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EVALUATION OF FINAL WEIGHT IN THE SELECTION OF PERFORMANCE TESTED BULLS

BY

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head of the Major Department

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INTRODUCTION

Selection of herd sires, in the past, by the beef breeders in South Dakota has primarily been based on type. In general, the beef breeder has attempted to purchase the bull with the most attractive conformation based on his personal judgment. This method of selection has brought limited progress to the largest industry in South Dakota from which 35 per cent of the cash farm income is derived.

The South Dakota Crop and Livestock Reporting Service (30) reported that there were 1,269,000 beef cows on farms and ranches in South Dakota as of January 1, 1959. This was the fourth largest number of beef cows reported by any of the 48 states.

Any additional criterion which would aid in more effective selection of herd sires should improve the beef cattle industry and likewise the economy of South Dakota. In recent years, several criteria have been studied and the findings have indicated that they definitely aid in more accurate selection. Before a criterion will be adopted by the beef breeders in South Dakota, there must be indications of greater financial return without excessive inconvenience.

The outlook for expanded beef production in the future is very optimistic. The United States Department of Agriculture has estimated a need for one-third more meat production by 1975. This increase may be obtained by either increasing livestock numbers or increasing production from the present numbers. The latter choice seems more practical since additional numbers would mean additional costs and probably less net profit for the beef breeder.

The need for additional meat production plus the importance of the beef cattle industry to South Dakota challenges research to find the most efficient criterion which the beef breeders may use in the selection of herd sires. The purpose of this study was to check the feasibility of using final weight as a criterion in the selection of performance tested bulls. The feasibility depends primarily upon the heritability of final weight as compared with the heritability of other criteria presently employed in selection indexes. Genetic correlations between final weight and other important beef cattle traits were also studied to determine the expected progress of other traits as affected by selection for final weight. The other phases of this study concerned final weight as affected by inbreeding and the importance of length of feeding period as it affects the accuracy of selection.

REVIEW OF LITERATURE

Inbreeding Effects

Inbreeding has generally had a detrimental effect on production characteristics studied in beef cattle. The detrimental effects reported include decreased growth rate, size, fertility, and an increase in the mortality rate. Most measurements of the effects of inbreeding on growth in beef cattle have been with weaning weight.

Koch (20) studied weaning weight as affected by inbreeding of dam and inbreeding of calf. The data utilized in his study included the weaning weights of 745 calves with a mean inbreeding of 12.4 per cent from 180 cows having two or more calves during the period 1938 to 1948 inclusive. The mean inbreeding for the dams was 5.9 percent and the regression of weaning weight per one per cent of inbreeding of dam was -2.54 pounds. The regression of weaning weight per one per cent inbreeding of calf was -0.48 pounds.

The effects of inbreeding on weaning weight reported by Burgess, ***et al.*** (2) were larger for inbreeding of the calf and smaller for inbreeding of dam than the findings of Koch listed above. This study included 546 Hereford calves with inbreeding percentages ranging from 0 to 40, however, 75 per cent of the total number were less than 20 per cent inbred. The regression of weaning weight on inbreeding of the calf was -1.76 pounds per one per cent, and on inbreeding of dam was -1.15 pounds. This study indicated a significant deviation from linearity for the calf inbreeding effects and the possibility of curvilinearity was indicated. However, the weight adjustments for curvilinearity were not superior to the linear adjustments for all calf crops studied.

Zoellner (34), in studying 18 month weights of heifers, reported finding a reduction in weight due to inbreeding, however, the reduction was not significant. This study included the records of 143 heifers ranging in percentage of inbreeding from 0 to 25. The author indicated that a heifer that was 25 per cent inbred would weigh 57 pounds less at 18 months of age than a non-inbred.

Margolin and Bartlett (24) found that inbreeding did not have a significant response on the growth rate of Holstein cattle. Their study included 548 head with inbreeding coefficients ranging from 0 to more than 20 per cent. They concluded from their study that inbreeding of less than 20 per cent does not affect growth at any stage from birth to maturity. They did mention that inbred animals with growth records at 72 months of age were lighter than outbreds at this age, however, the difference was not significant.

A study of body measurements by Tyler, et al. (31) on 152 Holstein heifers tends to agree with the findings of Margolin and Bartlett. This study indicated that the offspring of some sires may be inbred as much as 25 per cent without any apparent decrease in body size.

Heritability Estimates

Heritability estimates for final weight in beef cattle are fewer in number than estimates for rate of gain during the feeding period. Realizing that final weight is different between experiments due to large differences in age and large difference in length of feeding period, it would be expected that the heritability estimates would vary considerably. However, the heritability estimates reported in other studies for the various beef cattle traits indicate that final weight has the highest heritability of any important beef cattle trait.

From studies of livestock produced at the United States Range Livestock Experiment Station, Miles City, Montana, Knapp and Nordskog (15) reported .81 as a heritability estimate for final weight calculated by the paternal half-sib correlation method. This estimate was obtained from a study of 177 head of steers representing 23 sire groups. The heritability using the sire-progeny regression for estimation was .69. However, when year differences were adjusted for, the latter estimate was raised to .94. The length of feeding period was constant within each of the four years, with variations from 259 to 273 days between years. Knapp (13) later that same year, reported post weaning growth rate to be between 80 and 95 per cent heritable. He also commented that heritability of feed lot gain increases as length of period increases.

Comparable results were also found by Knapp and Clark (17) studying the progeny of 110 sires carried at the United States Range

Livestock Experiment Station, Miles City, Montana. The paternal half-sib heritability estimate found in this study was .86. Final weight in this case is based on 15 months of age and a 252 day feeding period. The authors conclude that since heredity plays a major role in determining post-weaning growth rate, individual performance can be used as a basis for selection.

Shelby, _et al_. (27) calculated heritabilities for various economic characteristics of beef cattle by the method of paternal half-sib correlations. Reporting on the record of performance data collected at the United States Range Livestock Experiment Station at Miles City, Montana, between 1942 and 1951, they estimated the heritability for final weight as .84. These data consisted of records of 635 steers representing 88 sires from nine inbred lines of different pedigree origins. The length of feeding period for this study varied from 252 to 273 days. It was constant for all calves within a year.

Heritabilities of some economic traits in bulls were reported by Shelby, _et al_. (28). These estimates are based on the records of 542 bull calves by 116 sires from 11 inbred lines tested at the above mentioned station. The estimate for final weight based on paternal half-sib correlations was .77. The average age for the final weights was 13 months.

Genetic and Phenotypic Correlations

Most genetic correlations reported for final weight-final type and daily gain-final type are positive and range somewhere between .2

and .5. Usually the correlation between final weight-final type is higher than the daily gain-final type correlation.

Durham and Knox (7) reported a phenotypic correlation between yearling grade and feed lot gain as -.006. This study included the data from 424 steers from 68 sires, fed during a 13 year period, and 59 calves representing two different types of cattle fed over a three year period. The yearling grade characteristic in this study is a conformation score prior to the final feed lot test. The association between live grade at the end of the feed lot test and feed lot gain was not studied; however, the correlation between feed lot gain and carcass grade was .349 which was highly significant.

