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Rate and Efficiency of Gains in Beef Cattle

III. Factors Affecting Weight and Effectiveness of Selection for Gains in Weight

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Table of Contents

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Rate and Efficiency of Gains in Beef Cattle

III. Factors Affecting Weight and Effectiveness of Selection for Gains in Weight.

Introduction

Research has yielded valuable information about the inheritance of body weight in many mammals. Results with one species may not be directly applicable to another species, but since results do not contradict genetic theory, one must assume that the same general rules apply to all species.

When the study of Mendelian inheritance was extended to such characters as size, research workers realized that inheritance of these characters involved too many genes to be classified individually. The term "quantitative inheritance" was applied to such characters. Body size is a case of quantitative inheritance.

Heritability is defined as that portion of the total variation which is due to additive genetic effects. A knowledge of heritability is important in determining breeding methods for improvement of quantitative characters. High heritabilities allow rapid progress with mass selection on individual merit; whereas, low heritabilities require family selection and management improvement.

All methods of calculating heritability depend on the fact that related animals resemble each other more closely than unrelated animals. Estimates of heritability may be obtained from samples drawn from populations. These estimates are subject to various biases and sampling errors. Inconsistent results are to be expected when estimates are based on small numbers of animals.

Large areas of the western United States are adapted to grazing by livestock. Much of this land is sparsely covered with vegetation and provides low levels of nutrition for livestock. Feed intake may be improved in quantity and quality by range improvement or supplemental feeding. Costs and returns have to be considered here, however.

Weight of animals sold is an important factor in determining the income of western ranchers. The objective of this study was to determine possibilities for attaining heavier sale weights on a low level of nutrition by selecting beef cattle for this characteristic.

Review of Literature

Birth weight

Heritabilities of birth weight in beef cattle have been reported by several workers. Dawson et al. (1947) considered .11 the best estimate from their data. Gregory and coworkers (1950) reported estimates of .45 and 1.00 from two sources of data. They recognized the unreliability of these estimates due to small numbers of animals involved. A significant effect of sires was reported by Woodward and Clark (1950), indicating heritability is significantly larger than zero. An estimate of .53 was reported by Knapp and Clark (1950). They used a large number of sires and offspring in a half-sib correlation. Burris and Blunn (1952) estimated the heritability of birth weight to be .22.

Weaning weight

The weaning weight of a range beef calf is determined largely by its genetic potential for growth and the milk production of its mother. Low heritabilities for this trait are generally attributed to variation in milk production among cows.

Knapp and Clark (1950) reported .28 as an estimate of heritability of weaning weight in Hereford cattle. Working with two sources of data, Gregory and associates (1950) reported .26 and .52. Estimates of heritability of body size at 6 months of age for Holsteins and Ayrshires were .15 and .20 to .35, respectively, in a report by Tyler et al. (1948). Woodward and Clark (1950) found that sires had a significant effect on the weaning weights of a group of Hereford calves.

Botkin and Whatley (1953) estimated .43 as the repeatability of production in range beef cows. Production was measured by the weaning weight of the calves. Koch (1945) reported .52 as the repeatability of calf weaning weights of range Hereford cows. This repeatability is based on differences in average production between cows, and indicates the tendency of a cow to produce calves of the same weight. Cow differences are the result of both genetic and permanent environmental influences.

Weights after weaning

Tyler et al. (1948) studied heritability of body size in Ayrshires and Holsteins, the estimates at 18 months and at maturity were .35 to .65 and .30 to .60, respectively. Estimates of .30 to .60, .20 to .40, and .15 to .30 in Ayrshires were found for animals at 12, 18, and 36 months of age, respectively. Knapp and Clark (1950) reported .86 as the heritability of final feed-lot weight in Hereford steers.

Effect of sex on weight of calves

The effects of sex on weights of beef cattle have been investigated by many authors. Generally, results have indicated that bulls grow faster than steers, and steers grow faster than heifers. Dawson and coworkers (1947) found that male calves were 4 to 5 pounds heavier than female calves at birth. Other investigators (Gregory, et al. 1950) have reported similar results.

