PREDICTING TOPCROSSING PERFORMANCE OF INBRED AND SELECTION LINES OF BEEF CATTLE

by

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INTRODUCTION

The use of inbreeding in beef cattle improvement programs has long been of interest to both the beef cattle producer and the animal scientist. Since the success of the commercial production of hybrid corn which started in the 1930's, breeders of domestic livestock have been interested in the possibility of producing inbred lines of animals to be used in subsequent crossing programs. During the late 1930's the agricultural experiment stations of eight mid-western states and the U. S. Department of Agriculture established the Regional Swine Breeding Laboratory which has developed over 40 inbred lines of swine. In the late 1940's and early 1950's several state experiment stations in co-operation with the U. S. Department of Agriculture started inbreeding experiments with beef cattle.

Theoretically inbreeding increases homozygosity, decreases genetic variation and leads to fixation of characters within a line. However, inbreeding increases genetic variation between lines. The purpose of inbreeding in a livestock improvement program is to allow subsequent selection and crossing between inbred lines. Inbreeding is therefore used to identify the superior genotypes i.e. lines, subsequently there is selection among the lines based on the inbred line's own performance or on its performance in crosses. However, the benefits of inbreeding can be utilized only if it is economically feasible to produce inbred lines. The breeder can afford some loss in productivity as a result of inbreeding if the genetic gain from subsequent crossing is greater than the gain that would be achieved from mass selection alone.

REVIEW OF THE LITERATURE

The scientific investigations on the effects of inbreeding in animal populations started in the early part of this century with the rebirth of Mendelism. Since the very beginning, the experimental evidence on the effects of inbreeding has been conflicting. Two of the classic papers from the early part of this century King (1918) and Wright (1929) illustrate the contradictory reports which have surrounded the studies on inbreeding. King reported that even after 28 generations of brother-sister mating, inbred rats had not decreased in body weight and that the inbred animals were superior to control animals reared under similar conditions. She concluded that depressing effects of inbreeding were avoided by the use of a strain of rats which had no inherent defects and by careful selection of breeding stock. Wright, however, reported that after 12 generations of brother-sister matings five strains of guinea pigs had fallen below the average of a control stock in body weight, fecundity and vitality. Each line differed significantly from every other line in body weight; and although there were marked fluctuations in family means over the years, the ranking among the lines for body weight remained the same from year to year. But with respect to fecundity and mortality, the ranking did not remain the same as conditions changed from year to year.

In spite of the conflicting evidence on the effects of inbreeding in animal populations, it had been clearly demonstrated by the mid-1930's that inbreeding could be used to produce hybrid varieties of corn which were superior to the open-pollinated varieties. As a result of this evidence, inbreeding experiments were started with swine. The early experiments with swine indicated that intensive inbreeding led to reduced fertility, prolificacy, viability and growth rate. The effects of inbreeding were so severe that some of the lines did not survive. At the Regional Swine Breeding Laboratory established in 1937 it was decided to inbreed more slowly and prevent as much inbreeding depression as possible by selection within lines. However, Dickerson et al. (1954) in a comprehensive report from this laboratory reported that selection during the development of mildly inbred lines did not improve the lines with respect to litter size and individual pig weight.

One of the earliest reports on the effects of inbreeding in beef cattle was by Burgess, Lamblom and Stonaker (1954). They estimated several environmental and genetic factors which affect weaning weight in Hereford cattle. The average inbreeding in the calves was 30% and in the dams 20%. They reported that a 1% increase in inbreeding of the calf significantly reduced weaning weight by 1.75 lb and that a 1% increase in inbreeding of the dam reduced weaning weight by 1.15 lb.

Swiger et al. (1961) also found depressing effects of inbreeding on birth weight, preweaning gain and postweaning gain in Hereford, Angus and Shorthorn cattle. However, these lines were only mildly inbred, averaging from 5 to 13% in the calves and 3 to 10% in the dams. Alexander and Bogart (1961) and Hoornbeek and Bogart (1966) studied the effects of inbreeding in three Hereford lines and one Angus line. The average inbreeding in the calves ranged from 10 to 30%. They found no significant effect of inbreeding of the calf or dam on birth weight, but a significant negative effect of inbreeding of the calf on preweaning gain and a significant positive effect of inbreeding of the dam on postweaning gain.

In the Montana Line 1 Hereford cattle Brinks, Clark and Kieffer (1965) found that increased inbreeding of the calf had a depressing effect on all traits studied. Increased inbreeding in the dam had a detrimental effect on preweaning gain and weaning weight. But inbreeding of the dam had a positive effect on postweaning growth. The positive response in the postweaning period was interpreted as compensatory growth resulting from the detrimental effect of inbreeding of the dam during the preweaning period. They also found a differential response of the sexes to the effects of inbreeding. Inbreeding in the calf had more effect on females than on males, but inbreeding of the dam had more effect on males than on females. It was concluded that males, having a faster growth rate, are affected more than heifers by decreased milk production that is associated with increased inbreeding in the dam. The maternal environment may also mask the response to inbreeding of the calf to a larger extent in males than in females. However, Dinkel et al. (1968) found just the opposite result with respect to effects of inbreeding of the dam and calf on the two sexes.

Part of the difficulty in studying the effects of inbreeding in mammals is the problem of separating the maternal effects from the effects of inbreeding in the offspring. It should be pointed out that although in most mammalian studies on inbreeding the effects of inbreeding of the dam and inbreeding of the offspring are estimated separately, they are not in fact independent estimates as inbreeding of the dam and offspring are confounded. The studies which have been done on the effects of inbreeding on milk production in dairy cattle help to substantiate the results found in beef cattle. Von Krosigk and Lush (1958) found that for Holstein cows the intra-sire regressions of each cow's average records were -1.74 lb of butterfat, -54 lb of milk and 0.003% of butterfat for each 1% increase in inbreeding of the cow. They also found a larger regression value for the first lactation record (-2.72 lb of butterfat) than for the average of all records. This result implies that inbreeding acts more to lower rate of development than to reduce production at maturity.

Brinks et al. (1965) concluded from the studies of the Montana Line 1 cattle that long term breeding programs which combine selection and mild inbreeding can be effective in making genetic improvement in growth traits. This conclusion is not in agreement with that of Dickerson et al. (1954) with respect to results of inbreeding and selection in swine.

The evidence which is available from the crossing of inbred lines indicates that there is a high correspondence between the performance of an inbred line and its performance in crosses. Hayes and Johnson (1939) and Johnson and Hayes (1940) found that the best performing inbred lines of corn produce the best hybrids. It has been shown by Craig and Chapman (1953) that for 13-week body weight in rats, a line's own performance is as reliable as topcrossing performance for indicating the relative value of inbred lines. Flower et al. (1963) found for final weight in Hereford cattle that inbred and topcross performance ranked the same where topcrossing was to an inbred tester.

The purpose of the present study was to determine the reliability of predicting the topcrossing performance of inbred and selection lines of beef cattle from the performance of the lines themselves.

DESIGN OF THE EXPERIMENT

Formation of the Inbred and Selection Lines

Part of the data for this study were obtained from the Shorthorn beef herds at the Beef Cattle Research Station, Front Royal, Virginia.[1] The basic objective of the breeding project at Front Royal was to compare two major breeding systems for making genetic improvement in traits of economic importance in beef cattle. The two major breeding systems were: (1) inbreeding with subsequent crossing among the lines and (2) single trait mass selection for growth rate or conformation score. The design required an equal effort, that is equal numbers of cattle, be given to each of the two breeding systems.

Four inbred and two selection lines of Shorthorns were established. Four foundation sires were selected to establish the lines after individual and/or progeny testing. Each foundation sire was bred to enough unrelated cows to produce thirty-two daughters. From each set of the thirty-two daughters, sixteen were randomly chosen as the foundation daughters for an inbred line. From the remaining sixteen, eight were randomly assigned to the Type selection line and eight were assigned to the Growth selection line. The objective was to start the two selection and four inbred lines from a common female foundation, i.e. the foundation females of both the inbred and the selection lines were random samples from sets of paternal half sibs. An illustration of this design

[1]Research at the Front Royal Station is conducted in cooperation with the Beef Cattle Research Branch, A.S.R.D., A.R.S., U.S.D.A., and the Virginia Agricultural Experiment Station.

is given in figure 1.

The foundation sire of each inbred line was mated to his daughters and granddaughters for as long as he was serviceable and then replaced by an inbred son. The sires used in the selection lines could come from within the line or from other lines or herds. All female replacements came from within the lines.

The selection criterion in the Growth line was growth rate from birth to about twelve months of age. In the Type line the criterion was conformation score at the same age. In the inbred lines selection was based on an index giving equal weight to growth rate and conformation score. Each year at least one bull from each of the inbred lines and at least two from each of the selection lines were placed on a 168-day postweaning performance test. In addition, several bull calves were purchased from private breeders at weaning and put on the postweaning performance test. At the end of the test the bull with the fastest growth rate, from birth to the end of the postweaning period, was selected to go into the Growth line. The bull with the highest conformation score was chosen to go into the Type line.

The inbred lines are hereafter designated as S-1, S-2, S-4 and S-5 and the selection lines as the Type line (S-7) and the Growth line (S-8).[2]

The above was the theoretical plan to be followed in forming the

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[2]In 1958 it became necessary to reduce the size of the entire cattle population at Front Royal. At this time it was decided to discontinue the S-3 line as a result of reproductive disease in the line.

lines. However, in practice there were certain deviations from this theoretical plan. They will be evident in the following description of the actual formation of the Shorthorn lines.

In the winter of 1948-49, the Shorthorn herd was established by transferring to Front Royal the beef Shorthorn herd from the Research Center of the United States Department of Agriculture (U.S.D.A.), Beltsville, Maryland. This herd of approximately 125 cattle had been maintained at Beltsville for almost twenty years as a closed and partially inbred herd. The cattle that were originally transferred from Beltsville were of two nearly distinct lines in which mild inbreeding had already been practiced. One of these lines descended from the bull Sni-A-Bar Type which was brought into the Beltsville herd in 1930. The other line descended from the imported bull, Calrossie Lord Rothes. In 1933 two cows and two bulls all sired by Calrossie Lord Rothes were introduced into the Beltsville herd. Among the cows transferred from Beltsville to Front Royal in 1949, there was one group of 32 cows which had a relationship of 0.50 to the bull Sni-A-Bar Type and another group of 32 cows which had a relationship of 0.50 to the bull Calrossie Lord Rothes. These two groups of 32 females were treated as conventional sets of foundation daughters. A random half of the cows descending from Sni-A-Bar Type were the foundation daughters of the S-1 line and a random half descending from Calrossie Lord Rothes were the foundation daughters of the S-2 line, the remaining half of each set were randomly assigned to the Growth and Type lines.

The four Shorthorn foundation sires were:

S-1 WAVERLEY'S STATESMAN (2291825) was bred by the United States Department of Agriculture, Beltsville, Maryland. He was strongly linebred to two sons of Saulton Claymore, Sni-A-Ensign and Sni-A-Bar Type. He was used as the herd sire until 1951.

S-2 BARON KINSMAN (2458011) was bred by the United States Department of Agriculture, Beltsville, Maryland. He was linebred to Calrossie Lord Rothes. His pedigree also contains some Sni-A-Bar breeding, and thus he was moderately related to Waverley's Statesman. He remained as head of this line until 1956.

S-4 BRITOMAC PRINCE COMMAND (2686140) was purchased in 1952 from Carl D. McKenzie, Armington, Illinois. He was a son of Air Raid Marshall and out of an Augusta cow by Morphie Command. He was the herd sire through 1960.

S-5 PRINCE ERIC (2655343) was purchased in 1951 from Berl A. Willson, Champaign, Illinois. He was sired by Ringwell Prince Eric by Barquhar Commander and was out of a dam tracing to Calrossie Mercy. He remained as the herd sire until 1962.

Table I gives the level of inbreeding of the foundation sires and daughters and the birth dates of the first and last foundation daughters for each line. The foundation sires and daughters in the S-1 and S-2 lines were mildly inbred. The last foundation daughters in the S-1 line were born in 1948 and in the S-2 line in 1949. In the S-4 and S-5 lines, the foundation sires and daughters were non-inbred and the last foundation daughters were born in 1958 and 1959, respectively.

A more complete description of the Front Royal inbred and selection lines has been published by Bovard and Priode (1963).

Testing of the Inbred and Selection Lines in Topcrosses

After approximately fifteen years of selection and inbreeding at Front Royal, testing of the Shorthorn lines was started at Blacksburg to determine the breeding values of these lines in topcrosses.[3] For four years, 1964-67, bulls from each of the six Shorthorn lines were mated to a test herd of cows which were unrelated to the bulls. The test herd assembled at Blacksburg consisted of about 120 cows which were randomized to the sire lines each year. In the first year the inbred bull from the S-4 line was infertile. In subsequent years two bulls from each of the six lines were used in the test herds. Since both bulls from each line were exposed to the cows, it was possible to identify calves only by sire lines and not by individual sires. Every year one bull was selected from each of the lines at Front Royal and used for two consecutive years for topcrossing at Blacksburg. In general the bull selected for top-crossing was the second ranking bull in each line.

