PREDICTING EFFICIENCY OF GAIN IN SWINE

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INTRODUCTION

Efficiency of gain is a trait of major importance in economical swine production. It indicates how well an individual pig utilizes the feed consumed to produce gain. Since feed cost is the major cost item in swine production, the economic importance of efficient feed utilization is easily understood.

Measuring efficiency of gain requires accurate records of feed consumed and total gain over the feeding period. Genetic improvement in efficiency of gain could be most effectively accomplished by direct selection for this trait. However, this is not easily accomplished because of the labor and expense involved in constructing and operating the extensive feeding facilities necessary for individual measurement of efficiency of feed conversion. This difficulty has led to a search for indirect methods of estimating efficiency of gain.

Many workers have reported substantial correlations between efficiency of gain and other post-weaning performance traits. This indicates that efficiency of gain may be highly predictable from a consideration of other traits.

The main objectives of this study were to determine the phenotypic correlations that exist among performance traits and to predict efficiency of gain when other traits have been measured. Measures taken during post-weaning performance included average weight on test, daily gain, and efficiency of gain for group fed pigs and average test weight, daily gain, efficiency of gain, backfat probe, and average daily feed consumption for individually fed boar pigs.

REVIEW OF LITERATURE

Efficiency of gain during post-weaning feeding tests has been studied and defined in various ways. Probably the most common expression of feed efficiency (efficiency of gain) is the ratio of total feed consumed to total gain over an allotted test period. This ratio may be expressed as feed required per pound of gain or as feed required per 100 pounds of gain.

Other measures of feed efficiency have been utilized in various studies. Carter and Kincaid (1959) expressed feed efficiency as pounds of T.D.N. (total digestible nutrients) required per 100 pounds of gain. They also adjusted this value for mean liveweight. Pierce *et al.* (1954) expressed feed efficiency as feed economy and defined it to be the ratio of T.D.N. to 100 pounds gained in liveweight. Similarly, Bernard *et al.* (1962) expressed feed efficiency as pounds of T.D.N. required per pound of gain.

Magee (1962) defined "desirable" feed efficiency as the ratio of pounds of gain to pounds of feed consumed over an allotted test period. This measure expresses the pounds of gain obtained from the pounds of feed consumed. It might be considered to be a positive measure of feed efficiency because higher values are associated with higher efficiencies; whereas, the conventional measures are negatively associated and higher efficiencies are associated with lower values. To clarify, the more efficient animals have a lower value than the less efficient animals when using the conventional ratio of feed/gain, but a higher value when feed efficiency is expressed as the ratio of gain/feed.

Smith _et al._ (1962) calculated feed efficiency by two methods. Feed conversion (live-weight) was the total feed eaten on test divided by the total liveweight gain. Feed conversion (dead weight) was expressed as total feed eaten on test divided by total dead weight gain. The total dead weight gain was carcass weight minus an estimated initial carcass weight of 30 pounds. All pigs were started on test at an initial live-weight of 50 pounds.

The method of measuring feed efficiency in this study is the more commonly used expression of feed/gain or feed required per pound of gain.

Realizing the economic importance of feed efficiency during post-weaning performance, the breeder must certainly be aware of the need for effective selection to improve feed efficiency. Weaver and Bogart (1944) studied various lines of Poland China swine and stated that there was evidence of considerable genetic control of rate of gain and feed efficiency. Craft (1958) reported that the heritability of feed efficiency is approximately 30 percent. Even though feed efficiency is moderately heritable, the facilities, labor, and individual records required make it an expensive trait to measure. Consequently, rate of gain has been widely used as an alternate measure of feed efficiency because of its association with feed efficiency.

Evvard _et al._ (1927), using group records on 2,833 pigs in 479 lots, reported the phenotypic correlation between daily gains and feed requirements (feed required per 100 pounds of gain) was -.59. Further analyses of the data by division into forage lot pigs and dry lot pigs revealed correlations of -.68 and -.54, respectively.

Lush (1936) studied 1,285 litter samples of Danish bacon pigs and reported that the phenotypic correlation between daily gain and feed units per unit of gain was -.69. Additional analyses on segments of 236 and 392 litter groups revealed correlations of -.76 and -.68, respectively. Dickerson and Grimes (1947) in a study of individually fed Duroc swine obtained a phenotypic correlation between feed per 100 pounds of gain and daily gain of -.66. This estimate had an associated 802 degrees of freedom. An identical estimate of -.66 between daily gain and food conversion (liveweight) was found by Smith *et al.* (1962).

Park *et al.* (1963) reported the phenotypic correlation between feed efficiency expressed as the ratio of gain/feed and gain was 0.15. Data used were from the litter averages of 999 Duroc and Hampshire litters fed from 42 to 154 days of age. The gain and feed consumption measures used to compute litter efficiency of gain were adjusted for litter size for analysis. Also, all measures were transformed into natural logarithms for statistical analyses.

Biswas *et al.* (1963) utilized individual records of Duroc and Yorkshire straightbreds and crossbreds and obtained a correlation estimate of 0.12 between daily gain and feed efficiency where feed efficiency was expressed as the ratio of gain to feed. Similarly, Magee (1962) using individual records of 80 Yorkshire boar pigs reported a phenotypic correlation of 0.24 between "desirable" feed efficiency and daily gain.

Genetic correlations between daily gain and feed efficiency, measured as the ratio of feed/gain, of -.69 and -.78 have been reported by Smith *et al.* (1962) and Dickerson and Grimes (1947), respectively. Biswas *et al.* (1963) reported the correlation to be 0.32 when daily gain and gain per pound of feed consumed were the variables measured. These estimates were all obtained using individual pig records. Genetic correlations between daily gain and feed efficiency using litter group performance records have been reported by Vogt et al. (1963) and Park et al. (1963). Vogt et al. (1963) reported the correlation to be -.22 when growth rate and feed required per 100 pounds of gain were the variables measured. Park et al. (1963) measured daily gain and gain per pound of feed consumed and obtained a genetic correlation of 0.54.

