.28	.21	.19	.28	.24	.28	.10
	1051	.13	.06	.14	.22	.30	.21	.24	.25	-.01	.02	.16	.42
2[b]	1007		.54	.31	.31		.34	.30		.42	.37	.26	.41
	1014		-.11	.20	.22		.13	.16		.11	-.10	.33	.07
	1034		.42	.33	.31		.38	.34		.38	.26	.29	.26
	1051		.24	.38	.29		.36	.32		.17	.15	.32	.38
3[c]	1007			.36	.40			.42			.43	.28	.51
	1014			.24	.18			.23			.11	.24	.06
	1034			.41	.38			.42			.29	.34	.31
	1051			.37	.37			.41			.18	.34	.44

[a] Based on first record.

[b] Based on first 2 records.

[c] Based on first 3 records.

TABLE XIII. CORRELATIONS OF POOLED MOST PROBABLE PRODUCING ABILITIES OVER ALL HERDS

MPPA	Method of Calculation	Average of Records							Single Record				
		2&3	3&4	4&5	5&6	2-6	3-6	4-6	2	3	4	5	6
1[a]	Herd-Year	.29	.24	.17	.08	.18	.13	.09	.23	.22	.17	.19	.04
	Sire-Year	.27	.25	.21	.13	.23	.19	.14	.22	.21	.17	.21	.08
2[b]	Herd-Year		.21	.12	.05		.10	.07		.21	.14	.09	.04
	Sire-Year		.32	.30	.27		.31	.28		.30	.20	.29	.22
3[c]	Herd-Year			.07	.03			.04			.08	.05	.03
	Sire-Year			.36	.31			.36			.27	.31	.25

[a] Based on first record.

[b] Based on first 2 records.

[c] Based on first 3 records.

year correlation coefficients were 0.18, 0.26 and 0.17. On a within herd basis, the correlation coefficients varied so greatly that they would be of little merit as predictive values. The low correlations were due to year effects resulting in herd-year means that varied drastically as shown in table III. Therefore, these results were not included in further analyses.

<u>t-test for Rho Equal to Zero</u>. When the correlations of the two methods of calculating MPPAs with the averages of subsequent records were evaluated by the t-test to test the hypothesis that the correlation coefficients were equal to zero on a within herd basis, the hypothesis was rejected twenty-one out of twenty-four times. Herd 1014 was the only herd whereby the magnitude of the correlation coefficients was small enough to be considered not significantly ($P < .05$) different from zero. The correlation coefficients between sire-year MPPA1 and the average of subsequent records and MPPA2 calculated by both methods with the average of subsequent records were not statistically different from zero. By MPPA3, however, the herd-year correlations were of the magnitude to reject the hypothesis at the $P < .05$ level and the sire-year correlation coefficient was large enough to reject the hypothesis at the $P < .01$ level. On a within herd basis, the other three herd-year correlation coefficients were of the magnitude that the hypothesis that the correlation coefficients were equal to zero was

rejected at the $P < .01$ level or greater.

Negative Correlation. Only in one instance was there a negative correlation between the MPPA values and any subsequent record or average of subsequent records in any herd other than Herd 1014. This was a correlation between MPPA1 and the third record of cows in Herd 1051 by the sire-year method (table XII). There were, however, several negative correlations associated with Herd 1014.

All correlations between MPPAs and subsequent records in Herd 1014 by the herd-year method were negative. The sire-year method appeared to be a more accurate measure in this herd. The correlation between MPPA1 and the average of subsequent records was negative (-0.03) and approached zero, but with the addition of the second record, the correlation was larger and positive (0.13) and even larger for MPPA3 (0.23).

The large difference in the correlation coefficients attributable to the two methods might be explained by the fact that there was a large number of sires represented in Herd 1014 in every year. Very few cows were ever repeat mated to the same sire in their lifetime. Thus, the large within cow variance component that did not permit a valid repeatability estimate for the herd may also have been due to these circumstances. The sire differences were so great that only by accounting for them in the MPPA equation can the predictive value be of merit.

A study of table XI revealed that the magnitude of the herd-year correlations increased in Herd 1007 from 0.43 to 0.45 to 0.50 for MPPA1, MPPA2 and MPPA3, respectively. Similarly, Herd 1051 herd-year correlations of MPPA1, MPPA2 and MPPA3 were 0.31, 0.33 and 0.40, respectively. The correlation coefficient for herd-year MPPAs of Herd 1034 increased from 0.30 to 0.36 with the inclusion of the second record, but declined to 0.21 with the inclusion of the third record. Herd 1014, as previously discussed, was negatively correlated in all three instances.