Koger and Knox (1945) found that steers averaged 26 pounds heavier than heifers at weaning. Koch (1951) reported that bulls were 31 pounds heavier than steers at weaning, and steers were 13 pounds heavier than heifers at weaning. The bull calves were a selected group, so their average may be higher than that of a random group. If this were the case, steers would have a lower average weight than would occur if all males were castrated.

Dahmen and Bogart (1952) found a significant sex difference in rate of gain. Between 500 pounds and 800 pounds the average daily gain was 2.3 pounds for bulls and 2.0 pounds for heifers.

Effect of age of dam on weight of calves

Both body weight and producing ability of a cow increase with age, up to a certain age. According to Sawyer et al. (1948), 2-year-old cows produced calves 75 pounds lighter at 30 weeks of age than those produced by mature cows. Their data indicated that weaning weights increased with the age of dam through 8 years. After that age, weaning weights declined with the increased age of dam. Dawson and coworkers (1947) reported an increase of .2 pound of birth weight for each month increase in age of Shorthorn dams until the dam was 6 years old. In this report, correlation coefficient of birth weight with age of dam was .45 for male calves and .36 for female calves. Knox and Koger (1945) found that the weight of cows and the weaning weights of their calves increased each year until the cows were 7 years of age and, after that, both weights decreased each year.

Correlations in weights and gains

The weight of an animal at any given time in its life is determined by the genetic and environmental influences which affected its growth up to that point. It is not surprising that weights of the same animal taken at different ages are positively correlated. Correlation coefficients between birth weight and weaning weight, calculated by Gregory and associates (1950) within two groups of Hereford calves, were .44 and .60. Dawson et al. (1947) reported a negative correlation between birth weight and the time required to reach 900 pounds.

Knapp and Black (1941) did not find a significant correlation between the gains of Hereford steers before and after weaning. Nonsignificant correlations between weaning weight and yearling gain on the range were reported by Koger and Knox (1951). In the same study, these authors found that the growth rate of yearling steers on the range was positively correlated with gain in the feed-lot, and the long-yearling weight of heifers was positively correlated with the gain between long-yearling weight and the weight at 3 years of age (Koger and Knox, 1951). Ruby et al. (1948) found high positive relationships among three different weights. These weights were fall calf weight, spring weight out of winter feed-lot, and weight out of pasture as a long yearling.

Selection experiments

Reports on experiments involving several generations of selection in beef cattle were not found in the literature. The natural course was to investigate first animals which provided information rapidly and economically.

MacArthur (1944) succeeded in developing large and small strains of mice through selection. Falconer (1953) estimated the heritability of body weight in mice by selecting for high and low body weight at 6 weeks of age. The heritability, as shown through several generations, for large size was found to be .20, while the heritability for small body size was .50. Krider et al. (1946) selected for fast-gaining and slow-gaining swine. Line differences obtained during four generations of selection gave a heritability estimate of .19 for the 180-day weight. Heritability calculated from differences between sire progenies within lines was .24. Intra-sire regression of offspring on dam gave .65 as the estimate of heritability for the 180-day weight.

Falconer and Latyszewski (1952) studied selection for large body size in mice, using two levels of nutrition. One line was fed ad libitum and the other line was fed about 75 per cent of the normal ration. Heritability of body size was .20 in the high-ration group and .30 in the low-ration group. A higher selection differential (difference between the average of the selected parents and the average of the generation in which they were born) made progress more rapid in the high-ration group. When animals from both groups were compared on the high level of nutrition, they were about equal in performance. Animals from the high-ration group were inferior to those from the low-ration when both were tested on the low ration.

Christian et al. (1952) reported the performance of three generations of swine which had been selected on two levels of nutrition. Rates of gain, in pounds per day, from weaning to a weight of 150 pounds for second, third, and fourth generation selection on the high plane of nutrition, were 1.24, 1.45, and 1.44 respectively. Swine selected on a low plane of nutrition gained .68, .80, and .98 pounds per day respectively, for the second, third, and fourth generations.