An extensive study of heritability, repeatability and correlations was made by Koch and Clark (21) (22). The portion of this study analyzed by the paternal half-sib correlation method for yearling weight and yearling type included records taken from 1483 calves representing 124 different sires during the period from 1936 to 1951. The genetic correlation between yearling weight and yearling score in this study was estimated at .49. This compares quite closely to an estimate of .44 obtained in the same study for gain from weaning to yearling age and yearling score. The phenotypic correlations were .56 for yearling weight and yearling score and .38 for gain from weaning to yearling age and yearling score. Slightly different correlations were obtained by utilizing the regression of offspring on dam method of analysis. In this case the phenotypic correlation between yearling weight and yearling score was .66 and .44 between gain from weaning to yearling age and yearling score.

Length of Feeding Period

Most previous studies concerning length of feeding period have dealt with heritability of rate of gain. It is of general agreement that the length of feeding period is of considerable importance. The previous results have led to recommendation of tests longer than 100 days. In most cases, the longer tests, such as 196 days or longer, have resulted in higher estimates of heritability for rate of gain.

One of the first studies concerning length of feeding period was reported by Knapp and Black (14). They studied rate of gain on a limited amount of data including only 62 calves from three sires. They concluded that when a short feeding period (168 days) was used, corrections in initial weight must be made in order to obtain a significant difference between sires. The corrections in this study were made by covariance analysis.

Knapp and Woodward (19) reported heritability estimates by months during the feeding period. The heritability estimate for rate of gain at the end of the first month was .28. Increases in heritability estimates rose rapidly until the end of the sixth period at which time they estimated heritability at .80. Their results showed heritability estimates increased at a decreasing rate from the sixth through the ninth periods. They concluded from their experiment that feeding periods as short as 112 days could be used to indicate genetic differences in ability when ad libitum feeding is practiced.

Dinkel (6), reporting on effects of length of feeding period on post weaning gain, reported heritability estimates of .45, .52, and .65 for 140, 168, and 196 day periods respectively. Using the product of heritability times the phenotypic standard deviation for each period, he reported expected progress due to selection on the basis of 140 day gain would be 79 percent of what could be expected using 196 day gain. The estimated value of the 168 day gain in comparison with 196 day gain was 84 per cent.

SOURCE OF DATA

The data used in this study were taken from records of 224 purebred Hereford calves representing 21 sires from the South Dakota Beef Cattle Breeding Project carried on in cooperation with the North Central Regional Beef Cattle Breeding Project.

These calves were raised on either the Cottonwood Range Field Station at Cottonwood, South Dakota, or the Antelope Range Field Station, Buffalo, South Dakota, and were carried on performance test at the Brookings Station. Four inbred lines and one control line were formed at the Antelope Station and one inbred line was formed at the Cottonwood Station in 1952. In 1955 two inbred lines were moved from the Antelope Station to the Reed's Ranch Station to be used in a different study. At the same time, one inbred line that had been formed at the Reed's Ranch Station was moved to the Antelope Station and subsequently used in this study. All of these lines were carried as one sire lines. The control line was increased to 60 cows in 1955 and was carried as a four sire line thereafter. The calving season averaged eight weeks during the months of April and May, however, a few of the calves were born in March and June. These calves were carried on the range with their dams until late in October. There was no supplemental feed available to the calves during the suckling period. The average annual precipitation for these two ranches is between 14 and 15 inches.

The calves were weaned in the latter part of October each year and transported to the South Dakota Agricultural Experiment Station at Brookings. After arriving at the main station, these calves went through an adjustment period prior to the actual feeding period. The adjustment period averaged 28 days and was constant in length for all calves within a year, however, it varied from year to year.

The calves were alloted to four pens at random except when there were enough calves from one sire to allow for stratified randomization. Each calf was assigned an individual feeder within the pen. The calves were chained to their feeders for a period of two hours each morning and again for two hours each afternoon. The feeders were equipped with covers and could not be entered at any other time during the day. The ration fed consisted of:

35% oats (ground)
30% corn (cracked)
30% brome-alfalfa hay (ground)
5% linseed oil meal

These ingredients were mixed thoroughly and self fed. Fresh feed was placed in each feeder prior to the feeding period. Twice each week the feeders were cleaned and the left over feed was weighed. This allowed an accurate measure of feed intake by each calf. Water was constantly available in automatic waterers. Salt and bonemeal were fed free choice.

The feeding period lasted 196 days each year and weights were taken every 28 days during the feeding period. The weights were taken between six and seven a.m. each weigh day in order not to disrupt the feeding schedule. The waterers were covered the night before to allow for a 12 hour shrink prior to weighing.

The final type score listed in the following tables is an average of three judges' scores, each working independently. The following scoring system was used:

Score	Code	
1+	17	model of perfection
1	16	
1-	15	
2+	14	
2	13	above average
2-	12	
3+	11	
3	10	average
3-	9	
4+	8	
4	7	below average
4-	6	
5+	5	
5	4	culls
5-	3	

The scores were coded to allow averaging the three judges' scores more readily. The code is used as the measurement of type score in the following tables. The average age of the bulls at the end of the 140 day feeding period was 358 days of age. For all practical purposes, the final weight at the end of the 140, 168, and 196 day periods could be called 12, 13, and 14 month weights.

Table I lists the mean final weight, mean rate of gain, and mean final type scores for each year, ranch, and inbreeding classification. Since this study includes different length performance tests, there are three rates of gain listed. The first is for a 140 day period, the

TABLE I. YEAR, RANCH, AND INBREEDING MEANS

Year	No. of Progeny	140 Day D G	168 Day D G	196 Day D G	140 Day F W	168 Day F W	196 Day F W	196 Day F T
1952	23	2.47	2.60	2.59	763.87	860.70	932.17	9.39
1953	21	2.47	2.53	2.42	764.81	842.81	892.48	10.10
1954	22	2.54	2.55	2.56	787.86	862.23	930.73	10.27
1955	35	2.37	2.45	2.50	729.06	809.80	887.14	9.97
1956	42	2.52	2.53	2.54	762.21	834.81	907.12	10.71
1957	47	2.48	2.56	2.50	735.19	816.89	876.57	9.64
1958	34	2.75	2.76	2.71	824.35	902.85	971.68	10.12
Ranch								
Antelope	184	2.53	2.57	2.55	765.53	843.19	910.41	10.19
Cottonwood	40	2.42	2.54	2.52	755.45	845.33	913.20	9.38
Inbreeding								
0- 5	106	2.53	2.58	2.54	776.58	857.62	922.10	10.13
6-10	47	2.55	2.61	2.61	781.85	863.72	935.57	9.96
11-15	30	2.43	2.45	2.44	733.17	807.73	875.40	10.40
16-20	18	2.52	2.59	2.57	755.61	836.72	907.17	10.22
21-25	10	2.57	2.58	2.59	740.60	815.00	888.40	9.80
26-30	5	2.51	2.56	2.50	749.40	829.00	888.20	9.00
31+	8	2.48	2.52	2.51	657.63	733.63	801.50	8.38

second is for 168, and the third is for 196. Final type score was only obtained at the 196 day period. The final weights listed include an adjustment for age. No correction for inbreeding differences has been made in these data.

