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I am submitting herewith a dissertation written by Thomas Bruce Turner entitled "Comparison of Methods of Selection to Increase Yearling Weight of Beef Cattle and Assessment of Influence of Sire Differences on Estimates of Repeatability of Cow Productivity." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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COMPARISON OF METHODS OF SELECTION TO INCREASE YEARLING
WEIGHT OF BEEF CATTLE AND ASSESSMENT OF INFLUENCE OF
SIRE DIFFERENCES ON ESTIMATES OF REPEATABILITY
OF COW PRODUCTIVITY

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ABSTRACT

The objectives of this study were: (1) to make a theoretical comparison of progress expected by selecting for a single trait with progress expected by selection based on an index including two traits and (2) to compare estimates of repeatability of cow productivity when the effect of sire is removed from the data and when it is not.

Data were collected over a period of seven years from 581 bull calves and 552 heifer calves from the purebred Angus herd at The University of Tennessee Plateau Experiment Station, Crossville.

Variables recorded at weaning (approximately seven and one-half months of age) were age, body length, heart girth, gain from birth to weaning, and ultrasonically measured fat thickness. Variables recorded at the post-weaning age (approximately 13 months) were heart girth, body length, gain from birth to postweaning age, postweaning gain and ultrasonically measured fat thickness.

Components of variance due to sire differences from a model including sex, year, age of dam, fat, age of calf, and sire within year were used to calculate estimates of heritability and genetic correlation in anticipation of construction of a selection index.

Most genetic correlation estimates exceeded unity and, although the index was a more effective selection method after arbitrary reduction of the genetic correlation estimates, little confidence can be placed in the comparison because of extreme uncertainty concerning the magnitude of the true genetic correlations existing in the population.

Components of variance due to dam differences were used to

calculate an estimate of repeatability of the various traits as traits of the cow. These dam components were taken from two models, one including sire effect and one from which sire effect was excluded. Due to appreciable sire variation among a cow's calves, removal of sire effect resulted in increased estimates of repeatability.

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CHAPTER I

INTRODUCTION

Two important factors in beef cattle production are yearling weight and an evaluation of a cow's productivity as evidenced by performance of her calves. Numerous investigators have studied these traits in herds in which these and other traits have been subjected to selection. A somewhat different set of data has accumulated at The University of Tennessee Plateau Experiment Station in which numerous variables are recorded, but only gain from birth to a year of age has been subjected to selection. The objectives of the study were to (1) make a theoretical comparison of progress expected from selection based solely on one trait to selection with more than one trait incorporated into a selection index and (2) to compare estimates of repeatability of cow productivity calculated when sire variance is removed from the data with those obtained when sire variance remains in the data.

CHAPTER II

REVIEW OF LITERATURE

I. ENVIRONMENTAL FACTORS AFFECTING PERFORMANCE TRAITS

Numerous studies have examined various environmental effects on weaning traits (Drewry et al., 1959; Gregory et al., 1950; Knapp and Black, 1941; Linton et al., 1968; Neville, 1962; Swiger et al., 1962; Jeffrey et al., 1971; and others). The general consensus is that performance traits of beef cattle up to weaning are influenced by sex of calf, age of dam, and by sire differences. These effects are not primary considerations in the present investigation, and, hence, a detailed review will not be included.

Studies investigating the effects of environmental factors on postweaning or yearling body measurements and performance traits are few in number. Brinks et al. (1962), studying mature Hereford cows, found a significant sire effect on mature weight. Guilbert and Gregory (1952), also working with Hereford cattle, found significant sire and sex effects on weight and body measurements (heart girth and body length) at 12 months of age. Neville et al. (1962) reported a significant ($P < .09$) age-of-dam effect on slaughter weight after adjustment of the records for differences in weights and milk production of dams. Sex effect was significant in the analyses, but sire effect was not.

Swiger (1961) used additive constants to remove from post-weaning records effects of sex, year, age of dam, and sire.

II. HERITABILITY AND CORRELATION AMONG PERFORMANCE TRAITS

Since several excellent summaries exist in the literature, it was not considered necessary to review all the work in this area. Table 1 lists pertinent estimates of heritability and genetic and phenotypic correlation summarized by Preston and Willis (1970). The values tabulated indicate that selection for growth traits should be fruitful, particularly selection for final weight (at approximately one year of age). Similar values were reported by Petty and Cartwright (1966).

III. CORRELATION OF MEASURES OF GROWTH RATE WITH BODY MEASUREMENTS

Of the many studies of body measurements of cattle, relatively few have been concerned with the correlation of these measurements with growth rate. Black et al. (1938) investigated the correlation of body measurements of slaughter steers with rate and efficiency of gain. They found a negative correlation ($-.05$) between gain and heart girth and a negative correlation ($-.32$) between body length and gain. These agree with those of Kohli et al. (1951) who reported estimates of the same correlations to be $-.29$ and $-.17$ respectively. Kohli et al. (1951) found also that the steers tended to vary independently with respect to the body dimensions measured as shown by the small correlation between them. Correlation between heart girth and body length was $.02$. They commented, in addition, that steers which are considered short rather than tall, short bodied and having small heart girths were slightly superior in the production characters studied. Both of these studies

TABLE 1
SUMMARY^a OF ESTIMATES OF HERITABILITY AND GENETIC
CORRELATION IN CATTLE^b

	1	2	3	4
1. Pre-weaning Growth Rate	.27(35)			
2. Final Wt	.54(1)	.70(30)		
3. Body Length			.34(6)	
4. Heart Girth				.42(4)

^aFrom Preston and Willis (1970).