Materials and Methods

Source of data

Data used in this study were collected from a herd of grade Hereford cattle at the Squaw Butte-Harney Experiment Station in central Oregon. The management is similar to that of most ranchers, depending on sagebrush-bunch grass range for summer feed. The summer range is about 45 miles west of Burns. Winter feeding is done on the meadows near Burns.

The summer range may be best described as a sagebrush-bunch grass type. Heavy use, drought, and perhaps other factors have caused depletion of the blue bunch wheatgrass (*Agropyron spicatum*), with a subsequent increase in big sagebrush (*Artemisia tridentata*), and perhaps of some poor range grasses. The soil is a fine sandy loam; rainfall is light (8 to 12 inches per year). Grasses drop in protein as the grazing season advances, reaching a low of about 3 per cent in the fall.

Sagebrush control has been started, and crested wheatgrass has been seeded on limited areas. This will eventually provide more feed, especially for early spring grazing. During the time data were collected, however, little grazing was done on such improved areas.

The meadows have a cover of native grasses, rushes, and sedges. Hay from these meadows is low in quality. Protein content is lower than that generally recommended for brood cows and young cattle.

Winter feeding is usually begun about December 1, and continues until late April. The main feed during this period is native meadow hay. At the end of the winter feeding program, cattle are moved to the sagebrush-bunch grass range where they are held until late September. The highest plane of nutrition is reached during May and June. Around the first of October, cattle are moved back to the valley where they clean up the meadows and graze on bunched hay until the early part of December. In general the plane of nutrition at the station is low, though typical of the area.

The study of weaning weights was based on the records of 722 grade Hereford calves. The study of yearling weights was based on records of 157 grade Hereford cows and their 376 offspring. The cow records were taken over the 11-year period from 1938 through 1948. Offspring records were taken over the 8-year period from 1944 through 1951.

Cows were bred to purebred Hereford bulls on summer range. In many cases, more than one bull ran in the same pasture. The effect of sire could not be removed from estimates of heritability and repeatability. Random mating was assumed.

Some of the animals were used on special experiments. The effects of these experiments were not removed from estimates. Since animals were assigned to the special experiments at random, it was assumed there would be no bias from this source. Those special treatments probably resulted in a greater variation and therefore reduced the reliability of estimates.

Methods of analysis

Corrected weights were used in some of the analyses. Weights were corrected only for age at the time weights were taken. All corrections for age were made along the line of regression of weight on age. The correction equation was $CW = W - bA + bK$; where CW was the corrected weight, W was the actual weight, A was the actual age, K was the constant age, and b was the slope of the regression line. This modification of the method described by Phillips and Brier (1940) was designed for rapid machine calculation.

The average corrected yearling weights of offspring are presented in Table 2.

The regression of yearling weight on yearling age was calculated for dams. Regression coefficients were calculated both with the effect of year removed and ignoring the effect of year (Table 3). Yearling weights of the dams were adjusted to 520 days along a line with the slope of 1.1 pounds per day. In this study, all weights are measured in pounds, and all ages are measured in days, except for age of dam which is measured in years.

Weaning weights for calves were adjusted to 225 days, with regression coefficients of 1.1 pounds per day and 1.2 pounds per day for heifers and for steers respectively (Table 4). Regression coefficients are averages for the "within-group" values. Calves were grouped according to sex of calf, year of birth, and age of dam.

A multiple regression analysis was run to determine the effect of age of offspring (X_1), age of dam when her offspring was born (X_2), and the corrected yearling weight of dam (X_3) on the actual yearling weight of the offspring (Y). The sums of squares and the sums of products were calculated within the sex and year groups.

The sums of squares and sums of products are presented in Tables 5, 6, and 7.