Table II lists the same information for each sire involved in this study. The number of progeny listed after each sire is not necessarily his total number of bull calves. Only calves for which a complete record was available were used in this study. All sire groups having less than two bull calves with complete records were also deleted.

The means in Tables I and II point out that considerable variation is due to years, inbreeding, and sires. Average final weight for 196 days varied from 877 pounds in 1957 to 972 pounds in 1958. The variation was slightly less for 140 and 168 day final weights. Average final weights for the various inbreeding classifications ranged from a high of 936 pounds for the 6 to 10 per cent classification to a low of 802 pounds for the group composed of the calves with 31 or more per cent inbreeding. The variation in final weights due to ranches was practically negligible. However, the bulls calved at the Antelope Station had an average final type score of 10.19 while the average final type score for the Cottonwood bulls was 9.38.

Sire means for 196 day final weight varied from a high of 977 pounds for sire number 300 to a low of 790 for sire number 132. The variation for 140 and 168 day final weights was approximately the same.

TABLE II. SIRE MEANS

Sire	No. of Progeny	140 Day D G	168 Day D G	196 Day D G	140 Day F W	168 Day F W	196 Day F W	196 Day F T
101	34	2.59	2.66	2.64	767.65	852.26	923.32	10.18
402	10	2.35	2.45	2.36	732.20	816.20	869.00	9.80
032	9	2.17	2.26	2.28	717.89	792.89	860.89	9.00
219	9	2.54	2.61	2.52	775.33	856.78	913.67	10.67
XX3	2	2.48	2.51	2.60	785.50	861.50	948.50	9.50
026	10	2.30	2.47	2.45	738.30	834.90	899.50	8.60
030	5	2.40	2.43	2.36	755.20	829.00	883.40	8.60
228	9	2.49	2.55	2.56	741.67	822.11	896.56	10.11
014	21	2.50	2.54	2.52	745.48	822.10	888.71	11.10
012	24	2.62	2.64	2.64	811.92	888.46	957.25	9.17
920	13	2.42	2.46	2.49	750.00	824.00	897.77	10.46
132	2	2.02	2.09	2.20	640.00	709.50	789.50	9.50
436	16	2.42	2.52	2.50	761.81	846.81	914.31	9.19
319	5	2.37	2.37	2.31	721.20	788.60	844.80	10.60
321	5	2.49	2.48	2.45	753.40	821.20	885.80	10.80
233	11	2.70	2.69	2.68	782.45	855.64	929.45	12.00
433	13	2.49	2.54	2.50	733.54	811.38	874.92	9.62
432	2	2.34	2.50	2.43	746.50	837.00	893.00	11.00
300	14	2.78	2.83	2.78	821.57	908.21	977.00	11.29
512	4	2.77	2.78	2.71	773.00	851.50	915.25	7.25
529	6	2.66	2.66	2.64	807.50	881.17	953.17	10.33

STATISTICAL ANALYSIS

Procedure

The least squares method studied and discussed by Yates (33), Crump (3), (4), Eisenhart (8), and Henderson (11) was used to analyze the non-orthogonal data in this study. This method allows for estimating the different sources of variation which influence the characteristics studied.

Formation of a mathematical model is the first step in this procedure. It must describe the manner in which the observations are influenced by the different sources of variation. The following mathematical model was assumed for this study:

$$Y_{ijkmo} = u + y_i + s_j + r_k + f_m + e_{ijkmo}$$

where:

Y_{ijkmo} = observation in ith year from jth sire group at the kth ranch, within the mth inbreeding group and of the oth individual

u = the effect common to all bulls

y_i = the effect common to all bulls born in ith year

s_j = the effect common to all bulls born from jth sire

r_k = the effect common to all bulls born at kth ranch

f_m = the effect common to all bulls within the mth inbreeding classification

e_{ijkmo} = sum of all other things which cause the individual to vary

The coefficient matrix derived from the model is presented in Table III. Constants were fitted for 20 sires, six years, one ranch, and seven inbreeding groups, since one sire group, one year, and one ranch have been deleted to make the equations independent. The estimates for the deleted equations are automatically set at zero and the estimate for any other equation is an estimate of the deviation from the deleted equation of the same subgroup. Since none of the inbreeding groups were deleted, the mean is estimated in this classification.

The following right hand sides were solved in connection with this matrix:

1. 140 day final weight
2. 168 day final weight
3. 196 day final weight
4. 140 day rate of gain
5. 168 day rate of gain
6. 196 day rate of gain
7. 196 day final type

The following method of age adjustment was used for adjusting the final weights mentioned above:

$$AFW = \frac{FW - BW}{a} \cdot da \neq FW$$

where:

AFW = adjusted final weight

FW = actual final weight

BW = birth weight

TABLE III. LEFT HAND SIDE OF MATRIX SHOWING DISTRIBUTION OF BULLS BY SIRE, YEAR, INBREEDING CLASSIFICATION AND RANCH.*

																					53	54	55	56	57	58	F1	F2	F3	F4	F5	F6	F7	A
101	34																				2	4	9		6	7	9		3	3	8	4	7	27
402		10																			8						10							8
032			9																			5	4				1	3	5					9
219				9																	6						9							9
xx3					2																						2							2
026						10																					10							
030							5														5						5							3
228								9														4	5					9						2
014									21													2	4	3	8	4	3	3	7	7			1	21
012										24												3	2	6	9	4	9	12		1	1	1		24
920											13											4	9				13							13
132												2											2						2					2
436													16											6	10		3	7	3	3				4
319														5										5				1	4					5
321															5									5			5							5
233																11								11			1	3	5	2				11
433																	13							6	7		13							13
432																		2							2		1		1					2
300																			14						5	9	5	9						14
512																				4						4	1			2	1			4
53	2	8		6			5														21						21							18
54	4		5					4	2	3	4											22					5	8	7		2			18
55	9		4					5	4	2	9	2											35				10	9	7	5	2	2		32
56									3	6			6	5	5	11	6							42			16	10	10	6				36
57	6								8	9			10				7	2	5						47		12	16	5	5	4	2	3	41
58	7								4	4									9	4						34	19	4	1	2	2	1	5	34
F1	9	10	1	9	2	10	5		3	9	13		3		5	1	13	1	5	1	21	5	10	16	12	19	106							82
F2			3					9	3	12			7	1		3			9			8	9	10	16	4		47						36
F3	3		5						7			2	3	4		5		1				7	7	10	5	1			30					28
F4	3								7	1			3			2				2			5	6	5	2				18				15
F5	8									1										1		2	2		4	2					10			10
F6	4									1													2		2	1						5		5
F7	7								1																3	5							8	8
A	27	8	9	9	2		3	2	21	24	13	2	4	5	5	11	13	2	14	4	18	18	32	36	41	34	82	36	28	15	10	5	8	184

*One sire, one year and one ranch have been deleted for solving.

a = age of bull at weigh day

da = difference in days from average age

This method is designed to give an average growth rate by subtracting the birth weight from the actual final weight and dividing by age. The average growth rate is then multiplied by the number of days that this bull varies in age from the mean age of all bulls. The product is either added to, or subtracted from, the actual final weight depending on whether the bull is younger or older than the average.