^bHeritability estimates are on the diagonal, genetic correlation estimates are off the diagonal (the paucity of genetic correlation estimates reported in the literature is astounding), and the number of studies used is in parentheses.

used Milking Shorthorn steers measured at weights of about 900 pounds (392 kg). In a more recent study involving Angus and Polled Hereford calves, Shannon (1975) found correlations of .93 between heart girth and weight, .88 between length and weight and .92 between length and heart girth. This is in agreement with Brody (1945) who also found that heart girth is highly correlated with weight.

IV. ACCURACY OF OBTAINING BODY MEASUREMENTS

A study of the accuracy of linear body measurements of dairy cattle was reported by Touchberry and Lush (1950). Withers height, chest depth, body length, heart girth, and paunch girth were observed at seven ages, viz., six months, one, two, three, four, five, and seven years. Relative accuracies at the various ages were not significantly different. In an earlier study by Lush and Copeland (1930), it was reported that little or no correlation exists between the average size of the measurement and the random error in taking the measurement. In both studies there was little improvement in the relative accuracy of obtaining the measurements by recording a second and third measurement of the same dimension. The repeated observations did serve as a check to insure against gross reading and recording errors.

V. SELECTION INDEXES

A selection index is a number intended to be proportional to an individual's overall breeding value and, therefore, usable as a criterion for selecting or rejecting that individual. Such an index is a combination of credits for the individual's appropriately weighted merits and,

possibly, penalties for its defects. The index, I , is so constructed that its correlation with the individual's net genic value, G , is maximized, the index being a function of the phenotypic characteristics, $X_1, X_2, \dots, X_n$, which are considered in constructing it (Lush, 1948).

Lush (1948) states that the economic value of an animal is a function of several characteristics. Hazel and Lush (1942), in a theoretical study, concluded that it is more efficient to consider each trait in every generation of selection, provided each trait is given proper weight relative to the others, than to follow the plan of improving the individual traits one at a time or by selecting simultaneously for all the traits with a system of independent culling levels.

The method for estimating optimum relative weights to be given several traits in concurrent selection for all was presented by Smith (1936). He discussed the theory of selection indexes and demonstrated its application with traits of wheat varieties. He used the method of discriminant functions to develop a selection index for the wheat traits to be subjected to selection.

Where the economic value of an organism is a function of several characteristics, it would seem plausible to let each trait receive attention proportional to its net economic value and the relative rate of improvement expected from a given level of selection. This would be an efficient method if the traits are genetically uncorrelated. However, Hazel (1943), working with traits in farm animals and using multiple regression procedures, showed that if the genetic correlations are known, they should be considered in order to construct the most efficient index.

Selection indexes for use with beef cattle have been reported by several workers. Hazel (1952) constructed an index not intended for use in selecting beef cattle but, mainly, to show how an index could be constructed once accurate estimates of the necessary parameters become available. Traits considered were weaning weight, weaning score, feed efficiency, slaughter grade and postweaning gain. Indexes were constructed by using various combinations of these traits. These indexes were most efficient when the postweaning traits were included. When only weaning traits were used, the efficiency was nearly 50 percent less than that of the indexes considering both postweaning and weaning traits. Therefore, Hazel concluded that selection on the basis of an index be more accurate if replacements were selected after a postweaning performance test.

VI. REPEATABILITY ESTIMATES

Several investigators have examined the repeatability of gain of calf from birth to weaning considered as a trait of the dam (Botkin and Whatley, 1953; Taylor et al., 1960; Petty, 1966; Loganathan, 1962; Koch and Clark, 1955) and have reported estimates ranging from .25 to .49. However, no reports were found which included estimates of repeatability of postweaning gain or yearling weight considered as traits of the dam.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE OF DATA

Data used for this study were obtained from Angus cattle born from 1968 through 1974 at the University of Tennessee Plateau Experiment Station, Crossville, Tennessee. The number of calves by sex and year is given in Table 2. A detailed description of the history of this herd was given by Butts (1966). Since 1966 the cow herd was maintained in four separate groups, a closed 60-cow group in which all replacements were taken at random from the young animals available in each sire progeny group, a closed 60-cow group in which those calves in each sire progeny group with the highest average daily gain to one year of age were used as replacements, a closed 60-cow group (referred to as the "inbred" group) in which replacements were selected as in the latter group but in which no attempt was made to control inbreeding level, and a 40-cow group in which replacement heifers were selected for highest average daily gain to one year of age but outside bulls were used and some bulls were retained for more than one breeding season.