Simultaneous equations were solved to obtain the partial regression coefficients. The c values, needed for calculating standard errors, were obtained in the same solution. Separate analyses were run for steers, heifers, and the sexes combined.

The partial regression coefficient b_1, for each sex, was used to adjust the yearling weight of offspring to 520 days for another analysis.

The partial regression coefficient b_3 was multiplied by 2 to obtain heritability (Lush, 1949). The 95 per cent confidence interval for b_3 was calculated and multiplied by 2 for the confidence interval of heritability.

To determine the effect of cow on the yearling weight of offspring, an analysis of covariance was run in order to eliminate the effects of age of offspring at the time of weighing. A separate analysis was made for each sex.

Estimates of repeatability were calculated from components of the mean squares. The formula for repeatability is $\frac{V_c}{V_c + V_o}$; where V_c is the variance component due to cows and V_o the variance component due to offspring (Fisher, 1950).

The effect of selecting for corrected yearling weights was studied by paper selection. Dams were ranked within year of birth on the basis of their corrected yearling weight. The high one-third and the low one-third were used to determine the effect of selection.

In the following discussion, cows selected for high corrected yearling weight will be called "high" cows, and the cows selected for low corrected yearling weight will be called "low" cows. Offspring will be designated "high" or "low" depending on the direction of the selection practiced on their dams.

For comparisons between high animals and low animals, dams and their offspring were grouped according to the sex and year of birth of offspring. The term "weighted mean difference" is employed by Snedecor (1946) to denote the weighted average of differences between several pairs of means. This term is used in this paper to refer to the weighted average of the within-group differences between the mean of the high animals and the mean of the low animals.

Weighted mean differences between high and low cows were calculated for yearling weight of the dam, and for weight of the dam the fall before her calf was born. For offspring, weighted mean differences between high groups and low groups were calculated for several factors. These factors were: corrected yearling weight, actual yearling weight, corrected weaning weight, birth weight, yearling condition score, and yearling grade score. The method for obtaining weighted mean differences is illustrated in Table 1.

Table 1. METHOD OF CALCULATING WEIGHTED MEAN DIFFERENCES

Year	Sex	Direction of selection	N	Average yearling weight	D[1]	W[2]	WD[3]
				Pounds			
1946	Steers	High	4	608.6	65.3	2.00	130.6
		Low	4	543.3			
	Heifers	High	4	515.9	48.8	2.86	139.6
		Low	10	467.1			
1947	Steers	High	11	636.4	50.2	4.28	214.9
		Low	7	586.2			
	Heifers	High	11	558.1	–3.0	4.28	–12.8
		Low	7	561.1			
TOTALS						13.42	472.3

[1] $D = \text{High} - \text{Low}$

[2] $W = \dfrac{N_1N_2}{N_1 + N_2}$

[3] Weighted mean difference $= \dfrac{\text{Total } WD}{\text{Total } W} = 35.2$

A summary of results of the paper selection analysis is presented in Table 9. The weighted mean difference for the corrected yearling weight of dam is the weighted average of differences between mean corrected yearling weight for high cows and mean corrected yearling weight for low cows. Other weighted mean differences show effects of the selection. The right-hand column in the table contains weighted mean differences divided by the weighted mean difference for corrected yearling weight of dam, multiplied by 100.

Since sires were not selected, and random mating was assumed, the weighted mean difference for corrected yearling weight of dam was divided by 2 to obtain the selection differential. The weighted mean difference for offspring corrected yearling weight was divided by the selection differential to obtain the heritability estimate (Lerner, 1950). The confidence interval for the weighted mean difference for corrected yearling weights of offspring was divided by the selection differential to calculate the confidence interval for heritability.

All confidence intervals and tests for significance were based on the .05 level of significance.

The hypothesis that a true value was equal to zero was tested for various estimates in this paper. The term "significant" means the hypothesis was rejected; conversely, the term "not significant" means the hypothesis was not rejected.

Experimental Results

Average corrected yearling weights of the offspring studied are presented in Table 2. There are marked differences due to sex and year; in each year, however, steers were heavier than heifers. Overall averages were 615 pounds and 572 pounds, for steers and heifers respectively.