[3]The testing of the Shorthorn lines was conducted in cooperation with the Department of Animal Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

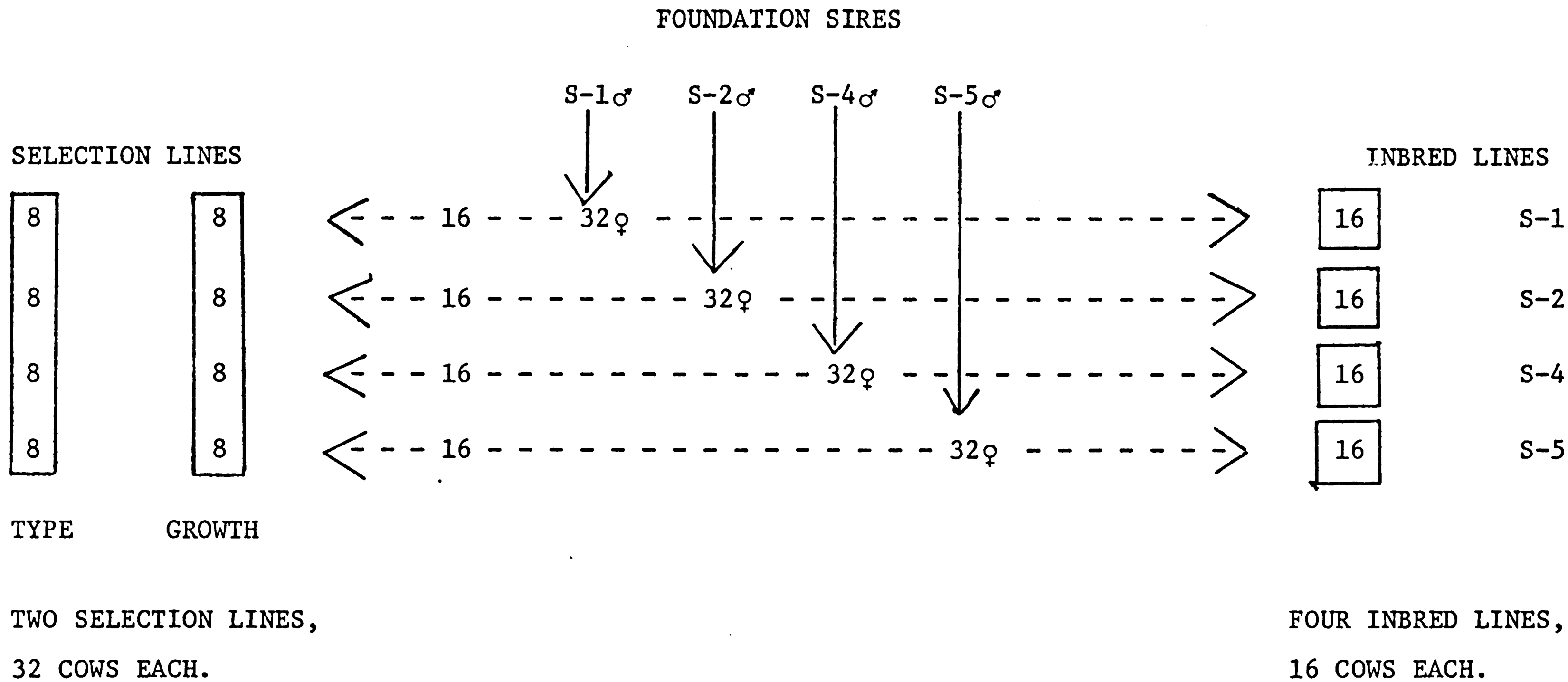

FIGURE 1. A SCHEMATIC DIAGRAM OF HOW THE SHORTHORN INBRED AND SELECTION LINES WERE ESTABLISHED.

TABLE I. LEVEL OF INBREEDING OF THE FOUNDATION SIRES (F_s) AND DAUGHTERS (F_d) AND THE BIRTH DATES OF THE FIRST AND LAST FOUNDATION DAUGHTERS

Lines	F_s[1]	F_d[2]	Birth dates of foundation daughters	
			First	Last
S-1	19	8	6-29-40	1-23-48
S-2	16	10	4-24-39	3-14-49
S-4	0	0	1-11-56	4-28-58
S-5	0	0	2-16-54	3-25-59
Type	-	-	1-21-40	3-3-59
Growth	-	-	7-14-39	3-15-59

[1]Level of inbreeding for each foundation sire described in the text.
[2]Average level of inbreeding of the 16 foundation daughters in each line.

PREWEANING PERFORMANCE OF INBRED AND SELECTION LINES

Original Line Performance

To evaluate the original line performance of the Front Royal inbred and selection lines, a group of five calf crops was chosen which included the calves born in the years from 1962-66. These years covered the birth dates of the bulls used for topcrossing at Blacksburg.

The preweaning traits measured were birth weight, B. wt.; average daily gain from birth to weaning, ADG (1); and conformation score at weaning, Grade (1). The average age of the calves at weaning was 200 days. Birth weight and average daily gain were measured in pounds. Grade at weaning was measured on a scale from 6 to 17. For each quality grade, which are defined as fancy, choice, good and medium, the scale is divided into thirds, high, average and low. Thus, on this scale, a grade of 13 is an average choice. The grades are based on visual appraisals of the conformation of the calves. The appraisals are made by at least three persons. The graders score the calves independently of each other and the observed grade for each calf is defined as the average of the three grade scores.

The statistical model which seems best to describe the data includes the following effects:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \theta(W_{ijkl} - \overline{W})$$

$$+ \lambda(X_{ijkl} - \overline{X}) + \phi(Z_{ijkl} - \overline{Z}) + \varepsilon_{(ijk)l}$$

where $i = 62,\ldots,66$
$j = 1,2,4,5,7,8$
$k = 1,2,$; 1=bull, 2=heifer
$l = 1,\ldots,n_{ijk}$

The terms in the model are defined as follows:

Y_{ijkl} = the observed value for the l^{th} offspring in the i^{th} year, j^{th} line, and the k^{th} sex of calf.

μ = the effect of the general mean.

α_i = fixed effect of the i^{th} year.

β_j = fixed effect of the j^{th} line.

γ_k = fixed effect of the k^{th} sex of calf.

θ = regression of Y on age of dam.

λ = regression of Y on inbreeding of the dam.

ϕ = regression of Y on inbreeding of the calf.

$\varepsilon_{(ijk)l}$ = random effect of the l^{th} offspring in the i^{th} year, the j^{th} line, and the k^{th} sex of calf.

All of the effects defined in the model above cannot be estimated independently and the model is not completely balanced. The ratio of bull calves to heifer calves is not the same for each line. The covariate age of the dam is partially confounded with lines and years. The covariate age of dam is also confounded with the two covariates inbreeding of the dam and inbreeding of the calf. The covariates inbreeding of the dam and inbreeding of the calf are also confounded with each other, and they are both partially confounded with lines and years. Table IV gives the simple correlations among the covariates.

Due to the confounding involved with inbreeding, the data were first analyzed excluding the effects of inbreeding of the dam and calf from the model. The analyses of variance for birth weight, average daily gain, and grade at weaning are given in table II and the unadjusted means in table III. The effect of years is non-significant for all variables measured. The effect of lines is highly significant for all variables measured. The effect of sex of the calf is highly siginifcant for birth weight and average daily gain, but it is non-significant for grade at weaning. The two factor interactions of years with lines and years with sexes range from highly significant to non-significant for the three variables. The interaction of lines with sexes is significant for birth weight and average daily gain. The effect of this on subsequent adjustments to the data and the biological interpretation will be discussed later.

In order to determine more accurately the genetic differences between the lines, the data were adjusted for the following effects: age of the dam, sex of the calf, inbreeding of the dam and inbreeding of the calf.

Adjustments for Age of Dam and Sex of Calf. The constants for the age of the dam effects were not estimated from the data under consideration, 1962-66 calf crop years, because of the confounding and correlations with other effects in the model which were discussed above. The constants used to adjust the data for the age of dam effects were those estimated by Bovard and Priode (1963). They estimated the age of dam effects of the Shorthorn breed from earlier generations of the Front Royal lines, the 1950-61 calf crops. In the earlier generations, the level of inbreeding of the dams and calves was lower and thus would have less effect on the dependent variables. The constants used to adjust the data for age of dam effects are given in table IV. They are in general agreement with other constants published in the literature and summarized by Perry and Cartwright (1966).

It has already been mentioned that the interaction between lines and sex of the calf was significant for birth weight and average daily gain. Because of this differential response of the sexes for the six lines, the least squares constants for the effect of sex of the calf were estimated within each line. Thus, the variables birth weight and preweaning daily gain were adjusted for sex of the calf by the constants estimated for each line. The adjustments were made to a bull base. Since there was no significant difference between the sexes for grade at weaning, no sex adjustment was made for this variable. An explanation of the possible causes of the sex by line interaction will be given later under the discussion of the effects of inbreeding. The Front Royal line means adjusted for age of dam and sex of calf effects are given in table IX. The 205-day weights given in table IX are defined as follows:

adj. 205 wt. = adj. B. wt. + adj. ADG (1) (205).

The S-5, Type and Growth lines had the heaviest birth weights, all averaging 78 lb; the S-1 and S-2 lines were only slightly lower, averaging 77 lb. However, the S-4 line was substantially lower in birth weight, averaging only 70 lb. The Growth line had the fastest preweaning daily gains, 2.02 lb per day, followed closely by the Type line, 1.96 lb per day and the S-1 line, 1.95 lb per day. The other three inbred lines were considerably lower in preweaning daily gains. The S-4 line averaged 1.78 lb per day and the S-2 and S-5, 1.71 and 1.70 lb per day, respectively. The Type line was the highest grading line at 13.3, average choice. The Growth line and the S-4 line both graded 12.1, low choice, and the S-5, S-1, and S-2 lines all graded high good, 11.5, 11.1, and 11.0, respectively.

After the data were adjusted for the effects of age of dam and sex of calf, the effects of inbreeding were estimated. The levels of inbreeding of the dam and calf for each line are shown in table V. The S-1 and S-2 lines are approaching high levels of inbreeding for the calves and moderately high levels for the dams. The S-4 and S-5 lines are at moderately high levels of inbreeding for the calves but the dams are only mildly inbred. There are two main reasons for the different levels of inbreeding in the lines. First, the S-1 and S-2 were mildly inbred at the time the lines were formed and were established earlier than the S-4 and S-5 lines. Second, the reproductive performance of the lines has not been equal. Krehbiel et al. (1969) reported that the Front Royal Shorthorn lines differ in reproductive performance and that it is not possible to predict reproductive performance of different lines even at the same levels of inbreeding. The reproductive performance is a unique property of the inbred line. The rate of inbreeding cannot be as rapid in those lines which show more depression in reproductive traits due to the effects of inbreeding. The reverse is also true, i.e. the rate of inbreeding is more rapid in a line which suffers little in reproductive performance as inbreeding increases. The S-1 line is an example of the latter situation. Although the S-1 line is the most highly inbred line, it has one of the highest reproductive performances of the Shorthorn lines.

Adjustments for Inbreeding of the Dam and Calf. The first statistical models to estimate the effects of inbreeding included the linear and quadratic effects for inbreeding of the dam and calf. Since for all the variables the quadratic effects were non-significant, in all subsequent models only the linear effects of inbreeding were included.

The effects of inbreeding were estimated by three different statistical models. The effects included in each model are as follows:

Model I

$$Y_{ijl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \lambda_1(X_{ijl} - \overline{X}...)$$
$$+ \phi_1 (Z_{ijl} - \overline{Z}...) + \varepsilon_{(ij)l}$$

where $i = 62,...,66$
$j = 1,2,4,5,7,8$
$l = 1,...,n_{ij}$

Model II

$$Y_{ijl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \lambda_2(X_{ijl} - \overline{X}...)$$
$$+ \phi_2(Z_{ijl} - \overline{Z}...) + \varepsilon_{(ij)l}$$

where $i = 62,...,66$
$j = 1,2,4,5$
$l = 1,...,n_{ij}$

Model III

$$Y_{ijl} = \mu + \alpha_i + \lambda_{3j}(X_{ijl} - \overline{X}...) + \phi_{3j}(Z_{ijl} - \overline{Z}...) + \varepsilon_{(ij)l}$$

where $i = 62,...,66$
$j = 1,2,4,5$
$l = 1,...,n_{ij}$

The terms in the models are the same as defined in the general model.

All three models include the effects of years and the linear regressions on inbreeding of the dam and calf. Model I includes the effects of both the inbred and selection lines. Model II contains only the effects due to the inbred lines, and Model III does not contain any line effects as a separate analysis was run for each of the four inbred lines. The analyses of variance for Models I and II are in table VI and for Model III in table VII.

The linear regression coefficients estimated by the three models are given in table VIII. The regressions on inbreeding for all models are in general negative which is an indication of the expected inbreeding depression. The only siginficant positive regression is in Model I for birth weight on inbreeding of the dam. Although in several of the analyses the effects of inbreeding on birth weight and preweaning daily gain are not significant, the regression coefficients and the mean squares for the effects of inbreeding of the calf are in general larger than those for inbreeding of the dam. Swiger et al. (1961) and Alexander and Bogart (1961) also found larger effects due to inbreeding of the calf for these growth traits in beef cattle. However, the reverse is true for grade at weaning; the effects of inbreeding of the dam are larger than those for inbreeding of the calf. It should be re-emphasized that although the effects of inbreeding of the dam and calf have been estimated separately in these analyses, they are not independent estimates as these effects are highly correlated in these date.

It is evident from Model III that the effects of inbreeding are greater in the S-2 line than in the other inbred lines. There are significant effects ($P \leq .10$) in the S-2 line for inbreeding of the calf on both of the growth traits and significant effects ($P \leq .05$) of inbreeding of the dam for grade at weaning. These results point again to the unique response of lines to the effects of inbreeding. The S-1 and S-2 lines have very similar histories and are at comparable levels of inbreeding in the dams and calves yet they show very different responses to the effects of inbreeding.

The differential response of the lines to the effects of inbreeding raises the question of using a pooled regression over all lines as in Models I and II. The method outlined by Ostle (1964) was used to test the hypothesis of using one regression line for all the observations and to test the hypothesis that the regression coefficients for each line are equal. Both of these hypotheses were rejected for the regressions of birth weight and preweaning daily gain on inbreeding of the calf. The first hypothesis was rejected for the regressions of birth weight, preweaning daily gain, and grade at weaning on inbreeding of the dam. These results indicate that separate regressions on inbreeding should be estimated for each of the lines.

The Front Royal inbred line means were adjusted for the effects of inbreeding by three methods using the regression coefficients estimated from the models described above. Only the inbred lines were adjusted for the effects of inbreeding as the effects of inbreeding in the two selection lines were not significant. The three methods of adjustment are as follows:

Method I

$$\text{adj. } \overline{Y}_{\cdot j \cdot} = \overline{Y}_{\cdot j \cdot} - \lambda_1(\overline{X}_{\cdot j \cdot} - 0) - \phi_1(\overline{Z}_{\cdot j \cdot} - 0)$$

Method II

$$\text{adj. } \overline{Y}_{\cdot j \cdot} = \overline{Y}_{\cdot j \cdot} - \lambda_2(\overline{X}_{\cdot j \cdot} - \overline{X}_{\cdots}) - \phi_2(\overline{Z}_{\cdot j \cdot} - \overline{Z}_{\cdots})$$

Method III

$$\text{adj. } \overline{Y}_{\cdot j \cdot} = \overline{Y}_{\cdot j \cdot} - \lambda_{3j}(\overline{X}_{\cdot j \cdot} - \overline{X}_{\cdots}) - \phi_{3j}(\overline{Z}_{\cdot j \cdot} - \overline{Z}_{\cdots})$$

where $j = 1,2,4,5$

The terms for each method are defined as follows:

adj. $\overline{Y}_{.j.}$ = the j^{th} line mean adjusted for the effects of inbreeding of the dam and calf.

$\overline{Y}_{.j.}$ = the j^{th} line mean adjusted for the effects of age of the dam and sex of the calf.

$\overline{X}_{.j.}$ = the average level of inbreeding of the dam for the j^{th} inbred line.

$\overline{X}_{...}$ = the average level of inbreeding of the dam of the four inbred lines.

$\overline{Z}_{.j.}$ = the average level of inbreeding of the calf of the j^{th} inbred line.

