GENETIC ASPECTS OF A CONTROL POPULATION OF SWINE

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CHAPTER 1

INTRODUCTION

Genetic controls are defined as genetically stable populations which when subjected to the same environmental conditions as the selected populations, provide the contrast needed to measure absolute genetic response to selection. The absence of adequate controls in animal breeding research has made it difficult, if not impossible, to interpret the results from many selection experiments. The results currently available on control populations are primarily limited to laboratory organisms and poultry. Knowledge of the feasibility and effectiveness of maintaining swine control populations is extremely limited. Also, estimates of genetic parameters in swine have been obtained from experimental populations under a wide variety of breeding and selection procedures and may be somewhat biased.

Oklahoma's contribution to the Regional Swine Breeding Laboratory consists of selection for crossing ability in swine. To measure the selection progress in this project, a zero-selection control line was established in the Oklahoma swine breeding herd in 1961.

The purpose of this investigation was to analyze the data collected in this control population from 1962 to 1968 with the following objectives: (1) to determine if the population had remained genetically stable since its foundation, (2) to determine the effectiveness of the selection procedures used in this study, (3) to obtain estimates of heritability for the various traits, and (4) to obtain genetic and phenotypic correlations between the various traits.

CHAPTER II

REVIEW OF LITERATURE

Control Populations

Gowe et al. (1959) summarized the functions of control populations as follows:

1. To assess the magnitude of short term fluctuations in environment and to furnish a means of correction.
2. To maintain genetic constancy over a period of time, thereby enabling the evaluation of long term trends in the environment.
3. To serve as a gene pool with known genetic parameters for use as base material in selection experiments.

The above functions are realized in varying degrees depending on the type of control population used.

Two important characteristics of random-bred controls are that each individual in the population has an equal chance of contributing progeny to the next generation and also, the effective number of breeding animals must be sufficiently large to avoid random drift and provide a reasonably accurate measure of the population mean. Goodwin et al. (1955 and 1960) recognized the value of random-bred controls but also noted several possible sources of error in estimating genetic changes in other populations maintained with this type of control. First of all the control populations do not remain stable genetically. Although these changes can be estimated, they are normally calculated with some degree of bias. The second point that could possibly be a source of error is that control populations do not always respond to environmental changes in the same manner as other populations under study. To avoid these sources of variation Goodwin et al. (1955) suggested the replication of generations of progeny from the same parents. This system of control is usually referred to as repeat mating controls. If the control population can be held genetically constant in two successive years, estimates of genetic change can be made without having to assume that no genetic changes have occurred from natural selection, relaxed selection, inbreeding, or random drift. Progeny from unselected repeat matings in successive years have identical expected genotypic means. This expectation is, of course, independent of sampling error. It also assumes that there is no change in any parental influence or progeny performance. This type of mating permits control populations of a given generation in two successive years to be maintained in an environment that differs only randomly from that for other populations under selection.

Lasley (1960) examined the relative efficiencies of random-bred and repeat-mating controls from a culture of Tribolium castaneum. The foundation stock consisted of 12 pairs of males and females with each pair of parents contributing equally to lines of three sizes. Thirty-six small lines, 12 intermediate lines, and eight large lines were used to compare the two types of controls. Each small line was propagated with one male and two females, each intermediate line with six males and 12 females, and each large line was propagated with 12 males and 24 females. Traits considered in this study were number of eggs laid in a 48-hour period, number of live forms born surviving to pupation, and individual pupa weight. It was concluded from this study that equal numbers of full-sib families will estimate environmental changes in single generation intervals more precisely when repeat matings are used instead of random-bred lines. However, after only a few generations, the advantage will shift in favor of the random-bred controls. From these data, greatest efficiency was obtained with the random-bred controls if the number of males in the breeding herd was equal to the number of females. Lasley also points out that a performance trend in the selected population, caused by inbreeding depression, will be classified as genetic if repeat matings are employed and as environmental if random-bred controls are utilized. If both types of controls are used, we can evaluate three trends in a single selection study: the trend caused by deliberate selection, the trend caused by environmental change, and the trend caused jointly by inbreeding depression and natural selection. These trends will not be confounded if both types of controls are used or if the population under selection and the random-bred controls are very large so that the effects of inbreeding are negligible.

The rate of inbreeding is influenced largely by population size. Falconer (1960) defines effective population size as the number of individuals that would give rise to the sampling variance or the rate of inbreeding appropriate to the conditions under consideration, if they bred in the manner of the idealized population. If the sexes are unequally represented among the breeding animals, the sampling variance attributable to the two sexes must be reckoned separately. Since the sampling variance is proportional to the reciprocal of the number, the effective number (Ne) is twice the harmonic mean of the numbers of the two sexes (Wright, 1931), so that

$$\frac{1}{Ne} = \frac{1}{4Nm} + \frac{1}{4Nf}$$

where Nm and Nf are the actual numbers of males and females, respectively. The rate of inbreeding (ΔF) is then

$$\Delta F = \frac{1}{8Nm} + \frac{1}{8Nf}.$$

If the sexes are equally distributed among the breeding animals and if two members of each family are deliberately chosen to be parents of the next generation, then the effective number is twice the actual number of breeding individuals. Under these special circumstances the rate of inbreeding is half what it would be in an idealized population of equal size.

In small populations, gene frequency changes can occur which are predictable in amount but not in direction. These random gene frequency fluctuations are attributed to the dispersive process, inadequate gamete sampling. It is possible to determine the size of this dispersive process in small populations by using the above formula which gives the anticipated increase in inbreeding. As a result, genetic equilibrium in the population may be upset and genetic drift can be in evidence.

Heritability Estimates

A summary of the heritability estimates for various genetic parameters is found in Table 1. The figure appearing under "Simple Average" is the arithmetic mean of all estimates found in the literature. Estimates in the literature were obtained by a variety of statistical

TABLE I

REVIEW OF HERITABILITY ESTIMATES

Trait	Number Estimates	Range	Simple Average	References
Number pigs born	9	-.04 to 0.44	0.12	7,8,18,37,39,55,60,75
Pig birth weight	3	0.00 to 0.05	0.02	48,52
Litter birth weight	1		0.36	18
Number pigs at 21 days	2	0.20 to 0.34	0.27	7,25
Pig 21 day weight	3	-.03 to 0.04	0.00	7,58,70
Number pigs weaned	12	-.09 to 0.32	0.14	3,7,11,15,16,18,29,52,53,56,57,79
Pig weaning weight	16	-.18 to 0.24	0.08	2,9,10,11,12,17,22,29,48,57,73,81,83,86
Litter weaning weight	3	0.02 to 0.37	0.16	3,7,16
Average daily gain	27	0.14 to 0.77	0.31	4,5,6,9,12,15,16,20,22,24,29,30,43,44, 51,54,58,63,65,71,72,73,81,83,86
Age at 200 pounds	6	-.07 to 0.68	0.39	1,9,28,43,59,76
Probe backfat	17	0.15 to 0.87	0.40	1,13,34,35,36,40,41,52,53,64,65,73,86

procedures and from populations varying greatly in size and genetic composition. The average given for each trait should be taken as such and not as the best estimate available.

Birth Traits

Estimates of the heritability of litter size in swine ranged from 0.10 to 0.44 in a review by Lush and Molln (1942). These workers considered that the estimate of 0.17 from their own data was in close agreement with other findings. Additional reports by Hallqvist (1942), Hetzer et al. (1940), and Olbrycht (1943) are within the range of earlier reports. Stewart (1945b) reported that litter size at birth had a heritability of 0.17.

In a study involving 1970 daughter-dam pairs, Boylan et al. (1961) found that the heritability for litter size ranged from -.04 ± 0.10 to 0.17 ± 0.14 for three breeds of swine studied. The overall heritability estimate was 0.03 ± 0.07. Cummings et al. (1947) reported heritabilities of 0.22 for number of pigs born alive and 0.36 for total litter weight at birth based on daughter-dam regression analysis. This exact same figure ($h^2 = 0.22$) for number of pigs farrowed alive was reported by Blunn and Baker (1949).

Louca and Robison (1965) studied the heritability of birth weight based on paternal half-sib correlations and found it to be essentially zero. In this same study the heritability of litter size at birth based on daughter-dam regression (245 pairs) was 0.05. Krider et al. (1946) stated that heritable differences in weight of swine increased steadily from five percent at birth to 24 percent at 180 days of age. The percentage of the variance due to non-heritable differences decreased from

40 percent at birth to 14 percent at 180 days of age.

Estimates of the heritability of litter size at birth range from -.04 to 0.44 with most estimates being below 0.20. Most estimates of the heritability of pig birth weight are near zero.

21 Day Weights

There are only a limited number of reports in the literature concerning the heritability of litter size, litter weight, or pig weight at 21 days of age. However, in an extensive study by Blunn and Baker (1949), information was secured on 561 litters. These litters were produced by 331 different sows and 76 different sires. Heritability of number of pigs alive at 21 days of age was 0.27 estimated from intra-sire regression of daughter on dam. Heritability estimated from repeatability of sow performance increased to 0.34 with the average heritability estimate being 0.27. Hetzer *et al*. (1940) reported a correlation of 0.16 between litters from the same sow for litter size at 28 days of age. The corresponding figure from the work of Blunn and Baker (1949) was 0.34 for litter size at 21 days of age.

Fahmy and Bernard (1969) analyzed the records of 751 gilts of three lines of Yorkshire pigs derived from a common population. Estimates of the heritability of litter weight at 21 days ranged from -.07 ± 0.22 to 0.31 ± 0.27 based on intra-sire regression of offspring on dam. The overall pooled estimate for the three lines was 0.14.

Number of Pigs Weaned

Louca and Robison (1965), using 245 daughter-dam pairs, found the heritability of litter size at 56 days to be 0.19. Cummings *et al*.

(1947) reported a heritability of 0.32 for litter size at weaning. In the study by Lush and Molln (1942), number of pigs weaned per litter was determined to be 16 percent heritable.

From a study of 969 gilt litters, Bernard et al. (1954) reported a heritability of 0.06 for number of pigs weaned at 56 days of age. Blunn and Baker (1949) reported that litter size at weaning had a heritability of 0.22. The lowest estimate of the heritability of litter size at weaning found in the literature was reported by Cockerham (1952). This study was based on a total of 1980 litters. Heritability of litter size at 56 days was found to be -.09 ± 0.08.

Heritability of litter size at weaning ranges from the -.09 reported by Cockerham to the estimate of 0.32 by Cummings et al. (1947). Additional reports by Craft (1953), Craft (1958), Fredeen (1962), Louca and Robison (1967), and Noland et al. (1966) are all within the range of the above estimates. The average of all estimates found in the literature was 0.14 for heritability of litter size at weaning.

Weaning Weight

Estimates of the heritability of litter weaning weight range from 0.02 reported by Bernard et al. (1954) to 0.37 reported by Blunn and Baker (1949). The average of all estimates found in the literature was 0.16 for litter weaning weight.

Heritability estimates found for individual pig weaning weight were slightly below those for total litter weaning weight. Cunningham (1969) reviewed the literature and found a range from -.18 to 0.24 for the heritability of individual pig weaning weight. The average of 16 estimates was 0.08.

Postweaning Daily Gain

Blunn et al. (1953) analyzed records from 2748 pigs to determine the heritability of gain in three growth periods. The growth periods studied were (1) birth to 56 days, (2) 56 to 112 days, and (3) 112 to 154 days. Based on intra-sire regression of offspring on dam, heritability estimates of gain were 0.11, 0.28, and 0.08 for the three periods, respectively. Heritability of gain based on paternal half-sib relationships in the three periods were 0.22, 0.51, and 0.25, respectively, for 2176 pigs at North Platt and 0.02, 0.35, and 0.34, respectively, for 572 pigs at the Lincoln station. These workers concluded that if growth rate is one of the criteria upon which selections are based, gain from 56 to 112 days of age can be used satisfactorily. It has the advantage of being available relatively early and it is based more upon growth in bone and muscle and less on fatness than is gain at a later period.

Biswas et al. (1966), studying the relationships between gain, efficiency, and consumption, estimated heritability of average daily gain at 0.77 ± 0.37. The Wisconsin work was based on 185 individually fed straightbred and crossbred pigs. Blunn and Baker (1947) estimated heritability of gain during two periods. The periods were (1) 56 to 112 days, and (2) 112 days of age to time of slaughter (at approximately 225 pounds). The heritability estimates were 18 percent and 14 percent, respectively. Hazel et al. (1943) found heritability to be 28 and 17 percent, respectively, for the two comparable periods.

In Craft's (1958) summary of heritabilities, growth rate from weaning to 180-200 pounds ranges from 14 to 58 percent with an approximate average of 29 percent. These estimates were based on reports of investigations largely in the Regional Swine Breeding Laboratory and from several foreign countries.

Dickerson and Grimes (1947) estimated heritability of gain at 0.43 ± 0.10 from the regression of offspring on the paternal mean. A total of 567 pigs from 87 litters were used in this study. When heritability was based on regression of offspring on dam the value dropped to 0.29 ± 0.09. El-Issawi and Rempel (1961) obtained estimates of the heritability of daily gain from weaning to 140 or 154 days of age for pigs of the Minnesota No. 1, Minnesota No. 2, and Minnesota No. 3 breeds on an intra-station and intra-year basis. Estimates were computed on the basis of the intra-sire regression of offspring on dam and from gross regression of offspring on dam. The final pooled estimates were 0.14 ± 0.10 based on intra-sire regression and 0.28 ± 0.06 based on gross regression. The degrees of freedom for the two estimates were 451 and 1419, respectively.

Nordskog _et_ _al_. (1944) estimated heritability of gain from birth to 200 pounds to be 0.03. From weaning to 200 pounds the estimate was 0.21. These estimates were from regression of offspring on dam with a total of 312 pairs of dams and their litters. Corresponding figures based on paternal half-sib correlation analysis were 0.21 and 0.40, respectively, for the two periods. The differences were attributed to sampling error.

Cunningham (1969) reported a range of 0.15 to 0.77 from a review of the literature. In this review, the simple average of 26 estimates of heritability of daily gain was 0.33.

Probe Backfat

Gray et al. (1968) reported a realized heritability of 0.32 for probe backfat. This estimate was based on the average of three probes. In another study, Gray et al. (1964) studied the genetic aspects of backfat probes at different weights. Probes from the shoulder, loin, and ham were obtained from 208 boars and 233 gilts from a mildly inbred herd of Poland China pigs. Heritability estimates based on paternal half-sib analysis were 0.62 ± 0.21, 0.42 ± 0.17, and 0.35 ± 0.16 for pigs weighing 125, 150, and 175 pounds, respectively. Heritability estimates for shoulder, loin, and rump probes were 0.34 ± 0.16, 0.53 ± 0.20, and 0.57 ± 0.20 for 125 pound pigs; 0.14 ± 0.10, 0.29 ± 0.14, and 0.53 ± 0.20 for 150 pound pigs; and 0.21 ± 0.12, 0.21 ± 0.12, and 0.42 ± 0.17 for 175 pound pigs, respectively.

Cox (1964) used the records of 7642 pigs to study heritability of backfat thickness at a constant age of 154 days. Using regression of offspring on dam a heritability estimate of 0.22 ± 0.02 was obtained. This is somewhat lower than other estimates in the literature but it should be remembered that most investigators probe at a constant weight instead of a constant age. Probing at a constant age would probably tend to increase the environmental component among pigs within a litter in comparison with what would be obtained by measuring probe at a nearly constant weight and ignoring age.

The lowest estimate for the heritability of probe backfat found in the literature was 0.09 reported for crossbred females by Louca and Robison (1967). The highest estimate found was 0.79 for a selected line reported by Hetzer and Harvey (1967). The wide range of heritabilities found in the literature can probably best be explained by the variation in methods used to determine probe backfat. Some reports are based on two probes per animal, some on four probes per animal, and others are the average of six probes per animal. The type of probing device is also variable. Therefore, when considering heritabilities of probe backfat, the methods employed by the experimenter should be carefully considered.