Table 2. AVERAGE CORRECTED YEARLING WEIGHTS OF STEERS AND HEIFERS

Year	Number of steers	Average steer weights	Number of heifers	Average heifer weights
		Pounds		*Pounds*
1944	....	....	9	597
1945	10	624	12	547
1946	12	567	23	497
1947	24	617	31	567
1948	34	635	18	578
1949	34	624	41	573
1950	23	611	32	591
1951	38	645	35	605
Weighted mean	....	615	....	572

The regression coefficient of yearling weight of dam on yearling age of dam was 1.13 within years, and 1.08 when years were ignored (Table 3).

Table 3. REGRESSION OF YEARLING WEIGHT ON YEARLING AGE FOR DAMS

	d.f.	ssx	sp	ssy	b	Standard error
Within years	147	263,907	297,469	745,452	1.13*	0.10
Total	156	325,784	351,806	1,221,669	1.08*	0.13

* Significant at 5% level.

The regression coefficient of weaning weight on weaning age was computed for each sex (Table 4). There was no significant difference between the two regression coefficients, 1.18 for steers and 1.08 for heifers. Effects of age of dam and year were removed from these estimates by calculating within the age of dam and year groups.

Table 4. REGRESSION OF WEANING WEIGHT ON WEANING AGE OF OFFSPRING

	d.f.	ssx	sp	ssy	b	Standard error
Steers	286	239,083	282,845	851,736	1.18*	0.08
Heifers	311	282,331	303,706	751,919	1.08*	0.08

* Significant at 5% level.

Multiple regression analyses were run to determine the effects of yearling age of offspring (X_1), age of dam when her offspring was born (X_2), and corrected yearling weight of dam (X_3), on the actual yearling weight of the offspring (Y). The sum of squares, sum of products, partial regression coefficients, and standard errors are presented for heifers in Table 5, for steers in Table 6, and for the combined groups in Table 7.

Age of the heifer had a significant effect on her yearling weight. The partial regression coefficient was 1.09 pounds per day. The age and yearling weight of dam were not significant as factors affecting yearling weights of heifers.

The significant partial regression coefficient, representing the effect of age on the yearling weight of steers, was 1.55 pounds per day. The effect of yearling weight of dam was significant; and again, as in the case of heifers, the effect of age of dam was not significant.

When the partial regression coefficients for heifers and steers were pooled, the effect of yearling weight of dam was significant, while the effect of age of dam was not. The partial regression coefficient, showing the effect of age of offspring, was significant.

The partial regression coefficients representing the effect of dam's corrected weaning weight and the confidence limits were multiplied by 2 to obtain the estimates of heritabilities, and the confidence limits of heritabilities. A partial regression coefficient must be significant for the corresponding heritability to be significant.

Table 5. SUMS OF SQUARES AND CROSS PRODUCTS FOR MULTIPLE REGRESSION ANALYSIS, HEIFER GROUP.

	Yearling age of offspring X_1	Age of dam X_2	Yearling weight of dam X_3	Yearling weight of offspring Y
	Days	*Years*	*Pounds*	*Pounds*
X_1	197,879	264	–54,196	211,855
X_2	....	795	–4,029	557
X_3	....	....	1,177,386	17,498
Y	....	....	....	643,428
Partial regression coefficient	$b_1 = 1.09$*	$b_2 = 0.68$	$b_3 = 0.07$	....
Standard error	.105	1.66	.044	d.f. = 190

* Significant at 5% level.

Table 6. SUMS OF SQUARES AND CROSS PRODUCTS FOR MULTIPLE REGRESSION ANALYSIS, STEER GROUP.