$\overline{Z}_{...}$ = the average level of inbreeding of the calf of the four inbred lines.

Method I adjusts the inbred line means using the regression coefficients, λ_1 and ϕ_1, estimated by Model I in which the regressions were pooled over the inbred and selection lines. All inbred lines were adjusted to a zero level of inbreeding. Method II adjusts the inbred line means using the regression coefficients, λ_2 and ϕ_2, estimated by Model II in which the regressions were pooled over the inbred lines. Method III adjusts the inbred line means using the regression coefficients, λ_{3j} and ϕ_{3j}, estimated by Method III in which separate regressions were made for each inbred line. For both Methods II and III each inbred line mean was adjusted to the mean level of inbreeding of the four inbred lines.

The theoretical situations in which these methods of adjusting for inbreeding would be appropriate are the following. Method II would be used if a comparison of line performances involved only inbred lines in which approximately the same level of inbreeding had been attained in all lines and the response to inbreeding was the same for all lines. If the comparison involved only inbred lines and they were at different levels of inbreeding and/or the response to inbreeding was not the same for all lines, then Method III would be appropriate. However, if inbred lines which met the conditions of Method II are to be compared to non-inbred lines, then Method I should be used.

The Front Royal lines do not meet the assumptions under any of these three theoretical situations. The Front Royal inbred lines are at different levels of inbreeding, show different responses to the effects of inbreeding, and yet they are to be compared to non-inbred lines. If Method I is used to adjust the means to a zero level of inbreeding so that non-inbred lines may be compared to inbred lines, the assumption that the regression coefficients for each line are equal is violated. If Method III is used to adjust the means to the average level of inbreeding of the four inbred lines, then the lines are being compared at different levels of inbreeding and the comparison of inbred lines to the non-inbred lines is invalid. Thus, there is a dilemma of how to adjust the Front Royal line means for the effects of inbreeding.

Theoretically, there seems to be no unique solution, but from a practical point of view the purpose of adjusting the means is so that the lines can be ranked; this ranking is then used to predict the performance of these lines in crosses to unrelated animals. Thus, in practice the optimum method for adjusting the means is that method which gives the best prediction of the general combining ability of the lines.

The discussion of the effects of inbreeding would not be complete without returning to the line by sex interactions referred to earlier. It is apparent from figure 2 that the line by sex interaction for birth weight is dependent upon the responses in the S-1 and Growth lines. For these two lines, the differences between the birth weights of bulls and heifers is much less than the differences between sexes in the other lines. It can be seen from figure 3 that the interaction for preweaning gain is dependent upon the responses in the S-4 and S-5 lines. The differences between the preweaning gains of the bulls and heifers in these two inbred lines is much less than the differences between the sexes of the other lines. The sex by line interactions cannot be definitely explained by these data. Nevertheless, the following seems a plausible explanation. Brinks et al. (1965) and Dinkel et al. (1968) have reported differential responses of males and females to the effects of inbreeding for growth traits in beef cattle. But even if a differential response of the sexes to inbreeding exists in the present study, this would not in itself create a line by sex interaction. The line by sex interaction implies that the sexes do not respond equally to the effects of inbreeding in the several lines. Since the lines are at different levels of inbreeding, it appears that the rate of response of the dependent variable to the effects of inbreeding for a particular sex change at different levels of inbreeding or that the response for the two sexes is unique for each inbred line. Neither of these two explanations can account for the small differences between the sexes observed for birth weight in the Growth line.

Topcross Performance

The topcrossing performance at Blacksburg was evaluated from the 1965-68 calf crops. The average inbreeding of the bulls used for topcrossing was 41%, 32%, 29%, and 21% in the S-1, S-2, S-4, and S-5 lines,

TABLE II. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES FOR PREWEANING TRAITS

Source	df.	Mean squares		
		B. wt.	ADG (1)	Grade (1)
Years (Y)	4	68.34	0.4815	1.4412
Lines (L)	5	527.80**	0.3395**	48.3743**
Sex (S)	1	2121.89**	2.9855**	3.8528
Y * L	20	118.90**	0.0815	2.6049*
Y * S	4	123.97	0.0524	5.8083**
L * S	5	186.49**	0.1374*	2.4626
Age of dam	1	2718.18**	3.1881**	13.3311**
Error	368	60.89	0.0520	1.4408

*F ratio is significant at probability level $\leq$ .05.
**F ratio is significant at probability level $\leq$ .01.

TABLE III. LEAST SQUARES MAIN EFFECT MEANS OF FRONT ROYAL INBRED AND SELECTION LINES FOR PREWEANING TRAITS

	Main effect means			
	No. obs.	B. wt.	ADG (1)	Grade (1)
Mean	409	68.6	1.62	11.6
Years				
62	93	67.9	1.62	11.4
63	81	67.4	1.58	11.8
64	84	70.5	1.67	11.5
65	74	68.2	1.66	11.7
66	77	68.8	1.60	11.5
Lines				
S-1	51	71.3	1.63	10.6
S-2	38	67.8	1.53	10.7
S-4	45	62.7	1.64	11.9
S-5	42	68.5	1.49	11.3
Type	103	69.9	1.71	13.1
Growth	130	71.4	1.73	11.8
Sexes				
Bulls	212	71.2	1.72	11.5
Heifers	197	65.9	1.52	11.7

TABLE IV. SIMPLE CORRELATIONS AMONG COVARIATES AND CONSTANTS USED TO ADJUST FOR AGE OF DAM AND SEX OF CALF

	Simple correlations		
	Age of dam	Inbreeding of dam	Inbreeding of calf
Age of dam		-.61	- .51
Inbreeding of dam			0.78
Inbreeding of calf			

	Age of dam constants[1]		
Age of dam	B. wt.	ADG (1)	Grade (1)
2	8.7	.25	1.1
3	4.8	.16	0.7
4	1.5	.08	0.3
5	0.0	.03	0.0
6-10	0.0	.00	0.0
>11	1.4	.05	1.0

	Sex of calf constants	
Line	B. wt.	ADG (1)
S-1	1.0	.30
S-2	9.0	.20
S-4	5.0	.03
S-5	8.0	.14
Type	6.0	.25
Growth	3.0	.32

[1] Age of dam constants estimated by Bovard and Priode (1963).

TABLE V. AVERAGE INBREEDING OF DAM (F_d) AND INBREEDING OF CALF (F_c) BY LINE AND YEAR

	F_d				F_c			F_d				F_c		
Year	No. obs.	Range	$\bar{x}$	σ	Range	$\bar{x}$	σ	No. obs.	Range	$\bar{x}$	σ	Range	$\bar{x}$	σ
	Line S-1							Line S-2						
1962	15	16-45	26	9	28-45	38	5	9	16-39	27	8	27-50	35	8
1963	7	17-30	23	6	28-45	40	6	10	15-39	26	7	28-49	36	7
1964	13	17-45	29	8	27-54	39	6	2	31-35	33	3	36-48	42	8
1965	11	20-41	32	6	38-55	44	7	8	15-50	30	11	23-44	35	7
1966	5	20-37	28	6	38-50	41	5	9	15-49	32	9	29-45	37	5
All years	51	16-45	27	8	28-55	40	6	38	15-50	29	8	23-50	37	7
	Line S-4							Line S-5						
1962	8	0-25	3	9	19-38	25	8	8	0	0	0	19-25	24	2
1963	8	0-25	6	11	19-38	24	7	9	0-25	3	8	25-38	26	4
1964	11	0-25	10	11	19-41	29	10	14	0-25	9	12	19-38	24	6
1965	8	0-19	10	10	19-41	30	10	10	0-25	8	12	19-38	24	7
1966	10	0-38	19	10	16-38	29	7	1	0	0	-	20	20	-
All years	45	0-38	10	12	16-41	27	9	42	0-25	4	10	19-38	23	5
	Type line							Growth line						
1962	22	0-8	2	3	0	0	0	31	0-13	3	4	0-14	3	4
1963	21	0-8	2	3	0	0	0	26	0-17	4	4	2-14	5	3
1964	20	0-8	2	3	0-1	0	0	24	0-9	2	3	2-27	9	7
1965	15	0-5	1	2	0	0	0	22	0-9	3	3	1-20	8	5
1966	25	0-8	1	2	0-17	3	5	27	0-27	5	6	0-22	8	4
All years	103	0-8	2	2	0-17	1	3	130	0-27	3	4	0-27	6	5

TABLE VI. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL LINES WITH REGRESSIONS ON INBREEDING

Source	df	Mean squares		
		B. wt.	ADG (1)	Grade (1)
Model I				
Year (Y)	4	108.00	0.1635*	2.1026
Line (L)	5	291.78**	0.3986**	13.5837**
Y * L	20	128.73**	0.0765	2.2658
F of dam[1]	1	377.60**	0.0550	3.6980
F of calf[2]	1	364.56*	0.2139*	1.4727
Error	377	55.86	0.0487	1.5173
Model II				
Year (Y)	4	35.61	0.0707	1.1887
Line (L)	3	493.58**	0.3320**	3.9056*
Y * L	12	136.42**	0.0789*	2.7955*
F of dam[1]	1	33.20	0.0230	2.1397
F of calf[2]	1	75.52	0.0516	0.0377
Error	154	49.97	0.0515	1.3536

*F ratio significant at the probability level $\leq .05$.
**F ratio significant at the probability level $\leq .01$.
[1]Linear regression on inbreeding of the dam.
[2]Linear regression on inbreeding of the calf.

TABLE VII. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL LINES WITH REGRESSIONS ON INBREEDING

Source	df.	Mean squares		
		B. wt.	ADG (1)	Grade (1)
Model III - Line S-1				
Year	4	188.46**	0.1493	1.9444
F of dam[1]	1	20.10	0.0049	0.0719
F of calf[2]	1	6.22	0.0074	0.0121
Error	44	49.16	0.0790	1.8230
Model III - Line S-2				
Year	4	93.71	0.0563	0.2701
F of dam[1]	1	14.20	0.0054	7.0910*
F of calf[2]	1	156.65†	0.2076††	0.6808
Error	31	49.32	0.0568	1.0342
Model III - Line S-4				
Year	4	125.08**	0.0771	3.5899**
F of dam[1]	1	17.32	0.0010	1.0230
F of calf[2]	1	2.03	0.0006	0.2440
Error	38	30.09	0.0406	0.9222
Model III - Line S-5				
Year	4	90.10	0.0372	3.4416
F of dam[1]	1	0.50	0.0304	0.0103
F of calf[2]	1	14.90	0.0018	0.2794
Error	35	76.46	0.0220	1.4963

*F ratio significant at the probability level ≤ .05.
**F ratio significant at the probability level ≤ .01.
†F ratio significant at the probability level = .08.
††F ratio significant at the probability level = .06.
[1]Linear regression on inbreeding of the dam.
[2]Linear regression on inbreeding of the calf.

TABLE VIII. REGRESSION COEFFICIENTS ESTIMATED BY THE REGRESSION OF PREWEANING TRAITS ON THE LINEAR EFFECTS OF INBREEDING THE DAM AND THE LINEAR EFFECTS OF INBREEDING OF THE CALF

Lines	Model[1]	No. obs.	B. wt.	ADG (1)	Grade (1)	Average inbreeding
			Regression coefficients for inbreeding of the dam			
4 inbred and 2 selection	I	409	+.0804 ± .0639	-.0021 ± .0018	-.0123 ± .0104	-
4 inbred	II	176	-.0138 ± .0742	-.0013 ± .0022	-.0099 ± .0118	18
S-1	III	51	+.2346 ± .1515	-.0005 ± .0060	-.0091 ± .0286	28
S-2	III	38	-.0610 ± .2020	-.0044 ± .0062	-.0688 ± .0256	29
S-4	III	45	-.0705 ± .1074	+.0014 ± .0037	-.0068 ± .0188	10
S-5	III	42	-.0905 ± .1605	-.0033 ± .0027	+.0104 ± .0231	4
			Regression coefficients for inbreeding of the calf			
4 inbred and 2 selection	I	409	-.1433 ± .0787	-.0048 ± .0023	-.0144 ± .0127	-
4 inbred	II	176	-.0888 ± .1035	-.0032 ± .0031	-.0052 ± .0164	32
S-1	III	51	-.1324 ± .1861	-.0036 ± .0073	-.0062 ± .0351	40
S-2	III	38	-.3253 ± .2569	-.0118 ± .0079	+.0288 ± .0326	37
S-4	III	45	+.0195 ± .1408	-.0004 ± .0048	-.0120 ± .0246	27
S-5	III	42	-.0197 ± .3180	-.0019 ± .0053	+.0115 ± .0457	23

[1]Statistical model used to estimate the regression coefficients.