The simple average of 16 estimates of the heritability of probe backfat was reported to be 0.40 by Cunningham (1969).

Age at 200 Pounds

Heritability estimates for age at approximately 200 pounds range from -.07 (Sviken, 1966) to 0.68 (Fredeen, 1953). Other estimates found were 0.11 (Arganosa, 1968), 0.45 (Broderick, 1961), 0.57 (Johansson and Korkman, 1951), and 0.45 (Norwichi, 1961). An approximate average of all estimates found in the literature would be 0.39 for the heritability of age at 200 pounds.

Genetic and Phenotypic Correlations

A brief summary of genetic and phenotypic correlations between various preweaning and postweaning traits are found in Tables II and III, respectively. These correlations are referred to in the Results and Discussion section of this thesis and will not be reviewed in this section.

Many of the genetic correlations, in particular, are based on inadequate numbers and insufficient sampling techniques. Values reported in the literature range from less than -1.0 to greater than 1.0. They are presented in table form for the convenience of the reader and should be studied with the above precautions in mind.

TABLE II

REVIEW OF GENETIC CORRELATIONS

Traits Correlated	Number Estimates	Range	Simple Average	References
Birth weight and:				
Probe backfat	5	<-1 to >1	?	53
154 day weight	5	-.46 to >1	?	53
Pig weaning weight and:				
Average daily gain	8	0.20 to 0.87	0.52	20,67,73,80,81,83
Probe backfat	2	-.05 to 0.61	0.28	73
Number pigs weaned and:				
Pig weaning weight	2	-.25 to 0.13	-.06	83
Average daily gain	2	0.04 to 0.07	0.06	83
154 day weight and:				
Probe backfat	5	<-1 to -.06	?	53
Age at 200 pounds and:				
Probe backfat	1		-.20	1
Average daily gain and:				
Probe backfat	4	-.98 to 0.70	-.18	67,73,86

TABLE III

REVIEW OF PHENOTYPIC CORRELATIONS

Traits Correlated	Number Estimates	Range	Simple Average	References
Birth weight and:				
Probe backfat	5	-.38 to -.06	-.17	53
154 day weight	5	0.20 to 0.41	0.27	53
Pig weaning weight and:				
Average daily gain	6	0.17 to 0.44	0.35	12,22,67,81,86
Age at 200 pounds	1		-.52	61
Probe backfat	3	-.29 to -.12	-.22	61,67,86
Number pigs weaned and:				
Pig weaning weight	1		-.51	62
154 day weight and:				
Probe backfat	5	-.34 to -.10	-.21	53
Age at 200 pounds and:				
Probe backfat	3	-.18 to -.13	-.16	1,61
Average daily gain and:				
Probe backfat	3	-.34 to 0.21	-.02	67,78,86

CHAPTER III

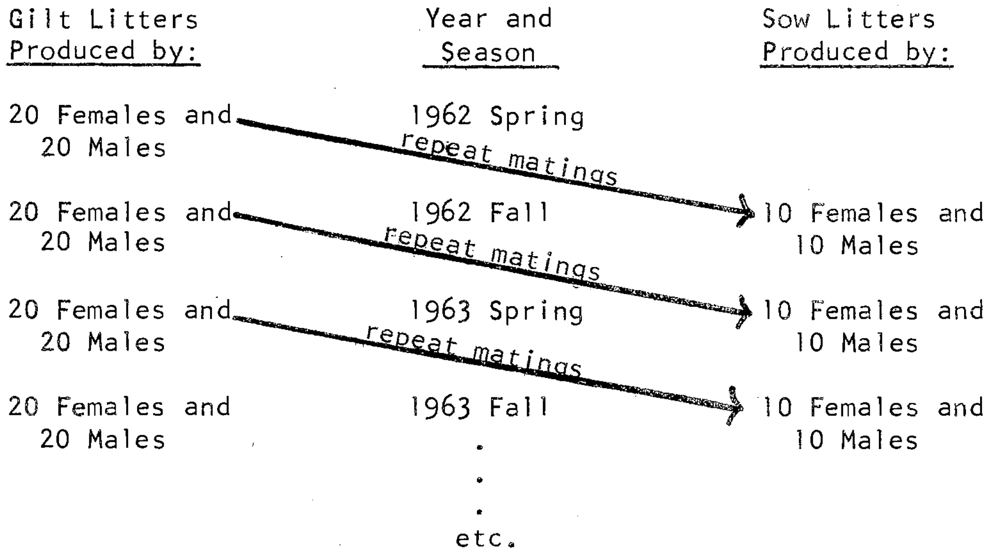
MATERIALS AND METHODS

General Procedures

The animals used in this study were obtained from the experimental swine breeding herd maintained at Ft. Reno using the "zero selection" control line animals. The data were collected over a period of 14 seasons, spring 1962 through fall 1968, and included records from 3860 pigs born in 363 litters.

Foundation females for this control line consisted of 27 sows and gilts obtained in the spring and fall of 1961 from a random mating population of crossbreds. The selected crossbred females were of Duroc, Hampshire, Beltsville, Poland China and Landrace origin. There were 20 boars used in the spring and fall of 1961. Sixteen of these boars were from the same stock as the females. The remaining four boars were purchased from outside sources and consisted of one Hampshire, one Landrace, one Duroc, and one Landrace-Beltsville cross. The breed composition of the males and females used as foundation stock are presented in Table IV.

After the fall of 1961 the line was closed. There were approximately 25 litters farrowed each season in this line. Of these 25 litters, 15 to 20 were farrowed by gilts and 5 to 10 were farrowed by second litter sows that had a litter the previous season by the same boar. Gilts maintained for a second litter were selected at random from all gilts farrowing in that season. After producing their second litter, all sows were removed from the herd. The total number of litters produced each season varied somewhat but the goal was to have approximately 20 gilt litters farrowed each season. The farrowing procedure can be outlined as follows:



Gilt Litters Produced by:	Year and Season	Sow Litters Produced by:
20 Females and 20 Males	1962 Spring	
20 Females and 20 Males	1962 Fall	10 Females and 10 Males
20 Females and 20 Males	1963 Spring	10 Females and 10 Males
20 Females and 20 Males	1963 Fall	10 Females and 10 Males
	. . . etc.	

TABLE IV

PERCENT BREED COMPOSITION IN BASE POPULATION

Breed	20 Males	27 Females	47 Combined
Duroc	35.8	29.8	32.4
Beltsville #1	32.6	15.0	22.5
Hampshire	11.6	38.4	27.0
Poland China	10.0	2.8	5.8
Landrace	10.0	14.0	12.3

Propagation of the line was carried out by selecting two boars of average weight and thriftiness at 21 days of age and two average gilts at weaning from each litter. An attempt was made to get all replacement breeding stock from first litter gilts so that full sibs were not selected in consecutive seasons. Final selection of one boar and one gilt from the pair saved from each litter was delayed until postweaning rate of gain and probe backfat thickness information were available on all boars and gilts initially chosen. The boar and gilt from each pair that were nearest the average for rate of gain and probe backfat were retained for breeding. Final selections were made with special emphasis on obtaining selection differentials as near zero as possible for growth rate and probe backfat thickness. To minimize inbreeding and gene drift, one boar was used per gilt and no matings were permitted between individuals having a common ancestor in the first or second generation of their pedigrees.

This study includes litters from both sows and gilts. Age designations, as used in this study, were made according to age of dam at farrowing. Gilts farrowed their first litter at approximately one year of age and sows farrowed second litters at about eighteen months of age. Spring litters were farrowed in March and April and fall litters were farrowed in September and October.

The breeding herd ration is shown in Table V and feeding levels at various stages of reproduction are given in Table VI.

All females were maintained in outside pasture lots from breeding until 109 days postbreeding. At this time they were placed in confinement and remained there until their litters were weaned at six weeks of age. Each pig was individually weighed and ear notched for identification within 24 hours after birth. Pigs were next weighed at 21 days of age and given access to creep. All pigs were weighed and weaned at approximately 42 days of age. Weaning weights for those not weaned at exactly 42 days were adjusted to a 42-day weight basis.

TABLE V

BREEDING HERD RATION

Ingredient	Pounds Per Ton
Wheat	727
Milo	728
Ground Alfalfa Hay	300
Soybean Meal (44%)	150
Molasses	50
Dicalcium Phosphate	30
Trace Mineral Salt	10
Vitamin-Mineral Premix	5
Total	2,000

TABLE VI

DAILY FEED INTAKE FOR FEMALES AT VARIOUS PERIODS OF REPRODUCTION

Period	Sows lb.	Gilts lb.
200 lbs. to month before breeding		$3\frac{1}{2}$-4
One month before breeding	7-8	$5\frac{1}{2}$-6
Breeding to month prior to farrowing	5-$5\frac{1}{2}$	$3\frac{1}{2}$-4
One month prior to farrowing	6-$6\frac{1}{2}$	5-$5\frac{1}{2}$
Farrowing to weaning	Full Fed	Full Fed
Weaning to month before breeding	6-$6\frac{1}{2}$	

Pigs were raised in confinement from birth to market and were self fed during the postweaning period. A ground ration of wheat, milo, soybean meal (44%), and alfalfa meal was fed from weaning to approximately 200 pounds market weight. Protein content of the ration was approximately 16 percent from weaning to 100 pounds and 14 percent from 100 pounds to market weight.

Pigs were removed from test at weekly intervals as they reached approximately 200 pounds. Age at 200 pounds was calculated by dividing the number of pounds above (or below) 200 pounds when removed from test by the postweaning average daily gain and subtracting this figure from (or adding it to) the actual age in days when removed from test.

Probe backfat thickness was determined from an average of six readings taken on both sides of the animal about one and one-half inches from the midline over the first rib, last rib, and last lumbar vertebra using a leanmeter. Pigs were probed as they were removed from test at approximately 200 pounds. Probes were adjusted to a constant weight of 200 pounds according to procedures described by Durham and Zeller (1955).

Statistical Procedures

The first statistical analysis was a hierarchal analysis within age of dam for each variable studied. For traits measured on a litter basis the analyses were for litters within season and year and for traits measured on the individual pig the analyses were for pigs within litter, season, and year. Although analyses were on a within litter basis for all traits measured on the individual pig, the means for all variables were taken on a litter basis to give equal weight to each litter.

To correct for age of dam, progeny from sow litters were converted to a gilt basis within season using additive correction factors. Repeat matings were utilized to correct for season differences. The first gilts to be used as repeat matings farrowed their first litters in the spring of 1962. Means for all variables except those measured at 21 days of age were adjusted back to the spring of 1962. Information on pigs at 21 days of age was not taken on a regular basis until the spring of 1965. Therefore, traits measured at 21 days of age were adjusted back to this season.

An example of the correction procedures used to evaluate the stability of the population is presented in Table VII. The example given is for postweaning average daily gain. The mean average daily gain of all progeny from gilt litters in the spring of 1962 was 1.36 pounds per day. This value was used as a reference point and all season means were adjusted relative to this season. In the fall of 1962 the difference between the mean performance from gilt litters and the mean performance from sow litters was -.08. This figure was used to adjust the mean performance of second-litter repeat matings to a gilt basis. This adjusted mean for second-litter repeat matings (1.49) was then compared to the mean of first-litter repeat matings the season before (1.35). Since these two figures represent the performance from identical matings in two successive seasons, the difference (-.14) was used as a measure of season effect giving an adjusted mean of 1.36 for the fall of 1962. The difference between first-litter repeat mating performance in 1962 fall and second-litter repeat mating performance in 1963 spring was 0.01. When combined with the adjustment obtained for 1962 fall, the adjustment for 1963 spring becomes -.13. The adjusted mean for 1963 spring is then 1.35. The above procedures were used to adjust the means of all

TABLE VII

EXAMPLE OF CORRECTION PROCEDURES FOR AVERAGE DAILY GAIN

Year and Season[a]	Uncorrected Mean for Gilt Litters	Additive Correction for Sow Litters[b]	Performance of Repeat Matings		Effect of Season[d]	Adjusted Mean
			1st Litter	2nd Litter[c]		
62S	1.36	-.04	1.35		00	1.36
62F	1.49	-.08	1.49	1.49	-.14	1.36
63S	1.48	-.11	1.47	1.48	-.13	1.35
63F	1.65	+.02	1.65	1.65	-.31	1.34
64S	1.56	+.04	1.54	1.56	-.22	1.34
64F	1.50	-.03	1.49	1.50	-.18	1.32
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.

[a] S = Spring, F = Fall.

[b] Mean of gilt litters minus mean of sow litters.

[c] Corrected to gilt basis.

[d] Difference in repeat mating performance relative to 1962 spring.

variables to a base point.

Variances were pooled across age of dam for each trait. Standard errors for traits measured on a litter basis within season were computed by the following formula:

$$s_{\bar{x}i} = \sqrt{\frac{EMS}{N_i}}$$

where,

$s_{\bar{x}i}$ = standard error of the i^{th} season mean
N_i = number of litters in i^{th} season
EMS = pooled within season variance for sows and gilts.

For traits measured on individual pigs within litters, standard errors were computed in the following manner:

$$s_{\bar{x}i} = \sqrt{\frac{1}{N_i^{2}} \sum_{j=1}^{N_i} \left[\frac{EMS}{N_{ij}}\right]}$$

where,

$s_{\bar{x}i}$ = standard error of the i^{th} season mean
N_i = number of litters in i^{th} season
N_{ij} = number of pigs in j^{th} litter in i^{th} season
EMS = pooled within litter variance for sows and gilts.

Heritability estimates for traits measured on the individual pig were calculated by the regression of offspring on mid-parent and by doubling the regressions of offspring on sire and offspring on dam. For litter traits, heritability estimates were computed by doubling the regression coefficients of daughter on dam. Standard errors of heritability estimates were computed by doubling the standard errors of the corresponding regression coefficients for offspring on sire and offspring on dam. For offspring on mid-parent the standard error of the regression coefficient is the standard error of the heritability estimate.

Genetic correlations were calculated from covariance terms between offspring and parent as described by Hazel (1943). For traits 1 and 2 measured on the parent (X) and the offspring (Y), the genetic correlation coefficient is given by:

$$r_g = \frac{\mathrm{Cov}_{x_1y_2} + \mathrm{Cov}_{x_2y_1}}{2\sqrt{\mathrm{Cov}_{x_1y_1} \quad \mathrm{Cov}_{x_2y_2}}}$$

where,

r_g = genetic correlation coefficient

$\mathrm{Cov}_{x_1y_2}$ = covariance between trait x_1 in parent and trait y_2 in offspring

$\mathrm{Cov}_{x_2y_1}$ = covariance between trait x_2 in parent and trait y_1 in offspring

$\mathrm{Cov}_{x_1y_1}$ = covariance between trait x_1 in parent and trait y_1 in offspring

$\mathrm{Cov}_{x_2y_2}$ = covariance between trait x_2 in parent and trait y_2 in offspring.

The above formula is valid regardless of whether the X value represents one parent or the mid-parent, since the offspring-parent covariance and the offspring-mid-parent covariance each estimate one-half of the additive genetic variance (Falconer, 1960).

Standard errors of genetic correlation coefficients were computed by procedures outlined by Reeve (1955) and Robertson (1959). The standard error was defined as the square root of the estimate of the sampling variance. The estimate of the sampling variance is given by:

$$\widehat{\mathrm{Var}(\hat{r}_g)} = \frac{(1-\hat{r}_g^{2})^{2}}{N-1}\left(\frac{2}{\hat{h}_a^2 \; \hat{h}_b^2} + \frac{1}{2}\right)$$

where,

$\hat{r}_g$ = estimate of genetic correlation coefficient

$\widehat{\mathrm{Var}(\hat{r}_g)}$ = estimate of the sampling variance of r_g

$\hat{h}_a^2$ = heritability estimate of trait a

$\hat{h}_b^2$ = heritability estimate of trait b

N = number of offspring-parent pairs.

Significance levels for phenotypic correlations were obtained from tables in Steel and Torrie (1960).