As an interesting note, studies with cattle have revealed very similar correlations to those in swine between daily gain and feed efficiency expressed either as the ratio of feed/gain or gain/feed. A phenotypic correlation of -.50 between daily gain and pounds of T.D.N. required per 100 pounds of gain adjusted for differences in initial mean liveweight was obtained by Carter and Kincaid (1959) from a study of 195 steers fed for 168 days. The genetic estimate was -.32. Nelms and Bogart (1955) utilized individual records of 43 bulls and heifers full-fed from 500 pounds to 800 pounds liveweight and found a phenotypic correlation of -.81 between gain on test and actual pounds of T.D.N. required per 100 pounds of gain for bulls. An estimate of -.56 was found when the T.D.N. required per 100 pounds of gain was adjusted for maintenance. Likewise, the estimates for females were -.63 between daily gain and actual pounds of T.D.N. required per 100 pounds of gain and -.35 between daily gain and corrected T.D.N. requirement per 100 pounds of gain.

Pepito (1961) obtained individual records on 242 Hereford and Angus bull calves and reported that the phenotypic correlation between rate of gain and pounds of feed required per 100 pounds of gain in the feedlot was -.43. Rollins et al. (1962) also studied individually fed Hereford bull calves and obtained a correlation estimate of -.60. Pierce et al. (1954) stated that a correlation of -.82 was observed between daily gain and feed economy. Feed economy was defined as pounds of T.D.N./100 pounds gained in liveweight. Data used were from the individual performance of 19 registered bull calves, 18 registered heifer calves, and 9 grade steer calves. A similar correlation of -.80 between rate of gain and feed efficiency expressed as pounds of T.D.N./pounds of gain was found by Bernard et al. (1962). This study utilized dairy calves fed from 180 to 240 days of age.

Lickley et al. (1960) studied 470 bulls and 202 cows of various breeding lines and computed phenotypic and genetic correlations between daily gain, feed efficiency and feed efficiency adjusted for differences in initial liveweight. They reported phenotypic correlations of -.26 and -.45 for daily gain with feed per pound of gain and adjusted feed per pound of gain, respectively. Genetic correlations were similarly -.41 and -.69. Knapp and Baker (1944) obtained a phenotypic correlation of 0.49 between rate of gain and gross efficiency, expressed as the ratio of feed/gain, from individual records of 66 steers fed for 273 days. This correlation should have been negative in light of the variables measured. However, the extended feeding period appears to have altered the relationship. Conclusions drawn by Knapp and Baker were that selection for feed efficiency by using rate of gain was often in error on animals of various sizes or on a time-constant feeding test period.

Koch et al. (1963) found a genetic correlation of 0.79 between gain and feed efficiency expressed as the ratio of gain/feed. Measures taken on 1,324 individually fed bull and heifer calves of Hereford, Angus and Shorthorn breeding were feed consumption adjusted for differences in gain,

gain adjusted for differences in feed consumption and the ratio of gain to feed consumed.

Brown and Gifford (1962) utilized individual records of 371 Hereford and Aberdeen Angus bulls fed 154 days and obtained a genetic correlation of -.34 between test gain and feed conversion.

Having established that a generally strong negative correlation exists between feed efficiency (feed required per pound or 100 pounds of gain) and daily gain, it should be understood that there is a certain automatic nature between the relationship of the two variables. Feed efficiency is the ratio of feed/gain over an allotted test period; whereas, daily gain is a measure of total gain respective to the period. Therefore, the correlation between feed efficiency and daily gain is the correlation between a ratio and its denominator with respect to a time period.

Sutherland (1963) studied the relationship and automatic element that existed between the correlation of a ratio with its denominator. The magnitude of automatic correlation between rate of gain and feed efficiency was found to be related to the coefficients of variation that exist for the two variables. When the coefficient of variation for gain was greater than the coefficient of variation for feed, the automatic correlation between the two variables was highly negative. An estimated correlation greater than -.87 was predicted if the ratio of coefficients of variation was 1:2 or greater.

The automaticity between daily gain and feed efficiency correlations still does not detract from their usefulness. The correlation still describes the biological situation. Clearly, the faster gaining animal is on feed less time and requires less feed per pound of gain than do the slower gaining animal on a weight constant feeding period. Therefore, the "automatic" nature should not detract from the value of reported correlations between daily gain and feed efficiency, expressed as the ratio of feed/gain.

Correlations between efficiency of gain and other post-weaning performance traits in swine have generally been lower than that for gain. Lush (1936) reported the correlation between units of feed per unit of gain and thickness of backfat as 0.09 from an analysis of 1,285 litters of Danish bacon pigs. Dickerson (1947) obtained an estimate of 0.12 between feed per 100 pounds of gain and backfat thickness. The data were collected from 746 pigs. Smith et al. (1962) reported a phenotypic correlation estimate of 0.19 between food conversion (live-weight) and backfat measured at midback (minimum depth). A genetic correlation of -.92 between carcass backfat and feed efficiency expressed as the ratio of gain to feed was found by Biswas et al. (1963). The phenotypic correlation estimate was -.28. Dickerson (1943) stated that the genetic superiority in growth rate and feed requirements from weaning to final weight was found to be significantly correlated with thicker backfat.

Correlations between efficiency of gain and feed consumption have been reported by some workers. Magee (1962) utilized individual boar pig records to obtain a phenotypic correlation of -.39 between "desirable" feed efficiency and daily feed consumption. Biswas et al. (1963) reported the phenotypic correlation to be -.42 when daily feed consumption and pounds of gain per pound of feed were the variables measured. The genetic correlation was 0.04 which indicates little genetic relationship between daily feed consumption and feed efficiency. Park et al. (1963) stated that the phenotypic correlation between feed consumption of litter groups adjusted for litter size and feed efficiency expressed as the ratio of [illegible] ys [illegible] age [illegible] typic correlation between rate of gain and carcass backfat as 0.29. Dickerson (1947) reported the correlation between rate of gain to 225 pounds liveweight and degree of fatness was 0.60 or more. Winters et al. (1949) supported Dickerson's results and stated that less feed is required to produce a lean animal; therefore, selection based on economy of gain should be inducive to the development of lean animals.

The genetic correlation between daily gain and daily feed consumption in beef cattle was reported by Koch et al. (1963) and Brown and Gifford (1962) to be 0.64 and 0.39, respectively.

Dickerson and Grimes (1947) in a study of Duroc swine reported a correlation of -.54 between feed per 100 pounds of gain and 72 day liveweight. Hazel et al. (1943) studied 152 barrows self-fed to 225 pounds liveweight and found the partial phenotypic correlation between 180 day weight and thickness of backfat was -.18 with final weight held constant. Taylor and Hazel (1955) and Headley et al. (1961) established that liveweight was an affecting trait in rate of gain and feed efficiency. Reviewing these results, it is evident that liveweight is an important variable concerned with post-weaning performance.