TABLE IX. ADJUSTED LEAST SQUARES MEANS OF FRONT ROYAL INBRED AND SELECTION LINES FOR PREWEANING TRAITS

Lines	B. wt.	ADG (1)	205 wt.	Grade (1)
Adjusted for age of dam and sex of calf				
S-1	77	1.95	477	11.1
S-2	77	1.71	427	11.0
S-4	70	1.78	435	12.1
S-5	78	1.70	427	11.5
Type	78	1.96	480	13.3
Growth	78	2.02	492	12.1
Adjusted for inbreeding by Method I				
S-1	80	2.20	531	12.1
S-2	80	1.95	480	11.9
S-4	73	1.93	469	12.6
S-5	81	1.81	452	11.9
Type	78	1.96	480	13.3
Growth	78	2.02	492	12.1
Adjusted for inbreeding by Method II				
S-1	78	1.99	486	11.2
S-2	78	1.74	435	11.1
S-4	69	1.75	428	12.0
S-5	77	1.65	415	11.3
Type	78	1.96	480	13.3
Growth	78	2.02	492	12.1
Adjusted for inbreeding by Method III				
S-1	76	1.97	482	11.1
S-2	79	1.83	454	11.5
S-4	69	1.80	438	12.0
S-5	74	1.65	412	11.9
Type	78	1.96	480	13.3
Growth	78	2.02	492	12.1

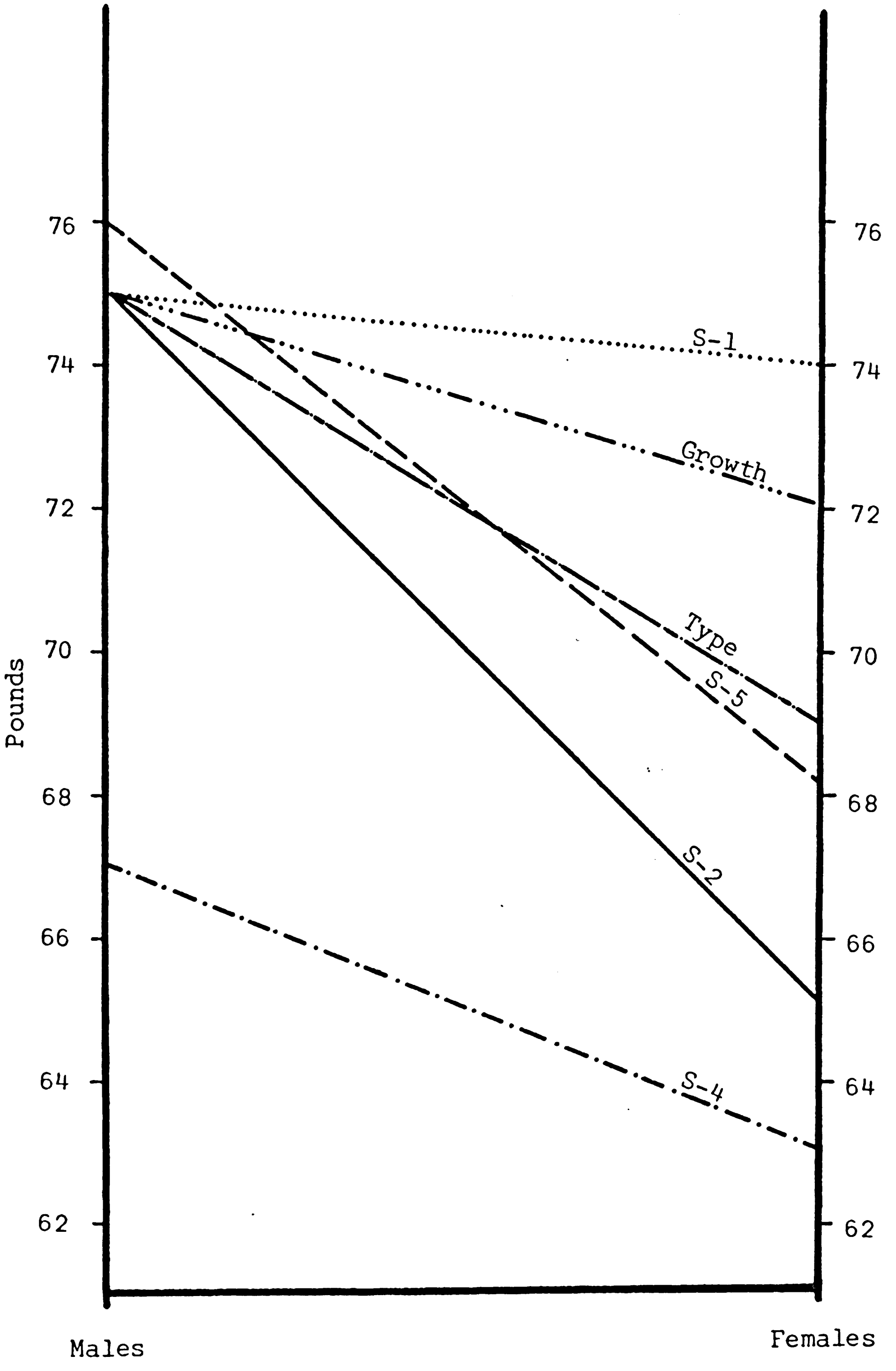

Figure 2. B. Wt.: Lines Plotted Against Sex of Calf

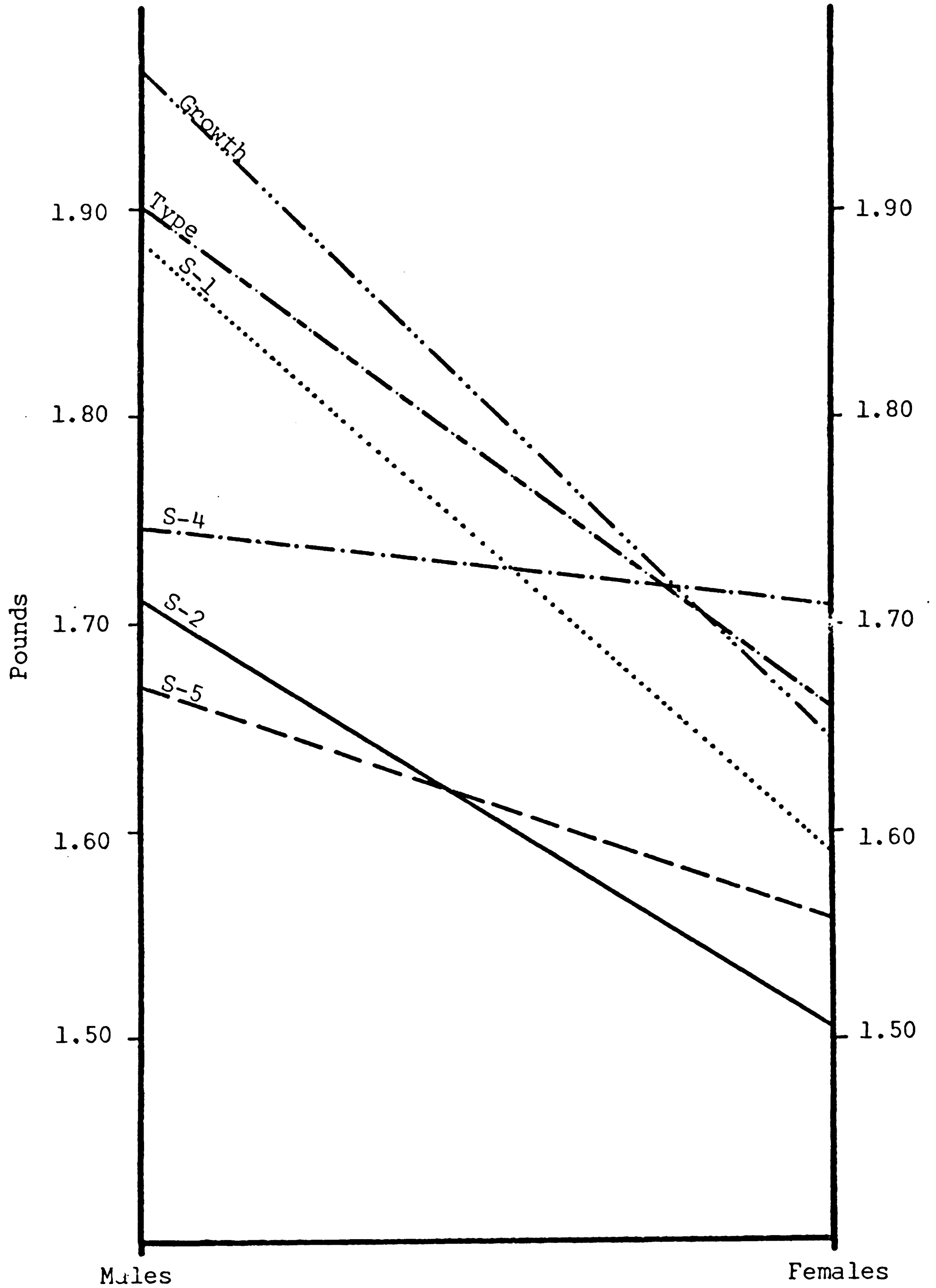

Figure 3. ADG (1): Lines Plotted Against Sex of Calf

respectively. In the Growth line, the average was 6% and in the Type line essentially zero. These figures are very comparable to the average inbreeding of the calves from the original inbred and selection lines at Front Royal for the calf crop years 1962-66. The preweaning traits measured were birth weight, B. wt.; average daily gain, ADG (1); and grade at weaning, Grade (1). The average weaning age was 230 days. The statistical model used to analyze the data included the effects due to years, lines, sex of calf, and the two factor interactions among these effects.

There were substantial differences in the age and breed of the dams in the test herd, both within and between years. During the four years of matings, the greatest percentage of the dams in the test herd was either 10 years of age or older; or they were first or second calving heifers. Some Angus and Angus x Shorthorn cows were used during the first two years, because there was not a sufficient number of Shorthorn cows available. However, only Shorthorn cows were used in subsequent years. Because of these differences, the data were adjusted for age and breed of dam effects within years. The analyses of variance for birth weight, average daily gain, and grade at weaning adjusted for age and breed of dam effects are given in table X and the main effect means are given in table XI. The line means adjusted to a steer base are given in table XII. The adjusted 205-day weights in table XII are defined as follows:

adj. 205 wt. = adj. B. wt. + adj. ADG (1) (205)

A selected set of contrasts for preweaning gain and grade are also given in table XII. The contrasts were made by the method proposed by Scheffe (1953).

Line differences for birth weight were not significant, but calves sired by Growth line bulls were heaviest, averaging 72 lb. Calves by Type and S-2 line bulls were only slightly lower, averaging 71 lb. Those sired by S-1 and S-5 averaged 70 and 69 lb, respectively; and calves sired by S-4 line bulls were lightest, averaging 68 lb.

The differences between line means for preweaning daily gain were significant. The calves by the Growth line bulls had the fastest daily gains, 1.79 lb per day, but were followed very closely by calves sired by S-1 line bulls, averaging 1.78 lb per day. Differences between calves by S-2 and S-4 sires were small. These lines averaged 1.75 and 1.72 lb per day, respectively. The preweaning daily gains of the calves by Type and S-5 line bulls were considerably lower than for the other lines; they averaged 1.68 and 1.66 lb per day, respectively. The differences between line means for 205-day weight follow the same pattern as the differences for preweaning daily gains.

Type line bulls produced the highest grading calves, 13.2; and the differences between line means were significant. Calves sired by the S-5 line bulls graded 12.8 and those sired by Growth and S-4 line sires both graded 12.7. The calves by S-1 and S-2 bulls had the lowest grades, 12.2 and 12.3, respectively.

Prediction of Topcrossing Performance for Preweaning Traits

The topcross line means for birth weight, preweaning daily gain, 205-day weight, and grade at weaning were regressed on the original Front Royal line means. Four sets of regressions were made for each dependent variable, where the different regression sets were defined by the method used to adjust the original line means. The topcross means and the original line means are given in tables XIII and XIV along with the regression coefficients and the R^2 values (the coefficient of determination) for each variable and method of adjustment.

The first set of regressions was on the original line means adjusted for age of dam and sex of calf with no adjustment made for inbreeding. These means are not good predictors of topcrossing performance for the three growth traits as indicated by the low R^2 values. The best prediction for this method of adjustment is for grade at weaning.

The second set of regressions was on the original line means adjusted for inbreeding by Method I. These adjusted means are worse predictors of topcrossing performance for birth weight and grade at weaning than the means which were not adjusted for inbreeding. The adjustment for inbreeding by Method I did improve the predictions for preweaning gain and 205-day weight.

The original line means adjusted for inbreeding by Method II are better predictors of topcrossing performance for birth weight and grade at weaning than means adjusted by Method I, but they are worse predictors of preweaning gain and 205-day weight.

The last regressions were made on the original line means adjusted for inbreeding by Method III. The line means adjusted by Method III are superior in predicting birth weight and grade at weaning than the means adjusted by any other method. However, the R^2 values for the regressions on the means of preweaning daily gain and 205-day weight adjusted by Method III are less than the R^2 values for the regression on the means of these traits adjusted by Method I.

The worst predictions of topcrossing performance are for preweaning gain and 205-day weight for all of the methods of adjustment considered. Means adjusted for inbreeding by Methods I and III are the best predictions for these two traits. However, when all traits are considered, the method which gives the best predictions of topcrossing performance is Method III. This implies that the original line performance for preweaning traits gives the best prediction of topcrossing performance when the original line means are adjusted for inbreeding by using regression coefficients estimated separately for each line and adjusted to the average level of inbreeding of the four inbred lines. The Front Royal line means adjusted for inbreeding by Method III and the topcross line means adjusted for age and breed of dam are plotted for birth weight, 205-day weight and grade at weaning in figures 4, 5, and 6, respectively.

From figure 5 it is evident that the Type line showed the greatest deviations between original line performance and topcrossing performance for 205-day weights. The Type line ranked fifth in topcrossing performance for this trait but ranked third in original line performance adjusted by Methods I or III. A plausible explanation of this result is that the Type line bulls may be more "like" the cows in the test herd. Some of the bulls used in the Type line at Front Royal came from the same area of West Virginia, Greenbriar County, where some of the cows in the test herd were purchased. However, the cows in the test here were not pedigreed so it was not possible to calculate relationships. But even if there was no direct relationship between the Type line bulls and the cows in the test herd, i.e. they would have genes that were identical by descent, there is the fact that the Type line was selected for the same trait for which most Shorthorn breeders have been selecting in recent years. Thus, the Type line bulls and the test cows could have genes that are alike in state. If either or both of these conditions existed, Type line bulls and test cows had more genes that were identical by descent or alike in state, less heterosis would be expected in the Type line progeny as compared to progeny of the other lines.

TABLE X. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE TOPCROSS PERFORMANCE FOR PREWEANING TRAITS

		Mean Squares		
Source	df.	B. wt.	ADG (1)	Grade (1)
Years (Y)	3	23.47	1.4046**	15.9130**
Lines (L)	5	97.66	0.1313*	4.6932*
Sex (S)	1	1353.90	0.6036**	0.2197
Y * L	14	33.69	0.0272	1.8112
Y * S	3	71.30	0.1497*	2.2614
L * S	5	53.05	0.0532	1.0277
Error	260	53.52	0.0417	1.8415

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.

TABLE XI. LEAST SQUARES MAIN EFFECT MEANS OF TOPCROSS PERFORMANCE FOR PREWEANING TRAITS

	Main Effect Means[1]			
	No. obs.	B. wt.	ADG (1)	Grade (1)
Mean	292	67.6	1.68	12.7
Years				
65	52	67.6	1.86	12.9
66	89	67.9	1.54	12.0
67	81	68.2	1.58	12.7
68	70	66.9	1.75	13.0
Lines				
S-1	50	67.6	1.72	12.1
S-2	49	68.3	1.70	12.5
S-4	42	65.5	1.68	12.7
S-5	50	66.4	1.61	12.8
Type	52	68.6	1.63	13.1
Growth	49	69.5	1.74	12.7
Sexes				
Steers	145	69.9	1.73	12.6
Heifers	147	65.4	1.63	12.7

[1] Data are adjusted for age and breed of dam.

TABLE XII. TOPCROSS LINE MEANS ADJUSTED FOR AGE OF DAM AND SEX OF CALF FOR PREWEANING TRAITS

Lines	B. wt.	ADG (1)	205 wt.	Grade (1)
S-1	70	1.78	435	12.2
S-2	71	1.75	430	12.3
S-4	68	1.73	423	12.7
S-5	69	1.66	409	12.8
Type	71	1.68	415	13.2
Growth	72	1.79	438	12.7

CONTRASTS OF LINE MEANS

Contrast	ADG (1)	Grade (1)
Type vs. growth	*	N.S.
S-1 + S-2 vs. growth	N.S.	*
S-4 + S-5 vs. growth	*	N.S.
S-1 + S-2 vs. type	N.S.	*
S-4 + S-5 vs. type	N.S.	N.S.