CHAPTER IV

RESULTS AND DISCUSSION

Population Stability

A general comparison between the overall performance of gilts and sows in the spring and in the fall is presented in Appendix Tables XXVII through XXX. Sows had consistently larger litters of heavier pigs at birth, 21, and 42 days than gilts. Gilts farrowing in March and April had more pigs per litter at birth, 21, and 42 days than gilts farrowing in September and October. However, sows farrowing in the spring farrowed fewer pigs but raised a higher proportion to weaning than sows farrowing in the fall. Only minor differences were observed in the postweaning performance of pigs from sow litters compared to those from gilt litters.

It should be remembered that the adjustment procedures for each variable in this study are independent of those for any other variable. For example, the adjusted number of pigs per litter at 42 days of age may exceed the adjusted number of pigs born per litter in a given season due to differences in survival from birth to weaning at 42 days of age. Variables of this nature are not meant for comparison purposes but only as an indication of the degree of stability for each variable.

The adjusted means for each variable studied are presented in graphic form in Figures 1 through 12. The intervals surrounding each mean represent two standard errors above or below the mean. The number of litters per season ranged from 21 to 31 and the corresponding "t" values for these degrees of freedom range from 2.042 to 2.080. Therefore, these intervals are all very similar to 95 percent confidence intervals. Corrected means and standard errors for each variable are presented in Tables VIII through XVI.

For number of pigs per litter at birth, 21, and 42 days of age and litter weight at birth, 21, and 42 days of age, the population was considered to have remained relatively stable from a genetic standpoint. The intervals surrounding the means for number of pigs born per litter and litter weight at birth all overlap as do those for number of pigs per litter at 21 days of age and litter weight at 21 days of age. For number of pigs per litter at 42 days and litter weight at 42 days, all intervals overlap except for the one in 1962 spring.

There was very little variation within litters for pig weight at birth, 21, or 42 days of age as reflected by the magnitude of the standard errors (Tables XI - XIII). Although the standard errors were small and the means for pig weight at birth and 21 days of age did show some variation from season to season, this should not be of major concern. The differences observed from season to season were quite small and while the data were adjusted for all known sources of non-genetic variation, random genetic drift could easily account for these small differences.

The variable showing the most marked change over the 14 seasons studied was pig weight at 42 days of age. Variation within litters was again small and means were quite constant for the first six seasons. A small but continuous rise in pig weight was noted for the next six seasons and a decline during the last two seasons. This rise and decline

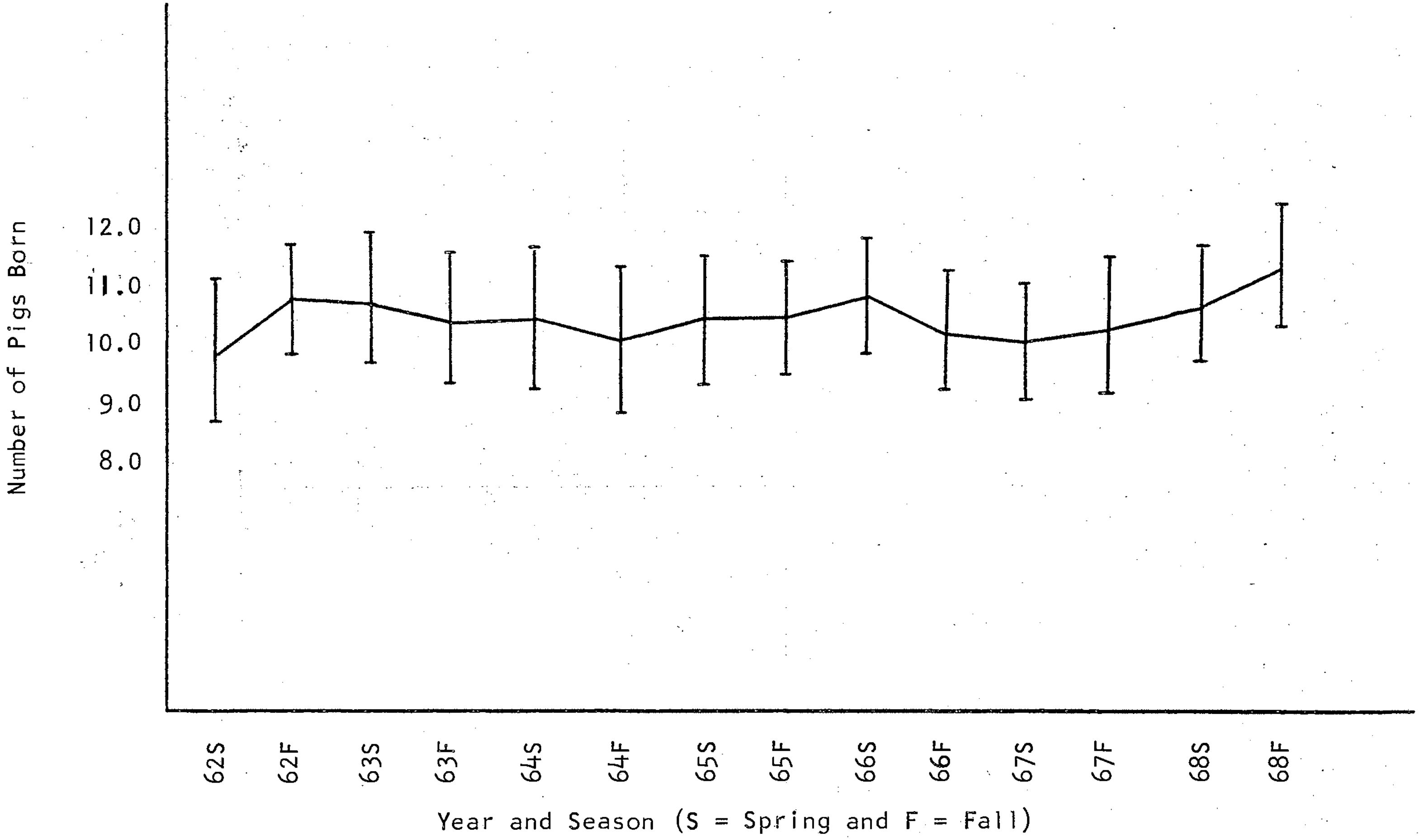


Figure 1. Means ± 2 Standard Errors for Number of Pigs Born per Litter Adjusted for Age of Dam and Season

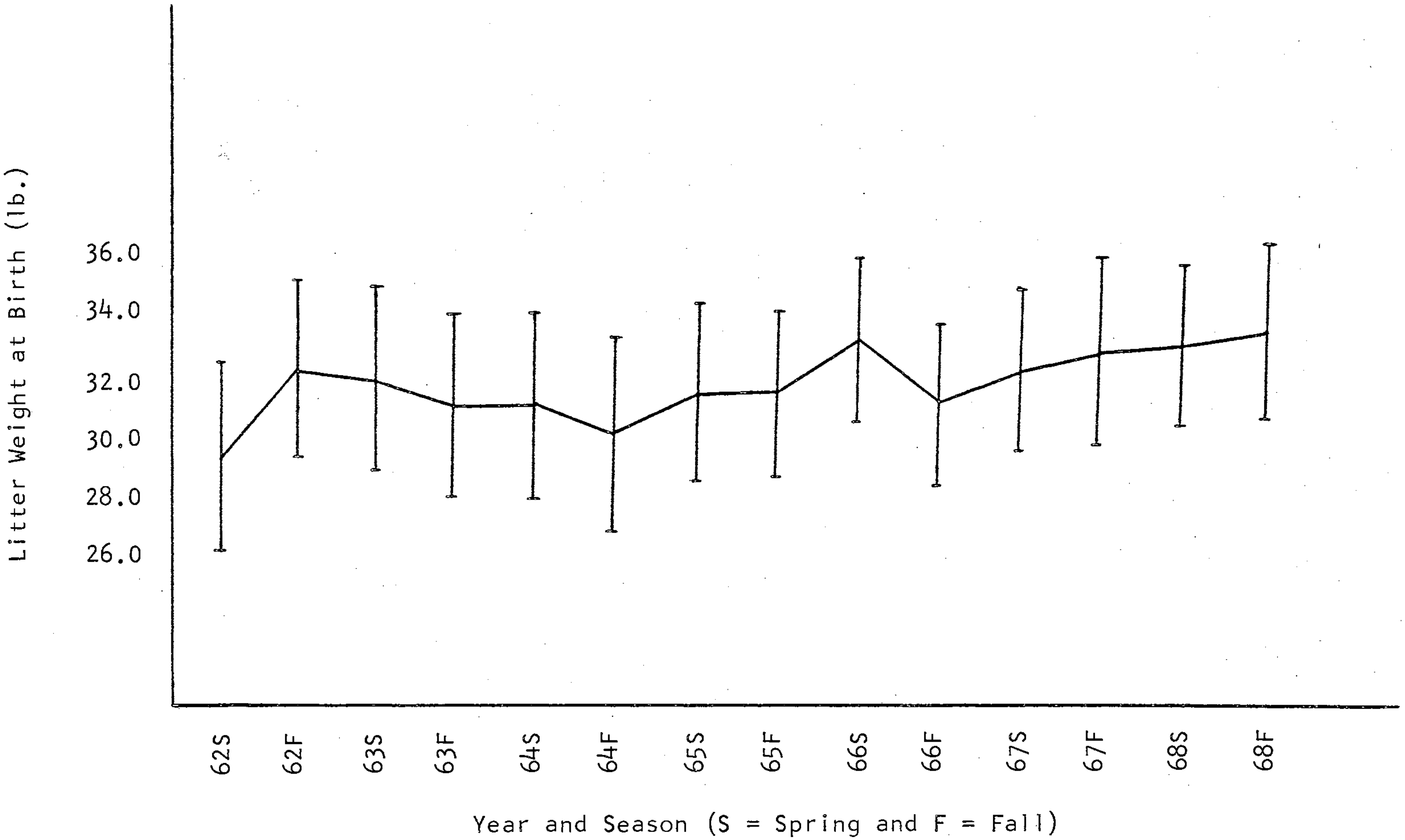


Figure 2. Means ± 2 Standard Errors for Litter Weight at Birth Adjusted for Age of Dam and Season

TABLE VIII

MEANS AND STANDARD ERRORS FOR NUMBER OF PIGS FARROWED PER LITTER AND LITTER WEIGHT AT BIRTH ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Pigs Farrowed per Litter ± S.E.	Litter Weight at Birth (lb.) ± S.E.
62S	22	9.9 ± 0.58	30.2 ± 1.59
62F	26	10.9 ± 0.53	33.2 ± 1.47
63S	24	10.8 ± 0.56	32.9 ± 1.53
63F	24	10.4 ± 0.56	32.0 ± 1.53
64S	22	10.4 ± 0.58	32.0 ± 1.59
64F	21	10.0 ± 0.59	30.9 ± 1.63
65S	26	10.4 ± 0.53	32.4 ± 1.47
65F	27	10.4 ± 0.52	32.4 ± 1.45
66S	30	10.9 ± 0.50	34.0 ± 1.36
66F	29	10.2 ± 0.50	32.0 ± 1.39
67S	30	10.1 ± 0.50	33.1 ± 1.36
67F	23	10.3 ± 0.57	33.8 ± 1.56
68S	31	10.6 ± 0.49	34.0 ± 1.34
68F	28	11.3 ± 0.51	34.3 ± 1.41

[a] S = Spring, F = Fall

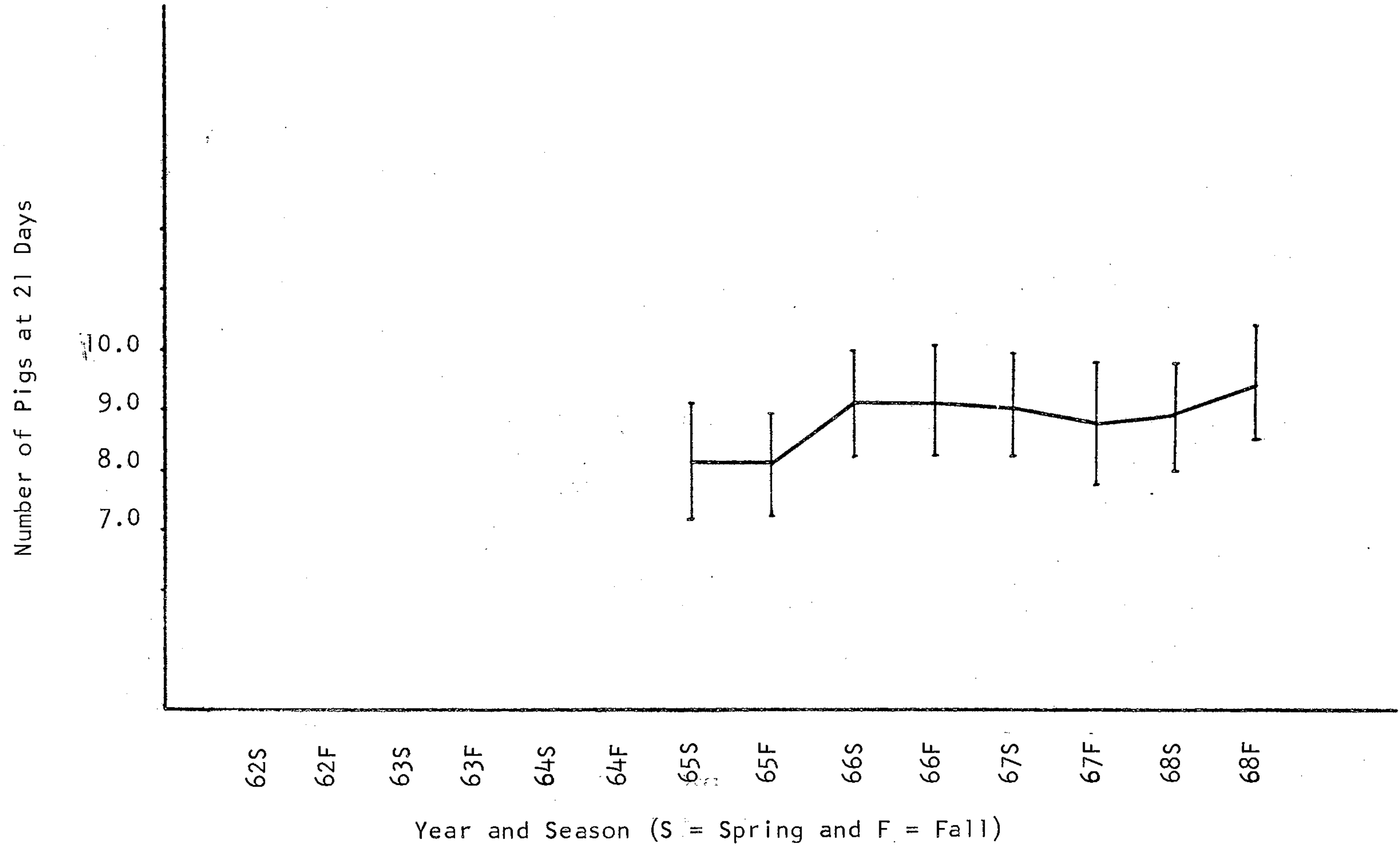


Figure 3. Means ± 2 Standard Errors for Number of Pigs per Litter at 21 Days Adjusted for Age of Dam and Season