This method of age adjustment was selected in preference to the following method in which the adjustment for age is made prior to the feeding period.

$$AFW = AWW + G$$

where:

AFW = adjusted final weight

AWW = age adjusted weaning weight

G = gain in feed lot

The adjusted final weight in this case is derived by adding the gain to the age adjusted weaning weight. The gain was calculated by subtracting actual starting weight from actual final weight. Since there was an adjustment period for all bulls, their gain for the adjustment period was also added except in a few cases in which they lost weight, then it was subtracted.

The results of these two methods were compared on 35 randomly chosen bulls as well as comparing the variance and components of variance for the total number.

In addition to the above mentioned matrix, a reduced matrix containing all variables except sires, was solved. The total reduction obtained by solving the large matrix minus the reduction due to ranches, years, and inbreeding obtained from solving the reduced matrix, provides an estimate of the sire sum of squares.

Effects of Inbreeding

The animals in this study were divided into seven different classifications based on percentage of inbreeding. The following shows the classifications and the number of animals involved in each classification:

classification	number of animals
0 - 5	106
6 - 10	47
11 - 15	30
16 - 20	18
21 - 25	10
26 - 30	5
31 +	8

All the bull calves were used in the inbreeding study even though there were no inbred animals in the first two years' data. The final weights were all adjusted to a common age. Estimates for the effects of inbreeding, obtained from the least squares analysis, contain the phenotypic differences due to inbreeding.

Heritability Estimates

Heritability estimates were obtained for final weight, rate of gain, and final type by use of the paternal half-sib correlation method. The final weight used in the least squares analysis contained an adjustment for age.

The phenotypic expression of a trait, as explained by Lush (23), is affected by many causes as is shown in the following formula:

$$P = G + D + I + E + EH$$

where:

P = phenotype
G = additive genetic effects
D = dominance effects
I = epistatic effects
E = environmental effects
EH = joint effects of heredity and environment

The heritability estimate obtained may be defined by either the broad or narrow sense definition, or it may fall somewhere between the two. The broad sense definition is explained by the following formula:

$$h^2 = \frac{\sigma G^2 + \sigma D^2 + \sigma I^2}{\sigma G^2 + \sigma D^2 + \sigma I^2 + \sigma E^2 + \sigma EH^2}$$

The narrow sense definition concerns only the additive genetic differences in the numerator as is explained in the following formula:

$$h^2 = \frac{\sigma G^2}{\sigma G^2 + \sigma D^2 + \sigma I^2 + \sigma E^2 + \sigma EH^2}$$

In a hypothetical case in which there were no effects due to dominance or epistasis, the two definitions would be the same. In a random mating population, the genic correlations between half-sibs would be one-fourth, dominance correlations would be zero, and the epistatic correlations would be very small. In a partially inbred population, the genic correlations increase, the dominance correlations have small values, and the epistatic correlations increase quite rapidly. These facts indicate that the paternal half-sib heritability estimates obtained in these data would fall somewhere between the broad and narrow sense definitions. Lush (23) points out that the least squares analysis insures there is no correlation between effects within an individual, however, the same effect may be correlated between related individuals.

The theoretical composition of the between sires mean square is A plus K_0B in which A equals the within sire mean square and K_0 is the weighted mean number of progeny within each sire group. In order to obtain B (between sire component), the within mean square is subtracted from the between sire mean square and the difference is divided by K_0.

The intraclass correlation is then calculated by dividing B by A plus B. In a random mating population, the intraclass correlation is multiplied by four to obtain the half-sib heritability estimate. However, in a partially inbred population, this multiplier must be changed because the relationship between half-sibs would be larger than one-fourth. Lush (23) presents the following formula to derive the multiplier in studying partially inbred populations:

$$r_{GG} = \frac{4(1 + F)}{1 + F' + 6F}$$

where:

F = inbreeding of progeny

F' = inbreeding of parents

The standard error for the paternal half-sib heritability estimates was computed by the following method outlined by Hazel and Terrill (9).

$$\frac{4}{1 + F' + 6F} \cdot \frac{A\ (A + K_o B)}{(A + B)^2 \sqrt{(\frac{1}{2})\ (K_o - 1)\ K_o\ n}}$$

where:

n = number of sires

Genetic, Environmental, and Phenotypic Correlations

The correlations in this study were estimated from an intra-ranch, intra-year analysis of variance and covariance. It has been mentioned previously in this paper that the phenotypic variance is derived from several sources. However, these sources may be grouped into (1) genetic, (G) due to the average effects of the genes, and (2) residual effect, (E) which includes all other effects such as dominance, epistasis, and the environment peculiar to the individual. Thus the expression of the trait (X) is due to the sources G plus E. Likewise the variance for any trait may be designated as:

$$V_X = V_G + V_E$$

The covariance between any two traits may also be designated in the same manner:

$$CV_{X1X2} = CV_{G1G2} + CV_{E1E2}$$

The covariance mean squares may be subdivided into covariance components in the same manner as the variance mean squares were divided into the variance components.

In a random mating population, the genetic variance in the sire component is one-fourth, computed on the basis of half-sibs. From this assumption, the genetic and environmental variances and covariances may be derived as follows:

$$V_G = 4\ V_S \qquad CV_G = 4\ CV_S$$

$$V_E = V_I - 3\ V_S \qquad CV_E = CV_I - 3\ CV_S$$

where:

V_G = genic component of variance

V_S = sire component of variance

V_E = environmental component of variance

V_I = within sire mean square

CV_G = genic component of covariance

CV_S = sire component of covariance

CV_E = environmental component of covariance

Since the relationship between half-sibs is greater than one-fourth in a partially inbred population, the sire component will contain more than one-fourth of the genetic variance. Thus the multiplier used to derive the genetic variance from the sire component should be smaller than four.

This multiplier may be calculated by the formula presented by Lush (23).

The within sire mean square in a random mating population contains the environmental component and three sire components. In a partially inbred population, the relationship between half-sibs is greater so the genic variance contained in the within sire mean square would be less.

The following algebraic equations were used to estimate the genic variance in the within sire mean square:

$$r\sigma_G^2 = \frac{1 + F' \ 6F}{4\ (1 + F)}\ \sigma_G^2$$

where:

r = relationship within half-sib groups

σ_G^2 = genetic component

Since the within sires mean square contains $(1 - r)\sigma_G^2$, and the sire component equals $r\sigma_G^2$, solving the following formula for X yields an estimate of the number of sire components present in the within sires mean square.

$$(1 - r)\sigma_G^2 = X \cdot \frac{1 + F' + 6F}{4\ (1 + F)}\ \sigma_G^2 .$$

The environmental component is derived by subtracting the portion due to genic variance from the within sire mean square.