Four sire lines were maintained in each of the former three groups, and bulls were used, in nearly all cases, as two year olds for one season only. Heifers were bred as yearlings, and all cows were randomized among sires within group while limiting inbreeding of each mating to .125 except in the "inbred" group. All calves were born from January through early April and were not creep fed. No castration was

TABLE 2
NUMBER OF CALVES BY SEX AND YEAR

Year	Males	Females	Total
1968	79	90	169
1969	70	69	139
1970	72	76	148
1971	88	71	159
1972	77	84	161
1973	94	78	172
1974	101	84	185

practiced. At weaning (at an average age of 231 days) all calves were placed on a high roughage postweaning test conducted at the station. Bulls and heifers were separated at this time. Bulls received 2.72 kg concentrate and heifers 1.36 kg concentrate. All calves were fed corn silage ad libitum.

Cows were culled from the breeding herd if open two seasons in succession or for obvious unsoundness. Older cows (on the basis of age alone) were culled in order to keep the generation interval as small as possible.

No differences between groups in the variables used in this study were discernible during this period.

II. DESCRIPTION OF DATA

The variables, and their abbreviations in parentheses, given consideration here are listed below.

1. Birth weight (BW)
2. Average daily gain from birth to weaning (WADG)
3. Heart girth at weaning (WHG) - circumference immediately posterior to the shoulders.
4. Body length at weaning (WBL) - measured on the dorsal midline from midpoint of scapula to a line connecting the posterior prominences of the pin bone.
5. Ultrasonic estimate of subcutaneous fat thickness (FAT) - measured over the longissimus dorsi muscle between the twelfth and thirteenth ribs about three-fourths of the

distance from the dorsal midline to the distal edge of the
1. dorsi.

6. Average daily gain from weaning to time of postweaning data collection (PADG).
7. Average daily gain from birth to approximately one year of age (LADG).
8. Body length at time of postweaning data collection (PBL).
9. Heart girth at time of postweaning data collection (PHG).
10. Body volume at weaning (VOL1) calculated by the following formula:

$$VOL1 = WBL \times (WHG)^2 / 12560$$

11. Body volume at one year of age (VOL2) calculated by the following formula:

$$VOL2 = PBL \times (PHG)^2 / 125600$$

12. Calculated 365-day weight (WT) by the formula:

$$WT = [(365 \times LADG) + BW] / 100$$

Weaning data were collected at 231 ± 26 days, and postweaning data were collected at 384 ± 26 days. All measurements were taken with a steel tape to the nearest one-half inch by the same person and were converted to metric units.

III. METHOD OF ANALYSIS

Analyses of variance were performed on the data to obtain estimates of appropriate components of variance and covariance for the calculation of estimates of heritability, genetic correlation, and repeatability. The following model was used to obtain the sire component of variance for use in calculating heritability and genetic

correlation estimates:

$$Y_{ijklmno} = \mu + r_i + s_j + d_k + a_l + f_m + si_{in} + e_{ijklmno}$$

where: $Y_{ijklmno}$ = an individual observation for a given variable

μ = overall mean

r_i = effect of i^{th} year

s_j = effect of j^{th} sex

d_k = effect of k^{th} age of dam

a_l = effect of l^{th} age of calf

f_m = effect of m^{th} fat thickness

si_{in} = the effect of the n^{th} sire in the i^{th} year

$e_{ijklmno}$ = a random independent error portion of an individual observation.

The model used to obtain the dam component for calculation of repeatability estimates was as follows:

$$Y_{ijklmnop} = \mu + r_i + s_j + d_k + a_l + f_m + si_{in} + m_o + e_{ijklmnop}$$

where all effects were as described above except for the addition of m_o the effect of the o^{th} dam with the subscript p identifying an individual observation in the $ijklmno^{th}$ subclass. Another model also was used to obtain dam components for the calculation of repeatability estimates which was identical to the latter one except that sire effect was not included.

Preliminary analyses showed FAT to be a significant effect in all models and, hence, records of all animals not containing a fat thickness measurement were eliminated. Those eliminated included post-weaning records of all calves born in 1971 and weaning records of all

calves born in 1968, 1971 and 1972 (see Table 2, p. 9).

Since all cows had birthdates of January thru March of their various years of birth, age of cow was calculated in years only. In addition, all cows eleven years old and older were pooled since they constituted only 10.9 percent of the total number of cows.

Interaction effects were not included on the basis of results of Sellers et al. (1970) and Cundiff et al. (1966) which showed them to be negligible.

Due to the inclusion of the "inbred" group of cattle in these analyses there were distinct differences in the level of inbreeding of the calves. However, because of the mating system employed, inbreeding level was markedly confounded with sire and, hence, no adjustment was made for this effect. In an earlier study utilizing data collected from this same cow herd, neither inbreeding level of the calf nor of the dam was a significant source of variation in calf performance (Butts, 1966).

Due to limitations of the computer programs utilized in analyzing these data, age of calf and FAT were entered as discrete variables in each of the models. Ages of calf were grouped by 10-day intervals while values for fat remained as they were recorded, ranging from .5 mm to 14.0 mm.

Values of VOL1, VOL2 and WT were divided by 1000, 10000 and 100, respectively, as shown earlier so as not to lose significant digits in the covariance analyses used in obtaining genetic correlation estimates.