Past results indicate that efficiency of gain, expressed as the ratio of feed/gain, is often closely associated with other post-weaning performance traits. Since these other traits are often much more easily measured, efficiency of gain could probably be predicted with reasonable accuracy from measurements on other traits.

Evvard et al. (1927) attempted to predict feed required per 100 pounds of gain using daily gain and initial liveweight. The prediction equation accounted for 47 percent of the variation in feed efficiency. Records of 191 dry lot fed pigs were used to derive the prediction equation. Nelms and Bogart (1955) constructed various equations to predict feed efficiency expressed as pounds of T.D.N. required per pound of gain. They found that 90 to 94 percent of the variation in feed efficiency could be accounted for by measuring birth weight, age on test, and rate of gain. Data used were the individual records of 43 bull and heifer calves of Hereford and Angus breeding full-fed from 500 to 800 pounds liveweight.

Pepito (1961) in a study of 242 Hereford and Angus bull calves measured birth weight, age at weaning, preweaning average daily gain, feeder score, average test weight, average daily gain in the feedlot and pounds of feed per 100 pounds of gain in the feedlot. A coefficient of determination of 56.9 percent was reported when all six variables were used in a prediction equation for feed per 100 pounds of gain in the feedlot. When only average test weight and average daily gain in the feedlot were used, a coefficient of determination of 50.2 percent was obtained. The results indicate that feed efficiency is fairly predictable using average test weight and average daily gain in the feedlot.

Since the coefficient of determination measures the percentage reduction in sum of squares due to regression and is obtained by squaring correlation coefficients, the magnitude of the correlations determine the accuracy of predicting a variable. Therefore, with other post-weaning performance traits correlated with efficiency of gain, one should be able to use these to predict efficiency of gain. This has been the basis for recommending rate of gain as an alternate measure of efficiency of gain.

MATERIALS AND METHODS

Two sources of data were analyzed separately to predict pounds of feed required per pound of gain using other post-weaning performance measures. Data collected came from the post-weaning performance of 184 individually fed boar pigs and from the group performance of 283 sire groups of approximately four pigs per group.

INDIVIDUAL DATA

The individual boar pig performance data were collected from boar pigs of a Hampshire line (OK 14), a Duroc line (OK 3), and a control line (OK 24) which was originally established from crosses involving the Hampshire, Duroc, Beltsville No. 1, Landrace, and Poland China breeds. Data were collected in both Fall and Spring seasons from 1954 to 1959 with an additional group in the Spring of 1963. The above lines were maintained and the boar pigs tested at the Fort Reno Livestock Research Station operated jointly by the Oklahoma State University and the Animal Husbandry Research Division, A.R.S., U.S.D.A.

All boar pigs were placed on test shortly after weaning at about 56 days and self-fed to approximately 175 pounds liveweight. Some pigs were continued on test to 200 pounds liveweight; however, measures used for analyses were generally taken at approximately 175 pounds liveweight. Self-fed rations were identical during a particular year and season, but did change from season to season over the years (appendix tables VI, VII, VIII, IX, and X).

Measures used for analyses of individual data were:

(1) Average test weight (X_1)

$$X_1 = \frac{\text{Initial weight + final weight}}{2}$$

(2) Daily gain (X_2)

$$X_2 = \frac{\text{Total gain on test}}{\text{Number of days on test}}$$

(3) Backfat probe (X_3)

$$X_3 = \frac{\text{Sum of four probes}}{4}$$ (2 behind the shoulder plus 2 over the loin)

(4) Average daily feed consumption (X_4)

$$X_4 = \frac{\text{Total feed consumed on test}}{\text{Number of days on test}}$$

(5) Pounds of feed required per pound of gain (Y)

$$Y = \frac{\text{Total feed consumed on test}}{\text{Total gain on test}}$$

SIRE GROUP DATA

Sire group data were collected from crossbred pigs of reciprocal crosses between Duroc (OK 8) and Beltsville No. 1 (OK 9) lines maintained at Stillwater in the Oklahoma project of the Regional Swine Breeding Laboratory. A total of 88 sires were represented in the 283 sire groups measured in both Fall and Spring seasons from 1953 through 1959 and in the Spring season of 1951. All sire groups were self-fed identical rations during one season and year, but rations did change slightly over seasons and years (appendix tables XI, XII, XIII, XIV, XV, and XVI). The four pigs fed in a lot were litter mates in the early years, but in later years pigs from two litters by the same sire were fed together.

Measures used for analyses were:

(1) Average test weight (X_1)

$$X_1 = \frac{\text{Sum of Individual test weights}}{\text{Number of individuals in group}}$$

(2) Daily gain (X_2)

$$X_2 = \frac{\text{Sum of Individual daily gains}}{\text{Number of pigs in group}}$$

(3) Pounds of feed required per pound of gain (Y)

$$Y = \frac{\text{Total feed consumed by group}}{\text{Total gain of group}}$$

Sire groups generally contained two gilts and two barrows, if possible. Pigs were placed on test at weaning (approximately 56 days) and removed at about 200 pounds liveweight. After the entire group completed the test, the above measures were calculated.

STATISTICAL PROCEDURES

Since sire group data were collected over seasons and years and boar data over seasons, years, and lines, correlation estimates were obtained by pooling corrected sums of squares and sums of crossproducts. This procedure should correct any season, year or line effect present in the data.