The following formula was used for calculating correlations:

$$r_{X1X2} = \frac{CV_{X1X2}}{\sqrt{(V_{X1})\ (V_{X2})}}$$

where:

X = either genetic, environmental, or phenotypic components

The phenotypic components were derived by pooling the genetic and environmental components.

Length of Feeding Period

The effectiveness of selection in one period was compared to the effectiveness of selection in another period by calculating an intra-ranch, intra-season standard deviation for each period and multiplying it by the corresponding estimate of heritability. The above mentioned standard deviation was derived by subtracting the reduction due to ranches, years, and inbreeding from the total sum of squares, dividing by the degrees of freedom and taking the square root of the computed mean square.

RESULTS

Statistical Analysis

Highly significant differences due to sires were obtained for daily gain and final weight for the 140, 168, and 196 day periods, and for final type. Table IV gives the mean squares for each of these traits:

TABLE IV. ANALYSIS OF VARIANCE FOR ALL TRAITS

Trait	Source of Variance	Theoretical Composition	Mean Square
140 Daily Gain	Between Sires	$A + K_oB$	.1644**
	Within Sires	A	.0633
168 Daily Gain	Between Sires	$A + K_oB$	.1514**
	Within Sires	A	.0520
196 Daily Gain	Between Sires	$A + K_oB$	.1364**
	Within Sires	A	.0489
140 Final Weight	Between Sires	$A + K_oB$	11,710.43 **
	Within Sires	A	4,330.90
168 Final Weight	Between Sires	$A + K_oB$	13,328.21 **
	Within Sires	A	4,674.66
196 Final Weight	Between Sires	$A + K_oB$	14,535.69 **
	Within Sires	A	5,137.88
196 Final Type	Between Sires	$A + K_oB$	10.54 **
	Within Sires	A	2.84

**Highly Significant ($P < .01$)

The highly significant F values indicate that the sire differences in this experiment have less than one chance in 100 of occuring due to chance. The null hypothesis that sires do not affect the above mentioned traits would be rejected in each case. The sire components derived from these mean squares appear in Table VII.

Effects of Inbreeding

The estimates of inbreeding effects derived from solving the matrix are presented in Tables V and VI. Table V consists of estimates as they affect 140, 168, and 196 day final weight and 196 day final type. Table VI contains the estimates as they affect 140, 168, and 196 day daily gain. The number of animals in the different inbreeding classifications varied from 5 to 106.

TABLE V. ESTIMATES OF INBREEDING EFFECTS ON FINAL WEIGHT AND FINAL TYPE

Percent F	No. of Animals	140 Day Final Wt.	168 Day Final Wt.	196 Day Final Wt.	196 Day Final Type
0 - 5	106	0	0	0	0
6 - 10	47	+ 5.06	+ 8.54	+ 17.04	- .8502
11 - 15	30	- 43.81	- 45.41	- 40.36	- .9571
16 - 20	18	- 25.43	- 23.16	- 17.76	-1.0077
21 - 25	10	-104.61	-112.83	-101.64	-1.8555
26 - 30	5	- 92.53	- 96.49	-101.95	-2.6846
31 +	8	-234.36	-240.01	-233.54	-4.0310

TABLE VI. ESTIMATES OF INBREEDING EFFECTS ON DAILY GAIN

Percent F	No. of Animals	140 Day Daily Gain	168 Day Daily Gain	196 Day Daily Gain
0 - 5	106	0	0	0
6 - 10	47	- .0361	- .0146	+ .0468
11 - 15	30	- .1134	- .1031	- .0643
16 - 20	18	- .0516	- .0318	+ .0072
21 - 25	10	- .1069	- .1440	- .0601
26 - 30	5	- .1264	- .1359	- .1307
31 +	8	- .2643	- .2552	- .1608

The linear regression of weight on per cent of inbreeding was calculated for 140, 168, and 196 day final weight. The linear regression was also calculated for final type on per cent of inbreeding. Figure 1 depicts the linear regression line of 140 day final weight on per cent of inbreeding. A graph showing either 168 or 196 day final weight would resemble this one very closely. The points on the graph are the estimates for each inbreeding classification. The following regression coefficients were calculated:

140 FW	-6.85 pounds per one per cent of inbreeding
168 FW	-7.13 pounds per one per cent of inbreeding
196 FW	-7.14 pounds per one per cent of inbreeding
196 FT	- .119 units per one per cent of inbreeding

Figure 2 shows the regression line of type score on inbreeding.