Heritability estimates were obtained from paternal half-sib comparisons as:

$$\hat{h}^2 = \frac{4\hat{\sigma}_s^2}{\hat{\sigma}_s^2 + \hat{\sigma}_w^2}$$

where: $\hat{\sigma}_s^2$ is the estimate of the component of variance due to differences between sires and $\hat{\sigma}_w^2$ is the estimate of the component of variance due to differences among paternal half-sibs.

The average number of progeny (k_o) per sire was computed according to the following formula:

$$k_o = \frac{\sum_{i=1}^n k_i}{n} - \frac{2}{\sum_{i=1}^n k_i}$$

where n = number of sires and k_i = number of offspring of the i^{th} sire.

Estimates of the standard errors of heritability estimates were calculated according to the following formula from Becker (1968):

$$S.E. (h^2) = \sqrt{\frac{2(n-1)(1-t)^2[1+(k-1)t]^2}{k^2(n-s)(s-1)}}$$

where t is the intraclass correlation, s is the number of sires, n is the number of calves and k is average number of calves per sire.

Estimates of genetic correlation were calculated using the following formula:

$$r_G = \frac{\text{Cov}_s(XY)}{\sqrt{s_s^2(X) s_s^2(Y)}}$$

where: r_G = estimate of genetic correlation

$\text{Cov}_s(XY)$ = sire component of covariance of trait X and trait Y

$s_s^2(X)$ = sire component of variance of trait (X)

$s_g^2(Y)$ = sire component of variance of trait (Y)

Estimates of standard errors of genetic correlations were calculated according to the following equation outlined by Becker (1968):

$$S.E. (r_g) = \left[r^2 \left(\frac{\text{Var}(\hat{\text{Cov}}_g)}{\text{Cov}_g^2} + \frac{\text{Var}(\hat{\sigma}_g^2(X))}{4(\hat{\sigma}_g^2(X))^2} + \frac{\text{Var}(\hat{\sigma}_g^2(Y))}{4(\hat{\sigma}_g^2(Y))^2} \right. \right. \\ \left. \left. - \frac{\text{Cov}(\hat{\sigma}_g^2(X), \hat{\text{Cov}}_g)}{\hat{\sigma}_g^2(X) \hat{\text{Cov}}_g} - \frac{\text{Cov}(\hat{\sigma}_g^2(Y), \hat{\text{Cov}}_g)}{\hat{\sigma}_g^2(Y) \hat{\text{Cov}}_g} + \frac{\text{Cov}(\hat{\sigma}_g^2(X), \hat{\sigma}_g^2(Y))}{2\hat{\sigma}_g^2(X) \hat{\sigma}_g^2(Y)} \right) \right]^{1/2}$$

where variances of the components of variance and covariance are utilized (pages 73-75).

The parameter estimates derived in this study were used to construct a selection index according to the methods and procedures described by Hazel (1943; 1952).

Such an index was defined as a linear function of the characters, X_1 , which has a maximum correlation with the aggregate genetic value of an animal.

The aggregate genotype of an animal may be written as:

$H = a_1 G_1 + a_2 G_2 + \dots + a_n G_n$, where the a_i 's are the relative economic values which measure the amount by which value is expected to increase for each unit change in X_1 , and the G_n 's are the expected values of the X_1 's due to additively genetic effects.

The index appears in the form: $I = b_1 X_1 + b_2 X_2 + \dots + b_n X_n$, where the X 's are observed phenotypic values of the traits and the b_i 's are partial regression coefficients.

The b_1 's are obtained by partial differentiation of the equation mentioned above with respect to each b_1 and equation the derivatives to zero. These b_1 values will minimize the sum of squares of differences between the index and aggregate genotype and, thereby, maximize the correlation between them. For this index, phenotypic correlation of each trait with WT was used as the economic value for that trait in the construction of an index including it.

Estimates of repeatability of the individual calf traits considered as cow traits were calculated from estimates of components of variance as the ratio $\hat{\sigma}_c^2 / (\hat{\sigma}_c^2 + \hat{\sigma}_w^2)$ where $\hat{\sigma}_c^2$ and $\hat{\sigma}_w^2$ are estimates of variance due to differences between cows and variance due to differences between calves of the same cow, respectively. The number of calves per cow (k_0) was calculated as stated earlier.

All records were included in the analysis yielding the intraclass correlation estimates; however, 23.9 percent of the cows had one weaning record only and did not contribute to the estimate of the within-cow variance ($\hat{\sigma}_w^2$) but only to the between-cows variance ($\hat{\sigma}_c^2$).

Standard errors of the intraclass correlations were calculated according to the formula of Fisher (1958) as reported and discussed by Sellers et al. (1970). The formula is as follows:

$$SE = \frac{(1-t)[1+(k-1)t]}{\sqrt{(1/2)k(k-1)(d-1)}}$$

where t is the intraclass correlation, k is the average number of calves per cow and d is the number of cows.

Tests for determining statistically significant differences between the intraclass correlations were conducted according to Fisher

(1958) in which all estimates were transformed to z by the following formula:

$$z = 1/2[\ln(1 + kr) - \ln(1 - r)]$$

where k is the average number of calves minus one.