Simple phenotypic correlations among traits for both sources of data were computed by the formula:

$$r_{ij} = \frac{\sum x_i x_j}{\sqrt{\sum x_i^2 \cdot \sum x_j^2}}$$

r_{ij} = Correlation coefficient between traits i and j

$\sum x_i x_j$ = Pooled corrected sum of crossproducts

$\sum x_i^2$ = Pooled corrected sum of squares for i trait

$\sum x_j^2$ = Pooled corrected sum of squares for j trait

Prediction equations were derived by forming a matrix of pooled corrected sums of squares and sums of crossproducts and solving for partial regression coefficients by the forward Doolittle procedure. Using a matrix of corrected sums of squares and sums of crossproducts will yield only partial regression coefficients for measured variables. Therefore, the b_o value for each prediction equation of the general model ($Y = b_o + b_1X_1 + \ldots + b_k X_k$) was not obtained by solving equations of the matrix. The b_o value was obtained by the theory formula:

$$b_o = \bar{y} - b_1 \bar{x}_1 - b_2 \bar{x}_2 - \ldots - b_k \bar{x}_k$$

In order to compute the multiple correlation coefficients respective to each equation, the standard partial regression coefficients were computed by the formula:

$$b_i' = \frac{s_i}{s_y} b_i$$

s_i = standard deviation of the i variable

s_y = standard deviation of the y variable

b_i = partial regression coefficient

b_i' = standard partial regression coefficient

Having computed the standard partial regression coefficients, the squared multiple correlation coefficient or reduction sum of squares attributable to regression was computed by the formula:

$$R^2_{y.1,2 \ldots k} = r_{Y1}\, b_1' + \ldots. + r_{Yk} b_k'$$

All formulas and statistical procedures are set forth by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Part I: Sire Group Analyses

Data collected from sire group fed pigs were divided into 15 groups according to year and season. Analysis of variance, Table I, revealed that type of cross (OK 8 x OK 9 or OK 9 x OK 8) had no significant effect; whereas, effects of year, season, and sire were highly significant. Daily gain was the trait used for analysis of variance.

TABLE I

ANALYSIS OF VARIANCE OF DAILY GAIN FOR SIRE GROUP FED PIGS

Source	d.f.		s.s.	m.s.	F
Total	283		861.5716		
Mean	1		855.0021		
Corrected Total	282		6.5695		
Cross	1		.0008	.0008	.037
Between Groups	14		2.8148	.2011	9.397**
Year		7	1.7072	.2439	11.397**
Season		1	.0873	.0873	4.079**
Y x S		6	1.0203	.1700	7.944**
Within Groups	267		3.7539		
Between Sires		59	1.2657	.0214	1.783**
Within Sires		208	2.4882	.0120	

* P<.05

** P<.01

Since analysis of variance revealed the highly significant effects of year and season, sums of squares and sums of crossproducts were corrected within each of the 15 groups. By pooling corrected sums of squares and sums of crossproducts of each group, the effect of year and season were removed.

The measures used for analyses were average test weight (X_1), daily gain (X_2), and pounds of feed required per pound of gain (Y). The mean values were 124.5 pounds for average test weight, 1.74 pounds per day for daily gain, and 3.43 pounds for pounds of feed required per pound of gain. The respective standard deviations were 4.08, 0.12, and 0.21. The coefficients of variation were 3.3 percent for average test weight, 6.8 percent for daily gain, and 6.1 percent for pounds of feed required per pound of gain.

Simple phenotypic correlations were 0.36 between average test weight and daily gain, -.24 between daily gain and pounds of feed required per pound of gain, and 0.05 between average test weight and pounds of feed required per pound of gain. The correlations between average test weight and daily gain and between pounds of feed required per pound of gain and daily gain were significant ($P<.01$), while the correlation between average test weight and pounds of feed required per pound of gain was not significant ($P>.05$).

Comparisons of correlations with those in the literature reveal that the correlation of -.24 between daily gain and pounds of feed required per pound of gain is rather low in comparison with correlations of about -.60 reported by many workers. However, the magnitude of the correlation, -.24, agrees with that of -.22 reported by Vogt et al. (1963) and the general magnitude found in several recent studies correlating daily gain with pounds of gain per pound of feed. Magee (1962) reported the correlation between daily gain and "desirable" feed efficiency as 0.24.

Park *et al.* (1963) found this correlation to be 0.15, and Biswas *et al.* (1963) found it to be 0.12. No specific correlations between average test weight and daily gain nor average test weight and pounds of feed required per pound of gain were found for swine. However, Pepito (1961) reported a correlation of 0.51 between average test weight and average daily gain in the feedlot for individually fed bull calves on a time constant feeding test. This generally agrees with the observed 0.36 correlation found in this study. Similarly, Pepito (1961) observed a correlation of 0.26 between average test weight and pounds of feed required per 100 pounds of gain in the feedlot. The correlation found in this study was 0.05 when average test weight and pounds of feed required per pound of gain were the variables measured. However, factors affecting each correlation are quite different. The sire group pigs were fed on a generally weight constant test; whereas, the individually fed bulls were fed a measured time period of 154 days after weaning.

One prediction equation for pounds of feed required per pound of gain was constructed. Both average test weight (X_1) and daily gain (X_2) were variables used. The equation obtained was:

$$\hat{Y} = 3.33343 + .00815902\ X_1 - .52847748\ X_2$$

$$s_{y.12} = .20114$$

$\hat{Y}$ = predicted pounds of feed required per pound of gain

X_1 = average test weight

X_2 = daily gain

This equation only accounted for 7.95 percent of the variation in pounds of feed required per pound of gain. The standard error of the estimate of $\hat{Y}$ was $\pm.20$.

Standard partial regression coefficients were 0.15875 for b_1 or average test weight and -.29836 for b_2 or daily gain. These results indicate that pounds of feed required per pound of gain is not highly predictable using measures of average test weight and daily gain. However, daily gain does reveal more information about efficiency of gain than does average test weight, when comparing standard partial regression coefficients.

PART II. Individual Analyses

Data from the 184 individually fed boar pigs were divided into 20 groups according to year, season, and line. Realizing that year and season effect were found significant for sire group fed pigs and that breed or line differences could exist, corrections of sums of squares and crossproducts were made within groups.

Mean values, standard deviations, and coefficients of variation for each measured trait are given in Table II.

TABLE II

MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION AMONG TRAITS OF INDIVIDUALLY FED BOAR PIGS

TRAIT	MEAN	S.D.	C.V.
X_1 - Average test weight	115.14	3.75	3.26%
X_2 - Daily gain	1.80	0.18	10.00%
X_3 - Backfat probe	1.33	0.14	10.46%
X_4 - Daily feed consumption	5.73	0.70	12.19%
Y - Pounds of feed required per pound of gain	3.19	0.39	12.20%

Simple phenotypic correlations among all traits measured were computed within each group. Results are presented in Table V in the appendix. Correlations among all traits using pooled sums of squares and sums of crossproducts are presented in Table III.