The sire-year MPPA values were more highly correlated with the average of subsequent records as additional records were included in all instances. Herd 1007 increased from 0.27 to 0.34 to 0.42 for correlation coefficients with the averages of subsequent records with MPPA1, MPPA2 and MPPA3, respectively. Likewise, correlation coefficients were 0.31, 0.38 and 0.42 for Herd 1034 and 0.30, 0.36 and 0.41 for Herd 1051 for the average of subsequent records with sire-year MPPA1, MPPA2 and MPPA3, respectively.

Pooled Most Probable Producing Ability Values. The herd-year and sire-year MPPAs were pooled over all herds and are reported in table XIII. The pooled values were correlated with the average of subsequent records and were evaluated by the t-test for the hypothesis that Rho is equal to zero.

The correlation coefficient with the first herd-year MPPA value was of the magnitude that the hypothesis could be rejected ($P < .025$). Correlation coefficients with MPPA2 and MPPA3 were not significantly different from zero. The coefficients were 0.08, 0.10 and 0.04 for MPPA1, MPPA2 and MPPA3, respectively.

The correlation coefficients with the sire-year MPPAs were large enough that all correlations of MPPAs with the averages of subsequent records were significantly different from zero (table XIV). The correlation coefficients were 0.23, 0.31 and 0.36 for MPPA1, MPPA2 and MPPA3, respectively.

<u>t-test for Herd-Year and Sire-Year Differences</u>. The pooled herd-year and pooled sire-year MPPA correlation coefficients with subsequent records were analyzed by the t-test for the equality of two dependent correlation coefficients.

Comparison of the pooled MPPA estimates for the first record by the two methods were different at the $P < .10$ level. The statistical difference increased with the addition of records so that the MPPA2 estimates were statistically different at the $P < .01$ level, and the MPPA3 estimates at the $P < .0005$ level.

<u>Means and Standard Errors</u>. The statistically higher correlations of the pooled sire-year MPPA values over the pooled herd-year MPPA values with the average of subsequent records might, in part, have been due to the differences in

TABLE XIV. LEVEL OF SIGNIFICANCE FOR T-TEST THAT RHO = 0.

		Level of Significance	
Herd	MPPA	Herd-Year	Sire-Year
1007	1	$P < .001$	$P < .001$
1014	1	$P < .01$	N.S.[a]
1034	1	$P < .001$	$P < .001$
1051	1	$P < .001$	$P < .001$
1007	2	$P < .001$	$P < .001$
1014	2	N.S.[a]	N.S.[a]
1034	2	$P < .001$	$P < .001$
1051	2	$P < .001$	$P < .001$
1007	3	$P < .001$	$P < .001$
1014	3	$P < .05$	$P < .01$
1034	3	$P < .01$	$P < .001$
1051	3	$P < .001$	$P < .001$
Pooled	1	$P < .025$	$P < .01$
Pooled	2	N.S.[a]	$P < .001$
Pooled	3	N.S.[a]	$P < .001$

[a] Non-significant at $P < .05$.

the herd-year and sire-year means and variances. The sire-year means and standard errors are reported in table XV and the herd-year means and standard errors are reported in table III.

The overall sire-year means and standard errors of Herds 1007, 1034 and 1051 were slightly less than those for herd-year. Herd 1014 had a lower overall sire-year mean, but the standard errors were almost equal (2.5 and 2.4 for herd-year and sire-year, respectively).

The pooled herd-year mean and standard error for all herds was 428.1±1.4. These values (in pounds) were higher than the pooled sire-year mean and standard error for all herds which was 426.6±0.8. The standard deviations were 55.2 and 42.2 pounds for pooled herd-year and sire-year means, respectively.

On a within herd basis, the standard deviations for the herd-year means were 42.7, 65.6, 46.5 and 47.7 pounds for Herds 1007, 1014, 1034 and 1051, respectively. The sire-year means had standard deviations of 38.1, 51.1, 41.7 and 40.5 pounds for Herds 1007, 1014, 1034 and 1051, respectively.

TABLE XV. SIRE-YEAR MEANS AND STANDARD ERRORS.