* Contrast is significantly different at the probability level $\leq .05$.
N.S. Contrast is not significantly different.

TABLE XIII. ADJUSTED LEAST SQUARES MEANS OF FRONT ROYAL (FR.) AND TOPCROSS (Top.) LINES FOR PREWEANING TRAITS

Lines	B. wt.		ADG (1)		205 wt.		Grade (1)	
	FR.	Top.[1]	FR.	Top.[1]	FR.	Top.[1]	FR.	Top.[1]
Front Royal line means adjusted for age of dam and sex of calf								
S-1	77	70	1.95	1.78	477	435	11.1	12.2
S-2	77	71	1.71	1.75	427	430	11.0	12.3
S-4	70	68	1.78	1.73	435	423	12.1	12.7
S-5	78	69	1.70	1.66	427	409	11.5	12.8
Type	78	71	1.96	1.68	480	415	13.3	13.2
Growth	78	72	2.02	1.79	492	438	12.1	12.7
	b = .34		b = .91		b = .18		b = .39*	
	R^2 = .52		R^2 = .23		R^2 = .22		R^2 = .83	
Front Royal line means adjusted for inbreeding by Method I								
S-1	80	70	2.20	1.78	531	435	12.1	12.2
S-2	80	71	1.95	1.75	480	430	11.9	12.3
S-4	73	68	1.93	1.73	469	423	12.6	12.7
S-5	81	69	1.81	1.66	452	409	11.9	12.8
Type	78	71	1.96	1.68	480	415	13.3	13.2
Growth	78	72	2.02	1.79	492	438	12.1	12.7
	b = .21		b = .31		b = .32		b = .50	
	R^2 = .17		R^2 = .54		R^2 = .56		R^2 = .59	

[1] Topcross line means are adjusted for age of dam and sex of calf.
* F ratio significant at the probability level $\leq .05$.
b is the regression coefficient for the regression of topcross line means on Front Royal line means.
R^2 is the coefficient of determination.

TABLE XIV. ADJUSTED LEAST SQUARES MEANS OF FRONT ROYAL (FR.) AND TOPCROSS (Top.) LINES FOR PREWEANING TRAITS

Lines	B. wt.		ADG (1)		205 wt.		Grade (1)	
	FR.	Top.[1]	FR.	Top.[1]	FR.	Top.[1]	FR.	Top.[1]
Front Royal line means adjusted for inbreeding by Method II								
S-1	78	70	1.99	1.78	486	435	11.2	12.2
S-2	78	71	1.74	1.75	435	430	11.1	12.3
S-4	69	68	1.75	1.73	428	423	12.0	12.7
S-5	77	69	1.65	1.66	415	409	11.3	12.8
Type	78	71	1.96	1.68	480	415	13.3	13.2
Growth	78	72	2.02	1.79	492	438	12.1	12.7
	b = .32		b = .19		b = .20		b = .37*	
	R^2 = .60		R^2 = .32		R^2 = .35		R^2 = .73	
Front Royal line means adjusted for inbreeding by Method III								
S-1	76	70	1.97	1.78	482	435	11.1	12.2
S-2	79	71	1.83	1.75	454	430	11.5	12.3
S-4	69	68	1.80	1.73	438	423	12.0	12.7
S-5	74	69	1.65	1.66	412	409	11.9	12.8
Type	78	71	1.96	1.68	480	415	13.3	13.2
Growth	78	72	2.02	1.79	492	438	12.1	12.7
	b = .36**		b = .25		b = .26		b = .46**	
	R^2 = .85		R^2 = .43		R^2 = .48		R^2 = .91	

[1] Topcross line means are adjusted for age of dam and sex of calf.
* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.
b is the regression coefficient for the regression of topcross line means on Front Royal line means.
R^2 is the coefficient of determination.

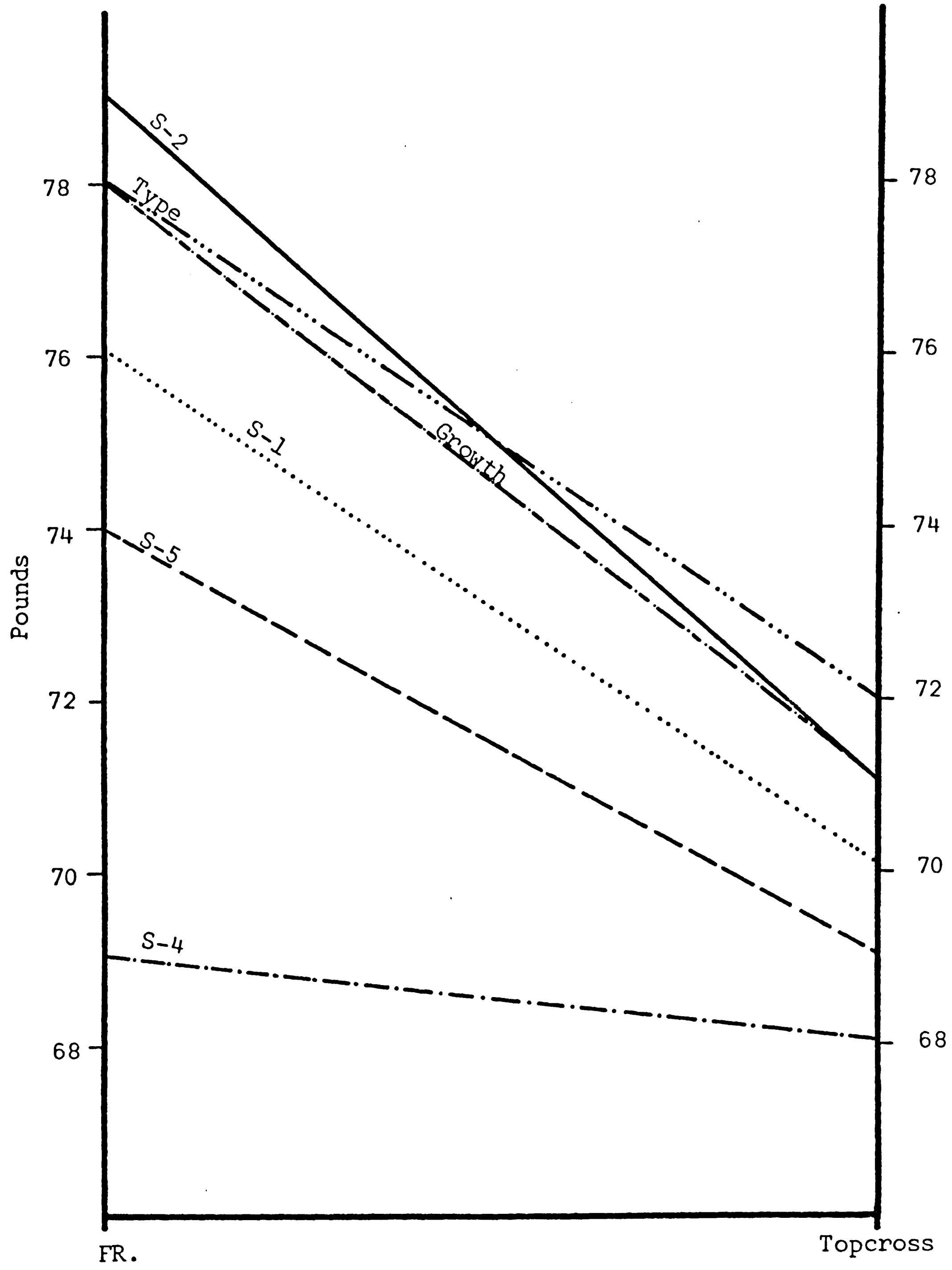

Figure 4. B. Wt.: Front Royal Lines vs. Topcross Lines

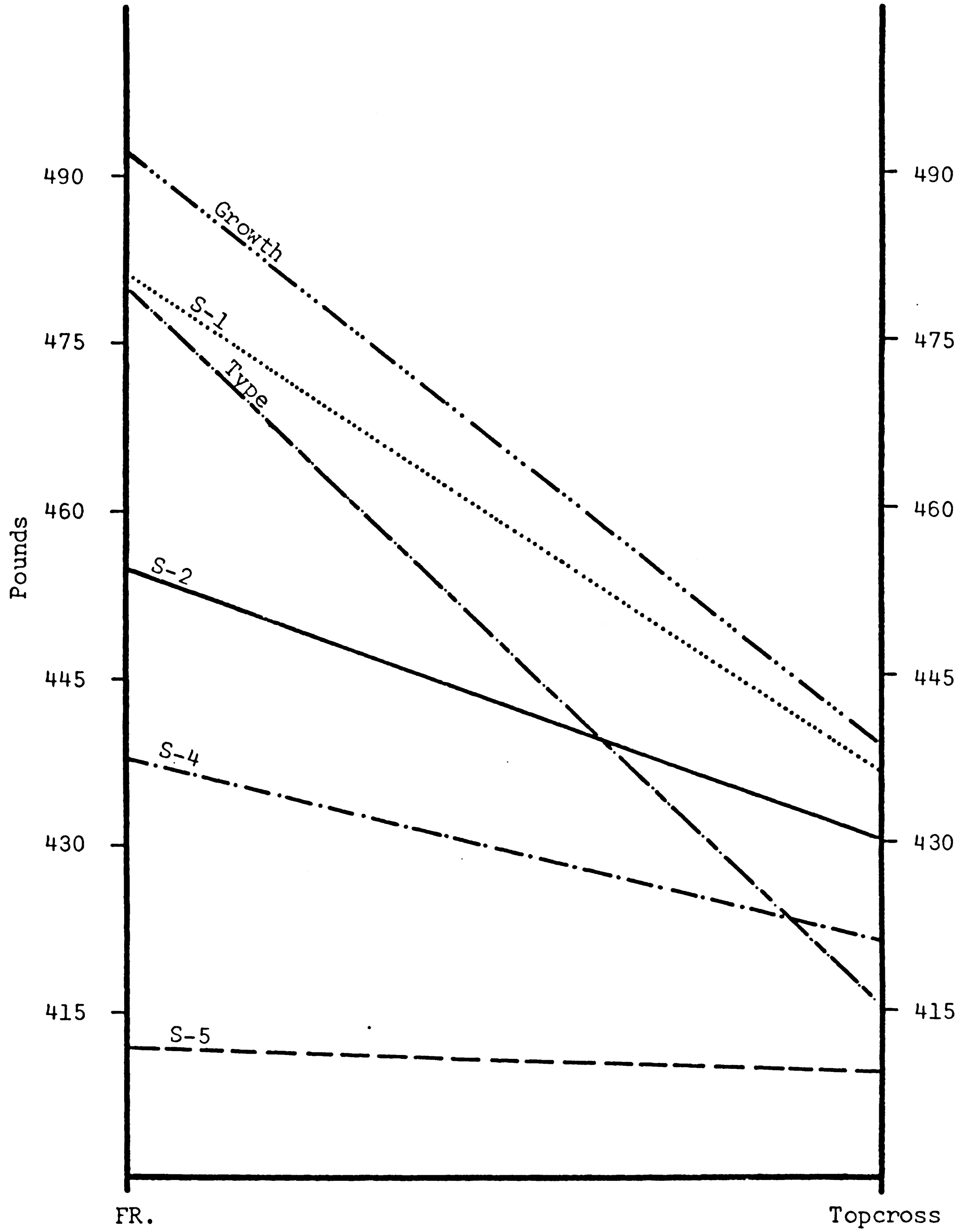

Figure 5. 205 Wt.: Front Royal Lines
vs. Topcross Lines

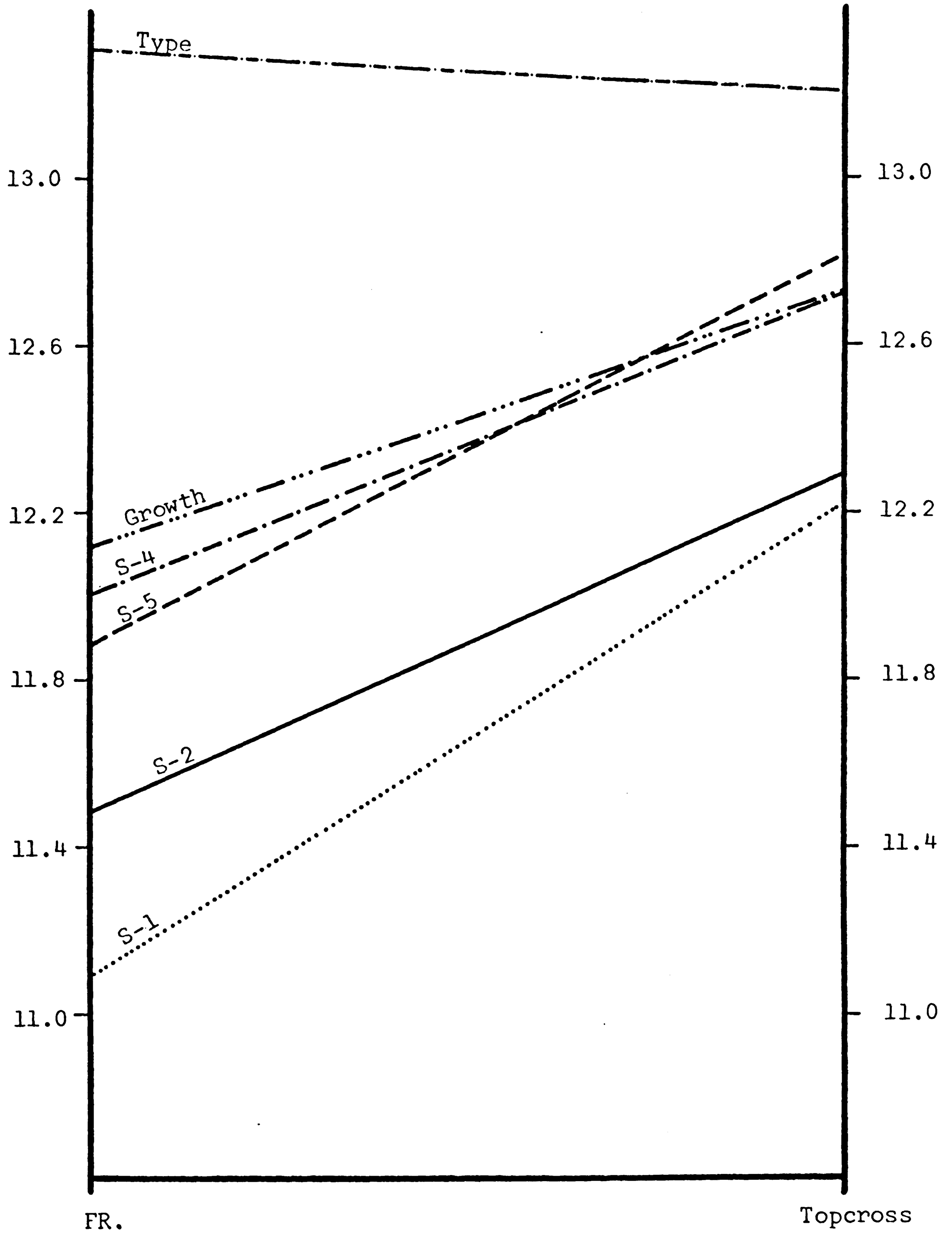

Figure 6. Grade (1): Front Royal Lines vs. Topcross Lines

POSTWEANING PERFORMANCE OF INBRED AND SELECTION LINES

Original Line Performance

Subsequent to weaning the bull and heifer calves at Front Royal were separated and placed under different management systems. The superior bulls in each line were placed on a feeding trial for 168 days. This type of feeding trial is commonly referred to as an ROP test (record of performance test). Generally two bull calves from each inbred line and four bull calves from each selection line, preferably one calf by each sire in the selection line, were included in each year's ROP test. All heifers that were physically sound at weaning were placed on an ROP test for 140 days. Both bulls and heifers were placed on the ROP tests directly after weaning. The average weaning age was 200 days.