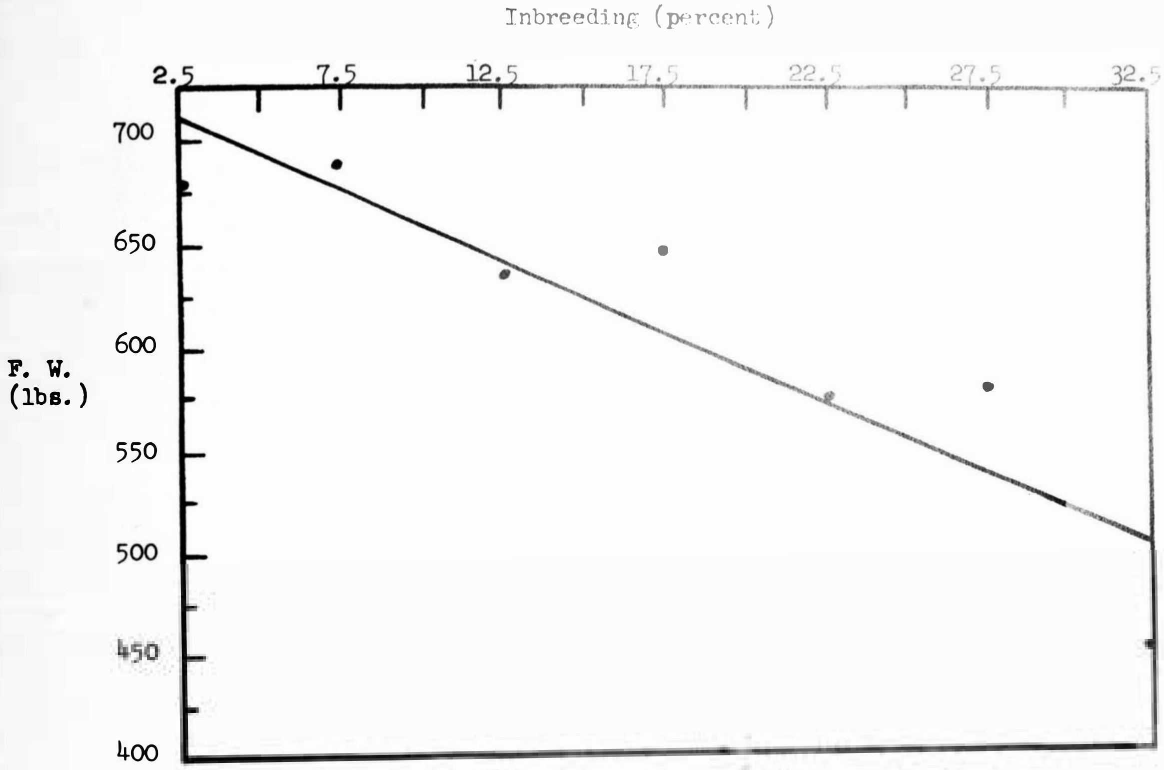

Figure 1. Linear Regression for 140 Day F. W. on Percent of Inbreeding

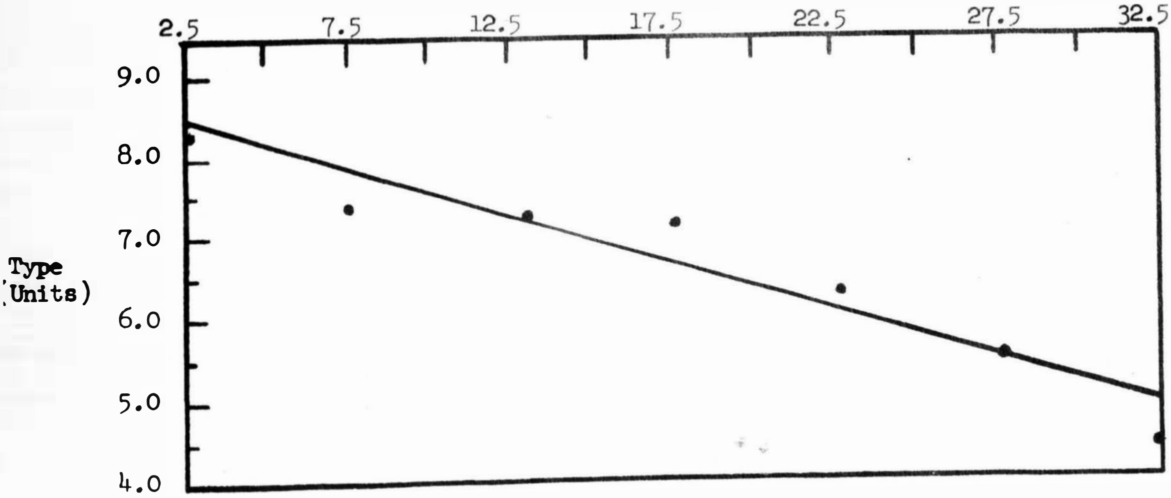

Figure 2. Linear Regression of Final Type on Percent of Inbreeding

The regression coefficient of -.119 indicates for every 10 per cent of inbreeding there would be a decrease of approximately one-third of a grade in type score. The fitness of the linear regression lines were found to be highly significant in each case.

Heritability Estimates

Heritability estimates were obtained for both daily gain and final weight for 140, 168, and 196 day periods. The heritability estimate for final type score was based on the 196 day period. Table VII presents the sire components and the within sire mean squares for the traits studied.

TABLE VII. SIRE COMPONENTS AND WITHIN SIRE MEAN SQUARES

Trait	Sire Component (B)	Within Sire Mean Square (A)
140 Day Daily Gain	.0097	.0633
168 Day Daily Gain	.0096	.0520
196 Day Daily Gain	.0084	.0489
140 Day Final Weight	710.82	4,330.90
168 Day Final Weight	833.54	4,674.66
196 Day Final Weight	905.23	5,137.88
196 Day Final Type	.74	2.84

The intraclass correlations, half-sib heritability estimates, and the fiducial limits for each trait are presented in Table VIII.

TABLE VIII. INTRACLASS CORRELATIONS, HERITABILITY ESTIMATES, AND FIDUCIAL LIMITS

Traits	Intraclass Correlation	Heritability Estimate	Fiducial Limits
140 Day Daily Gain	.1329	.39	± .18
168 Day Daily Gain	.1558	.45	± .19
196 Day Daily Gain	.1466	.43	± .18
140 Day Final Weight	.1410	.41	± .18
168 Day Final Weight	.1513	.44	± .19
196 Day Final Weight	.1498	.44	± .19
196 Day Final Type	.2067	.60	± .21

The intraclass correlations were calculated by dividing B by A + B. The heritability estimates were obtained by multiplying the intraclass correlation by 2.91. This multiplier has been corrected for the additional relationship between half-sibs due to inbreeding according to the formula presented by Lush (23). The average inbreeding of the progeny in this study was 7.85 per cent and the average inbreeding for the parents was one per cent. The fiducial limits were calculated by the method outlined by Hazel and Terrill (7).

Genetic, Environmental, and Phenotypic Correlations

The genetic, environmental, and phenotypic correlations were calculated for 196 day daily gain-final type, 196 day final weight-final type, and for 196 day daily gain-196 day final weight. This study is based on the same data; however, it is analyzed on an intra-ranch, intra-year basis. The data were corrected for inbreeding by applying the estimates obtained from the matrix analysis. Table IX contains the analysis of variance and covariance for the traits involved in the correlation study.

TABLE IX. ANALYSIS OF VARIANCE AND COVARIANCE

		Mean Squares		
		196 D G	196 F W	196 F T
196 Day Daily Gain	Between Sires	.1164	31.66	.4467
	Within Sires	.0379	7.34	.0874
196 Day Final Weight	Between Sires		14,165.91	184.10
	Within Sires		2,709.45	24.29
196 Day Final Type	Between Sires			9.70
	Within Sires			2.29

Table X contains the genetic, environmental and phenotypic components of variance and covariance.

TABLE X. GENETIC, ENVIRONMENTAL, AND PHENOTYPIC COMPONENTS

		196 D G	196 F W	196 F T
196 Day Daily Gain	Genetic	.0471	14.61	.2159
	Environmental	.0070	-2.25	-.0543
	Phenotypic	.0541	12.36	.1616
196 Day Final Weight	Genetic		6,888.09	96.09
	Environmental		-1,811.60	-38.78
	Phenotypic		5,076.49	57.31
196 Day Final Type	Genetic			4.45
	Environmental			-.63
	Phenotypic			3.82

The following formula was used for computing correlations:

$$r_{X1X2} = \frac{CV_{X1X2}}{\sqrt{(V_{X1})(C_{X2})}}$$

The correlations are presented in Table XI.

TABLE XI. GENETIC, ENVIRONMENTAL, AND PHENOTYPIC CORRELATIONS

		196 Day F W	196 Day F T
196 Day Daily Gain	Genetic	.81	.46
	Environmental	0	0
	Phenotypic	.75	.36
196 Day Final Weight	Genetic		.55
	Environmental		-1.14
	Phenotypic		.41

The environmental correlations containing a negative variance component in the denominator were set at zero due to the impossibility of obtaining the square root of a negative number.