Comparing reported correlations with the pooled estimates reveals general agreement in most cases. The correlation between daily gain and pounds of feed required per pound of gain of -.40 is somewhat lower than the estimate of -.66 found by Dickerson and Grimes (1947) and Smith _et al._ (1962) using individual records. Dickerson and Grimes (1947) measured feed per 100 pounds of gain and daily gain for individually fed Duroc pigs. Their correlation estimate had an associated 802 degrees of freedom. Smith _et al._ (1962) measured daily gain and feed conversion (liveweight) on 1,936 British Large White bacon pigs individually fed from 50 pounds to 200 pounds liveweight.

Biswas _et al._ (1963) and Magee (1962) reported the correlation between daily gain and pounds of gain per pound of feed to be 0.12 and 0.24, respectively, for individually fed swine. Comparison of the magnitudes of these correlations with the magnitude of the observed correlation of -.40 between daily gain and pounds of feed required per pound of gain reveals a higher linear relationship in these individually fed boar pig data.

Correlations among all performance traits generally agreed with reported findings. However, the correlation between pounds of feed required per pound of gain and average daily feed consumption was greater than reported results. The correlation found in this study was 0.63. Magee (1962) obtained a correlation of -.39 between "desirable" feed efficiency and daily feed consumption using records of 80 individually fed Yorkshire boar pigs. Biswas _et al._ (1963) reported this correlation to be -.42 using the same measures on individually fed Duroc and Yorkshire straightbred and crossbred swine. Park _et al._ (1963) stated that the phenotypic correlation between feed consumption of litter groups adjusted for litter size and pounds of gain per pound of feed was -.28.

TABLE III

PHENOTYPIC CORRELATIONS AMONG TRAITS FOR INDIVIDUALLY FED BOAR PIGS

TRAIT[a]	X_2	X_3	X_4	Y
X_1	0.24**	0.11	0.20**	0.05
X_2		0.21**	0.42**	-.40**
X_3			0.26**	0.12
X_4				0.63**

* $P < 05$

** $P < 01$

a X_1 - Average test weight

X_2 - Daily gain

X_3 - Backfat probe

X_4 - Average daily feed consumption

Y - Pounds of feed required per pound of gain

The correlation between pounds of feed required per pound of gain and backfat probe was 0.12. Lush (1936) reported the correlation to be 0.09 and Dickerson and Grimes (1947) found it to be 0.12. Biswas _et al._ (1963) reported the correlation between carcass backfat and pounds of gain per pound of feed as -.28.

The correlation between daily gain and average daily feed consumption of 0.42 is somewhat lower than that reported by Magee (1962) of 0.79. Similarly, Park _et al._ (1963) reported the correlation to be 0.90 and Biswas _et al._ (1963) reported a correlation of 0.76.

The correlation between average test weight and daily gain was 0.24. This estimate agrees with the correlation of 0.36 found for sire group fed pigs. Pepito (1961) reported the correlation to be 0.51 between average test weight and average daily gain in the feedlot for individually fed bull calves on a time constant feeding test.

Prediction equations derived by regression analysis are presented in Table IV. Equation I utilizes average test weight, daily gain, backfat probe, and average daily feed consumption to predict pounds of feed required per pound of gain. Equation II omits backfat probe and Equation III omits backfat probe and average test weight. Each of these prediction equations account for approximately 94 percent of the variation found in pounds of feed required per pound of gain.

Equation IV omits average daily feed consumption and uses average test weight, daily gain, and backfat probe measures to predict pounds of feed required per pound of gain. Similarly, Equation V omits average daily feed consumption and average test weight. These two equations account for only about 20 percent of the variance in feed efficiency. Therefore, it appears that average daily feed consumption is of major importance in predicting pounds of feed required per pound of gain.

Equation VI is a simple regression equation using only daily gain to predict feed efficiency. This equation only accounts for 16 percent of the variation found in feed efficiency.

As an interesting point, it appears that pounds of feed required per pound of gain is highly predictable using at least daily gain and average daily feed consumption. However, the same facilities and labor are required to measure these two traits as are needed to directly measure pounds of feed required per pound of gain. Therefore, Equation I, II, and III are of little practical value.

Having disqualified Equations I, II and III, one finds that the predictability of feed efficiency is rather poor using measures of average test weight, daily gain and backfat probe.

TABLE IV

PREDICTION EQUATIONS

Y	= b_0	+ b_1X_1	+ b_2X_2	+ b_3X_3	+ b_4X_4	$R^2y.1..k$
I	2.61242	+ .00488X_1	- 1.78972X_2	+ .12203X_3	+ .53671X_4	.9453
II	2.70441	+ .00407X_1	- 1.77857X_2	______	+ .54160X_4	.9436
III	3.23219	______	- 1.75816X_2	______	+ .54494X_4	.9411
IV	2.60001	+ .01448X_1	- 1.02956X_2	+ .58349X_3	______	.2223
V	4.10838	______	- .95960X_2	+ .60819X_3	______	.2035
VI	4.73602	______	- .85890X_2	______	______	.1600

X_1 - Average test weight

X_2 - Daily gain

X_3 - Backfat probe

X_4 - Average daily feed consumption

GENERAL DISCUSSION

In light of previous reported results, it appears that efficiency of gain could be predictable with a small degree of error using other measures of post-weaning performance. A generally strong negative correlation has been reported between daily gain and efficiency of gain, expressed as the ratio of feed/gain. Similarly, other post-weaning performance traits have been found correlated to efficiency of gain. Therefore, one should expect that efficiency of gain would be predictable with a small degree of error.

Results from the analyses of 283 sire groups of crossbred pigs and 184 individually fed boar pigs reveal efficiency of gain is not highly predictable using a measure of daily gain. Correlations found between efficiency of gain and other post-weaning performance measures of average test weight and backfat probe do not add greatly to the predictability of pounds of feed required per pound of gain. The predictability of efficiency of gain seemingly relied upon average daily feed consumption. However, the labor and facilities required to measure average daily feed consumption are the same as those needed to directly measure efficiency of gain.

Comparison of standard partial regression coefficients yields information concerning the importance of single variables that affect efficiency of gain. Figure 1 represents a path coefficient diagram for phenotypic relationships among efficiency of gain, average test weight, daily gain, backfat probe, and average daily feed consumption for boar pig data. Figure 2 represents the phenotypic relationships among efficiency of gain, average test weight, daily gain, and backfat probe. By comparisons of standard partial regression coefficients, it is evident from Figure 1 that average daily feed consumption yields more information concerning efficiency of gain than the other variables. Figure 2 study shows that by omitting average daily feed consumption, daily gain yields more information concerning efficiency of gain.