CHAPTER IV

RESULTS AND DISCUSSION

Least-squares means and residual standard errors of all variables are presented in Table 3. The mean of PADG was less than that of WADG. This was due, in part, to the postweaning feeding regime in which heifers are fed to gain not more than .5 kg per day and this would, in turn, lower the overall least-squares mean for this trait along with the well-known compensation effect.

Least-squares means of all traits by years are presented in Table 4. There does not appear to be a time trend in any of the variables, except VOL1 and VOL2 for which the 1973 and 1974 values are considerably higher than those for the earlier two years. This is particularly interesting when the high positive phenotypic correlations, in Table 5, of VOL1 and VOL2 with the various gain variables are considered.

I. RESULTS PERTINENT TO SELECTION INDEX

The objective of this part of the present study was to make a theoretical comparison of the progress expected from selecting solely for a single trait with that expected from selection based on an index with more than one trait incorporated into it.

The cattle used in this study were involved in a single-trait selection experiment with that trait being average daily gain to one year of age (LADG).

TABLE 3
LEAST-SQUARES MEANS AND STANDARD ERRORS

Variable	Mean ^a	SE ^b
WADG (kg)	.808	.003
PADG (kg)	.498	.004
LADG (kg)	.682	.002
WT (kg)	276.528	.957
VOL1 (cu.m)	.144	.001
VOL2 (cu.m)	.201	.001
INDEX	.876	.003

^aLeast-squares means obtained from the following model:

$$Y = \mu + \text{Sex} + \text{Age of Dam} + \text{Age of Calf} + \text{Fat}$$

^bResidual standard errors from analysis of variance according to the above model.

TABLE 4
LEAST-SQUARES MEANS AND STANDARD ERRORS BY YEARS^a

Year	WADG(kg)	PADG(kg)	LADG(kg)	WT(kg)	VOL1(cm ³)	VOL2(cm ³)	INDEX
1969	.805 ±.007	.511 ±.009	.679 ±.005	275.550 ±2.130	134000 ±1196.0	196000 ±1639.0	.869 ±.007
1970	.850 ±.006	.491 ±.006	.712 ±.005	287.390 ±2.000	148000 ±1049.0	195000 ±1311.0	.900 ±.006
1973	.814 ±.006	.480 ±.007	.677 ±.005	274.070 ±1.950	151060 ±1131.0	211300 ±1475.0	.881 ±.006
1974	.819 ±.006	.499 ±.008	.691 ±.005	280.674 ±1.950	151100 ±1196.0	210900 ±1639.0	.895 ±.006

^aAdjusted for sex, age of dam, age of calf and fat thickness.

TABLE 5
PHENOTYPIC CORRELATIONS AMONG THE TRAITS STUDIED

	PADG	LADG	WT	VOL1	VOL2	INDEX
WADG	-.012	.744	.738	.797	.630	.734
PADG		.651	.642	.137	.459	.597
LADG			.988	.693	.779	.953
WT				.714	.785	.949
VOL1					.641	.709
VOL2						.932

WT was selected as a reference variable with which to compare progress attained by various selection methods.

VOL2 was considered worthy of study because it offered a unique method to express the size of an animal free of the errors inherent in body weights.

Analyses of variance of these selected traits is presented in Table 6. It may be argued that nonsignificant effects should have been deleted from the model. However, several of these, although not significant at low levels of probability, cannot be considered negligible.

Regression of LADG on age is apparently linear during the age range considered here (298-432 days of age) and, as would be expected, VOL2, which is based on body measurements, was significantly ($P < .01$) affected by age of calf.

In the remaining portion of this discussion only LADG, VOL2, WT and INDEX will be considered.

Heritability Estimates

Estimates of heritability of the traits of interest in this analysis are given in Table 7. Estimates of heritability of all traits are in Table 8. The .405 estimate of heritability of WT is considerably smaller than the "preferred" value of .70 given by Preston and Willis (1970) and somewhat smaller also than the weighted regression average of .49 given by Petty and Cartwright (1966). These latter two estimates were supposedly of heritability of final weight after a feedlot performance test. The estimates included in the averages of Petty and Cartwright (1966) and Preston and Willis (1970) were probably from

TABLE 6
ANALYSES OF VARIANCE OF SELECTED TRAITS

Source of Variation	Degrees of Freedom	Mean Square			
		LADG	VOL2	WT	INDEX
Sex	1	4.96**	2556.27**	70.79**	2.81**
Year	5	.12**	88.60**	1.60**	.03*
Age of Dam	9	.04**	29.56**	.67**	.06*
Fat	20	.06**	82.90**	.89**	.02*
Age of Calf	12	.01	90.12**	.09	.01
Sire Within Year	84	.01	6.28**	.12**	.01
Error	791	.01	3.88	.06	.01
Total	922				

*(.01 < P < .05)

** (P < .01)

TABLE 7

ESTIMATES OF HERITABILITY AND GENETIC CORRELATION (AND THEIR STANDARD ERRORS)
OF SELECTED TRAITS^a

	LADG	WT	VOL2	INDEX
LADG	.395 <u>±.044</u>	1.623 <u>±.249</u>	1.506 <u>±.098</u>	1.114 <u>±.040</u>
WT		.405 <u>±.044</u>	1.961 <u>±.479</u>	1.329 <u>±.541</u>
VOL2			.243 <u>±.038</u>	1.261 <u>±.524</u>
INDEX				.485 <u>±.047</u>

^aEstimates of heritability are on the diagonal and estimates of genetic correlation are above the diagonal.