	Herd			
	1007	1014	1034	1051
Year	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.	$\bar{X}$ ± S.E.
53		397.9±20.6		
54		433.4±15.4		
55	430.3± 6.6	405.5±10.8	417.0±5.8	
56	463.3± 6.7	419.3± 8.4	424.9±4.0	
57	457.7± 4.8	410.0± 6.2	418.8±4.8	
58	493.0± 5.5	436.5±11.0	412.0±6.4	433.8± 5.6
59	461.5± 5.2	433.6±14.7	406.9±4.5	456.2± 7.5
60	457.9± 5.5	425.4± 6.7	394.1±3.7	467.2± 9.0
61	453.7± 5.5	426.9± 7.6	422.5±3.7	446.7± 6.0
62	463.0± 5.9	417.6± 9.4	414.0±3.6	437.5±11.4
63	504.4± 8.5	399.3± 8.3	407.3±3.2	416.0± 6.5
64	505.8± 7.3	430.7± 7.1	400.0±3.1	421.9± 8.9
65	483.3± 5.1	438.0± 9.4	407.0±3.6	434.6± 5.8
66	447.9± 6.3	489.0± 8.5	401.2±3.5	446.8± 5.4
67	467.9± 6.5	461.9±12.5	412.8±3.0	452.3± 6.6
68	492.4± 7.8	451.7± 6.4	414.5±3.8	425.8±12.5
Mu	462.1± 2.1	430.6± 2.4	409.8±1.0	438.2± 2.3

SUMMARY

Cow progeny records from four large Angus herds enrolled in the Virginia BCIA performance testing program for 11 to 16 years were studied to estimate repeatability of cow performance and to determine the most accurate method of estimating most probable producing ability (MPPA) from early records.

A preliminary analysis of 9,515 calf records on three preweaning traits, average daily gain (ADG), 205-day weight and index value, was conducted. ADG was adjusted additively for five environmental factors, multiplicatively for age of dam only, and multiplicatively for age of dam and sex of calf. Additive adjustments for 205-day weight were also included. All possible correlation coefficients among the traits were determined.

The correlation coefficients between ADG adjusted additively and the two multiplicative adjustments were large (correlations > 0.9). The coefficients were slightly larger and the variances slightly lower when both age of dam and sex of calf were included, but the differences between the multiplicative adjustments were quite small.

Since all of the measures listed above were related to some degree, the trait adjusted 205-day weight was selected for further study as being the most useful measurement for the cattle industry.

Repeatability of this trait was measured in several ways. Correlation coefficients were obtained for the first nine records of all dams. The average correlation between first and second records was 0.39; whereas, the average correlation of adjacent records was 0.48. The regression coefficient for the regression of second records on the first was 0.51. The correlation coefficients of adjacent records were higher than non-adjacent records, and in general, the coefficients decreased with the time existing between records.

Intraclass correlation coefficients were calculated for the four herds and pooled over all herds for an estimate of repeatability of 0.31. The individual herd estimates were 0.34, 0.0, 0.35 and 0.14 for herds 1007, 1014, 1034 and 1051, respectively. The overall estimate of 0.31 was used in all subsequent calculations.

Since repeatability requires more than one record per dam, all dams with single progeny records were removed from the data. Those dams that were four years of age or older at first calving or had missed calving two or more consecutive years were also removed from the data. This reduced the number of dams to 630 with 182 having six or more progeny records.

Most probable producing ability (MPPA) was calculated by the method of Lush (1949) using a dam's progeny performance record as a deviation from the herd-year average and by a second method using the dam's progeny performance record as a deviation from the average of all calves bred to a particular sire in a given year.

MPPA values were calculated for one, two and three records of each dam by both methods and correlated with the average of her subsequent records. All correlations were tested by the t-test for the hypothesis that Rho was equal to zero. The hypothesis was rejected ($P < .05$) in 21 out of 24 instances on a within herd basis. All three exceptions were in Herd 1014.

When the herds were pooled, only MPPA1 by the herd-year method was significantly ($P < .025$) different from zero; whereas, the correlation coefficients were significantly different ($P < .01$ or greater) from zero for all three MPPAs and subsequent records by the sire-year method.