	Yearling age of offspring X_1	Age of dam X_2	Yearling weight of dam X_3	Yearling weight of offspring Y
	Days	*Years*	*Pounds*	*Pounds*
X_1	139,084	747	–76,884	207,462
X_2	....	775	–3,551	2,177
X_3	....	....	861,838	–17,796
Y	....	....	....	678,568
Partial regression coefficient	$b_1 = 1.55$*	$b_2 = 1.89$	$b_3 = 0.13$	....
Standard error	.128	1.68	.052	d.f. = 165

* Significant at 5% level.

Table 7. SUMS OF SQUARES AND CROSS PRODUCTS FOR MULTIPLE REGRESSION ANALYSIS, COMBINED STEER AND HEIFER GROUPS.

	Yearling age of offspring X_1	Age of dam X_2	Yearling weight of dam X_3	Yearling weight of offspring Y
	Days	*Years*	*Pounds*	*Pounds*
X_1	336,963	1,011	–131,080	419,317
X_2	....	1,570	–7,580	2,734
X_3	....	....	2,039,224	–297
Y	....	....	....	1,321,996
Partial regression coefficient	$b_1 = 1.27$*	$b_2 = 1.34$	$b_3 = 0.09$*	....
Standard error	.082	1.19	.033	d.f. = 358

* Significant at 5% level.

The estimate of heritability of yearling weight from the heifer group was .14, with a confidence interval from —.02 to .31. The lower limit of the confidence interval falls below zero because heritability is not significantly different from zero. Significant heritability in the steer group was .25, with a confidence interval from .04 to .46.

There is no significant difference between the heritabilities. The two analyses were combined in Table 7 to allow calculation of an average heritability of weaning weight. Average heritability was .17, with a confidence interval from .04 to .30.

Number of offspring per cow in this study ranged from one to seven; therefore, some of the yearlings studied in the multiple regression analysis had the same mother. The effect of cow age on corrected yearling weight of her offspring was not significant (Table 8). Although this indicates that the repeatability was not significant, estimates of repeatability were calculated from components of the mean squares. Estimates of repeatability were .03 for cows with male offspring, and .15 for cows with female offspring.

The paper selection experiment was designed to serve as a check on average heritability calculated from the multiple regression analysis, and to yield other information about the effects of selecting for yearling weight.

In the following discussion, cows selected for heavy yearling weights will be referred to as "high" cows, and cows selected for light yearling weights will be referred to as "low" cows. Offspring will be referred to as "high" offspring or "low" offspring, depending on which cows were their dams. Results of the paper selection are presented in Table 9.

Weight of the dam out of summer range was taken the fall before each calf was born. There was a significant difference between the high and low cows for this weight. The weighted mean difference was 74.5 pounds in favor of the high cows.

The superiority, 9.3 pounds, of the high offspring for corrected weaning weights, was significantly different from zero. On the average, high calves exceeded low calves in birth weight by 2.9 pounds, a significant difference. The small weighted mean differences for condition and grade scores were not significant.

Actual yearling weights were higher for high calves than for low calves; however, the weighted mean difference, 7.5, was not significant. The significant weighted mean difference of 22 pounds for corrected yearling weight indicates that the high offspring had a higher growth rate than the low offspring.

Table 8. ANALYSIS OF COVARIANCE OF YEARLING WEIGHTS OF CALVES ON AGE OF COWS

	d.f.	Sums of squares and products			Errors of estimate			Components of mean square[1]
		x^2	xy	y^2	d.f.	ssy	msy	
Heifers								
Among cows	56	159,094	200,032	464,821	56	215,511	3,848	$V_o + k_o V_c$
Within cows	82	89,264	129,722	404,874	81	216,357	2,671	V_o
TOTAL	138	248,358	329,754	869,695	137	431,868	....	....
Steers								
Among cows	46	72,054	108,881	278,800	46	114,284	2,484	$V_o + k_o V_c$
Within cows	63	93,634	143,201	361,623	62	142,616	2,300	V_o
TOTAL	109	165,688	252,082	640,423	108	256,900	....	....

[1] k_o for heifers = 2.434; k_o for steers = 2.336.