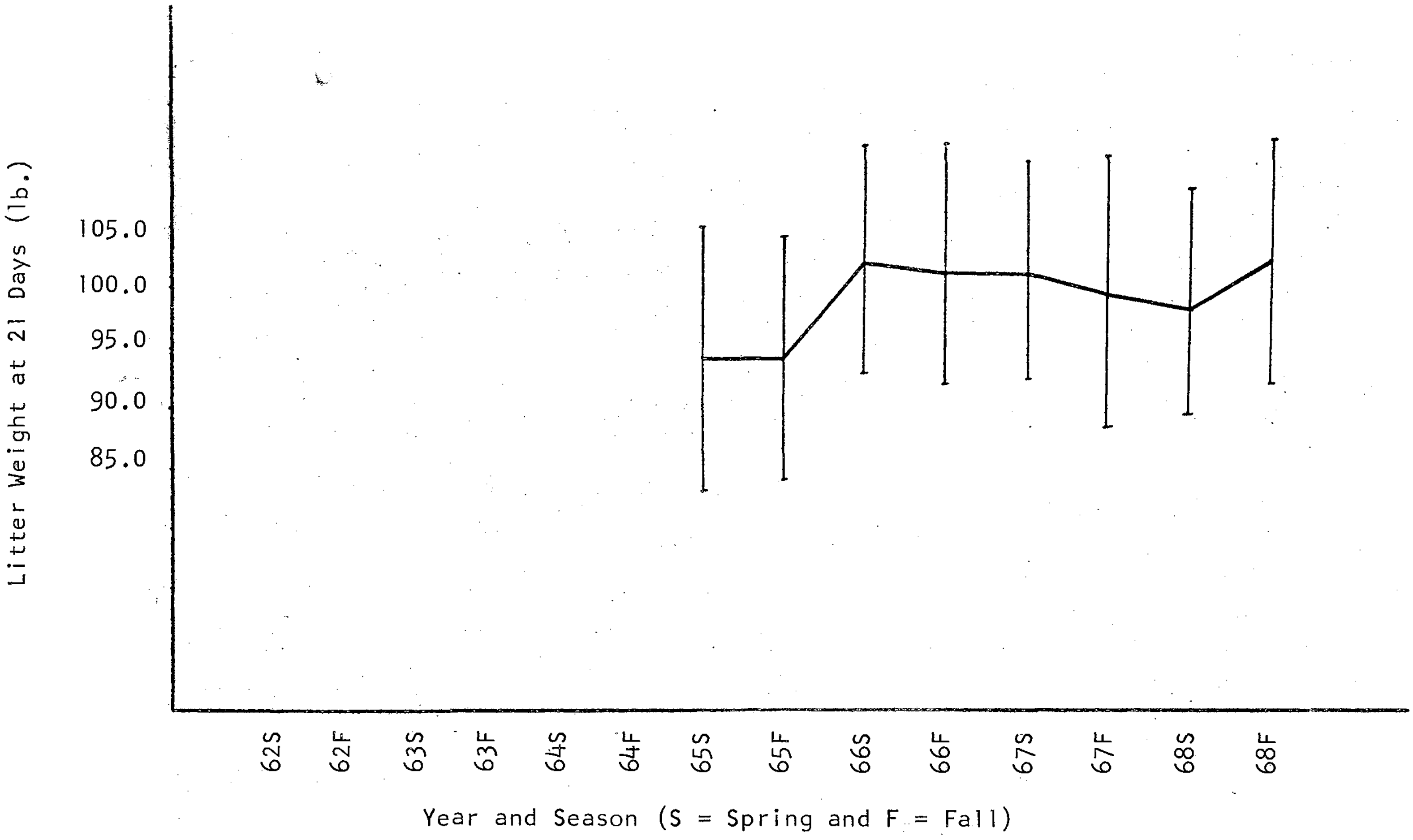


Figure 4. Means ± 2 Standard Errors for Litter Weight at 21 Days Adjusted for Age of Dam and Season

TABLE IX

MEANS AND STANDARD ERRORS FOR NUMBER OF PIGS PER LITTER AT 21 DAYS AND LITTER WEIGHT AT 21 DAYS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Pigs per Litter at 21 Days ± S.E.	Litter Weight at 21 Days (lb.) ± S.E.
65S	25	8.1 ± 0.49	93.7 ± 5.50
65F	26	8.1 ± 0.48	93.7 ± 5.41
66S	30	9.1 ± 0.45	103.2 ± 5.02
66F	28	9.1 ± 0.46	102.5 ± 5.19
67S	30	9.0 ± 0.45	102.4 ± 5.02
67F	23	8.7 ± 0.51	99.5 ± 5.73
68S	31	8.8 ± 0.44	98.6 ± 4.93
68F	28	9.4 ± 0.46	102.3 ± 5.19

[a] S = Spring, F = Fall

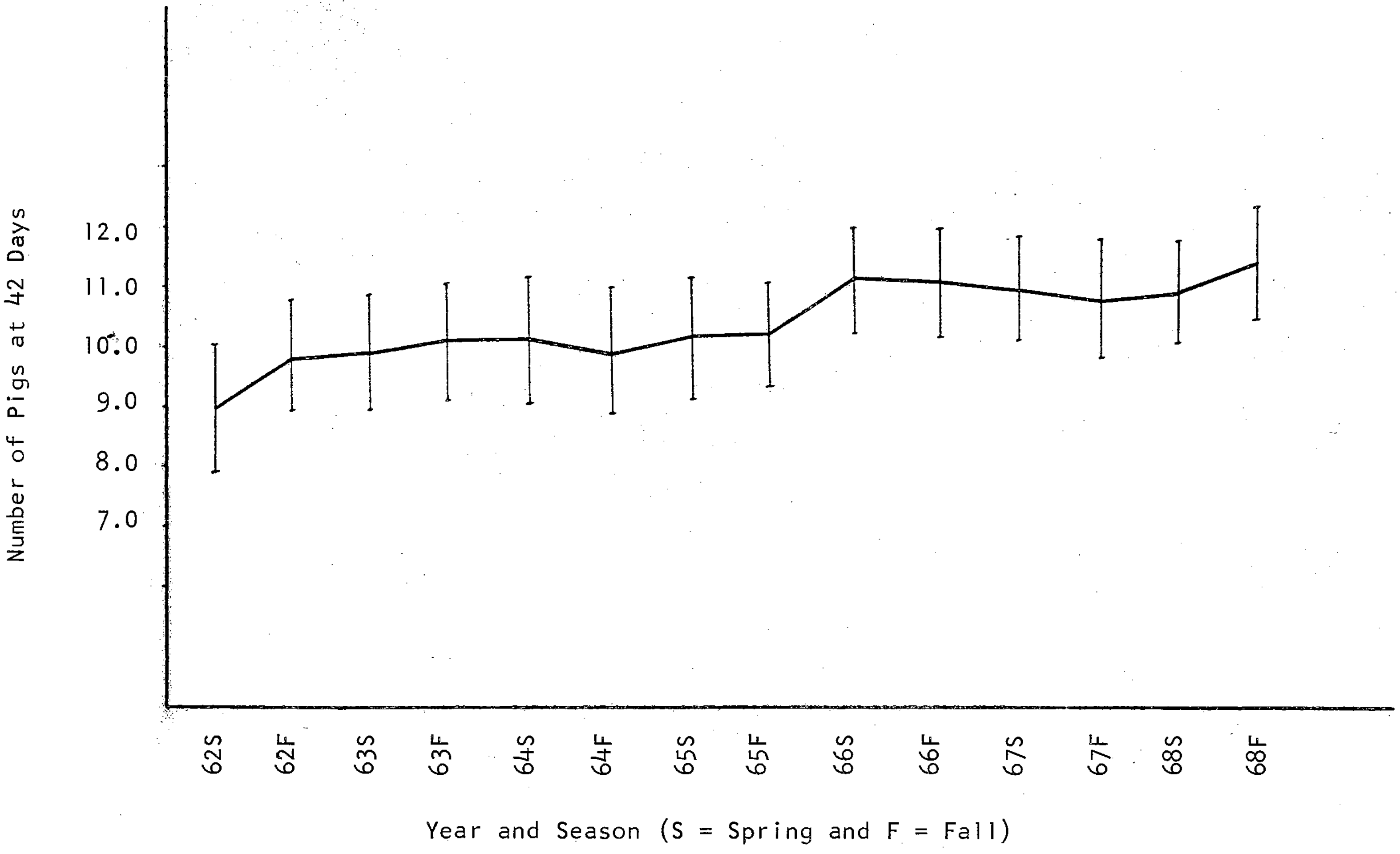


Figure 5. Means ± 2 Standard Errors for Number of Pigs per Litter at 42 Days Adjusted for Age of Dam and Season

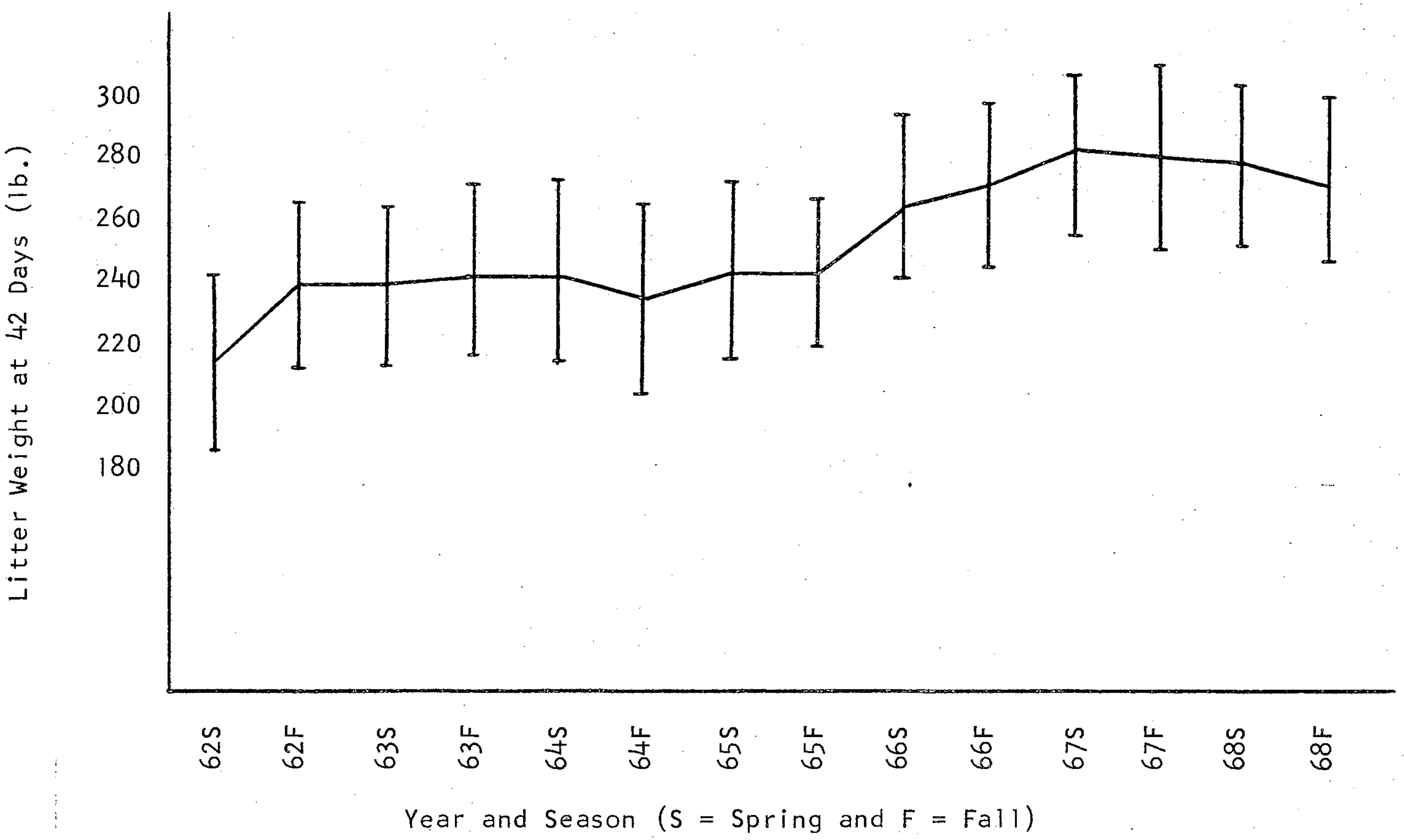


Figure 6. Means ± 2 Standard Errors for Litter Weight at 42 Days Adjusted for Age of Dam and Season

TABLE X

MEANS AND STANDARD ERRORS FOR NUMBER OF PIGS PER LITTER AT 42 DAYS AND LITTER WEIGHT AT 42 DAYS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Pigs per Litter at 42 Days ± S.E.	Litter Weight at 42 Days (lb.) ± S.E.
62S	21	9.0 ± 0.53	218.5 ± 13.68
62F	26	9.8 ± 0.47	239.7 ± 12.30
63S	24	9.9 ± 0.49	240.9 ± 12.80
63F	24	10.1 ± 0.49	243.7 ± 12.80
64S	21	10.1 ± 0.53	243.7 ± 13.68
64F	20	9.9 ± 0.54	235.2 ± 14.02
65S	25	10.1 ± 0.48	243.8 ± 12.54
65F	26	10.1 ± 0.47	243.8 ± 12.30
66S	30	11.1 ± 0.44	267.4 ± 11.45
66F	28	11.0 ± 0.46	269.9 ± 11.85
67S	30	11.0 ± 0.44	279.4 ± 11.45
67F	23	10.8 ± 0.50	277.7 ± 13.08
68S	31	10.9 ± 0.43	276.2 ± 11.26
68F	28	11.4 ± 0.46	271.0 ± 11.85

[a] S = Spring, F = Fall

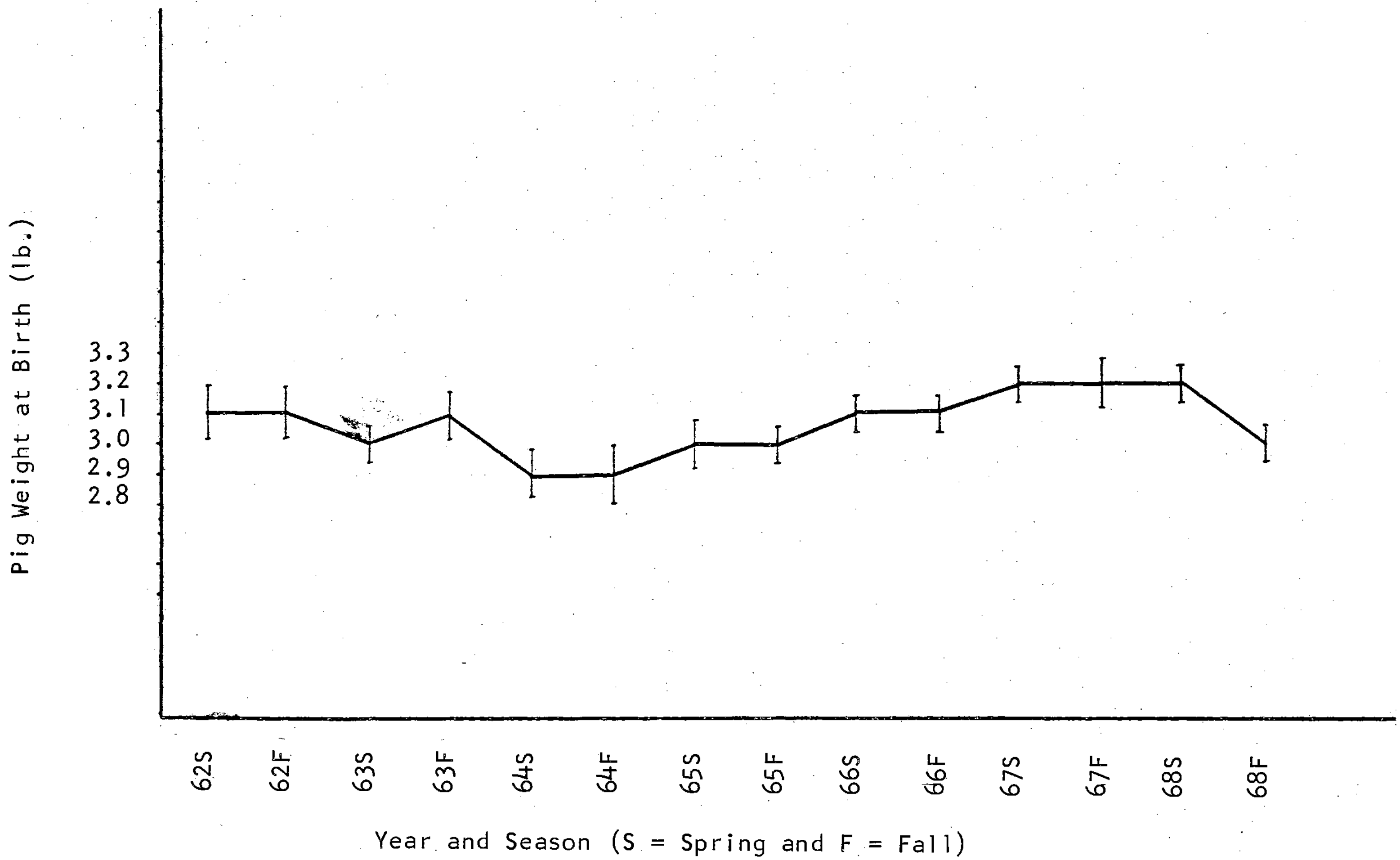


Figure 7. Means ± 2 Standard Errors for Pig Weight at Birth Adjusted for Age of Dam and Season