On a within herd basis, the sire-year method was the most accurate method of estimating MPPA. In all instances, the magnitude of the sire-year correlations increased with the addition of the second and third records. Herd 1014, which was negatively correlated with all three averages of subsequent records by the herd-year method, had nearly a zero (-0.03) correlation between the first sire-year MPPA value and the average of subsequent records. The magnitude of the correlations with the second and third sire-year MPPAs increased to 0.13 and 0.23, respectively.

Very little significance was observed when the herds were tested by the t-test for the dependency of two correlation coefficients on a within herd basis. When the herds were pooled, the correlation coefficients of 0.18, 0.10 and 0.04 were calculated for the herd-year method for MPPA1, MPPA2 and MPPA3, respectively. Sire-year correlations were 0.23, 0.31 and 0.36 for corresponding MPPA values. The difference in MPPA1 by the two methods approached significance ($P < .10$) and the difference increased to $P < .01$ for the MPPA2 values and to $P < .0005$ for the MPPA3 values.

MPPAs were also calculated substituting the contemporary herd-year average for μ in the MPPA equations. However, the magnitude of year effects was so large that the correlation coefficients between the MPPAs and the averages of subsequent records varied so greatly that they would be of little merit as predictive values. Therefore, it was concluded that μ must be a constant value.

The overall pooled herd-year mean (in pounds) and standard error was 428.1±1.4 compared to 426.6±0.8 for the sire-year method. The standard deviations (in pounds) were 55.2 and 42.2 for the overall pooled herd-year and sire-year means, respectively. The pooled within herd standard deviations were lower for the sire-year method, also.

I have concluded from these results that the sire-year method of calculating most probable producing ability is more accurate than the herd-year method. The sire-year method is particularly useful to a herd, such as Herd 1014, where a large number of sires were used in each year and when a zero or low estimate of repeatability exists.

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APPENDIX

APPENDIX I. MULTIPLICATIVE ADJUSTMENT FACTORS USED IN THE VIRGINIA BEEF CATTLE IMPROVEMENT ASSOCIATION PROGRAM*

Age of Dam (years)	Adjustment Factor
2	1.10
3	1.05
4	1.03
5 - 11	1.00
12 & 13	1.02
14 and over	1.05

Sex of Calf	Adjustment Factor
1 Bulls	0.95
2 Heifers	1.07
3 Steers	1.00

* These factors were calculated from the 1954-1963 Virginia Beef Cattle Improvement Association records by Dr. T. J. Marlowe.

APPENDIX II. ADDITIVE ADJUSTMENT FACTORS FOR VIRGINIA BEEF CATTLE IMPROVEMENT ASSOCIATION ANGUS CALF PREWEANING AVERAGE DAILY GAINS FOR AGE OF CALF AND AGE OF DAM*

Age of Calf (days)		No Creep	Creep
1	90-119	-0.16	-0.05
2	120-145	-0.06	+0.01
3	150-179	-0.04	+0.02
4	180-209	-0.01	0.00
5	210-239	0.00	0.00
6	240-269	+0.01	+0.02
7	270-299	+0.04	+0.06
Age of Dam (years)			
	2.0 - 2.9	+0.17	+0.16
	3.0 - 3.9	+0.09	+0.08
	4.0 - 4.9	+0.05	+0.04
	5.0 - 5.9	+0.03	+0.02
	6.0 - 6.9	+0.02	+0.01
	7.0 - 11.9	0.00	0.00
	12.0 - 12.9	+0.02	+0.01
	13.0 - 13.9	+0.03	+0.02
	14.0 - 14.9	+0.04	+0.03
	15+	+0.05	+0.04

* Marlowe _et_ _al_. (1965).

APPENDIX III. ADDITIVE ADJUSTMENT FACTORS FOR VIRGINIA BEEF CATTLE IMPROVEMENT ASSOCIATION ANGUS CALF PREWEANING AVERAGE DAILY GAINS FOR SEX OF CALF AND MONTH OF BIRTH OF CALF*

Sex of Calf	No Creep	Creep
1 Bulls	-0.11	-0.14
2 Heifers	+0.11	+0.12
3 Steers	0.00	0.00
Month of Birth		
1	+0.03	+0.03
2	0.00	0.00
3	-0.07	-0.04
4	-0.02	-0.05
5	0.00	-0.04
6	+0.03	+0.05
7	+0.16	+0.04
8	+0.23	+0.06
9	+0.26	+0.12
10	+0.18	+0.10
11	+0.12	+0.08
12	+0.06	+0.06

* Marlowe *et al.* (1965).