These results indicate that rate of gain does yield more information about efficiency of gain when no individual measures of feed consumption are made. However, the magnitude of the correlation between daily gain and pounds of feed required per pound of gain is not sufficient to accept daily gain as a good alternate measure of efficiency of gain.

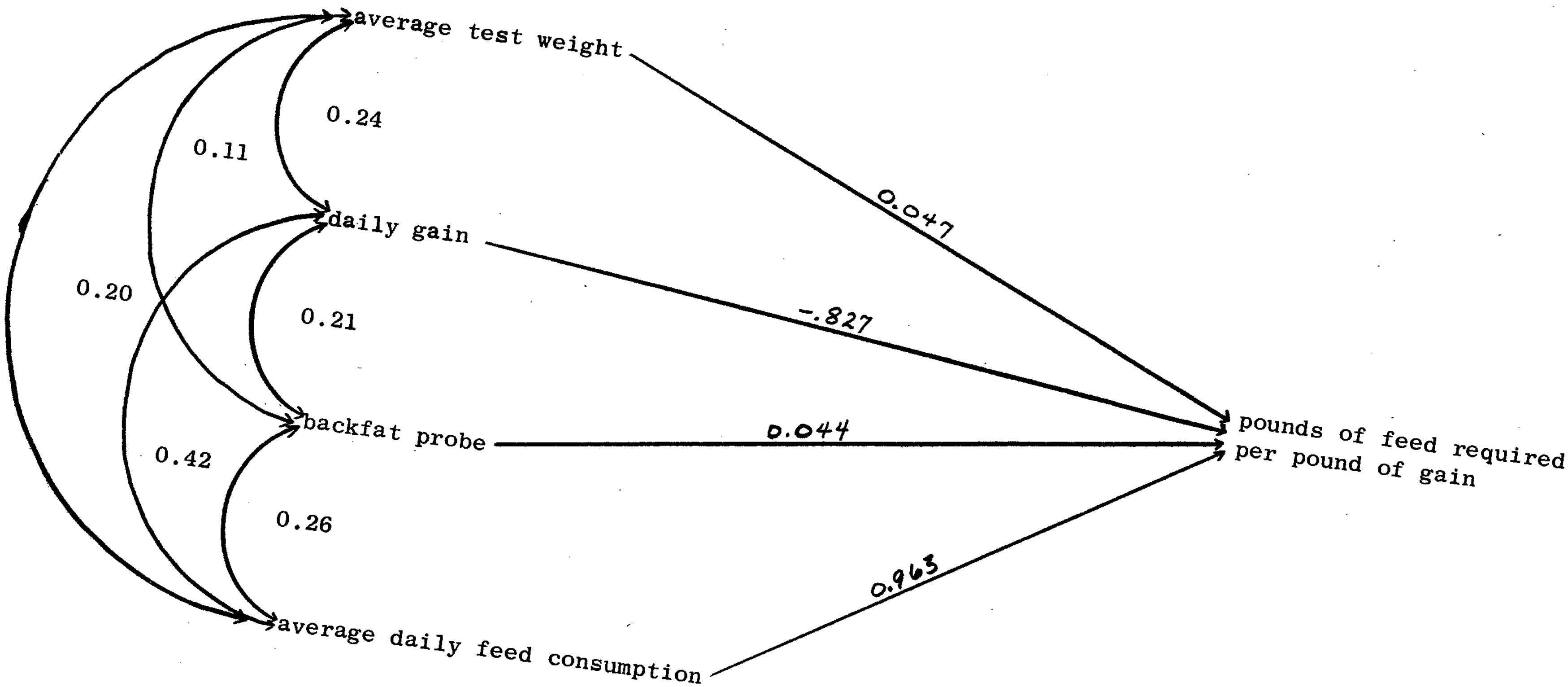

Figure 1. Path coefficient diagram for phenotypic relationships among all traits in individual boar pig data.

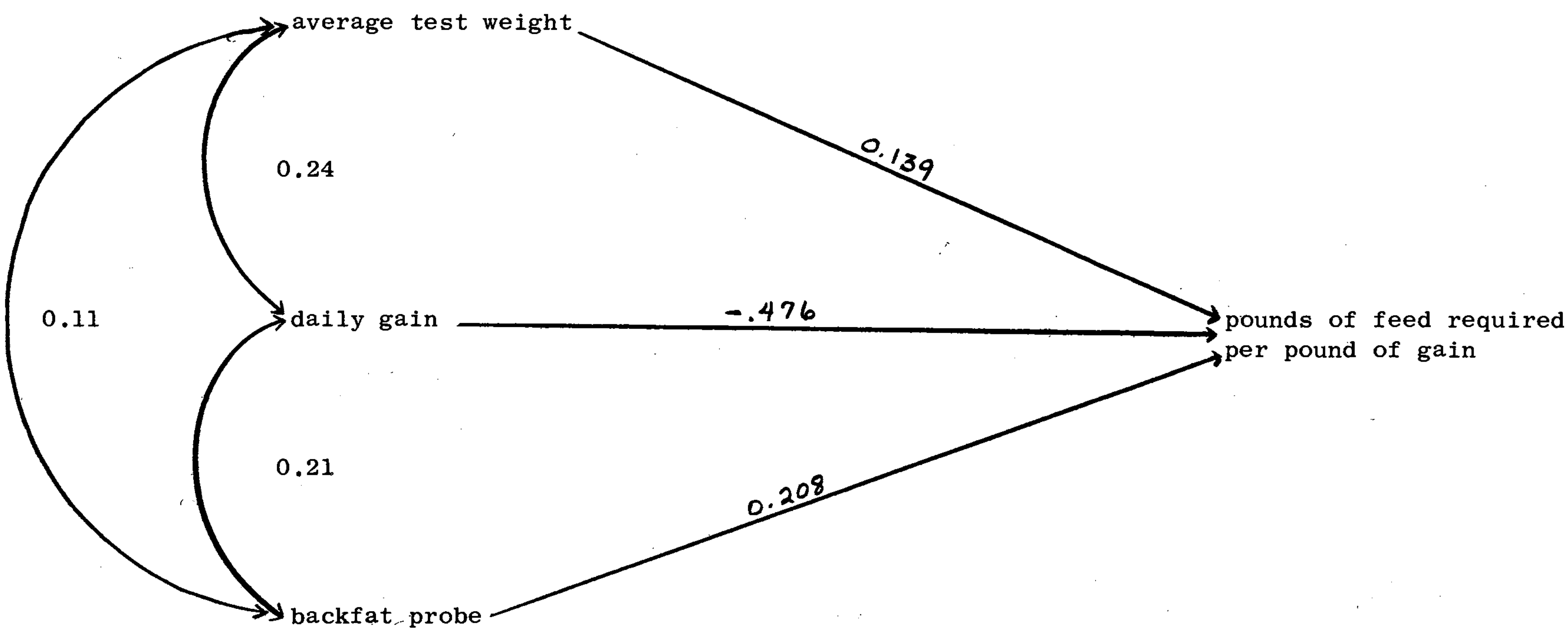

Figure 2. Path coefficient diagram for phenotypic relationships among average test weight, daily gain, backfat probe, and pounds of feed required per pound of gain for individually fed boars.