TABLE XI

MEANS AND STANDARD ERRORS FOR PIG WEIGHT AT BIRTH ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Pig Weight at Birth (lb.) ± S.E.
62S	22	219	3.1 ± 0.04
62F	26	302	3.1 ± 0.03
63S	24	269	3.0 ± 0.03
63F	24	235	3.1 ± 0.04
64S	22	233	2.9 ± 0.04
64F	21	178	2.9 ± 0.05
65S	26	266	3.0 ± 0.04
65F	27	315	3.0 ± 0.04
66S	30	362	3.1 ± 0.03
66F	29	312	3.1 ± 0.03
67S	30	335	3.2 ± 0.03
67F	23	238	3.2 ± 0.04
68S	31	313	3.2 ± 0.03
68F	28	283	3.0 ± 0.03
Total	363	3,860	

[a] S = Spring, F = Fall

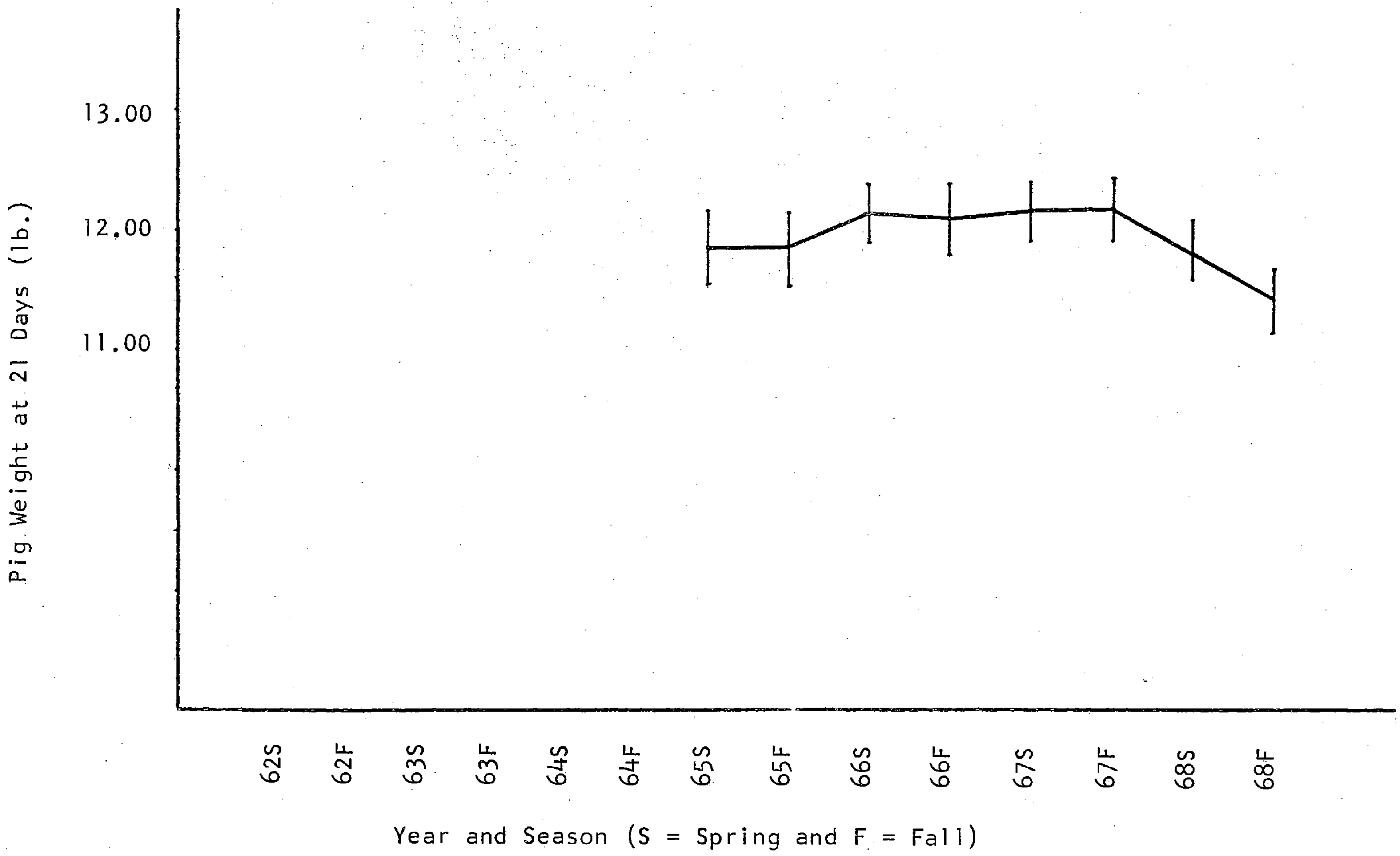


Figure 8. Means ± 2 Standard Errors for Pig Weight at 21 Days Adjusted for Age of Dam and Season

TABLE XII

MEANS AND STANDARD ERRORS FOR PIG WEIGHT AT 21 DAYS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Pig Weight at 21 Days (lb.) ± S.E.
65S	25	200	11.8 ± 0.17
65F	26	233	11.8 ± 0.17
66S	30	287	12.2 ± 0.14
66F	28	244	12.1 ± 0.15
67S	30	300	12.2 ± 0.13
67F	23	184	12.2 ± 0.17
68S	31	273	11.8 ± 0.13
68F	28	239	11.4 ± 0.15
Total	221	1,960	

[a] S = Spring, F = Fall

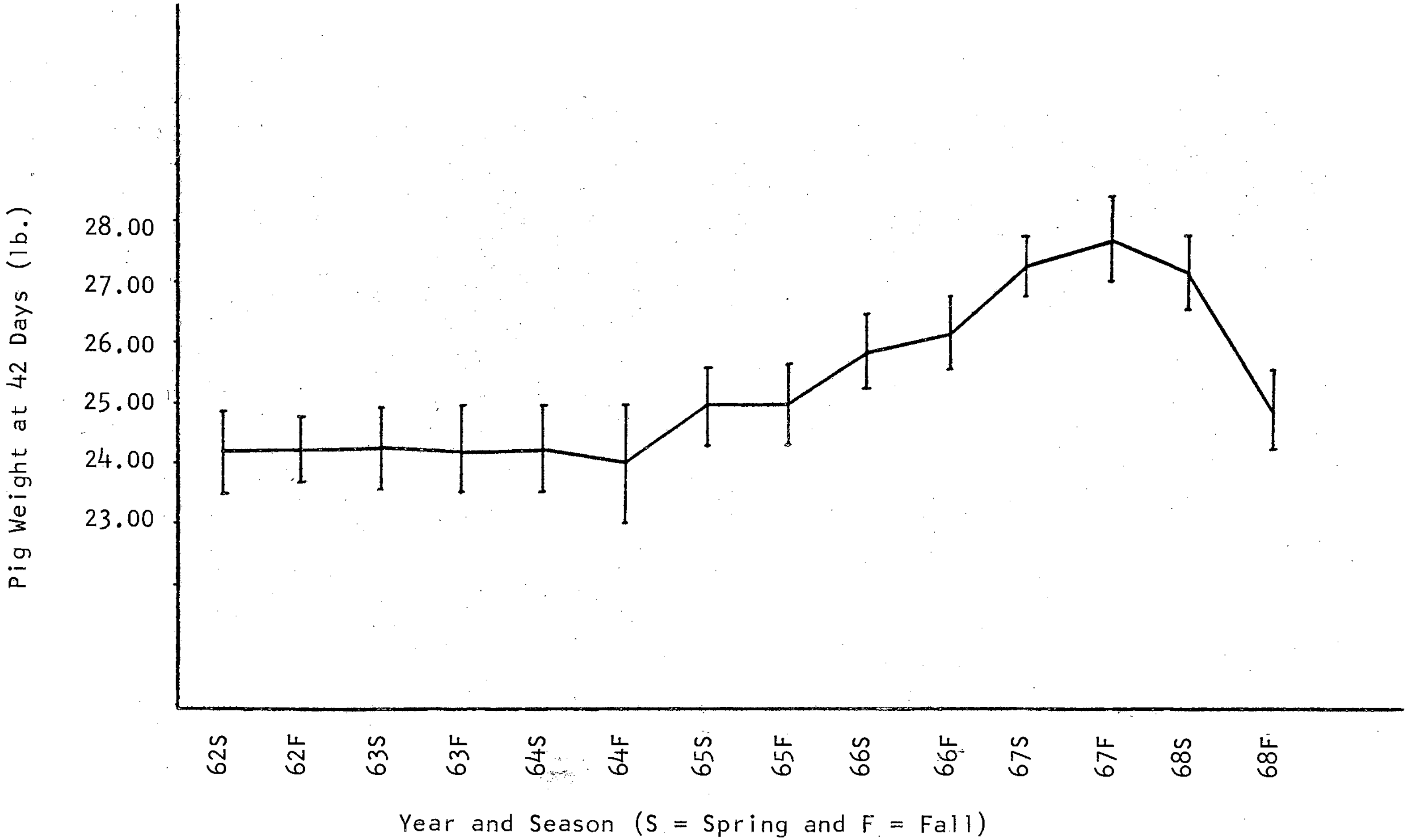


Figure 9. Means ± 2 Standard Errors for Pig Weight at 42 Days Adjusted for Age of Dam and Season

TABLE XIII

MEANS AND STANDARD ERRORS FOR PIG WEIGHT AT 42 DAYS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Pig Weight at 42 Days (lb.) ± S.E.
62S	21	186	24.2 ± 0.35
62F	26	227	24.3 ± 0.30
63S	24	196	24.3 ± 0.33
63F	24	186	24.3 ± 0.33
64S	21	177	24.3 ± 0.38
64F	20	132	24.0 ± 0.51
65S	25	200	25.0 ± 0.34
65F	26	232	25.0 ± 0.34
66S	30	286	25.9 ± 0.30
66F	28	241	26.2 ± 0.31
67S	30	298	27.3 ± 0.30
67F	23	183	27.8 ± 0.38
68S	31	261	27.2 ± 0.30
68F	28	238	24.9 ± 0.31
Total	357	3,043	

[a] S = Spring, F = Fall

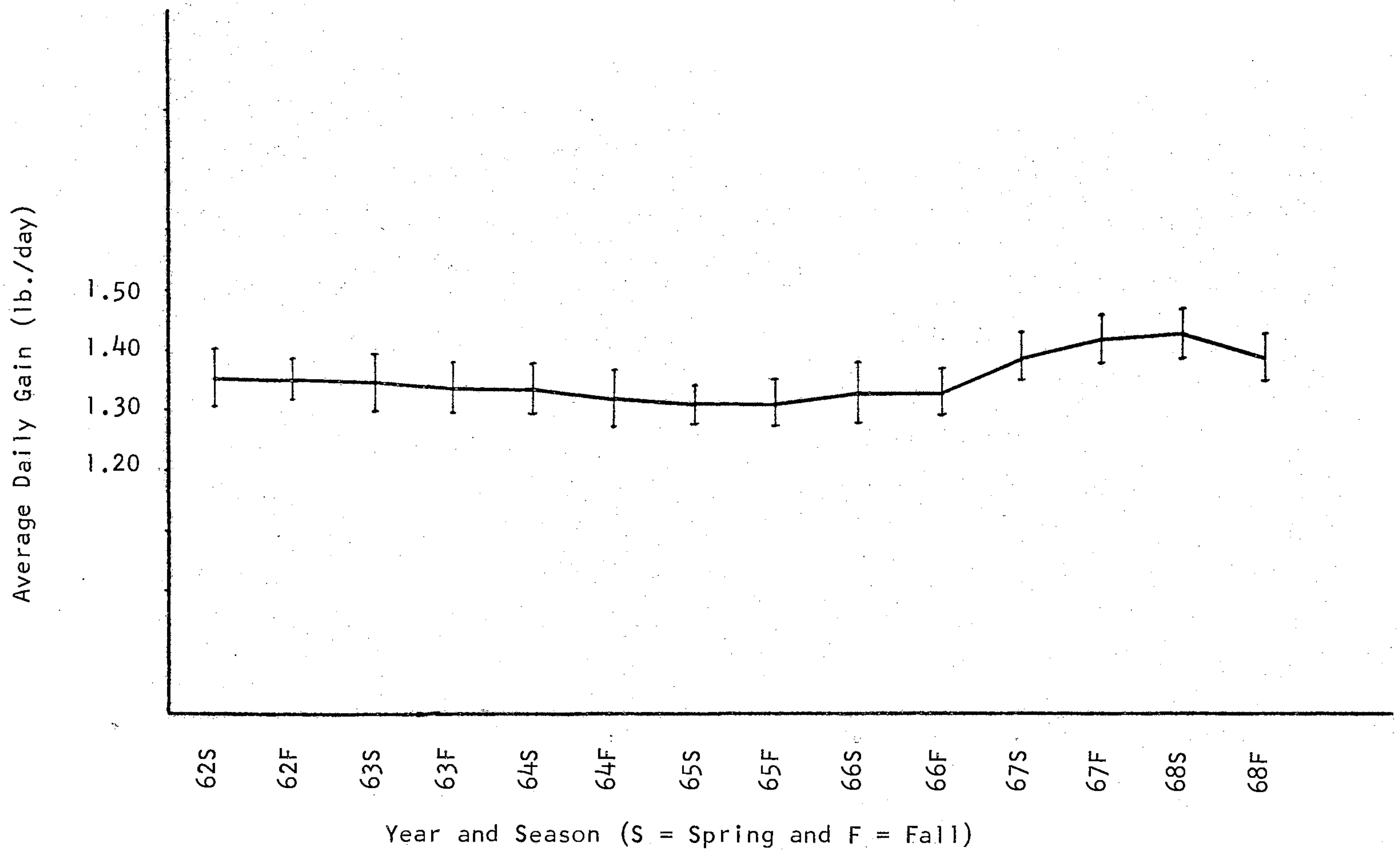


Figure 10. Average Daily Gain ± 2 Standard Errors for Female Offspring Adjusted for Age of Dam and Season

TABLE XIV

MEANS AND STANDARD ERRORS FOR AVERAGE DAILY GAIN OF GILTS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Avg. Daily Gain (lbs./day) ± S.E.
62S	20	98	1.36 ± 0.023
62F	25	121	1.36 ± 0.015
63S	20	43	1.35 ± 0.024
63F	24	84	1.34 ± 0.019
64S	21	80	1.34 ± 0.018
64F	20	71	1.32 ± 0.023
65S	24	107	1.31 ± 0.017
65F	26	85	1.31 ± 0.018
66S	29	82	1.33 ± 0.025
66F	26	81	1.33 ± 0.019
67S	30	131	1.39 ± 0.019
67F	23	94	1.42 ± 0.018
68S	30	111	1.43 ± 0.020
68F	27	102	1.39 ± 0.018
Total	345	1,290	