The bulls in pens of 10-15 animals were fed *ad libitum* a ration which consisted of 25% ground, mixed grass and legume hay and 75% concentrates. This ration was about 10% digestible protein and 70% total digestible nutrient (TDN). The heifers in pens of 20-25 animals were fed 6 lb per head per day of the mixture fed to the bulls plus corn silage *ad libitum*.

The postweaning data included calves born in the years 1962-67. An additional year was included in the postweaning data because substantially fewer of the bull calves weaned were placed on the ROP tests each year. Thus, from the approximately 40 bulls weaned each year, only about 16 bulls per year were placed on the ROP tests. The postweaning traits measured for each sex were average daily gain on the ROP test, ADG (2), and conformation score at the end of the ROP test, Grade (2). The same scale defined for the preweaning grades was used for the postweaning grades.

The general model given for the preweaning data is also applicable for the postweaning data with the exception that there is a separate model for each sex of calf. The first statistical model used to analyze the data did not include the effects due to inbreeding. The analyses of variance for average daily gain on the ROP test and postweaning grade for bulls and heifers are given in table XV; the least squares means are given in table XVI. The effect of years was significant only for post-weaning grade of the bulls. The effect of lines was highly significant for postweaning daily gain and postweaning grade of bulls and heifers. The effect of age of the dam was non-significant for both traits for bulls and heifers. Since these parameters are not well established in the literature, the data were not adjusted for the effects of age of dam.

Four statistical models were used to estimate the effects of inbreeding in the postweaning period. Models IV A and IV B included the pooled regressions over the four inbred lines and the two selection lines, and Models V A and V B included the pooled regressions over the four inbred lines. In Models IV A and V A the linear effects of inbreeding of the dam and calf were fitted. In Models IV B and V B linear and quadratic effects were fitted. It should be noted that in these analyses non-orthogonal polynomials were fitted for the partial regressions on inbreeding. Because of this procedure, the only test of significance was for the highest degree polynomial fitted in each model. Therefore, in Models IV A and V A the linear effects of inbreeding were tested; and in Models IV B and V B, although linear effects were fitted, only the quadratic effects were tested. The analyses of variance for these models are in tables XVII, XVIII, XIX, and XX and the regression coefficients for inbreeding of the dam and calf are given in table XXI. For the preweaning traits it was possible to estimate the effects of inbreeding for each line after the data had been adjusted for the sex of calf effects. However, for the postweaning traits each sex must be considered a separate population as the environments were different for the two sexes. With this restriction there was not sufficient data available to estimate the effects of inbreeding within a line-sex of calf subclass.

For the bulls the linear effects of inbreeding of the calf on postweaning daily gain were highly significant in Model IV A and significant in Model V A. The regression coefficients were negative in both models indicating a continued depressing effect of inbreeding of the calf on growth rate in the postweaning period.

The linear effects of inbreeding of the dam on the bulls' postweaning growth rate was significant in Model IV A but non-significant in Model V A. The regression coefficients for inbreeding of the dam in both models were positive indicating compensatory growth in the postweaning period. Inbreeding of the dam and calf did not have a significant effect on postweaning grade of the bulls. The quadratic effects of inbreeding estimated in Models IV B and V B were non-significant for both postweaning traits measured in the bulls.

For the heifers the linear effects of inbreeding of the calf on postweaning daily gain were non-significant in Model IV A but significant in Model V A. However, the reverse is true for the quadratic effects of inbreeding of the calf; they were highly significant in Model IV B but non-significant in Model V B. These results at first seem to indicate different responses for the two sexes to the effects of inbreeding. However, the two sexes were in different environments; therefore, the results should not be interpreted as showing strictly genetic differences. Since the heifers were not fed to make maximum gains, they were not able to express their maximum genetic potential. The two selection lines are the least inbred, however, for the heifers they made slower gains than the S-1 line which is the most highly inbred. Thus, it would appear that the heifers in the non-inbred lines were less able to express their genetic potential for growth in the limited environment. This situation is expressed by the significant quadratic effect for the heifers when the regression was pooled over the inbred and selection lines. When the regression was pooled over just the inbred lines in Models V A and V B, the results were the same as observed for the bulls; the linear effect of inbreeding of the calf was significant. These results indicate that the inbred heifers in the limited environment were more nearly able to express their genetic potential.

The linear effects of inbreeding of the dam on the heifers' post-weaning daily gain was non-significant in Models IV A and V A. The quadratic effects of inbreeding of the dam were significant (P=.08) in Model IV B but non-significant in Model V B. Again, the quadratic effect involving the inbred and selection lines is most probably an indication of environmental effects.

The linear effects of inbreeding of the calf on the heifers' post-weaning grade was significant for Model IV A but non-significant for Model V A. The quadratic effects of inbreeding of the calf on postweaning grade were non-significant for Models IV B and V B. The linear and quadratic effects of inbreeding of the dam were non-significant for postweaning grade.

The postweaning daily gain was adjusted for the effects of inbreeding of the dam and calf for bulls and heifers. The postweaning daily gain of the bulls was adjusted by two methods. The two methods used were Methods I and II which were defined for the preweaning traits. Method I adjusts the inbred line means using the regression coefficients estimated by Model IV A in which the linear regressions were pooled over the inbred and selection lines. Method I adjusts the inbred lines to a zero level of inbreeding. Method II adjusts the inbred line means using the linear regression coefficients estimated by Model V A in which the linear regressions were pooled over the inbred lines. For Model II the inbred lines were adjusted to the mean level of inbreeding of the four inbred lines.

Postweaning daily gain of the heifers was adjusted by Method II. Method I was not used for the heifers, because the linear effects of inbreeding in Model IV A were non-significant and the significant quadratic effects in Model IV B. were interpreted to be a result of the limited environment.

The line means adjusted for inbreeding are given in table XXII. The postweaning grades were not adjusted, since the effects of inbreeding on this trait were non-significant. In table XXII the adjusted 365-day weight for the bulls and the 345-day weight of the heifers are defined as follows:

adj. 365 wt. = adj. 205 wt. + adj. ADG (2) (160)

adj. 345 wt. = adj. 205 wt. + adj. ADG (2) (140)

The adjusted 205-day weights were estimated for bulls and heifers separately and are adjusted for age of dam and inbreeding by Method III.

Topcross Performance

After the topcross calves were weaned in early October the steer and heifer calves were separated and placed under different management systems. The calves averaged about 230 days of age at weaning. Directly after weaning the steers were put on ROP tests for another 230 days, and the heifers were fed 175 days. The steers were fed a fattening ration consisting of corn silage *ad libitum* plus protein supplement and grain at the rate of 1% of body weight per day. The heifers were fed silage *ad libitum* plus hay and grain at a rate sufficient to gain about 1.00 lb per day. The steers were fed out for slaughter at 900 to 1000 lb. The heifers were retained for breeding.

The postweaning data for the steers included the calves born in the years 1965-68. The postweaning data for the heifers included three calf crops for calves born in the years 1966-68. No postweaning data for the heifers were available from the 1965 calf crop. The postweaning traits measured on the steers were average daily gain from weaning to the end of the ROP test, ADG (2), and grade at the end of the test, Grade (2). For the heifers the only postweaning trait measured was daily gain from weaning to the end of the test period. Because of the differences among ages and breeds of cows in the test herd, the data were first adjusted for these effects on a within year basis. The model

TABLE XV. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES FOR POSTWEANING TRAITS

		Mean Squares	
Source	df.	ADG (2)	Grade (2)
Bulls			
Years (Y)	5	0.0950	1.7130*
Lines (L)	5	0.5307**	23.3539**
Y * L	25	0.0633	1.0472
Age of Dam[1]	1	0.0650	1.0674
Error	55	0.0520	0.6982
Heifers			
Years (Y)	5	0.0985	1.9484
Lines (L)	5	0.4351**	28.4744**
Y * L	25	0.0574	1.4168
Age of Dam[1]	1	0.0070	0.1718
Error	198	0.0545	0.9287

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.
[1] Linear regression on age of the dam.

TABLE XVI. LEAST SQUARES MAIN EFFECT MEANS OF THE FRONT ROYAL INBRED AND SELECTION LINES FOR POSTWEANING TRAITS

	Main Effect Means					
	Bulls			Heifers		
	No. obs.	ADG (2)	Grade (2)	No. obs.	ADG (2)	Grade (2)
Mean	92	2.72	12.0	235	1.35	12.0
Years						
62	14	2.60	11.6	51	1.38	11.9
63	15	2.75	12.1	31	1.46	11.8
64	11	2.79	11.7	34	1.26	12.1
65	19	2.67	11.8	31	1.33	12.5
66	16	2.84	12.1	35	1.33	11.8
67	17	2.70	12.6	47	1.37	11.7
Lines						
S-1	15	2.74	10.7	24	1.50	10.5
S-2	11	2.68	11.2	22	1.37	11.9
S-4	12	2.69	12.1	27	1.20	12.6
S-5	11	2.40	11.5	24	1.17	11.5
Type	20	2.79	14.2	61	1.43	13.4
Growth	23	3.04	12.3	77	1.47	11.9

TABLE XVII. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES WITH REGRESSIONS ON INBREEDING FOR POSTWEANING TRAITS

Source	df.	Mean Squares ADG (2)	Mean Squares Grade (2)
Model IV A: Heifers			
Years (Y)	5	0.0993	1.5188
Lines (L)	5	0.2633**	16.8736**
Y * L	25	0.0549	1.3225
Age of Dam[1]	1	0.0135	1.1700
F of Dam[2]	1	0.0097	0.0881
F of Calf[3]	1	0.0002	4.0081*
Error	196	0.0550	0.9160
Model V A: Heifers			
Years (Y)	5	0.0627	1.3589
Lines (L)	3	0.2876**	10.2052**
Y * L	15	0.0542	0.8171
Age of Dam	1	0.0529	1.2248
F of Dam	1	0.0076	0.5862
F of Calf	1	0.3492*	0.0191
Error	70	0.0573	0.7882

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.

[1] Linear regression on age of dam.
[2] Linear regression on inbreeding of dam.
[3] Linear regression on inbreeding of calf.

TABLE XVIII. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES WITH REGRESSIONS ON INBREEDING FOR POSTWEANING TRAITS

Source	df.	Mean Squares	
		ADG (2)	Grade (2)
Model IV B: Heifers			
Years (Y)	5	0.1027	1.6012
Lines (L)	5	0.3391**	14.5557**
Y * L	25	0.0594	1.1708
Age of Dam[1]	1	0.0008	0.6604
F of Dam[2]	1	0.0743	0.0060
F^2 of Dam[3]	1	0.1637†	0.1326
F of Calf[2]	1	0.1921	0.5065
F^2 of Calf[3]	1	0.5218**	2.2309
Error	194	0.0526	0.9103
Model V B: Heifers			
Years (Y)	5	0.0719	1.2295
Lines (L)	3	0.3128**	9.8898**
Y * L	15	0.0523	0.7247
Age of Dam[1]	1	0.0754	1.5441
F of Dam[2]	1	0.0038	0.8978
F^2 of Dam[3]	1	0.1313	0.6704
F of Calf[2]	1	0.3735	0.0000
F^2 of Calf[3]	1	0.0421	0.0829
Error	68	0.0536	0.8010

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.

† F ratio significant at the probability level = .08.

[1] Linear regression on age of dam.
[2] Linear regressions on inbreeding.
[3] Quadratic regressions on inbreeding.

TABLE XIX. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES WITH REGRESSIONS ON INBREEDING FOR POSTWEANING TRAITS

		Mean Squares	
Source	df.	ADG (2)	Grade (2)
Model IV A: Bulls			
Years (Y)	5	0.0832	1.0964
Lines (L)	5	0.3870**	7.7636**
Y * L	25	0.0551	0.8797
Age of Dam[1]	1	0.1022	1.5416
F of Dam[2]	1	0.1897*	0.7221
F of Calf[3]	1	0.3504**	0.2313
Error	53	0.0463	0.7103
Model V A: Bulls			
Years (Y)	5	0.0447	0.6020
Lines (L)	3	0.1662**	2.4874*
Y * L	15	0.0505	0.7765
Age of Dam	1	0.0223	1.3527
F of Dam	1	0.0666	0.8721
F of Calf	1	0.1975*	0.0443
Error	22	0.0419	0.7861

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.

[1] Linear regression on age of dam.
[2] Linear regression on inbreeding of the dam.
[3] Linear regression on inbreeding of the calf.

TABLE XX. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE FRONT ROYAL INBRED AND SELECTION LINES WITH REGRESSIONS ON INBREEDING FOR POSTWEANING TRAITS

Source	df.	Mean Squares ADG (2)	Mean Squares Grade (2)
Model IV B: Bulls			
Years (Y)	5	0.0815	1.2085
Lines (L)	5	0.3368**	5.7158**
Y * L	25	0.0532	0.7909
Age of Dam[1]	1	0.0853	0.6586
F of Dam[2]	1	0.1650	0.2323
F^2 of Dam[3]	1	0.0064	1.2538
F of Calf[2]	1	0.2670	0.0168
F^2 of Calf[3]	1	0.0020	1.6610
Error	51	0.0480	0.6965
Model V B: Bulls			
Years (Y)	5	0.0484	0.5950
Lines (L)	3	0.1273	2.8419*
Y * L	15	0.0523	0.8428
Age of Dam[1]	1	0.0034	0.5486
F of Dam[2]	1	0.0453	1.1522
F^2 of Dam[3]	1	0.0128	3.1065
F of Calf[2]	1	0.2325	0.2844
F^2 of Calf[3]	1	0.0374	1.4017
Error	20	0.0442	0.7068

* F ratio significant at the probability level $\leq .05$.
** F ratio significant at the probability level $\leq .01$.