Length of Feeding Period

The study of effectiveness of selection revealed smaller differences than have been reported previously for the different length of feeding periods. Comparison of length of feeding period in this study is based on comparing the products derived by multiplying the heritability estimate times the appropriate intra-ranch, intra-year standard deviation. Table XII contains the intra-ranch, intra-year standard deviation, the heritability estimate, the product of the two, and the estimated effectiveness as compared to another period.

TABLE XII. EFFECTIVENESS OF LENGTH OF FEEDING PERIOD

	σ	H^2	Product	% Effectiveness
140 Day Final Weight	70.95	.41	29.0895	
				.89
168 Day Final Weight	74.15	.44	32.6260	.85
				.95
196 Day Final Weight	77.67	.44	34.1748	

The above table indicates that selection for final weight would be 89 per cent as effective in the 140 day period as it would be in the 168 day period and 85 per cent as effective as the 196 day period. The selection for final weight in the 168 day period would be 95 per cent as effective as the 196 day period.

DISCUSSION

The purpose of this study was to analyze the importance of final weight as a criterion for selection. The areas of study included heritability of final weight, correlations with other traits and the effect of length of feeding period. Effects of inbreeding were also studied, however, this was approached on the basis of analyzing these data for future experiment station use rather than recommendations for use in the field.

Two methods of final age adjustment were compared in the evaluation of these data. The first method studied is explained by the following formula:

$$AFW = \frac{FW - BW}{a} \not- da \neq FW$$

where:

AFW = adjusted final weight

FW = actual final weight

BW = birth weight

a = age at weigh day

da = difference from average age

This method may be used in any situation in which final weight and age are known. Actual birth weights were used in this analysis, however, an average birth weight could be used if birth weights were not known. This method of age adjustment assumes a linear growth rate from birth to final age.

The second method was based on an adjustment for age prior to the feeding period and is explained by the following formula:

$$AFW = AWW + G$$

where:

AFW = adjusted final weight
AWW = age adjusted weaning weight
G = gain in feed lot

The first method of final age adjustment discussed was chosen in preference to the second method because it gave comparable results and could be used if weaning weights were not taken. Heritability estimates calculated by the two different methods varied only one per cent. These similar estimates might not be typical of all data analyzed by these two methods. Method one might not be as satisfactory as method two in data where there was a large difference in pre-weaning and post-weaning growth rate or where the calving period extended longer than the eight to ten week period typical of these data. Even though the first age adjustment method does not necessitate taking weaning weights, their value in a selection program must always be considered. Weaning weight aids in partial culling at an early age as well as in helping to evaluate the dam.

The analysis of these data indicates that the sires used play an important role in determining final weight. Differences due to sires for 140, 168, and 196 day final weights were all highly significant. This is true also for 140, 168, and 196 day daily gain and final type, which were also studied.

In agreement with previous studies, this analysis indicates that growth is affected by inbreeding. Both Koch (19) and Burgess, et al. (2) reported significant regressions of weaning weight on inbreeding of the individual. The linear regressions reported were -0.48 and -1.75 pounds per one per cent inbreeding respectively. The regression coefficients found in these data were high, varying from -6.85 pounds per one per cent inbreeding for 140 day final weight to -7.14 pounds per one per cent inbreeding for 196 day final weight. The effects due to inbreeding on the three different final weights seem to follow the same trend, however, the estimates of effects of inbreeding show higher reductions of weight for 140 and 168 day periods than for 196. This was especially true of animals that were more than 31 per cent inbred. This may be due to one or both of the following possibilities:

(1) Inbreeding affects growth rate more severely at younger ages than it does later in life. This possibility is supported by the findings of Nelson and Lush (25) in their work with dairy cattle. They indicated that growth rate was depressed at an early age, however, rapid growth continued longer in high inbreds. They concluded that even though inbreeding resulted in smaller size at two years of age, it did not depress the final mature size.

(2) The low inbred animals, being heavier than the high inbred animals in the latter part of the feeding period, may have passed their growth peak. Since the high inbred animals were lighter, they would tend to be growing at their maximum rate. This may be supported by the fact that the mean daily gain for the 168 day period is higher than the mean for the 196 day period. However, the possibility that this may be due to

flies, hot weather, or some other environmental factor cannot be decisively ruled out. Branaman and Howe (1) in studying growth and composition of beef carcasses reported that growth rate decreased after 425 days of age. Their study started with calves 300 days of age and was carried on for 200 days. They used Hereford steers and heifers that were produced at the Miles City, Montana, Station. However, in this study, since the bulls went on feed at an earlier age, their maximum growth rate may have been reached at an earlier age. It may also be possible that weight is the limiting factor rather than age.

The 6 - 10 per cent inbreeding group showed a higher final weight for each of the three periods studied than did the 0 - 5 per cent inbred group. This did not hold true for 140 and 168 day rate of gain, so the positive effects must have been present in weaning weights. Even though this inbreeding group did show higher final weights, the goodness of fit of the linear regression line was highly significant.

Inbreeding caused a substantial decrease in final type score indicated by the linear regression of -.119 type score per one per cent inbreeding. Zoellner (34) found one-third of a grade reduction for the 16 to 20 per cent inbreeding group. This agrees with the findings in this study, however, the higher inbreeding classifications in this study showed a larger decrease in type score. This would be expected since the higher inbred animals were lighter in weight when scored for final type and this analysis indicated a highly significant correlation of .41 between final weight and final type score. It would seem possible that size may affect final type score more in bulls than in heifers since size, ruggedness, and substance of bone are desired in a bull.

This study produced estimates of inbreeding effects on growth and type score of bulls. However, since some of the inbreeding classifications contained a limited number of bulls, the sampling errors of these estimates must be large. A study of more animals within each inbreeding classification would be helpful in more accurately determining correction factors for inbreeding.

The estimates of heritability in this study were obtained by using the paternal half-sib correlation method. The data were analyzed by using the least squares method of solving simultaneous equations. Since all the lines involved in this study were single sire lines, there was no random assortment of cows to be mated to each bull. The heritability estimates will be biased upwards if the breeding value of the cows is not equal among the several lines since any inequality among the dams will be attributed to sire differences in the paternal half-sib analysis.

Environment which was peculiar to an individual line would also increase differences between lines, and this would also tend to give a larger heritability estimate. In these data, the carryover effects from pasture differences prior to weaning would be the major source of such an environmental bias, and it is impossible to evaluate the size of this bias.

The heritability estimates obtained for rate of gain in this study of .39, .45, and .43 for 140, 168, and 196 day periods compare quite closely with those reported by Dawson et al. (5) and Warwick et al. (32). They are slightly lower than those reported by Dinkel (6), Shelby et al.

(27), and Knapp and Clark (17). They are considerably lower than those reported by Knapp and Nordskog (15). In comparing the heritability estimates for rate of gain in this study to the ones just mentioned, they seem comparable or possibly on the conservative side. Kincaid and Carter (12) studied progeny data from selected high and low gaining sires. The difference in daily gain between the group of high gaining bulls and low gaining bulls was 0.59 pounds per day. This was slightly more than two standard deviations. The difference between the progeny from the high and low gaining sires was 0.1 pounds per day for the steers and 0.06 pounds for the heifers. The heritability estimates obtained from these data ranged from .21 to .49 depending on sex and method of adjusting for differences in progeny numbers. They concluded that heritability estimates for rate of gain that exceed .5 are probably too high. They further concluded that the heritability of post-weaning gain is positive and probably somewhere around .33.