TABLE 8

ESTIMATES OF HERITABILITY AND GENETIC CORRELATION OF ALL TRAITS

	WADG	PADG	LADG	WT	VOL1	VOL2	INDEX
WADG	.589 <u>±.051</u>	-.175	.748	1.060	.520	.705	
PADG		.234 <u>±.038</u>	.462	.790	-.139	.568	
LADG			.395 <u>±.044</u>	1.623	.431	1.506	1.114
WT				.405 <u>±.044</u>	.752	1.961	1.329
VOL1					.477 <u>±.047</u>	.401	
VOL2						.243 <u>±.038</u>	1.261
INDEX							.485 <u>±.047</u>

cattle being fed at a higher postweaning level of nutrition than were those in the present study. Petty and Cartwright (1966) did, however, present several estimates of heritability of yearling pasture weight. The weighted regression average of these was .41, almost of the same magnitude as the estimate from the present study.

Preston and Willis (1970) reported only one estimate of heritability of weight per day of age in beef cattle. This estimate of .77 is considerably larger than the estimate of .395 as heritability of LADG found here. The difference between these values is probably due to the fact that birth weight, a relatively highly heritable trait, is a part of the weight used in calculating weight per day of age.

No reports were found of studies of variables similar to the "volume" variable examined here. However, several investigators have estimated heritability of heart girth and body length (components of VOL1 and VOL2). Estimates of heritability of body length range from .00 to .67, and estimates of heritability of heart girth range from .06 to .71. These estimates were summarized by Preston and Willis (1970).

Genetic Correlation Estimates

Estimates of genetic correlation (and their standard errors) of selected traits also are presented in Table 7. Genetic correlations for all traits are in Table 8. The correlations were computed as paternal half-sib correlations discussed earlier. It happens that all of the estimates of genetic correlation between the members of selected pairs of traits are greater than unity. The nature of the apparent

bias which must have caused these impossibly large values is not obvious. The magnitude of the calculated standard errors is certainly too small to permit one to suggest validly that the large errors of estimate are random sampling errors. Animal breeding literature contains numerous reports of values exceeding unity as estimates of parameters with known upper limits of 1.0 (such as heritability and genetic correlation). In many cases, the authors give the matter no attention whatever, while in others the obviously erroneous estimates are attributed to chance in sampling. Standard errors of estimates of heritability and genetic correlation are not always reported with the parameters estimates. Hence, no judgment can be made as to the validity of a suggestion that the errors in the estimates are due to chance in sampling. This troublesome point should be given more basic research attention by competent animal breeding researchers. In the present case, standard errors of several estimates are large enough to reduce the values of the estimates to less than unity if one standard error is subtracted from them. Estimates of genetic correlation between LADG and WT reported by other investigators are generally in the .80 - 1.00 range (Preston and Willis, 1970; Petty and Cartwright, 1966; Shelby et al., 1963).

Selection Index

A selection index was constructed by methods described by Hazel (1943) utilizing LADG and VOL2. Some difficulty arises, however, in determining the economic value of an increase in VOL2. Therefore, using WT as the reference variable, the correlation between LADG and

WT and between VOL2 and WT were substituted for their economic values. Dividing through by the larger of the two "economic values" yielded the following index:

$$I = LADG - .966VOL2$$

In any multiple regression prediction equation, the ideal situation for maximum effectiveness of the prediction, is to have the correlations between the independent variables included approach zero but with high correlations of the independent variables with the dependent variable. In the present case this ideal is not approached very closely.

The traits in this index are highly correlated with WT (see Table 5, p. 21), but a high correlation between them exists also. However, it was decided that these two variables be used since they permit combining the two basic, commonly used criteria for assessing growth in beef cattle, viz., body dimensions and body weight. In addition, no combination of variables available from the postweaning data collection period possessed ideal qualities for use in a selection index.

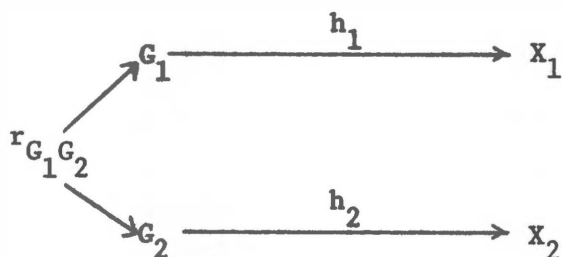
In the final analysis, there is some question about the appropriateness of this index in view of the genetic correlation estimates obtained from the same data (see Table 7, p. 24).