[1] Linear regression on age of dam.
[2] Linear regressions on inbreeding.
[3] Quadratic regressions on inbreeding.

TABLE XXI. REGRESSION COEFFICIENTS ESTIMATED BY REGRESSION OF POSTWEANING TRAITS ON THE LINEAR AND QUADRATIC EFFECTS OF INBREEDING OF THE DAM AND CALF

		Bulls			Heifers		
Lines	Model	No. obs.	ADG (2)	Grade (2)	No. obs.	ADG (2)	Grade (2)
		Regression Coefficients for Inbreeding of the Dam					
4 inbred and 2 selection	IV A[1]	92	+.0121±.0060	+.0236±.0234	235	+.0015±.0035	+.0044±.0142
	IV B[2]	92	-.0086±.0237	-.1210±.0902	235	+.0248±.0140	+.0223±.0584
4 inbred	V A[1]	49	+.0098±.0078	+.0354±.0336	97	+.0018±.0049	-.0158±.0183
	V B[2]	49	-.0159±.0296	-.2482±.1184	97	+.0313±.0200	+.0709±.0774
		Regression on Inbreeding of the Calf					
4 inbred and 2 selection	IV A[1]	92	-.0168±.0061	-.0137±.0240	235	-.0002±.0036	-.0307±.0147
	IV B[2]	92	+.0049±.0236	+.1389±.0900	235	-.0405±.0129	+.0838±.0535
4 inbred	V A[1]	49	-.0157±.0073	-.0075±.0315	97	-.0147±.0060	-.0034±.0222
	V B[2]	49	+.0489±.0532	+.2996±.2127	97	+.0323±.0364	-.0453±.1409

[1] Linear regression coefficients.
[2] Quadratic regression coefficients.

TABLE XXII. LEAST SQUARES MEANS OF THE FRONT ROYAL INBRED AND SELECTION LINES FOR POSTWEANING TRAITS

Lines	Bulls			Heifers		
	ADG (2)	365 wt.	Grade (2)	ADG (2)	345 wt.	Grade (2)
			Unadjusted			
S-1	2.74	904	10.7	1.50	613	10.5
S-2	2.68	880	11.2	1.37	590	11.9
S-4	2.69	856	12.1	1.20	584	12.6
S-5	2.40	786	11.5	1.17	536	11.5
Type	2.79	911	14.2	1.43	607	13.4
Growth	3.04	963	12.3	1.47	614	11.9
			Adjusted for Inbreeding by Method I			
S-1	3.07	957	10.7			
S-2	2.95	922	11.2			
S-4	3.06	915	12.1			
S-5	2.75	842	11.5			
Type	2.79	911	14.2			
Growth	3.04	963	12.3			
			Adjusted for Inbreeding by Method II			
S-1	2.77	909	10.7	1.60	627	10.5
S-2	2.65	874	11.2	1.41	594	11.9
S-4	2.72	861	12.1	1.17	580	12.6
S-5	2.40	786	11.5	1.08	523	11.5
Type	2.79	911	14.2	1.43	607	13.4
Growth	3.04	963	12.3	1.47	614	11.9

[1] Grade (2) was not adjusted for the effects of inbreeding; see text for explanation.

for the analyses of variance by least squares included the effects due to years, lines and the interaction of these effects. The analyses of variance for both sexes are given in table XXIII. The line means are in table XXIV. For steers and heifers a postweaning weight was estimated for each line. The 435-day weight of the steers and the 380-day weight of the heifers were estimated as follows:

adj. 435 wt. = adj. 205 wt. + adj. ADG (2) (230)

adj. 380 wt. = adj. 205 wt. + adj. ADG (2) (175)

The 205-day weights were estimated separately for each sex. The 205-day weights of the steers were based on four year's data, those for the heifers were based on three year's data.

There was a significant difference between the lines for feedlot gain of the steers. The steers sired by the Growth line bulls had the fastest postweaning gain, 2.13 lb per day. Steers by the S-1 and S-2 bulls ranked second and third, averaging 2.07 and 2.04 lb per day, respectively. Steers sired by the S-4 and Type line bulls ranked fourth and fifth, averaging 1.98 and 1.95 lb per day, respectively. Steers by S-5 sires had the slowest postweaning gains of 1.88 lb per day. The lines ranked in the same order for 435-day weight.

Although the differences among the lines for postweaning daily gain of the heifers were significant only at the 0.10 probability level, the 380-day weight of the heifers indicate real differences among the lines. The rank of the lines for 380-day weight of the heifers is essentially the same as the 435-day weight of the steers.

The three traits (1) preweaning daily gain, (2) feedlot gain of the steers, and (3) 380-day weight of the heifers have been used to measure the general combining ability of these lines for growth rate. Calves sired by Growth line bulls had the fastest gains and gained about 0.15 lb per day faster than calves sired by Type line sires or the S-4 and S-5 inbred sires; but Growth line calves did not gain significantly faster than calves sired by S-1 and S-2 inbred bulls. A selected set of contrasts among the line means for postweaning daily gain and grade of the steers are in table XXIV. The comparisons among the means were made by the method proposed by Scheffe (1953).

Differences among the line means for postweaning grade were significant. Steers by Type line bulls had the highest grades, 13.1, but those by Growth bulls graded only slightly lower, 12.9. Steers by S-4 and S-5 line bulls both graded 12.6 and those by the S-1 and S-2 inbred sired had the lowest grades, 12.2 and 12.4, respectively. The rank was the same for preweaning grade. The preweaning grade of the steers and heifers, and the postweaning grade of the steers have established the breeding value of these lines for conformation score. The calves sired by the Type line bulls have the highest preweaning and postweaning grades. However, calves sired by Type line bulls do not score significantly higher for preweaning or postweaning grade than calves sired by Growth line bulls. The calves by Type line sires grade significantly higher at weaning than calves by S-1 and S-2 line bulls; and steers by Type line bulls have significantly higher postweaning grades than steers by any of the inbred bulls.

It is interesting to note that among the inbred calves, those by S-1 and S-2 sires were highest in growth rate but lowest in conformation score; while those by S-4 and S-5 bulls which scored highest in conformation score were lowest in growth rate. A possible explanation of this result is that there has been some fixation of genes affecting growth rate and conformation score in these lines as a result of inbreeding. Klosterman, Moxon and Kunkle (1956) found similar results in topcrosses from inbred lines of Hereford cattle. Calves sired by Montana Line 1 bulls were highest in growth rate but lowest in conformation score as compared to calves sired by Nebraska Line 1 and outbred bulls. Bogart, McArthur and Hoornbeek (1967) also reported that inbred lines differ in their abilities to produce topcross calves. From the progeny of four inbred lines one line produced calves with the highest growth rate, while two other lines sired calves with the highest grades at weaning.

Prediction of Topcrossing Performance for Postweaning Traits

The topcross line means for postweaning weight and grade were regressed on the original Front Royal line means. Three sets of regressions were made which were defined by the method used to adjust the Front Royal line means. Postweaning daily gain was not included as a regression variable, because the bulls at Front Royal and the topcross steers at Blacksburg were on the ROP tests for different time periods. The bulls were fed for 168 days and the steers for 230 days. Steers do not grow as fast as bulls and therefore take a longer period of time to reach the desired market weight of 900 to 1000 lb. Postweaning gain of the heifers was also measured over different time periods. The heifers at Front Royal were fed for 140 days and at Blacksburg for 175 days. The different time periods for the heifers were a result of different management practices at the two locations. For these reasons the weights at the end of the postweaning period should be better measures than daily gain for comparisons between the two groups of cattle.

The topcross means which were adjusted for age and breed of dam together with the means of original lines are given in table XXV. The first set of regressions was on the original line means unadjusted for the effects of inbreeding in the postweaning period. The regression of 435-day weight of the steers on 365-day weight of the bulls was significant, but the R^2 value was low. The regression of postweaning grade of the males was highly significant indicating that inbreeding had little or no effect on this trait. This is in agreement with the results for preweaning grades. For the heifers the regression of 380-day weight on unadjusted 345-day weight was significant and the R^2 value was high.

The second set of regressions was on the original line means adjusted for inbreeding by Method I. The only regression variable in this set was postweaning weight of the males. The regression of 435-day weight of the steers on adjusted 365-day weight of the bulls was highly significant and the R^2 value was larger than for the regressions on the unadjusted 365-day weight. The adjustment of postweaning weight of the males by Method I has improved the prediction of topcrossing performance.

The third set of regressions was on the original line means adjusted for inbreeding by Method II. These adjusted means for postweaning weight showed no improvement in predicting topcrossing performance of males or females than the means which were not adjusted for inbreeding.

For postweaning weight the best prediction of topcrossing performance was from 435-day weight of the steers regressed on 365-day weight of the bulls adjusted for inbreeding by Method I. Thus, the best prediction of topcrossing performance resulted when the original line means were adjusted for inbreeding by using the regression coefficients estimated from pooling over the inbred and selection line; and the means were adjusted to a zero level of inbreeding. This agrees with the results for the preweaning 205-day weights for which Method I also gave the best predictions of topcrossing performance.

Postweaning weight of the males was a better predictor of topcrossing performance than was postweaning weight of the females. The superior predictive value of the males was no doubt a result of different environmental conditions. The nutritional regime for the males permitted expression of maximum genetic differences among the lines, but the environmental conditions of the females did not. However, the management practices for the females in this study were those commonly accepted as good husbandry. Females that are to be used for future breeding purposes which are fed high energy rations for maximum growth rate have in general a lower reproductive performance. Thus, the results from this study for postweaning growth of female replacements should be expected in breeding projects where sound husbandry practices are followed. The Front Royal line means adjusted for inbreeding and the topcross line means adjusted for age and breed of dam are plotted for postweaning weight and grade of the bulls and postweaning weight of the heifers in figures 7, 8 and 9, respectively.

TABLE XXIII. ANALYSES OF VARIANCE BY LEAST SQUARES OF THE TOPCROSS PERFORMANCE FOR POSTWEANING TRAITS

	Mean Squares				
	Steers			Heifers	
Source	df.	ADG (2)	Grade (2)	df.	ADG (2)
Years (Y)	3	0.4445**	2.3495**	2	4.9095**
Lines (L)	5	0.1451*	2.1116*	5	0.0670†
Y * L	14	0.0443	1.7693*	10	0.0594
Error	85	0.0590	0.7380	87	0.0335

* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.
† F ratio significant at the probability level $\leq$ .10.

TABLE XXIV. TOPCROSS LINE MEANS ADJUSTED FOR AGE OF DAM FOR POSTWEANING TRAITS

	Steers				Heifers		
Lines	No. obs.	ADG (2)	435 wt.	Grade (2)	No. obs.	ADG (2)	380 wt.
S-1	19	2.07	911	12.2	16	0.95	566
S-2	15	2.04	900	12.4	18	0.99	555
S-4	16	1.98	878	12.6	20	0.87	533
S-5	17	1.88	841	12.6	18	0.84	514
Type	21	1.95	863	13.1	12	0.98	544
Growth	20	2.13	928	12.9	21	1.00	575

Contrasts of line means of the steers

Contrast	ADG (2)	Grade (2)
Type vs. growth	*	N.S.
S-1 + S-2 vs. growth	N.S.	*
S-4 + S-5 vs. growth	*	N.S.
S-1 + S-2 vs. type	N.S.	*
S-4 + S-5 vs. type	N.S.	*

* Contrast is significantly different at the probability level $\leq .05$.
N.S. Contrast is not significantly different.

TABLE XXV. ADJUSTED LEAST SQUARES MEANS OF FRONT ROYAL (FR.) AND TOPCROSS (Top.) LINES FOR POSTWEANING TRAITS

	Males[1]				Heifers	
	365 wt.	435 wt.	Grade (2)		345 wt.	380 wt.
Lines	FR.	Top.	FR.	Top.	FR.	Top.
Front Royal line means not adjusted for inbreeding						
S-1	904	911	10.7	12.2	613	566
S-2	880	900	11.2	12.4	590	555
S-4	856	878	12.1	12.6	584	533
S-5	786	841	11.5	12.6	536	514
Type	911	863	14.2	13.1	607	544
Growth	963	928	12.3	12.9	614	575
	b = .44*		b = .24**		b = .67*	
	R^2 = .65		R^2 = .87		R^2 = .79	
Front Royal line means adjusted for inbreeding by Method I						
S-1	957	911				
S-2	922	900				
S-4	915	878				
S05	842	841				
Type	911	863				
Growth	963	928				
	b = .69**					
	R^2 = .87					
Front Royal line meand adjusted for inbreeding by Method II						
S-1	909	911			627	566
S-2	874	900			594	555
S-4	861	878			580	533
S-5	786	841			523	514
Type	911	863			607	544
Growth	963	928			614	575
	b = .44*				b = .54*	
	R^2 = .65				R^2 = .80	

[1] FR. 365 wt. is for bulls; Top. 435 wt. is for steers.
* F ratio significant at the probability level $\leq$ .05.
** F ratio significant at the probability level $\leq$ .01.
b is the regression coefficient for the regression of topcross line means on Front Royal line means.
R^2 is the coefficient of determination.