APPENDIX IV. SUMMARY OF REPEATABILITY ESTIMATES OF WEANING WEIGHT OF BEEF CATTLE

Author	Estimate of Repeatability
Knapp *et al.* 1942	.20
Koger and Knox 1947	.49 to .59
Gregory *et al.* 1950	.35 to .50
Koch 1951	.52
Botkin and Whatley 1953	.43 and .49
Koch and Clark 1955b	.34
Hoover *et al.* 1956	.33
Rollins and Wagnon 1956	.51 and .34
Minyard and Dinkel 1960	.42
Taylor *et al.* 1960	.26 to .42
Berg 1961	.31
Lueker *et al.* 1963	.45
Brinks *et al.* 1964	.37
Minyard and Dinkel 1965	.52 and .42
Jamison 1966	.45 and .39
Hohenboken and Brinks 1969	.25

APPENDIX V. PROGRESS WHEN SELECTING BETWEEN ANIMALS WITH n RECORDS EACH, AS A MULTIPLE OF THE PROGRESS WHICH COULD BE MADE BY SELECTING BETWEEN THEM WHEN THEY HAD ONLY ONE RECORD EACH*

	r								
n	.1	.2	.3	.4	.5	.6	.7	.8	.9
2	1.35	1.29	1.29	1.20	1.15	1.12	1.08	1.05	1.03
3	1.58	1.46	1.37	1.29	1.22	1.17	1.12	1.07	1.04
4	1.75	1.58	1.45	1.35	1.26	1.20	1.14	1.08	1.04
6	2.00	1.73	1.55	1.41	1.31	1.22	1.15	1.10	1.04
10	2.29	1.89	1.64	1.47	1.35	1.25	1.17	1.10	1.05

* Lush (1949).

APPENDIX VI. NESTED ANALYSIS OF VARIANCE TABLE

Sum of Squares	Degrees of Freedom	Expected Mean Squares	Variance Component
Total	dn-1		
Between Dams	d-1	$V_W + kV_B$	V_B
Within Dams (error)	d(n-1)	V_W	V_W

n = number of offspring per dam
d = number of dams
V_B = variance due to the between dam component
V_W = variance due to error or within dam component
k = effective number of calves in each subclass

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METHODS OF ESTIMATING REPEATABILITY AND MOST PROBABLE PRODUCING ABILITY IN BEEF CATTLE

by

Carl E. Thompson

Abstract

The purpose of this study was to determine the most accurate method of calculating most probable producing ability (MPPA) of beef cows based on one, two or three records. A preliminary analysis of preweaning records on 9,515 calves from 4 Angus herds enrolled in the Virginia Beef Cattle Improvement Association program was conducted on average daily gain, 205-day weight and index value. Adjusted 205-day weight was selected for further study. To obtain a realistic repeatability value of adjusted 205-day calf weight, needed for calculating MPPA, separate estimates were first obtained for each herd by intraclass correlation. These values were 0.34, 0.00, 0.35 and 0.14. The individual herd sums of squares and degrees of freedom were then pooled to obtain an overall estimate of 0.31. Repeatability was also calculated by the correlation of adjacent records ($r = 0.48$) and by the regression of second record on the first ($b = 0.51$). The pooled intraclass correlation coefficient (0.31) was selected as the best for the calculation of all MPPAs. MPPAs were calculated by the method of Lush (1949), using the dam's progeny

record: (1) as a deviation from the herd-year average, and (2) as a deviation from the sire progeny average within years. MPPAs were calculated by both methods based on each of one, two and three records and each of these correlated with the average of all subsequent records (maximum of six). The first, second and third MPPA values by the herd-year method yielded correlation coefficients of 0.18, 0.10 and 0.04 with the average of all subsequent records, respectively. Corresponding sire-year correlation coefficients were 0.23, 0.31 and 0.36, respectively. The differences between the correlation coefficients obtained by the two methods for MPPA one, two and three were significant at the level of $P < .10$, $P < .05$ and $P < .0005$, respectively, indicating that the sire-year method is more accurate. The variance was also lower for the sire-year method (427 ± 44.2 pounds) than for the herd-year method (428 ± 55.2 pounds).

Thus, the author has concluded from these results that the sire-year method of calculating most probable producing ability is a more accurate measure of the true productivity of beef cows.