Correlated Responses to Indirect Selection

If two variables are genetically correlated, then any genotypic change in one will be accompanied by a change in the other. The size of the genetic correlation will govern the magnitude of accompanying

change. The genetic correlation and the heritability can be used to calculate the expected response in a variable when selection is practiced on a correlated variable.

The genetic relationship between two variables X_1 and X_2 may be illustrated by a path diagram.



where G represents the genotype for the trait, h represents the square root of the heritability of the trait and $r_{G_1G_2}$ represents the genetic correlation between the traits. The correlation of the phenotype of one trait, X_2 , and the genotype of the other, G_1 , can be estimated by $h_2 r_{G_1G_2}$.

The ratio

$$\frac{h_2 r_{G_1G_2}}{h_1}$$

may be used to compare the gain accomplished in X_1 by selecting for X_2 .

The relative improvement expected in WT and LADG by selection based on the variables is presented in Table 9. This improvement is expressed as a percentage of what would be expected if selection were based only on WT or LADG.

Values obtained initially for this table were unreasonably high as a result of the large values for the estimates of genetic correlation of which those used here were all greater than unity.

TABLE 9

THE RELATIVE IMPROVEMENT EXPECTED IN WT AND LADG BY SELECTION
BASED ON OTHER VARIABLES

Variable to be Selected	Percent Improvement In LADG Compared to Selection Based Solely on LADG		Percent Improvement In WT Compared to Selection Based Solely on WT	
VOL2	100	79 ^a	153	78 ^a
LADG	100	100 ^a	160	99 ^a
WT	164	101 ^a	100	100 ^a
INDEX	123	111 ^a	145	109 ^a

^aValues when $r_{G_i G_j}$ was set at 1.00.

A second set of expected responses were calculated after arbitrarily setting all values of genetic correlation at 1.00.

II. COMPARISON OF REPEATABILITY ESTIMATES

Use of lifetime averages as an aid to selection for traits on which repeated observations of phenotype can be obtained involves using estimates of repeatability to calculate adjusted averages appropriate for comparing individuals with averages based on different numbers of records. Breeders of beef cattle have followed the precedent of breeders of dairy cattle in using calf performance as a trait of the cow, analogous to milk production of dairy cows in successive lactations. Each lactation yield of a dairy cow is a phenotypic expression of the cow's supposedly constant genotype functioning in a unique set of environmental circumstances prevailing at the time that performance is recorded. Correlation among a sire's sperm would contribute to the correlation between performance records of successive calves of the same cow and sired by the same bull. To the extent that this contribution could be removed or reduced, an estimate of repeatability of beef cow productivity more nearly comparable to that of dairy cow lactation yield could be obtained, and the use of such an estimate would result in a more nearly correct ranking of beef cows which have produced different numbers of calves, especially if considerable numbers of the calves of individual cows are full sibs sired by different bulls from cow to cow.

Although repeatability of preweaning performance of beef calves as a trait of the cow has been studied extensively, few investigators have published results of consideration of contributions of sire

differences to estimates of repeatability, nor have many investigators studied repeatability of postweaning or lifetime traits of offspring as traits of the cow.

Sire differences become particularly critical when comparisons are made between beef cows on the basis of calf performance records in herds in which several different sires are used and sire variance is relatively large. The purpose here was to compare repeatability estimates calculated from data from which sire effects have not been removed with those obtained after the removal of sire effects.

Analyses of variance of weaning traits according to the two models are presented in Table 10, while analyses of variance of the postweaning and lifetime traits according to the same two models are shown in Table 11.

It is interesting to note that sire was a significant effect on every trait analyzed. It is a common practice to assume sire to be a random effect (Boston, et al., 1975; Cunningham and Henderson, 1965; Sellers, et al., 1970; Minyard and Dinkel, 1965; and Taylor, 1960).

The effects of other factors on the various traits are generally what would be expected. That is, age of calf made a larger contribution at younger ages and on the non-linear postweaning variables (WT, VOL2). Dam effect on PADG was not significant, as might be expected also.

Repeatability, as estimated by intraclass (intracow) correlation, measures the proportion of the total variation in the trait in question attributable to permanent differences between cows. Estimates of repeatability of the traits in this study, considered as cow traits, were calculated from components of variance as the ratio: $\hat{\sigma}_c^2 / (\hat{\sigma}_c^2 + \hat{\sigma}_w^2)$

TABLE 10
ANALYSES OF VARIANCE OF WEANING TRAITS ACCORDING TO TWO MODELS^a

Source of Variation	Degrees of Freedom	Mean Square	
		WADG	VOLI
Sex	1	1.905**	35991.313**
Year	3	.067**	10370.506**
Age of Dam	9	.104**	3781.493**
Fat	20	.040**	2459.769**
Age of Calf	10	.019**	7133.868**
Sire/Year	56	.026**	689.326**
Dam	324	.006**	218.855**
Residual	188	.003	112.516
Total	611		

(differing mean squares from model without Sire/Year) ^a			
Dam	324	.009**	258.867**
Residual	244	.004	156.287

^aThe second model did not include Sire/Year; and, thus, residual degrees of freedom and mean square changed while only mean square for Dam was changed. All other mean squares were the same in analyses according to both models.