SUMMARY

Post-weaning performance records of 283 sire groups of approximately four pigs per group and 184 individually fed boar pigs were used to estimate phenotypic correlations among performance traits and to predict efficiency of gain. The two sources of data were analyzed separately.

Performance measures on the sire groups were average test weight, daily gain, and pounds of feed required per pound of gain. Phenotypic correlations obtained by pooling corrected sums of squares and cross-products within season and year were 0.36 between average test weight and daily gain, -.24 between daily gain and pounds of feed required per pound of gain, and 0.05 between average test weight and pounds of feed required per pound of gain.

One prediction equation was constructed by the forward Doolittle procedure to estimate pounds of feed required per pound of gain using measures of average test weight and daily gain. Approximately 8 percent of the variation of actual pounds of feed required per pound of gain was accounted for by the equation.

Performance measures on individually fed boar pigs were average test weight, daily gain, backfat probe, average daily feed consumption, and pounds of feed required per pound of gain. Phenotypic correlations among traits were computed within each year, season, and line. Pooled sums of squares and crossproducts within each year, season, and line were also used

to obtain pooled estimates of correlation coefficients among traits. The correlation between daily gain and pounds of feed required per pound of gain was -.40. The correlation between average daily feed consumption and pounds of feed required per pound of gain was 0.63. The correlation between daily gain and pounds of feed required per pound of gain was 0.42. These correlations were of the greatest magnitude and importance in predicting efficiency of gain. The correlation of 0.63 between average daily feed consumption and pounds of feed required per pound of gain is somewhat larger than reported elsewhere. The correlation of 0.42 between daily gain and average daily feed consumption is lower than reported results.

Six prediction equations were constructed to predict pounds of feed required per pound of gain. Those equations containing measures of daily gain and average daily feed consumption accounted for approximately 94 percent of the variation. Equations omitting average daily feed consumption failed to account for more than 23 percent of the variation.

The results of this study indicate that the correlation between daily gain and efficiency of gain is lower under these conditions than that generally reported. The predictability of efficiency of gain relied upon a measure of average daily feed consumption. To measure average daily feed consumption would involve the same labor and facilities as needed to directly measure efficiency of gain. By omitting average daily feed consumption measures, daily gain yields more information toward predicting efficiency of gain. However, the magnitude of the correlation between daily gain and efficiency of gain is not sufficient to accept daily gain as a good alternate measure of efficiency of gain.

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APPENDIX

TABLE V

WITHIN GROUP PHENOTYPIC CORRELATIONS AMONG TRAITS FOR INDIVIDUALLY FED BOAR PIGS

GROUP	r_{X1X2}	r_{X1X3}	r_{X1X4}	r_{X1Y}	r_{X2X3}	r_{X2X4}	r_{X2Y}	r_{X3X4}	r_{X3Y}	r_{X4Y}	NO.
1954 Fall line 3	0.45	-.51	0.12	-.19	0.50	0.07	0.59	0.14	-.20	0.77	6
1954 Spring line 3	0.47	0.09	0.30	-.14	0.00	0.71	-.25	0.26	0.34	0.51	9
1955 Fall line 3	0.45	0.18	0.42	0.37	-.31	0.63	-.49	0.40	0.74	0.17	6
1955 Fall line 14	0.26	0.29	0.14	0.18	-.25	0.09	-.20	0.12	0.23	0.74	12
1955 Spring line 3	-.69	0.48	0.26	0.79	-.39	0.15	-.74	-.09	0.60	0.34	9
1955 Spring line 14	0.33	-.64	-.33	-.54	0.26	0.38	-.20	0.45	0.30	0.83	6
1956 Fall line 3	0.64	0.37	0.29	0.21	0.05	0.54	0.19	0.09	0.09	0.93	11
1956 Fall line 14	0.02	-.04	0.12	0.05	-.07	0.47	-.62	0.54	0.55	0.39	12
1956 Spring line 3	0.15	0.00	-.52	-.37	0.93	-.37	-.82	-.49	-.83	0.82	5
1956 Spring line 14	0.14	0.14	0.42	0.41	-.64	0.57	-.04	-.24	0.16	0.79	9

TABLE V

(continued)

GROUP	r_{X1X2}	r_{X1X3}	r_{X1X4}	r_{X1Y}	r_{X2X3}	r_{X2X4}	r_{X2Y}	r_{X3X4}	r_{X3Y}	r_{X4Y}	NO.
1957 Fall line 14	0.29	-.22	-.04	-.35	0.38	0.70	-.30	0.38	-.00	0.47	12
1957 Spring line 3	-.04	0.37	0.65	0.61	0.62	0.60	-.75	0.60	-.31	0.07	9
1957 Spring line 14	0.41	0.39	0.64	0.26	0.69	0.59	-.42	0.53	-.12	0.48	13
1958 Spring line 3	0.74	0.74	0.32	-.24	0.73	0.63	-.08	0.77	0.34	0.72	7
1958 Spring line 14	0.57	-.03	0.07	-.45	0.73	0.54	-.28	0.31	-.29	0.64	8
1959 Fall line 3	0.13	0.16	0.41	0.70	0.86	0.92	0.58	0.76	0.44	0.85	6
1959 Fall line 14	0.81	0.38	0.66	-.31	0.24	0.52	-.63	0.16	-.06	0.33	6
1959 Spring line 3	-.04	-.24	0.48	0.40	0.73	-.20	-.60	-.17	-.45	0.90	6
1959 Spring line 14	0.34	0.04	0.14	-.19	0.44	0.40	-.58	0.54	0.09	0.49	14
1963 Spring line 24	-.09	0.09	0.10	0.23	0.17	0.45	-.46	0.32	0.18	0.58	18

TABLE VI

RATION FOR INDIVIDUALLY FED BOARS
FROM 1954 THROUGH 1955

Components	Percentage
Ground wheat	73.3
Ground alfalfa hay	5.0
Soybean meal (44%)	13.6
Tankage (60%)	5.0
Salt	1.0
Bone meal	1.5
Aurofac	0.5
Fortafeed	0.1
Vitamin A and D oil	20 cc per 100 lbs.