The weighted mean difference for corrected yearling weight of offspring, and its confidence limits, was divided by the weighted mean difference for corrected yearling weight of dams to obtain a heritability estimate with appropriate confidence limits. This estimate of heritability was .39, with a confidence interval from .25 to .53.

The weighted mean difference for actual yearling weight is much smaller than the weighted mean difference for corrected yearling weight. If the average yearling age of offspring born to high cows had been equal to the average yearling age of offspring born to low cows, weighted mean differences would have been equal. Apparently high cows tended to calve later in the season than did low cows. The negative sum of products between the corrected yearling weight of the dam and the age of the offspring (Table 7) is added proof that this relationship existed.

Table 9. SUMMARY OF RESULTS OF PAPER SELECTION FOR HIGH AND LOW YEARLING WEIGHTS

Variable	Dam - offspring comparisons	Weighted mean differences between high and low	Effect per 100 pounds difference in corrected yearling weight of dams
	Number	*Pounds*	*Pounds*
Dams			
Corrected yearling weight	243	112.7	....
Weight of dams out of summer range	243	74.5*	66.1
Offspring			
Corrected yearling weight	243	22.0*	19.6
Actual yearling weight	243	7.5	6.7
Corrected weaning weight	243	9.3*	8.2
Birth weight[1]	200	2.9*	2.6
Condition score[2,3]	146	0.03	0.03
Grade score[2,3]	146	0.16	0.14

* Significant at 5% level.

[1] Weighted mean difference in corrected yearling weight for dams of these offspring was 113.2 pounds.

[2] Weighted mean difference in corrected yearling weight for dams of these offspring was 111.9 pounds.

[3] Condition and grade scores were placed on each animal by one person. Grades of 1 to 4 were used, with 1 best and 4 the least desirable. Condition scores of a to d were used with a highest, d lowest.

Discussion

Discussion of statistical methods used

Adjustment of weights along a straight line requires the assumption that growth rate is linear during the age range when weights were taken (Phillips and Brier, 1940). Frequent weighings were necessary to check the validity of this assumption in any particular set of data. Weights were not available to determine whether growth between actual age and constant age was linear for each individual used in this analysis; if they had been available, corrections would not have been necessary. The small standard errors for regressions of weight on age are proof that any deviations from linearity were slight.

Appropriate correction factors for year of birth and age of dam are difficult to obtain. In this study, groups of dams, according to age, were not equally represented within years, and all age-of-dam groups were not present each year. The method of fitting constants could be used to adjust for effects of both year and age of dam. This is a method involving the solution of a large set of simultaneous equations (Koch, 1951).

Age of dam when offspring was born was included in the multiple regression analysis on yearling weight as a precaution. It is known that age of dam affects a calf's weight until weaning (Knox and Koger, 1945; Sawyer, et al., 1948). These effects may or may not carry over to yearling weights.

Partial regression coefficients for effects of age of dam were small and standard errors were large. To check if this could have been due to nonlinear effects, averages of corrected yearling weights of offspring were plotted with the ages of dams within years. Results were so inconsistent that they could only be explained by the small number of offspring per age group of dam.

The year effects were not dealt with in the same manner in all analyses; therefore, repeatabilities and heritabilities cannot be compared. In the repeatability calculation, effect of year on yearling weight of offspring was ignored. In the multiple regression analyses, year effects were removed for offspring, but the year of birth of dam was ignored. For the paper selection experiment, dams were selected within year of birth, and offspring were compared within years.

It should be stated here that heritability, calculated from the multiple regression analysis, is subject to two biases. With the effect of year on the dam's yearling weight ignored, the estimate was biased in the negative direction. All heritabilities based on the relationship between dam and offspring are biased due to maternal effects other than the additive genetic material passed from dam to offspring. Since partial regression coefficients contain such effects, heritabilities are biased by these maternal effects (Lush, 1949).

Heritability arrived at by paper selection is free from the first bias because dams were selected within years. The second bias is still present.