* (.01 < P < .05)

** (P < .01)

TABLE 11

ANALYSES OF VARIANCE OF POSTWEANING AND LIFETIME TRAITS
ACCORDING TO TWO MODELS^a

Source of Variation	Degrees of Freedom	Mean Square			
		WT	LADG	PADG	VOL2
Sex	1	70.787**	4.956**	7.796**	2570.405**
Year	5	1.816**	.136**	.351**	103.386**
Age of Dam	9	.832**	.048**	.093**	39.743**
Fat	20	1.045**	.076**	.135*	96.941**
Age of Calf	12	.120**	.008**	.040*	89.690**
Sire/Year	84	.217**	.015**	.064**	12.890**
Dam	367	.076**	.005**	.021	4.565**
Residual	427	.039	.003	.027	3.222
Total	925				

(Differing mean squares from model without Sire/Year) ^a					
Dam	367	.085**	.006**	.019	4.834**
Residual	511	.052	.003	.026	3.759

^aThe second model did not include Sire/Year; and, thus, residual degrees of freedom and mean square changed while only mean square for Dam was changed. All other mean squares were the same in analyses according to both models.

* (.01 < P < .05).

** (P < .01).

where $\hat{\sigma}_c^2$ and $\hat{\sigma}_w^2$ are estimates of variance due to differences between cows and variance due to differences between calves of the same cow, respectively. These estimates of repeatability and their standard errors are presented in Table 12.

The only estimates here that can be compared to estimates reported in the literature are those for WADG simply because no reports were found containing estimates of repeatability of the other traits in this study or of any postweaning or lifetime traits.

Petty and Cartwright (1966) reported the weighted average of nine estimates of repeatability of preweaning gain to be .38, almost exactly the same as the two estimates of the present study (Table 12).

The influence of sire effect on the magnitude of $\hat{\sigma}_c^2$ and/or $\hat{\sigma}_w^2$ would in turn affect the magnitude of the estimates of repeatability. Apparently, sire effect had a significant influence on the magnitude of $\hat{\sigma}_w^2$ of VOL1, WT and LADG while it affected both $\hat{\sigma}_c^2$ and $\hat{\sigma}_w^2$ of WADG and VOL2, resulting in a nonsignificant change in the estimates of repeatability.

The significant change in the estimate of repeatability of PADG is of academic interest only because the dam effect on this variable was not significant (Table 11, p. 34).

The greater influence of sire effect on $\hat{\sigma}_w^2$ than on $\hat{\sigma}_c^2$ of VOL1, WT and LADG can be logically attributed to the mating system practiced in this herd in which sires were used for one year only in all but a few cases, resulting in appreciable sire variation among a cow's calves.

TABLE 12
ESTIMATES OF REPEATABILITY AND THEIR STANDARD ERRORS

Variable	A		B	
	r	SE	r	SE
VOL1	.335* ^(a)	.054	.259	.057
WADG	.371	.052	.381	.052
WT	.333**	.054	.255	.057
LADG	.333**	.081	.237	.058
PADG	-.127	.063	-.168*	.062
VOL2	.171	.060	.155	.060

A. Estimates of repeatability obtained from the following model:
 $Y = \mu + \text{Sex} + \text{Year} + \text{Age of Dam} + \text{Fat} + \text{Age of Calf} + \text{Sire/Year} + \text{Dam} + \text{Error}$

B. Estimates of repeatability obtained from the following model:
 $Y = \mu + \text{Sex} + \text{Year} + \text{Age of Dam} + \text{Fat} + \text{Age of Calf} + \text{Dam} + \text{Error}$

^aTests of significance are between estimates of repeatability within a variable.

* (.01 < P < .05).

** (P < .01).

CHAPTER V

SUMMARY

The objectives of this study were: (1) to make a theoretical comparison of progress expected by selecting for a single trait with progress expected by selection based on an index including two traits and (2) to compare estimates of repeatability of cow productivity when the effect of sire is removed from the data and when it is not.

Data were collected over a period of seven years from 581 bull calves and 552 heifer calves from the purebred Angus herd at The University of Tennessee Plateau Experiment Station, Crossville.

Variables recorded at weaning (approximately seven and one-half months of age) were age, body length, heart girth, gain from birth to weaning, and ultrasonically measured fat thickness. Variables recorded at the postweaning age (approximately 13 months) were heart girth, body length, gain from birth to postweaning age, postweaning gain and ultrasonically measured fat thickness.

Components of variance due to sire differences from a model including sex, year, age of dam, fat, age of calf, and sire within year were used to calculate estimates of heritability and genetic correlation in anticipation of construction of a selection index.

Most genetic correlation estimates exceeded unity and, although the index was a more effective selection method after arbitrary reduction of the genetic correlation estimates, little confidence can be placed in the comparison because of extreme uncertainty concerning the magnitude of the true genetic correlations existing in the population.

Components of variance due to dam differences were used to calculate estimates of repeatability of the various traits as traits of the cow. These dam components were taken from two models, one including sire effect and one from which sire effect was excluded. Due to appreciable sire variation among a cow's calves, removal of sire effect resulted in increased estimates of repeatability.

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