[a] S = Spring, F = Fall

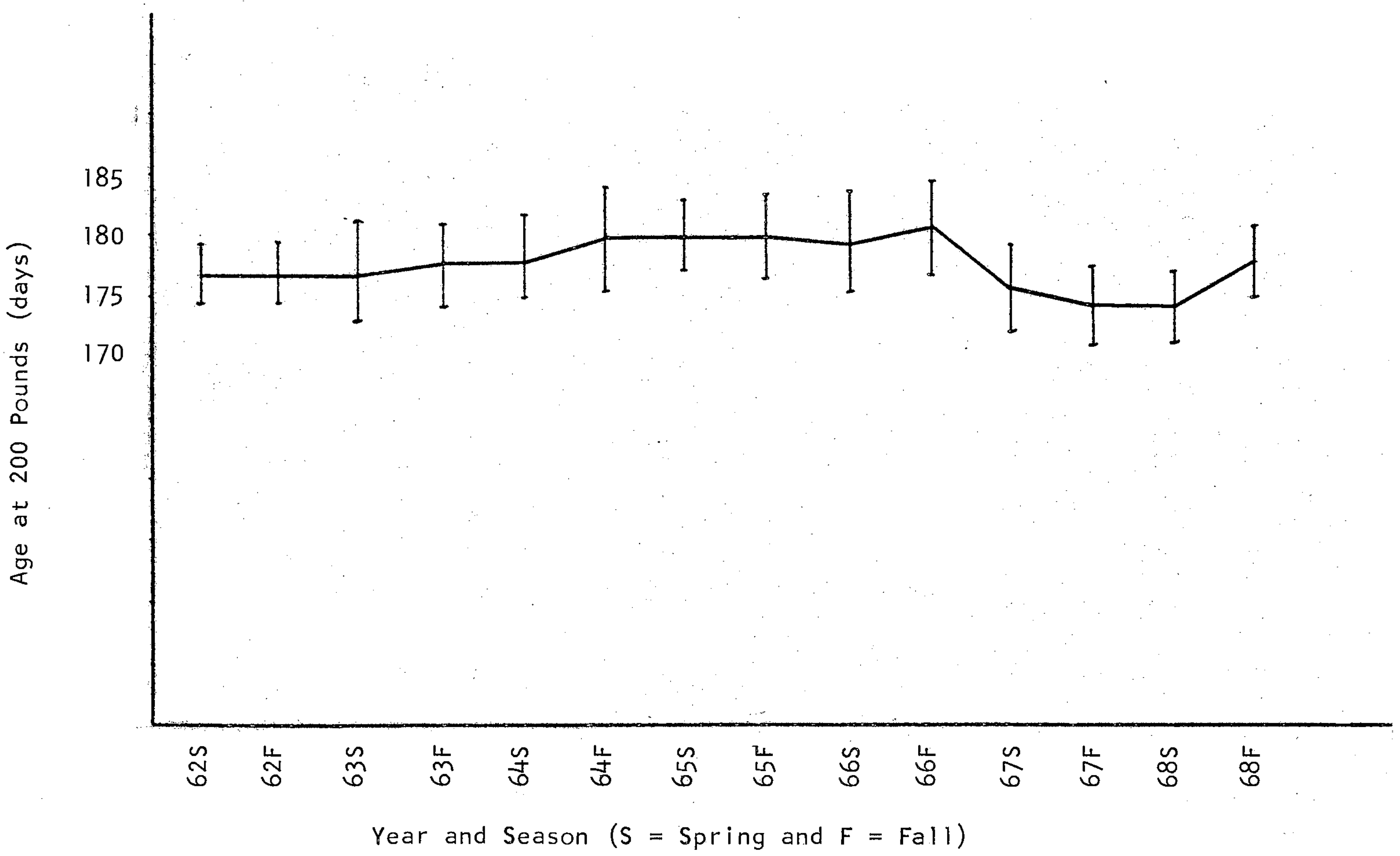


Figure 11. Age at 200 Pounds ± 2 Standard Errors for Female Offspring Adjusted for Age of Dam and Season

TABLE XV

MEANS AND STANDARD ERRORS FOR AGE OF GILTS AT 200 POUNDS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Age at 200 Pounds (days) ± S.E.
62S	20	98	177.4 ± 1.36
62F	25	121	177.4 ± 1.41
63S	20	43	177.1 ± 2.26
63F	24	84	177.3 ± 1.78
64S	21	80	178.3 ± 1.87
64F	20	71	179.8 ± 2.10
65S	24	107	179.9 ± 1.54
65F	26	85	179.9 ± 1.71
66S	29	82	178.4 ± 2.29
66F	26	81	180.9 ± 1.76
67S	30	131	175.3 ± 1.41
67F	23	94	173.2 ± 1.62
68S	30	111	173.6 ± 1.41
68F	27	102	178.0 ± 1.62
Total	345	1,290	

[a] S = Spring, F = Fall

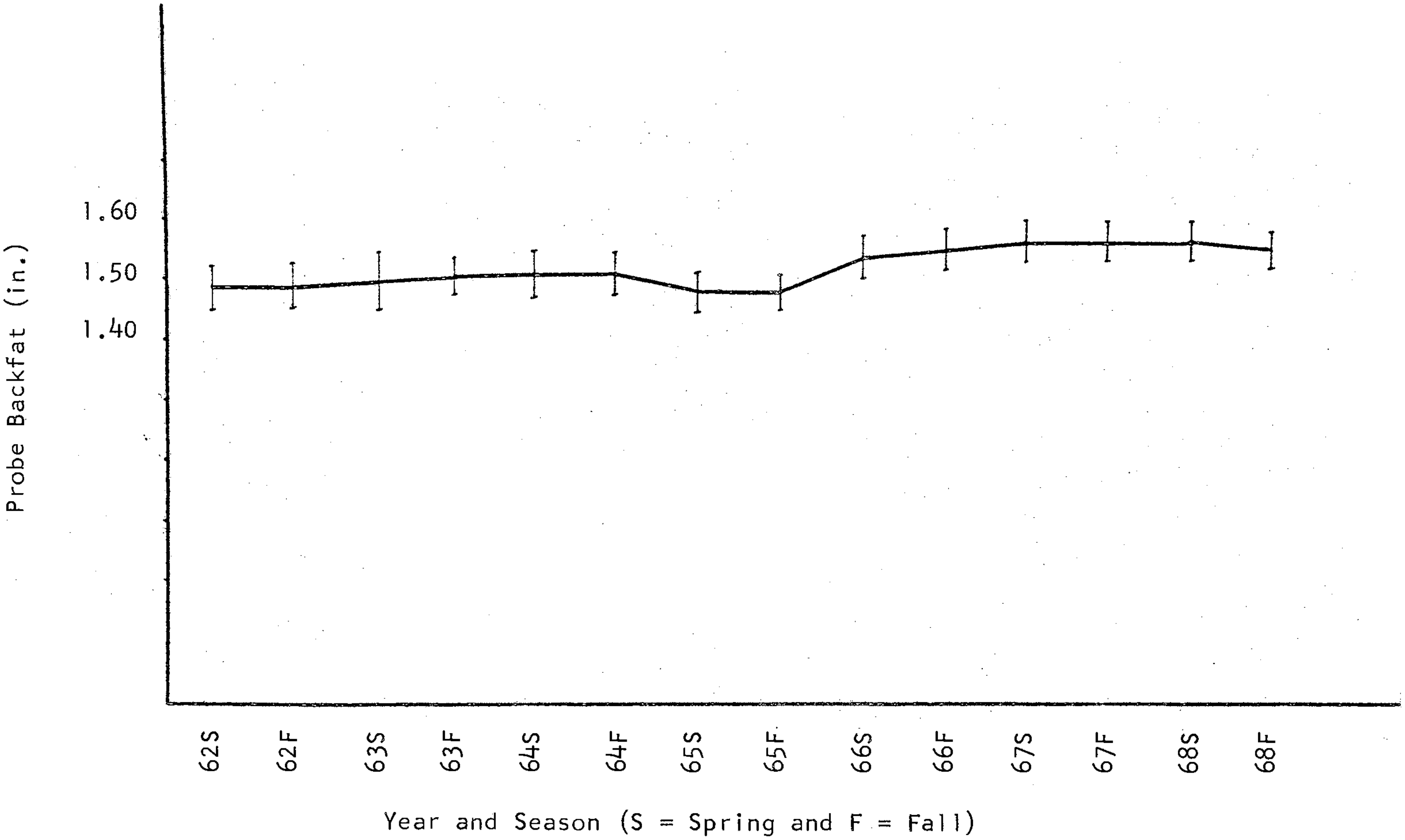


Figure 12. Average Probe Backfat ± 2 Standard Errors for Female Offspring Adjusted for Age of Dam and Season

TABLE XVI

MEANS AND STANDARD ERRORS FOR PROBED BACKFAT THICKNESS OF GILTS AT 200 POUNDS ADJUSTED FOR AGE OF DAM AND SEASON

Year and Season[a]	Number of Litters	Number of Observations	Probe Backfat (in.) ± S.E.
62S	20	86	1.49 ± 0.016
62F	25	113	1.49 ± 0.014
63S	20	35	1.50 ± 0.024
63F	24	79	1.51 ± 0.016
64S	21	79	1.51 ± 0.017
64F	20	71	1.51 ± 0.019
65S	24	107	1.48 ± 0.014
65F	26	84	1.48 ± 0.016
66S	29	81	1.54 ± 0.016
66F	26	81	1.55 ± 0.016
67S	30	131	1.56 ± 0.013
67F	23	87	1.56 ± 0.015
68S	29	100	1.56 ± 0.013
68F	27	99	1.55 ± 0.014
Total	344	1,233	

[a] S = Spring, F = Fall

did not involve large differences and again, random genetic drift could be the factor in operation.

Since very few barrows were probed in any given season, only female offspring were included in the analyses for average daily gain, age at 200 pounds, and probe backfat thickness.

Average daily gain and age at 200 pounds were available on 1290 gilts. Since age at 200 pounds is dependent on average daily gain, these two variables should show an indirect relationship across all seasons. This can be seen in Figures 10 and 11. Variation within litters was small and differences observed in means were quite negligible. A difference of 0.12 pound was observed in means for average daily gain between the highest and lowest season averages and the difference between the highest and lowest season averages for age at 200 pounds was less than eight days.

A total of 1233 gilts were probed during the 14 seasons. There was very little variation within litters for probe backfat thickness. Several of the intervals (± 2 standard errors) surrounding the means do not overlap but differences again are quite small. Although there is some indication of an increase in probe backfat thickness (Figure 12), it should be noted that there was only 0.08 inch difference between the highest and lowest season averages.

Although means for all variables studied showed some variation from season to season, it was not felt that these differences represented major genetic changes in the population. The means plus or minus two standard errors, which approximate 95 percent confidence intervals, were not drastically different for any variable studied. Although the question of genetic stability is not one that is easily handled, it was concluded from this data that the population had served adequately as a genetic control population.

Effectiveness of Selection Procedures

Selection of breeding stock in this study was made with two objectives in mind. The objectives were (1) to maintain selection differentials as near zero as possible for average daily gain and probe backfat and (2) to keep inbreeding coefficients at a minimum. From each litter, two boars of average weight and thriftiness were selected at 21 days of age and the other male pigs were castrated at this time. Therefore, no means were available for evaluating the effectiveness of boar selection.

Two average gilts were selected from each litter at 42 days of age. The remainder of the females in each litter were fed to 200 pounds and treated in the same manner as the two that were selected as potential replacements. This provided a means of evaluating the effectiveness of gilt selection.

Through the course of this study there were litters involved in which only two female pigs were available for selection at 42 days of age. These litters were not included in the present analysis. Only those litters with complete information on at least three females were considered in the calculation of selection differentials.

Selection differentials for the two gilts saved at 42 days of age and for the one gilt from each litter saved for breeding are shown in Tables XVII and XVIII, respectively.

As stated in Chapter III, the two main items considered in the final selection of replacement gilts were postweaning average daily gain and probe backfat thickness. For the two gilts selected at weaning

TABLE XVII

SAMPLING SELECTION DIFFERENTIALS FOR FEMALES SAVED AT 42 DAYS OF AGE

Year and Season[a]	Birth Weight (lb.)	21 Day Weight (lb.)	42 Day Weight (lb.)	Average Daily Gain (lb./day)	Age at 200 Pounds (days)	Probe Backfat (in.)
62S	0.240		2.090	0.071	-7.51	-.008
62F	0.090		1.240	0.033	-3.46	-.026
63S	0.327		-.560	0.003	0.80	0.021
63F	0.297		1.290	0.046	-3.41	0.003
64S	0.078		0.630	0.077	-6.41	0.016
64F	0.151		0.840	-.008	0.09	0.014
65S	0.103	0.230	1.230	0.038	-4.29	-.038
65F	0.042	-.100	1.040	0.027	-2.76	0.033
66S	0.097	0.330	1.010	0.023	-2.68	0.030
66F	-.039	0.440	0.790	0.004	-1.05	-.023
67S	0.065	0.700	2.060	0.023	-2.79	-.006
67F	0.089	0.190	1.080	0.007	-.16	0.006
68S	0.117	0.380	1.250	0.044	-5.02	-.005
68F	-.057	0.470	2.020	0.005	-.91	0.030
Overall	0.104	0.420	1.500	0.024	-3.86	0.002

[a] S = Spring, F = Fall

TABLE XVIII

SELECTION DIFFERENTIALS FOR FEMALES SAVED AS BREEDING STOCK

Year and Season[a]	Birth Weight (lb.)	21 Day Weight (lb.)	42 Day Weight (lb.)	Average Daily Gain (lb./day)	Age at 200 Pounds (days)	Probe Backfat (in.)
62S	0.093		2.040	0.030	-4.70	-.042
62F	0.102		1.640	0.078	-7.78	-.014
63S	0.165		-1.110	0.010	0.18	0.047
63F	0.420		2.290	0.101	-6.64	0.008
64S	0.047		1.710	0.131	-11.28	0.047
64F	0.151		0.690	-.005	0.09	0.005
65S	0.205	0.540	1.760	0.058	0.81	-.060
65F	0.075	0.630	0.750	-.008	-.01	-.027
66S	0.186	0.470	1.490	0.042	-5.77	0.036
66F	0.152	0.910	1.150	0.078	-8.72	0.052
67S	-.165	0.060	0.950	0.010	-1.54	0.004
67F	0.131	-2.190	-2.170	0.014	-1.12	0.048
68S	0.085	0.000	0.750	0.029	-3.34	-.017
68F	0.050	0.050	2.220	0.011	-3.03	0.023
Overall	0.102	0.350	1.510	0.037	-3.99	-.002

[a] S = Spring, F = Fall

(Table XVII), the small overall selection differentials for average daily gain (0.024) and probe backfat (0.002) indicate that this method of selection at weaning was effective in maintaining selection differentials near zero for these two traits. The expected response to selection for these two traits in this study would be negligible.

The negative selection differential obtained for age at 200 pounds (-3.86) should be expected because of the positive selection differentials obtained for pig weight at birth, 21, and 42 days of age.

The rather large selection differential for 42 day weight (1.50) was not expected in this study. If gilts of average weight and thriftiness were selected at weaning, the selection differential should be near zero. The estimate obtained would indicate that the two gilts from each litter selected at weaning tended to be heavier than the average of all gilts available for selection. However, if a litter consisted of only three females and one of these had an exceptionally light weight at 42 days of age, the two heavier females would have been selected in an effort to obtain healthy pigs. Litters of this type could be the primary cause of the positive selection differential for 42 day weight. As would be expected, the two females selected at weaning also tended to be heavier at birth and at 21 days of age than the average of all gilts available for selection.

Selection differentials for females saved as replacement breeding stock (Table XVIII) were very similar to those obtained for the two gilts selected from each litter at weaning.

These results would indicate that the selection procedures practiced at weaning were adequate in maintaining selection differentials near zero for the two traits on which final selection was based (average daily gain and probe backfat). However, the selection differentials obtained for 42 day weight would suggest that it is difficult to select pigs of average weight and thriftiness at weaning. Apparently, the tendency to disregard individuals with light weaning weights was the major factor contributing to the positive selection differentials for weaning weight.