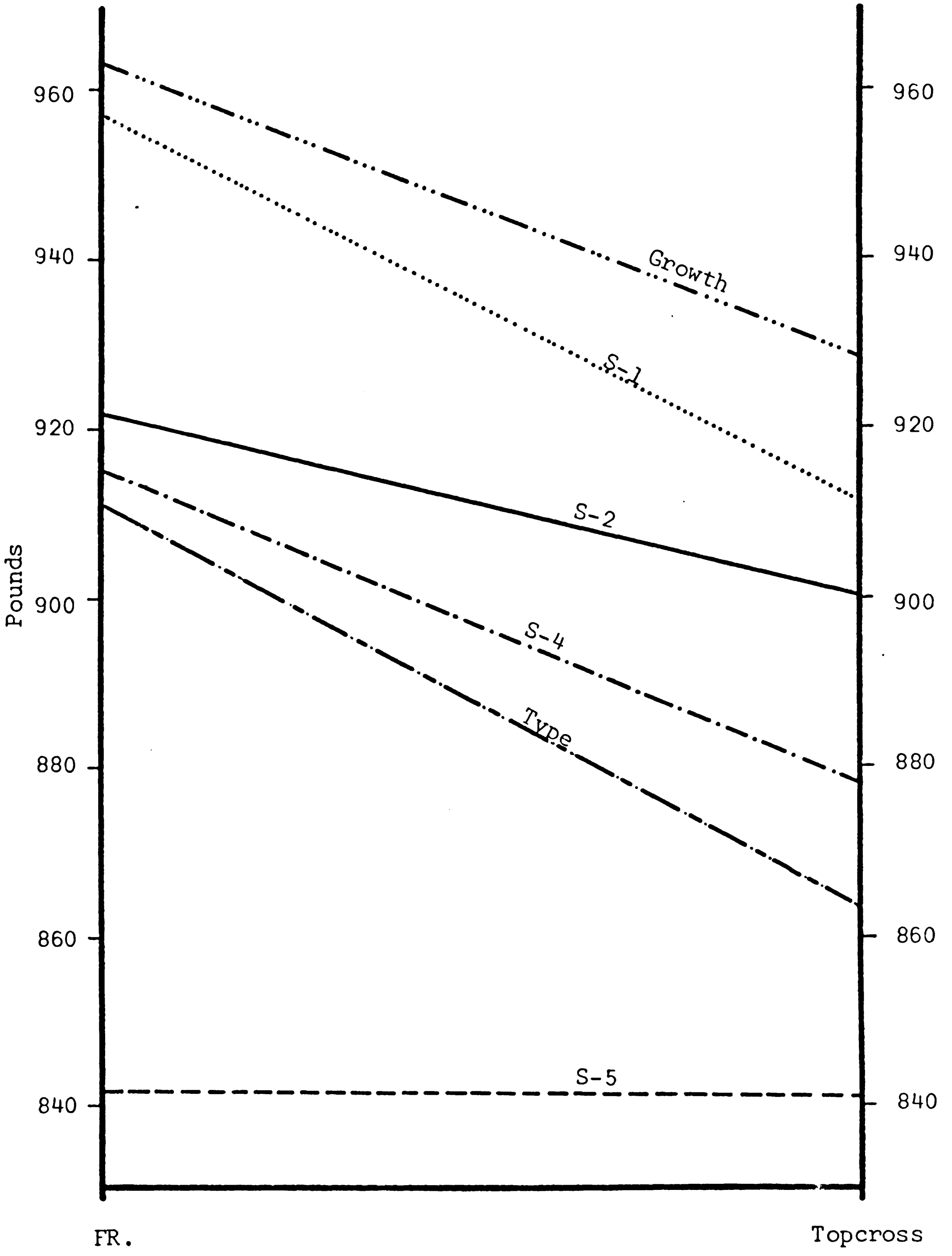

Figure 7. Postweaning Wt. (Males): Front Royal Lines vs. Topcross Lines

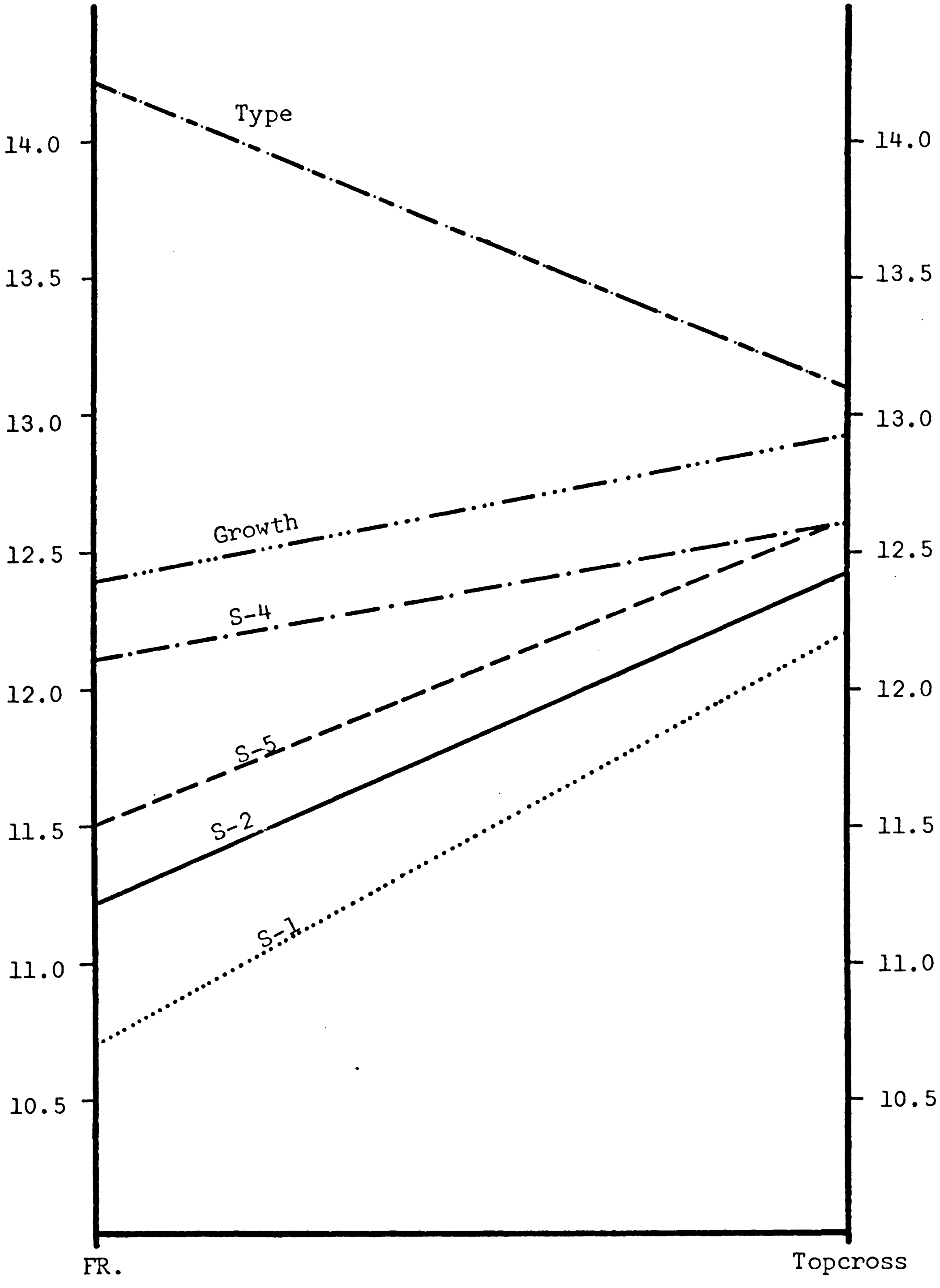

Figure 8. Grade (2) (Males): Front Royal Lines vs. Topcross Lines

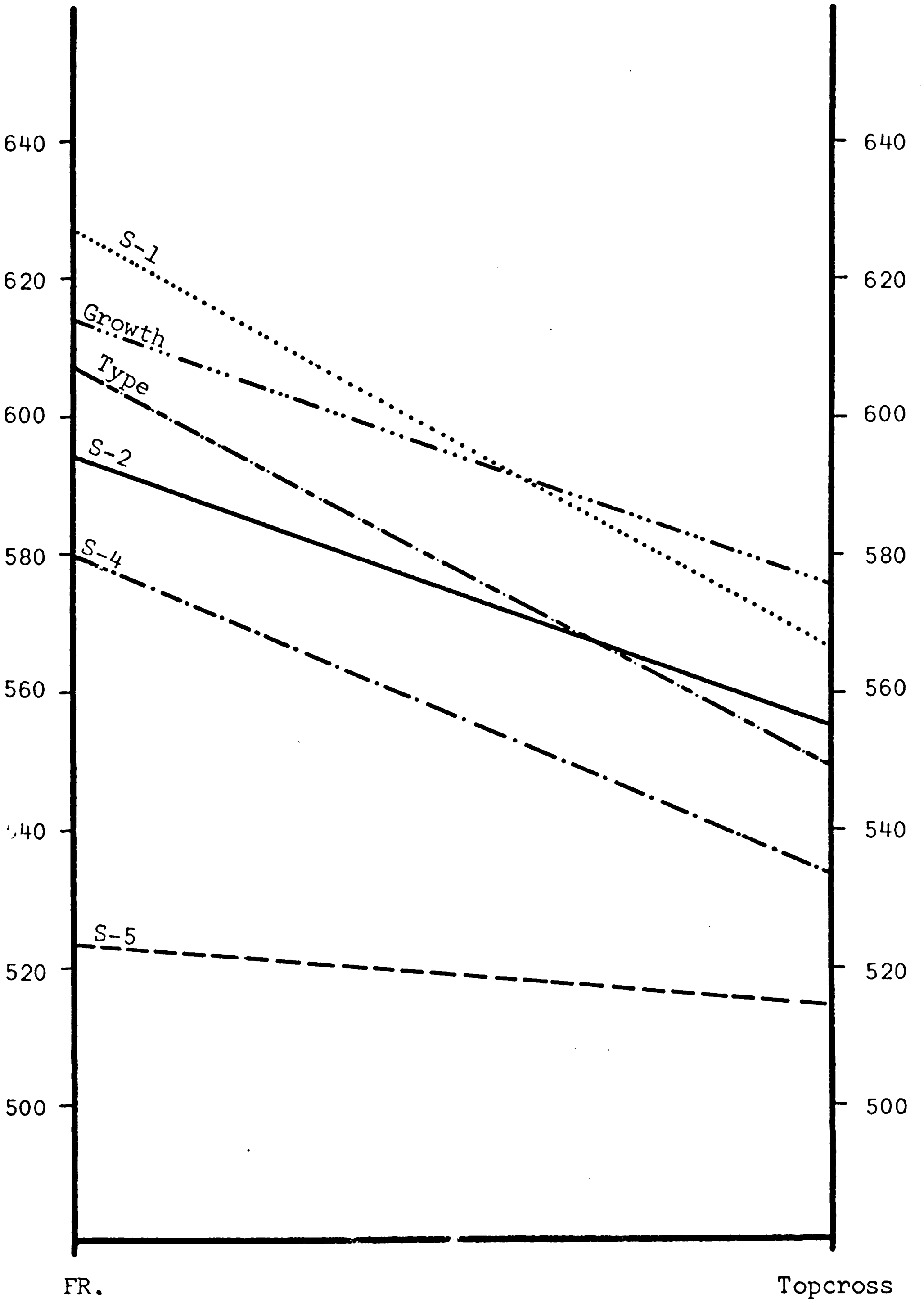

Figure 9. Postweaning Wt. (Females): Front Royal Lines vs. Topcross Lines

SUMMARY AND CONCLUSIONS

The results from this study have shown that topcrossing of inbred and selection lines of cattle can be predicted from the line's own performance. This result is in agreement with reports in the literature. Hayes and Johnson (1939) and Johnson and Hayes (1940) found that the best performing inbred lines of corn produce the best hybrids. It has been shown by Craig and Chapman (1953) that for 13-week body weight in rats, a line's own performance is as reliable as topcrossing performance for indicating the relative value of inbred lines. Flower et al. (1963) found for final weight in Hereford cattle that inbred and topcross performance ranked the same where topcrossing was to an inbred tester.

Prediction of topcrossing performance for preweaning and postweaning growth rate was improved by adjusting for the effects of inbreeding. Since conformation score showed little response to the effects of inbreeding, the adjustment for inbreeding made almost no improvement in predicting topcrossing performance for this trait.

Postweaning weight of the males was a better predictor of topcrossing performance than postweaning weight of the females. The environmental conditions for the males in the postweaning period permitted expression of maximum genetic differences between the lines. Since the management conditions for replacement heifers were those commonly used, the superior value of males for predicting postweaning growth should be utilized in future breeding projects.

Topcrossing, the use of inbred males on outbred females, is the most practical method of using inbred lines of cattle since it avoids the use of inbred females. In topcrossing performance the S-1 and S-2 inbred lines were not significantly different from the Growth line for preweaning or postweaning rate of gain. This result indicates that inbreeding in beef cattle can be as effective in improving growth rate as single trait selection. There is also evidence from topcrossing in the Landrace breed of swine, Bradford, Chapman and Grummer (1958), that certain lines can be selected which produce progeny superior to outbreds in rate of gain. Another important result of the topcrossing experiments of Bradford et al. (1958) was that gilts sired by inbred boars of all breeds appeared to have superior productivity compared to outbred gilts. Rotational topcrossing of the inbred and selection lines of Shorthorn cattle is in progress at Blacksburg. In this system, daughters of bulls of each of the four inbred lines are being mated to bulls of the other three lines. The calves from these matings will be compared to calves sired by Growth and Type selection line bulls. The first calves from these matings were born in 1970. The rotational topcrossing is a further test of the two major breeding systems, inbreeding with crosses among the inbred lines versus mass selection for growth rate or conformation score.

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PREDICTING TOPCROSSING PERFORMANCE OF INBRED

AND SELECTION LINES OF BEEF CATTLE

by

Kitty Phillips Smith

Abstract

Four inbred and two single trait selection lines of Shorthorn cattle were established. Each of four foundation sires, which had been selected on individual performance or progeny testing, were mated to enough unrelated cows to produce thirty-two daughters. Sixteen from each set of the thirty-two daughters were randomly assigned to one of the four inbred lines and of the remaining sixteen, eight were assigned to the Type line and eight to the Growth line. The foundation sire of each inbred line was bred to his daughters and granddaughters for as long as he was serviceable and then replaced by an inbred son. The selection criteria were growth rate from birth to about twelve months of age in the Growth line and conformation score at the same age in the Type line.

The performance of the lines was evaluated from the 1962-66 calf crops. The average level of inbreeding of the calves born in these years was 0.40, 0.37, 0.27 and 0.23 in the S-1, S-2, S-4 and S-5 inbred lines, respectively, essentially zero in the Type line and .06 in the Growth line. The preweaning traits were birth weight, average daily gain, 205-day weight and grade at weaning. After the data were adjusted for age of dam and sex of calf, three statistical methods were used to adjust the data for the effects of inbreeding.

From 1964 to 1967 bulls from each of the inbred and selection lines were mated to unrelated females. Two bulls from each line were used in

the test herd of about 120 cows. The cows were randomized to the sire lines each year. The preweaning traits of the topcross calves birth weight, average daily gain, 205-day weight and grade at weaning were adjusted for sex of calf and age of dam effects.

The topcross line means for the preweaning traits were regressed on the means of the lines themselves. The line's own performance was a good predictor of topcrossing performance for preweaning traits. The best method of adjusting for inbreeding was based on regression coefficients estimated separately for each line and the adjustment made to the average level of inbreeding of the four inbred lines. The best predictions of topcrossing performance were made for birth weight and grade at weaning. The Type line showed the greatest deviations between original line performance and topcrossing performance for average daily gain and 205-day weight.

After weaning the male and female calves, from the lines themselves and the topcross lines, were separated. The male calves were put on postweaning performance tests, and the replacement heifers were fed growing rations. The topcross line means for postweaning weight of the males and females and the postweaning grade of the males were regressed on the means of the lines themselves. The line's own performance, adjusted for inbreeding, was a good predictor of topcrossing performance. The adjusted line means of the males were better predictors of postweaning weight than the adjusted line means of the females.