The heritability estimate for 196 day daily gain was also calculated from the intra-ranch, intra-year analysis and found to be considerably higher. This estimate is not reported since the estimates obtained from the least squares analysis should be more accurate. The reason for the large difference in estimates obtained from the two methods of analysis is unknown.

The heritability estimates for 140, 168, and 196 day final weight obtained in this study were .41, .44, and .44 respectively. These estimates are considerably lower than those reported by Knapp and Nordskog (15), Knapp and Clark (17), and Shelby *et al*. (27) (28). It is difficult to compare studies on this trait since the age and length of feeding period varies considerably among studies. However, the final weight studied by Shelby <u>et</u> <u>al</u>. (28) is based on 13 months of age. These two studies are quite comparable for age of bull and length of feeding period. Shelby <u>et</u> <u>al</u>. (28) reported .77 as the paternal half-sib heritability estimate for final weight, however, his method of analysis was not presented.

Heritability estimates for final weight and daily gain found in this study are slightly less than those reported in the review. The estimated heritability for final type was considerably higher in this study than the .27 reported by Koch and Clark (21). This large difference may be caused by sampling error.

The genetic correlation found in this study of .55 for 196 day final weight-final type is comparable to .49 reported by Koch and Clark (21) between yearling weight and yearling score. A genetic correlation of this size would certainly indicate that either trait would be affected by direct selection for the other trait.

Table XIII includes all the correlations studied in these data and also the corresponding estimates reported by Koch and Clark (21).

The genetic correlations in these two studies agree quite closely. The high genetic correlation between 196 day daily gain and 196 day final weight indicates that selection for either one would give comparable results in the other trait. There was very little difference in the genetic correlations between 196 day daily gain-final type and 196 day

TABLE XIII. COMPARISONS OF CORRELATIONS

		Present Study	Koch & Clark
196 Day D G-F T	Genetic	.46	.44
	Environmental	0	.35
	Phenotypic	.36	.38
196 Day F W-F T	Genetic	.55	.49
	Environmental	-1.14	.61
	Phenotypic	.41	.56
196 Day D G-F W	Genetic	.81	.83
	Environmental	0	.56
	Phenotypic	.75	.67

final weight-final type. The large phenotypic correlation reported by Koch and Clark (21) as well as the highly significant correlation in this study would tend to indicate the larger animals may have been given a slight advantage when scored for type. The environmental correlations set at zero resulted from the impossibility of finding the square root of a negative number. The environmental correlation of -1.14 for 196 day final weight-final type is theoretically impossible. Negative environmental components were found and could be expected since the sire components were so large. Both the negative components and the correlation exceeding 1.00 are indications of the large sampling errors associated with all the correlation coefficients presented.

Effectiveness of selection for final weight varied only slightly between lengths of feeding periods in this study. The following table presents the effectiveness of the shorter periods as they compare to the 196 day period. The left hand column contains the estimates obtained from these data when selection is based on final weight and the middle column when selection is based on daily gain. The right hand column contains the estimates obtained by Dinkel (6) when selection is based on daily gain for the three corresponding periods.

TABLE XIV. COMPARISON OF LENGTH OF FEEDING PERIOD

	Present Study Final Weight	Present Study Daily Gain	Dinkel Study (1958) Daily Gain
140 Day Period	.85	.83	.79
168 Day Period	.95	1.00	.84
196 Day Period	1.00	1.00	1.00

Table XIV shows the effectiveness of selection for the 140 and 168 day periods as compared to the effectiveness of selection for the 196 day period. The comparison of the three studies agrees quite closely with the exception that the 168 day period was more efficient in this study than was found by Dinkel (6) in 1958.

The results of these three studies would tend to indicate that the 196 day feeding period would result in more efficient selection than either the 140 or 168 day feeding periods. However, if one of the shorter feeding periods worked into the breeder's schedule more conveniently, he would be sacrificing very little additional progress if he chose either the 168 or 140 day feeding periods.

The findings in these data would tend to indicate no advantage for selection for final weight in preference to selection for daily gain. The heritability estimates obtained were practically equal for daily gain and final weight for the same length feeding period. The progress due to selection for either criterion should be comparable, and in actual use one should be as practical as the other. There may arise a situation in which weaning weights were not taken, and in this case, no starting weights for a feeding period would be available. Selection for final weight could then be used if the birth dates had been accurately recorded, provided the calving period and the difference between pre-weaning and post-weaning growth rate are not greater than reported in this study.

SUMMARY

The purpose of this study was to investigate the feasibility of using final weight as a criterion in selection of beef cattle. The main phases included: the effects of inbreeding, heritability estimates, genetic correlations and comparison of different length feeding periods. Regression coefficients of final weight on inbreeding of the individual were calculated. Heritability estimates for daily gain and final weight were calculated for 140, 168, and 196 day periods. Heritability was also estimated for final type. Genetic, environmental, and phenotypic correlations were calculated for 196 day daily gain-196 day final weight, 196 day daily gain-final type, and 196 day final weight-final type. The effectiveness of selection for final weight for the three different length feeding periods was compared.

The data in this study include records from 224 Hereford bulls completing the performance test at the South Dakota Agricultural Experiment Station during the period 1952 to 1958 inclusive. The least squares method of analysis was used in the analysis of these data. The results are as follows:

(1) Inbreeding of the individual affects final weight and final type. The regression coefficients are -6.85, -7.13, and -7.14 pounds per one per cent inbreeding for the 140, 168, and 196 day periods respectively. The regression coefficient for type was -.119 units.

(2) The estimates of inbreeding effects on rate of gain indicated

less effects for daily gain during the 196 day period than for daily gain for either the 140 or 168 day periods.

(3) The heritability estimates obtained in this study are as follows: 140 day daily gain, 39 per cent; 168 day daily gain, 45 per cent; 196 day daily gain, 43 per cent; 140 day final weight, 41 per cent; 168 day final weight, 44 per cent; 196 day final weight, 44 per cent; final type score, 60 per cent.

(4) The genetic correlations computed in this study are as follows: 196 day daily gain-196 day final weight, .81; 196 day daily gain-final type, .46; 196 day final weight-final type, .55.

(5) The study of the length of feeding period indicated an advantage for the 196 day period over either the 140 or 168 day periods. The difference was so small, however, that the breeder who chooses the shorter period for more convenience would be sacrificing very little progress.

(6) This study indicates that selection for either daily gain or final weight would give comparable results. Selection for final weight could be used when weaning weights were not taken. However, weaning weights allow for partial culling at an earlier age as well as evaluation of the dam.

(7) This study indicates that selection for either daily gain or final weight would aid in improving type as well. This comparison can only be made for the 196 day period, since type score was not available for the 140 or 168 day periods.

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