In the introduction of this paper, heritability was defined as that portion of the total variation due to additive genetic effects. Use of statistical methods to eliminate parts of the total variation may seem inconsistent with this definition of heritability. If the variation remaining after statistical corrections is considered the total variation, the definition is still valid. This, of course, limits the procedures of selection in that the same corrections must be made if results comparable to the heritability estimate are expected.

Discussion of results

The average corrected yearling weight was 43 pounds greater for steers than for heifers. This difference is higher than that usually reported for weaning weight (Koger and Knox, 1945; Koch, 1951). The difference in weight between steers and heifers, however, could be expected to increase with increasing age since males usually have a higher growth rate than females (Dahmen and Bogart, 1952).

Regressions of weight on age were all significant. The values appear to be reasonable estimates of growth rate during the dry fall months. Estimates were calculated for use in this study; they may not be useful for adjusting weights of animals in another environment.

Age of dam when the offspring was born had little effect on yearling weight of the offspring.

Heritability of the corrected yearling weight was .17 from the combined multiple regression analysis and .39 from the paper selection analysis. These estimates are much lower than the estimates of .86 for heritability of the final feed-lot weight of Hereford steers in Montana (Knapp and Clark, 1950). The two estimates of heritability in this study are more in agreement with the results in dairy cattle where heritabilities of size at 15 months have been reported from .20 to .65 (Tyler, et al., 1948).

Estimates in the present study are close to the heritability of body size in mice, which has been reported as .20 and .50 (Falconer, 1953). From a selection experiment in swine, heritability of the 180-day weight was .19 when determined by line differences and

.65 when calculated by regression of offspring on dam (Krider, et al., 1946). Even though both methods of estimating heritability in the present study may be considered regressions of offspring on dam, results compare more favorably with the lower estimate of heritability of the 180-day weight in swine.

Paper selection of dams on the basis of corrected yearling weight resulted in differences in birth weights of offspring and corrected weaning weights of offspring, along with differences in the corrected yearling weights of offspring. This finding agrees with results of an actual selection experiment in swine where selection for the 150- and 180-day weights changed the weights of animals at other ages (Krider, et al., 1946).

Dams selected for higher corrected yearling weights were heavier in later years, while dams selected for lower yearling weights were lighter. Since maintenance requirements increase with increased body weight, this result of selection must be considered.

In the paper selection experiment, no relationship was apparent between corrected yearling weight of dam and either the condition or grade score of her offspring.

The negative relationship between yearling weight of dams and yearling age of offspring may be due to the practice of breeding some as yearlings and others as 3-year-olds. Some of the cows were bred as yearlings. In the paper selection experiment, 71 offspring in the high group were from cows which calved as 2-year-olds, while 53 were from cows which calved at 3 years of age or older. Only 42 offspring in the low group were from cows which first calved as 2-year-olds, and 76 were from cows which first calved at 3 years of age or older. In other words, the high cows, as a group, were at a disadvantage because more of them calved as 2-year-olds.

Summary and Conclusions

1. Estimates of heritability of corrected yearling weight were .17 and .39 when calculated by two different methods. Apparently mass selection for yearling weight would be effective in this environment.

2. Repeatability estimates were not significant when years were ignored. For maximum progress in selection, animals should be compared with other animals born in the same year, or an attempt should be made to make the environment from one year to the next more constant.

3. No evidence was found that age of the dam needs consideration when selection is based on yearling weights.

4. Selection for high yearling weights, adjusted for age, would be effective in increasing both weaning weights and birth weights.

5. Mature weights of cows would be increased by selecting for high yearling weights.

6. The condition and grade scores of offspring were not affected by selecting their dams on the basis of yearling weight.

7. Heifers having a heavy yearling weight calved as 2-year-olds more frequently than did heifers with a light yearling weight. In subsequent years, dams which were large as yearlings tended to calve later than those which were small as yearlings. Because of this, selection for heavier yearlings would tend to give lower, rather than higher, actual yearling weights in offspring when dams are allowed to breed as yearlings.

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