Phenotypic standard deviations for the traits involved in this study are presented in Appendix Tables XXVII - XXX. The standard deviations were fairly uniform across all seasons, indicating that the phenotypic variation remained rather constant. However, the procedure of selecting breeding stock on the basis of average performance could have the effect of reducing the genetic variation present. If this was indeed the case, it should become evident when heritability estimates are calculated for the various traits. If the additive genetic variance was substantially reduced, the estimates of heritability would not be expected to coincide with those reported by other workers. Further discussion of this possibility is delayed until heritability estimates are obtained for the various traits involved.

Population Inbreeding

In an effort to keep inbreeding at a minimum in the population, one boar was used per gilt and no matings were permitted where a common ancestor appeared in the first or second generation on either side. At the conclusion of this study, it was desirable to know how successful the selection procedures had been in keeping inbreeding at a minimum level.

Inbreeding coefficients were calculated for each litter using

Wright's (1934) formula adapted to the IBM 360 computer. The range of inbreeding coefficients, means and coefficients of variation for each season are presented in Table XIX.

In an idealized population the expected increase in inbreeding per generation is given by the formula

$$\Delta F = \frac{1}{2N}$$

where,

ΔF = expected increase in inbreeding per generation

N = actual number of breeding individuals.

The most convenient way of dealing with any deviation from the idealized breeding structure is to express the situation in terms of the effective number of breeding individuals (N_e). Thus, by converting the actual number, N, to the effective number, N_e, the expected increase in inbreeding becomes

$$\Delta F = \frac{1}{2N_e}$$

just as for the idealized population.

The average number of matings per season in this study was 26.2, giving an average actual number of breeding individuals of 52.4. Since two members of each family were deliberately chosen to be parents of the next generation, the variance of family size was zero. Under these special circumstances and with the sexes equal in number, the effective number is twice the actual number (Falconer, 1960). Therefore, N_e would take on the value of 104.8 and the expected increase in inbreeding per

TABLE XIX

RANGE OF INBREEDING COEFFICIENTS, MEANS, AND COEFFICIENTS OF VARIATION FOR LITTERS FARROWED

Year and Season[a]	Number of Litters	Range of Litter F_x	Mean Litter F_x	C.V.[b]
62S	22		0.000	
62F	26		0.000	
63S	24	0.000 - 0.031	0.003	300.0
63F	24	0.000 - 0.062	0.006	283.0
64S	22	0.000 - 0.062	0.010	230.0
64F	21	0.000 - 0.062	0.018	128.0
65S	26	0.000 - 0.078	0.014	150.0
65F	27	0.000 - 0.125	0.013	207.0
66S	30	0.000 - 0.031	0.011	54.5
66F	29	0.000 - 0.030	0.017	52.9
67S	30	0.000 - 0.046	0.017	64.7
67F	23	0.000 - 0.034	0.015	46.7
68S	31	0.000 - 0.027	0.012	66.7
68F	28	0.000 - 0.027	0.014	42.8

[a] S = Spring, F = Fall

[b] Coefficient of variation

generation would be given by

$$\frac{1}{2N_e} = \frac{1}{209.6} = 0.0048.$$

With seven generations involved, the expected inbreeding should reach a maximum of 3.36 percent.

The calculated inbreeding in the present population did not reach the expected maximum. The procedure of not permitting matings where a common ancestor appeared in the first or second generation on either side was apparently effective in controlling inbreeding. Falconer (1960) states that under this controlled breeding system the rate of inbreeding is the lowest possible with a given number of breeding individuals. One could go further by choosing pairs for mating that have the least possible relationship with each other based upon pedigree information. However, results of the present study would indicate that the selection procedures used were effective in maintaining inbreeding at a safe level. The undesirable effects resulting from inbreeding depression should be of little concern in this population.

Heritability Estimates

Basically, two procedures have been practiced in obtaining heritability estimates from regression of offspring on parent in swine. The first is to regress the individual offspring on the parent with the parent value repeated for each pig in the litter. While this procedure does give considerably more degrees of freedom in the regression analysis, it may be argued that this type of analysis is somewhat biased because of the variation that exists in number of pigs per litter.

Certainly, each litter is not equally represented in this type of regression. The second approach is to regress the mean of each litter on the parent observation. This method gives equal weight to each litter. For triats measured on the individual pig, both methods of regression analyses were employed in this study.

Individual Pig Traits

Heritabilities estimated from regression of individual offspring on sire, dam, and mid-parent are presented in Table XX. Estimates obtained from regression of offspring mean on sire, dam, and mid-parent are presented in Table XXI.

No significant differences were found between the heritability estimates obtained from the two regression analyses. This agrees with work by Kempthorne and Tandon (1953) who found no significant differences in the heritability of milk production in Holstein cows using regression of individual offspring on dam compared to offspring mean on dam. The Iowa work was based on 133 cows and their 185 daughters, so that the number of offspring per dam did not vary to any great extent. These workers also suggest that the offspring value may be weighted according to the number of offspring in each family. However, since no significant differences were observed between the first two methods, the procedure of weighting each offspring value was not employed in this study.

Pig Birth Weight

Heritability estimates for pig weight at birth were essentially zero (Tables XX and XXI). Other workers (Baker _et al_., 1943; Krider _et_

TABLE XX

HERITABILITY ESTIMATES AND STANDARD ERRORS OBTAINED FROM REGRESSION OF INDIVIDUAL OFFSPRING ON SIRE, DAM, AND MID-PARENT

Trait	Number of Individuals	Regression of individual offspring on: Sire	Dam	Mid-Parent
Pig birth weight	3760	0.044 ± 0.041	-.040 ± 0.042	0.003 ± 0.028
Pig weight at 21 days of age[a]	1576	0.222 ± 0.037	-.104 ± 0.050	0.057 ± 0.046
Pig weight at 42 days of age	2956	0.080 ± 0.042	0.022 ± 0.044	0.052 ± 0.030
Post-weaning average daily gain[b]	1244	0.288 ± 0.061	0.178 ± 0.078	0.243 ± 0.095
Age at 200 pounds[b]	1244	0.344 ± 0.072	0.188 ± 0.090	0.313 ± 0.118
Probe backfat thickness[b]	1108	0.304 ± 0.068	0.310 ± 0.061	0.305 ± 0.060

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[a] Includes only those pigs born after 1965 Fall.

[b] Female offspring only.

TABLE XXI

HERITABILITY ESTIMATES AND STANDARD ERRORS OBTAINED FROM REGRESSION OF OFFSPRING MEAN ON SIRE, DAM, AND MID-PARENT

Trait	Number of Litters	Regression of offspring mean on: Sire	Dam	Mid-Parent
Pig birth weight	353	0.062 ± 0.092	0.034 ± 0.096	0.050 ± 0.066
Pig weight at 21 days of age[a]	174	0.256 ± 0.032	-.122 ± 0.032	0.060 ± 0.054
Pig weight at 42 days of age	349	0.128 ± 0.090	0.064 ± 0.094	0.098 ± 0.065
Post-weaning average daily gain[b]	340	0.234 ± 0.090	0.118 ± 0.116	0.185 ± 0.070
Age at 200 pounds[b]	340	0.240 ± 0.098	0.160 ± 0.124	0.230 ± 0.080
Probe backfat thickness[b]	314	0.318 ± 0.098	0.308 ± 0.086	0.363 ± 0.068

[a] Includes only those pigs born after 1965 Fall.

[b] Female offspring only.

al., 1946; Louca and Robison, 1967) have reported similar results for the heritability of birth weight. This would suggest that pig birth weight is largely a reflection of maternal environment.

Pig 21 Day Weight

Heritability estimates for pig weight at 21 days of age obtained from regression of offspring on sire were significantly higher than those obtained from regression of offspring on dam. The negative estimate obtained from regression of offspring on dam suggests that the heritability of this trait is low or near zero. Falconer (1960) states that, in general, the regression on mid-parent values yields a more precise estimate of heritability for a given total number of individuals measured. The estimates obtained from regression of offspring on mid-parent would also suggest that heritability of pig weight at 21 days of age is near zero. However, in this study, the sampling variance associated with mid-parent values was as large or larger than that associated with sire or dam values. No apparent explanation for the higher estimate obtained from regression of offspring on sire is available.

Pig weight at 21 days of age should be affected more by the maternal environment than pig weight at birth or weaning. The degree to which mothering ability and maternal environment are associated with pig weight at 21 days is probably the primary reason for the lower estimate of heritability obtained from offspring-dam analysis. Very few studies have been conducted where pig weight at 21 days of age was obtained. Therefore, other estimates are unavailable for comparison purposes.

Pig 42 Day Weight

Estimates of the heritability of weaning weight obtained in this study are in general agreement with those found in the literature. Cunningham (1969) reviewed 16 estimates of the heritability of weaning weight and found a range of -.18 to 0.24 with a simple average of 0.08. Again, the results obtained in this study would suggest that very little additive genetic variance exists for pig weaning weight.

Average Daily Gain

Estimates in the literature for heritability of average daily gain range from -.09 (Louca and Robison, 1967) to 0.77 (Biswas et al., 1966). The difference in growth periods in which average daily gain is measured could be partly responsible for this wide range in estimates.

Estimates obtained in this study (0.118 ± 0.116 to 0.288 ± 0.061) are somewhat lower than those reported by some workers but are in general agreement with the average of all estimates found in the literature. Louca and Robison (1967) studied the heritability of average daily gain in different growth periods. Their estimates ranged from -.09 ± 0.10 for average daily gain from 140 days to puberty to 0.34 ± 0.17 for average daily gain from 42 to 140 days of age. Most of the available literature indicate moderate heritabilities (0.20 to 0.30) for average daily gain.

Although not significantly different, the estimates obtained from regression of offspring mean on parent (or mid-parent) were slightly lower than estimates obtained from individual offspring on parent (or mid-parent). These observed differences could be a reflection of the method of regression analysis. If the sire or dam of a large litter had a superior (or inferior) growth rate, then the parent performance would be repeated for each offspring in the regression of individual offspring on parent. This could, and conceivably would, introduce some form of bias into the data when compared with regression of offspring mean on sire, dam, or mid-parent.

Age at 200 Pounds

The estimates for the heritability of age at 200 pounds in this study were relatively low. Other estimates found in the literature ranged from -.07 (Sviken, 1966) to 0.68 (Fredeen, 1953).

The regression of individual offspring on parent resulted in slightly higher estimates of heritability than did regression of offspring mean on parent. The same pattern was observed in estimates of heritability of average daily gain. However, no significant differences were found between the two methods of regression in either trait.

Probe Backfat

Probe backfat thickness is another trait which is subject to wide variations in heritability estimates. The different methods employed in determining probe backfat could lead to heritability estimates with considerable variation.

All heritability estimates of probe backfat obtained in this study were considered to be in close agreement with those reported in the literature. The extreme values reported in the literature range from 0.09 (Louca and Robison, 1967) to 0.88 (Arganosa, 1968). However, in a review of heritability estimates by Cunningham (1969), the average of 16 estimates of the heritability of probe backfat thickness was 0.40. The estimates obtained in this study were all around 0.30.

Litter Traits

To obtain heritability estimates for litter traits at birth and 42 days of age, 202 daughter-dam pairs were available. For traits measured at 21 days of age, 114 daughter-dam pairs were included in the analysis. Heritability estimates and standard errors for litter traits are presented in Table XXII.

Number of Pigs Born

The heritability estimate for number of pigs born per litter was essentially zero in this study. This estimate agrees well with those reported by Bernard _et al_. (1954), Boylan _et al_. (1961), Cockerham (1952), Louca and Robison (1967), and McClung (1955). Dickerson _et al_. (1954) found a linear decrease of 0.03 and 0.01 per year for litter size at birth and weaning, respectively. Estimates reported in the literature would suggest that little, if any, progress can be made through mass selection for litter size.

Number of Pigs at 21 Days

Number of pigs at 21 days of age also had a rather low heritability (0.098 ± 0.194). Blunn and Baker (1949) reported a heritability estimate of 0.27 for litter size at 21 days of age. Very few estimates were found in the literature for the heritability of litter size at 21 days of age.

Number of Pigs Weaned

The heritability estimate of 0.238 ± 0.152 for number of pigs weaned per litter agrees with most estimates reported in the literature.

TABLE XXII

HERITABILITY ESTIMATES AND STANDARD ERRORS OBTAINED FROM REGRESSION OF DAUGHTER ON DAM FOR LITTER TRAITS[a]

Trait	Number of daughter-dam pairs	Heritability ± S.E.
Number of pigs born per litter	202	0.004 ± 0.144
Number of pigs per litter at 21 days	114	0.098 ± 0.194
Number of pigs per litter at 42 days	202	0.238 ± 0.152
Litter weight at birth	202	0.266 ± 0.147
Litter weight at 21 days	114	0.244 ± 0.220
Litter weight at 42 days	202	0.292 ± 0.162

[a] Gilt litters only, pooled across year and season.

Estimates by other workers range from -.09 (Cockerham, 1952) to 0.32 (Cummings _et al_., 1947) and the simple average of 12 estimates found in the literature was 0.14.

In this study the heritability of number of pigs per litter increased from 0.004 at birth to 0.238 at weaning. The standard errors on these estimates would suggest that the two are not significantly different.

Litter Weight

Heritabilities for litter weight in this study were rather low. Estimates of 0.266 ± 0.147, 0.244 ± 0.220, and 0.292 ± 0.162 were obtained for litter weight at birth, 21 days, and 42 days, respectively. Other workers have reported similar findings for the heritability of litter weight.

Size and weight of the dam's litter at birth may largely be a manifestation of prolificacy of the dam. However, litter size and weight at weaning should be influenced more by genes concerned with survival.

As previously mentioned, the selection procedures used in this study could have had the effect of reducing the genetic variation present in the population. However, the heritability estimates obtained for preweaning and postweaning traits are in general agreement with the average of estimates reviewed in the literature. Therefore, it would seem unlikely that a substantial reduction in the additive genetic variance occurred due to the selection procedures followed.

Genetic Correlations

The general procedure for obtaining genetic correlations was first outlined by Hazel (1943). Since that time the procedure has been used by various workers wishing to obtain genetic relationships between certain traits. Unfortunately, many of the genetic correlations published are misleading and subject to wide variation. Theoretically, genetic correlations should, like any correlation, fall within the range of -1.0 to 1.0. However, several workers have reported genetic correlations above and below these bounds (Arganosa, 1968; Jensen et al., 1967; Louca and Robison, 1967; and Reutzel and Sumption, 1968). The general feeling among research workers seems to be that the magnitude of these genetic correlations is not as important as the direction. Certainly, in determining response to selection, the direction in which two traits are genetically correlated is of ultimate importance.

When the two traits in question have the same heritability and these heritability estimates are relatively high, the calculation of the genetic correlation takes on added meaning. The major problem with genetic correlations seems to arise when the two traits differ in heritability, particularly if one of the estimates of heritability is near zero. According to Robertson (1959), "it seems that we should not say that if heritability is low, it is very difficult to obtain estimates of genetic correlations, but rather that it is equally difficult to obtain estimates of tolerable accuracy of both heritabilities and genetic correlations." At any rate, when dealing with traits of very low heritability, not only can the magnitude of the genetic correlation differ, but also the sign can differ in certain cases.

The variance of the genetic correlation coefficient has been studied by several workers (Reeve, 1955; Robertson, 1959; Tallis, 1959). The method described by Reeve for calculating standard errors of genetic correlations has been widely used in previous studies. Recently, the procedure described by Tallis (1959) has received considerable attention. However, this procedure applies to paternal half-sib data and assumes a constant number of offspring for each sire. Therefore, for the data in this study, it was felt that the formula for the standard error of a genetic correlation developed by Reeve (1955) and supported by Robertson (1959) provided the most meaningful estimate.