TABLE VII

RATION FOR INDIVIDUALLY FED BOARS
FROM 1956 THROUGH 1957[a]

Components	Percentage
Ground yellow corn	73.0
Dehydrated alfalfa meal	5.0
Soybean meal (44%)	13.6
Tankage (60%)	5.0
Bone meal	1.5
Iodized salt	1.0
Aurofac	0.5
Fortafeed	0.1
Vitamin A and D premix	3.0

[a] pelleted

TABLE VIII

RATIONS FOR INDIVIDUALLY FED BOARS FOR 1958[a]

Components	Percentage	
	Weaning to 100 lbs.	100 lbs. to 175 lbs.
Ground yellow corn	38.0	41.0
Ground milo	38.0	41.0
Soybean meal (44%)	13.0	10.0
Meat and bone scrap	5.0	3.0
Dehydrated alfalfa meal	4.0	3.0
Dicalcium phosphate	0.5	0.5
Trace mineral salt	0.5	0.5
Vitamin-antibiotic premix	0.75	0.5
Hygromix	0.25	0.0

[a] pelleted

TABLE IX

RATIONS FOR INDIVIDUALLY FED BOARS FOR 1959[a]

Components	Percentage	
	Weaning to 100 lbs.	100 lbs. to 175 lbs.
Ground yellow corn	38.0	41.0
Ground milo	38.0	41.0
Soybean meal (44%)	13.0	10.0
Meat and bone scraps	5.0	3.0
Dehydrated alfalfa meal	3.5	3.0
Dicalcium phosphate	1.0	1.0
Trace mineral salt	0.5	0.5
Vitamin-antibiotic premix	0.75	0.5
Hygromix	0.25	0.0

[a] pelleted

TABLE X

RATIONS FOR INDIVIDUALLY FED BOARS FOR 1963

Components	Percentage	
	Weaning to 100 lbs.	100 lbs. to 175 lbs.
Ground milo	69.75	40.00
Ground wheat	0.00	40.00
Molasses	5.00	5.00
Soybean meal (44%)	20.00	10.00
Dehydrated alfalfa meal	2.50	2.50
Dicalcium phosphate	1.00	1.00
Ground limestone	1.00	0.75
Salt	0.50	0.50
Antibiotic-Trace mineral-Vitamin premix	0.25	0.25

TABLE XI

RATION FOR SIRE GROUP FED PIGS FOR 1951

Components	Percentage
Shelled corn	Free choice
Protein-mineral supplement	Free choice
Tankage (60%)	19.42
Soybean meal (44%)	29.13
Cottonseed meal	19.42
Alfalfa meal	19.42
Aurofac	3.88
Trace mineralized salt	2.91
Bone meal	2.91
Ground limestone	2.91

TABLE XII

RATIONS FOR SIRE GROUP FED PIGS FROM 1953 THROUGH 1955

Components	Percentage		
	1st Month	2nd month to 140 lbs.	140 lbs. to market wt.
Ground yellow corn	75.000	80.00	85.00
Tankage (60%)	5.000	4.00	3.00
Soybean meal (44%)	12.500	10.00	7.50
Alfalfa meal	5.000	4.00	3.00
Aurofac	.625	.50	.375
Iodized salt	.625	.50	.375
Bone meal	.625	.50	.375
Ground limestone	.625	.50	.375

TABLE XIII

RATIONS FOR SIRE GROUP FED PIGS FOR 1956

Components	Percentage	
	Weaning to 100 lbs.	100 lbs. to market wt.
Ground yellow corn	75.00	80.00
Soybean meal (44%)	12.50	10.00
Alfalfa meal	5.00	4.00
Tankage (60%)	5.00	4.00
Bone meal	1.00	.80
Iodized salt	.89	.72
Aurofac	.50	.40
Fortafeed	.10	.08
Vitamin A and D powder	10 grams	8 grams

TABLE XIV

RATIONS FOR SIRE GROUP FED PIGS FOR 1957

Components	Percentage	
	Weaning to 100 lbs.	100 lbs. to market wt.
Ground milo	78.00	85.00
Soybean meal (44%)	11.11	7.45
Tankage (60%)	4.40	2.95
Alfalfa meal	4.40	2.95
Bone meal	.99	.66
Ground limestone	0.00	.25
Trace mineralized salt	.55	.30
Aurofac	.44	.30
Fortafeed	.09	.06
Vitamins A and D	.02	.01
Zinc sulfate	.01	.01

TABLE XV

RATIONS FOR SIRE GROUP FED PIGS FOR 1958[a]

Components	Percentage	
	Ration 3[b]	Ration 8[c]
Ground yellow corn	38.0	41.0
Ground milo	38.0	41.0
Soybean meal (44%)	13.0	10.0
Meat and bone scraps	5.0	3.0
Alfalfa meal	4.0	3.0
Ground limestone	0.0	0.5
Dicalcium phosphate	0.5	0.5
Trace mineralized salt	0.5	0.5
Vitamin-antibiotic premix	0.75	0.5
Hygromix	0.25	0.0

[a] pelleted
[b] initial ration fed until 150 lbs. consumed
[c] ration fed to market weight after 150 lbs. consumption of ration 3

TABLE XVI

RATIONS FOR SIRE GROUP FED PIGS FOR 1959[a]

Components	Percentage	
	Ration 9[b]	Ration 10[c]
Ground yellow corn	38.00	41.00
Ground milo	38.00	41.00
Soybean meal (44%)	13.00	10.00
Meat and bone scraps	5.00	3.00
Alfalfa meal	3.50	3.00
Dicalcium phosphate	1.00	1.00
Trace mineralized salt	.50	.50
Vitamin-antibiotic premix	.75	.50
Hygromix	.25	0.00

[a] pelleted
[b] initial ration fed until 150 lbs. consumed
[c] ration fed until market weight after 150 lbs. consumption of ration 3

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