Individual Pig Traits

In the calculation of genetic correlations, 1108 female offspring from 308 litters were available for all traits except pig 21 day weight. Since 21 day weights were not obtained on a regular basis until the spring of 1965, only 602 female offspring from 174 litters were available for correlations involving 21 day weight. Because of the design of this study, genetic correlations, like heritability estimates, could be calculated from the covariance terms obtained from regression of individual offspring on sire, dam, and mid-parent (Table XXIII) and also from regression of offspring mean on sire, dam, and mid-parent (Table XXIV). With few exceptions the two methods of calculation gave comparable results. The covariance terms between individual offspring and sire for birth weight, individual offspring and dam for 21 day weight, and offspring mean and dam for 21 day weight were all negative. Since these terms appear in the denominator of the formula for the genetic correlation, no correlations were calculated where these terms were involved.

In many cases the genetic correlation obtained from offspring-sire analysis was different from that obtained from offspring-dam analysis, both in magnitude and direction. Louca and Robison (1967) found that

TABLE XXIII

GENETIC CORRELATIONS AND STANDARD ERRORS[a] OBTAINED FROM INDIVIDUAL OFFSPRING[b]-PARENT RELATIONSHIPS

Traits Correlated	Number of Observations	Individual Offspring and: Sire	Dam	Mid-Parent
Pig birth weight and:				
Pig 21 day weight	602	1.485 ± 0.511	*	0.534 ± 0.435
Pig 42 day weight	1108	*	0.145 ± 0.609	-.102 ± 0.820
Average daily gain	1108	*	-.954 ± 0.029	-.452 ± 0.334
Age at 200 pounds	1108	*	1.190 ± 0.159	0.433 ± 0.304
Probe backfat	1108	*	-.255 ± 0.209	0.733 ± 0.182
Pig 21 day weight and:				
Pig 42 day weight	602	0.743 ± 0.125	*	0.269 ± 0.469
Average daily gain	602	0.295 ± 0.169	*	0.365 ± 0.328
Age at 200 pounds	602	-.556 ± 0.120	*	-.566 ± 0.239
Probe backfat	602	-.206 ± 0.125	*	-.211 ± 0.250
Pig 42 day weight and:				
Average daily gain	1108	1.471 ± 0.349	-1.091 ± 0.105	0.694 ± 0.196
Age at 200 pounds	1108	-1.540 ± 0.365	1.320 ± 0.473	-.799 ± 0.123
Probe backfat	1108	0.445 ± 0.243	0.003 ± 0.373	0.223 ± 0.292
Average daily gain and:				
Age at 200 pounds	1108	-.981 ± 0.005	-1.012 ± 0.008	-.982 ± 0.006
Probe backfat	1108	-.309 ± 0.136	0.649 ± 0.114	0.086 ± 0.154
Age at 200 pounds and:				
Probe backfat	1108	0.141 ± 0.133	-.492 ± 0.174	-.077 ± 0.137

[a] Standard error (Reeve, 1955).

[b] Female offspring only.

*Not calculated due to negative covariance term in denominator.

TABLE XXIV

GENETIC CORRELATIONS AND STANDARD ERRORS[a] OBTAINED FROM OFFSPRING MEAN[b]-PARENT RELATIONSHIPS

Traits Correlated	Number of Observations	Offspring Mean and:		
		Sire	Dam	Mid-Parent
Pig birth weight and:				
Pig 21 day weight	174	1.213 ± 0.406	*	0.547 ± 1.366
Pig 42 day weight	308	0.778 ± 0.355	-.834 ± 0.525	0.115 ± 1.143
Average daily gain	308	0.239 ± 0.633	-2.102 ± 4.354	-.533 ± 0.607
Age at 200 pounds	308	-.648 ± 0.385	1.796 ± 1.804	0.331 ± 0.673
Probe backfat	308	-1.815 ± 1.320	-.164 ± 0.770	-.989 ± 0.012
Pig 21 day weight and:				
Pig 42 day weight	174	0.801 ± 0.207	*	0.614 ± 0.866
Average daily gain	174	0.399 ± 0.373	*	0.420 ± 0.839
Age at 200 pounds	174	-.738 ± 0.199	*	-.871 ± 0.219
Probe backfat	174	-.021 ± 0.380	*	0.059 ± 0.725
Pig 42 day weight and:				
Average daily gain	308	1.230 ± 0.238	-.567 ± 0.631	0.645 ± 0.349
Age at 200 pounds	308	-1.446 ± 0.506	0.490 ± 0.610	-.735 ± 0.248
Probe backfat	308	0.574 ± 0.269	0.354 ± 0.505	0.462 ± 0.337
Average daily gain and:				
Age at 200 pounds	308	-.988 ± 0.008	-.973 ± 0.031	-.980 ± 0.016
Probe backfat	308	-.398 ± 0.251	0.680 ± 0.228	0.029 ± 0.311
Age at 200 pounds and:				
Probe backfat	308	0.145 ± 0.288	-.413 ± 0.301	-.101 ± 0.280

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[a] Standard error (Reeve, 1955).

[b] Female offspring only.

[c] Not calculated due to negative covariance term in denominator.

the genetic correlation between birth weight and probe backfat was greater than 1.0 for boar progeny but less than -1.0 for barrows. These workers concluded that little significance should be placed in these correlations due to negligible additive genetic variance for birth weight. In the present study, birth weight, 21 day weight, and 42 day weight were all found to have negligible additive genetic variance. While it is true that the magnitude of these correlations may or may not have meaning, several interesting observations should be noted from the results. The correlations obtained using individual offspring were very similar to those obtained using offspring mean. However, since results obtained from offspring-sire analyses were not consistent with those obtained from offspring-dam analyses, they will be discussed separately.

Offspring-Sire Correlations. Pig birth weight had a positive genetic relationship with pig 21 day weight, pig 42 day weight, and average daily gain and a negative relationship with age at 200 pounds and probe backfat. Pig 21 day weight was positively correlated with pig 42 day weight and average daily gain, and negatively correlated with age at 200 pounds and probe backfat. Highly significant relationships were obtained between pig 42 day weight and average daily gain (positive) and between pig 42 day weight and age at 200 pounds (negative). These results would indicate that the genes which cause heavier weights at 42 days of age also act to increase average daily gain and to decrease age at 200 pounds. Reutzel and Sumption (1968) reported a genetic correlation of 0.62 between 42 day weight and average daily gain. The positive relationship between 42 day weight and probe backfat in this study is contradictory to the high negative estimate (-.77) reported by Reutzel and Sumption (1968).

Genetically, average daily gain was negatively correlated with age at 200 pounds and probe backfat. These results agree with those of Blunn and Baker (1947) and Fredeen and Jonsson (1957) who found negative estimates between daily gain and carcass backfat. Also, Louca and Robison (1967) found negative relationships between 154 day weight and probe backfat. However, Dickerson (1947) reported high positive estimates for backfat thickness with daily gain and backfat thickness with live weight 154 days.

Age at 200 pounds had a low genetic relationship with probe backfat which agrees favorably with the estimate of -.20 ± 0.48 reported by Arganosa (1968).

<u>Offspring-Dam Correlations</u>. The genetic correlations obtained from offspring-dam analyses were somewhat different from those obtained from offspring-sire analyses. Pig birth weight was positively correlated with pig 42 day weight when calculated from covariances between individual offspring and dam but had a negative relationship when calculated from covariances between offspring mean and dam. However, the magnitude of the standard errors indicate no significant difference between the two estimates. Pig birth weight had a negative relationship with average daily gain and a positive relationship with age at 200 pounds. These estimates do not agree with those reported in the literature and are opposite in direction from those obtained in this study from offspring-sire analyses. The same pattern was observed in pig 42 day weight.

Genetically, pig 42 day weight was negatively correlated with average daily gain but showed a positive relationship with age at 200 pounds. The standard errors on the correlations obtained from covariances between offspring mean and dam suggests that these correlations probably are not different from zero.

The genetic relationship between pig 42 day weight and probe backfat was essentially zero.

Average daily gain had a high negative relationship with age at 200 pounds which agrees with estimates in the literature and also with the estimate obtained in this study from offspring-sire analyses. Average daily gain was positively correlated with probe backfat. This would agree with work by Dickerson (1947) and Zoellner (1963) who reported high positive relationships between average daily gain and probe backfat. However, it is contradictory to estimates by other workers (Blunn and Baker, 1947; Fredeen and Jonsson, 1957; Louca and Robison, 1967). In this study, age at 200 pounds had a negative genetic relationship with probe backfat.

Most estimates of genetic correlations obtained from offspring-dam covariances were not in agreement with other estimates reported in the literature. The lack of additive genetic variance for many of the traits in this study would lead one to question the validity of the formula for the genetic correlation. However, if the formula for the calculation of the genetic correlation (r_g) were valid, for traits influenced to a high degree by maternal environment, the expectation is not r_g. Koch and Clark (1955a,b) suggest that the expectation is a complex function of the genetic correlation between traits, the direct effect of maternal environment, and the correlation between genotypes for maternal environment and the traits in question. Thus, genetic correlations between traits obtained from any set of data not suited to obtaining estimates of maternal effects, may be subject to considerable bias.

The estimates obtained from the covariance between offspring and mid-parent were intermediate between those obtained from offspring-sire covariances and offspring-dam covariances. These values also include the effects from maternal environment. Therefore, it would seem that the most meaningful and least biased genetic correlations were those obtained from the covariance terms between offspring and sire.

Phenotypic Correlations

Phenotypic correlations among the six traits measured on the individual pig and among litter traits are presented in Tables XXV and XXVI, respectively.

Individual Pig Traits

Pig Birth Weight. Heavier pigs at birth were heavier at 21 and 42 days, had a higher rate of gain, reached 200 pounds at an earlier age, and had less probe backfat at 200 pounds. Pig birth weight accounted for about 25 percent of the variation in pig weaning weight. Birth weight was significantly correlated with average daily gain (0.268) and age at 200 pounds (-.364). Louca and Robison (1967) found significant positive correlations between birth weight and 154 day weight. The inverse relationship between average daily gain and age at 200 pounds was, of course, to be expected since faster gaining pigs would reach 200 pounds at an earlier age.

Pig birth weight was negatively correlated (-.178) with probe backfat thickness. This estimate is very similar to those reported by Louca and Robison (1967).

TABLE XXV

PHENOTYPIC CORRELATIONS BETWEEN TRAITS MEASURED ON THE INDIVIDUAL PIG

Traits Correlated	Number of Observations	Pooled Correlation Coefficient[a]
Pig birth weight and:		
Pig 21 day weight	602	0.451**
Pig 42 day weight	1108	0.506**
Average daily gain	1108	0.268**
Age at 200 pounds	1108	-.364**
Probe backfat	1108	-.178**
Pig 21 day weight and:		
Pig 42 day weight	602	0.701**
Average daily gain	602	0.213**
Age at 200 pounds	602	-.389**
Probe backfat	602	-.140**
Pig 42 day weight and:		
Average daily gain	1108	0.322**
Age at 200 pounds	1108	-.537**
Probe backfat	1108	-.083**
Average daily gain and:		
Age at 200 pounds	1108	-.918**
Probe backfat	1108	0.032
Age at 200 pounds and:		
Probe backfat	1108	0.017

[a] Female offspring only. Pooled across year, season, and age of dam.

**Significantly different from zero ($P < .01$).

Pig 21 Day Weight. Individual pig weight at 21 days of age was positively correlated with 42 day weight (0.701) and average daily gain (0.213) and negatively correlated with age at 200 pounds (-.389) and probe backfat (-.140). These estimates are similar to those obtained between birth weight and the various traits except that pig 21 day weight accounted for roughly 50 percent of the variation in weaning weight, whereas birth weight accounted for only 25 percent. The correlation between birth weight and average daily gain (0.268) was slightly higher than the correlation between 21 day weight and average daily gain (0.213). It should be noted that the two correlations are based on different numbers of observations. Few studies have been designed where pig weight at 21 days of age was measured. As a result, other estimates are not available for comparison purposes.

Pig 42 Day Weight. Pig weight at 42 days of age, like birth weight and 21 day weight, was positively correlated with average daily gain (0.322) and negatively correlated with age at 200 pounds (-.537) and probe backfat (-.083). Other estimates of the relationship between weaning weight and average daily gain range from 0.17 to 0.44 and the simple average of six estimates reported in the literature was 0.35. The only other estimate found for the phenotypic correlation between weaning weight and age at 200 pounds was by Omtvedt et al. (1967). These workers reported a correlation of -.52 compared to the estimate of -.537 obtained in this study.

The correlation between weaning weight and probe backfat in this study was -.083, indicating that weaning weight accounts for a negligible portion of the variation in probe backfat. This estimate is in agreement with those reported by Zoellner et al. (1963), Omtvedt et al.

(1967), and Reutzel and Sumption (1968). These workers reported correlations ranging from -.29 to -.12 for these same two traits. Although all correlations between pig weight and probe backfat were significant ($P < .01$), the variation in probe backfat that was accounted for by pig weight was negligible.

Average Daily Gain. A high negative correlation (-.918) was obtained between average daily gain and age at 200 pounds. Other estimates of the relationship between average daily gain and age at 200 pounds are not available in the literature. However, other workers (Warnick *et al*., 1951; Self *et al*., 1955; and Foote *et al*., 1956) have reported high negative correlations between 154 day weight and age at puberty.

Average daily gain was not significantly correlated with probe backfat in this study, indicating that differences in rate of gain have little effect on the deposition of fat measured at 200 pounds live weight. Estimates by other workers (Reutzel and Sumption, 1968; Turner, 1964; and Zoellner *et al*., 1963) range from -.34 to 0.21 with a simple average of -.02.

Age at 200 Pounds. No significant relationship was found between age at 200 pounds and probe backfat. Omtvedt *et al*. (1967) reported a correlation of -.18 between age at 200 pounds and probe backfat and Arganosa (1968) found a correlation of -.15 between age at slaughter (approximately 200 pounds) and probe backfat. Age at puberty and probe backfat were positively correlated (0.08) in a report by Reutzel and Sumption (1968).

Litter Traits

Number of pigs born per litter had a positive phenotypic relationship with number of pigs at 21 days (0.813) and number of pigs at 42 days (0.731). Louca and Robison (1967) found that litter size at birth was positively correlated with litter size at weaning (0.58) and litter size at 154 days (0.48). The North Carolina workers also found a correlation of 0.81 between litter size at weaning and litter size at 154 days. In the present study, number of pigs born accounted for 79 percent of the variation in litter birth weight. The correlation between number of pigs born and litter weight at 21 days (0.370) was somewhat lower than the correlation between number born and litter weight at 42 days (0.641). These two correlations were based on different numbers of observations which could account for the lower value obtained between number born and litter weight at 21 days.

Number of pigs at 21 days accounted for 99 percent of the variation in number of pigs at 42 days, indicating an extremely high survival rate from 21 to 42 days of age. Litter size at 21 days was positively correlated with litter weight at birth, 21, and 42 days (0.631, 0.778, and 0.843, respectively).

Number of pigs per litter at 42 days was positively correlated with litter weight at birth (0.736), litter weight at 21 days (0.772), and litter weight at 42 days (0.911).

Litter weight at birth could account for only about 50 percent of the variation in litter weight at 21 or 42 days, while litter weight at 21 days accounted for 69 percent of the variation in litter weight at 42 days.

Results would indicate that there is a moderate to high relationship between all litter traits observed in this study.

TABLE XXVI

PHENOTYPIC CORRELATIONS BETWEEN LITTER TRAITS

Traits Correlated	Number of Observations	Pooled Correlation Coefficient[a]
Number of pigs born and:		
Number of pigs at 21 days	114	0.813**
Number of pigs at 42 days	202	0.731**
Litter weight at birth	202	0.887**
Litter weight at 21 days	114	0.370**
Litter weight at 42 days	202	0.641**
Number of pigs at 21 days and:		
Number of pigs at 42 days	114	0.988**
Litter weight at birth	114	0.631**
Litter weight at 21 days	114	0.778**
Litter weight at 42 days	114	0.843**
Number of pigs at 42 days and:		
Litter weight at birth	202	0.736**
Litter weight at 21 days	114	0.772**
Litter weight at 42 days	202	0.911**
Litter weight at birth and:		
Litter weight at 21 days	114	0.711**
Litter weight at 42 days	202	0.747**
Litter weight at 21 days and:		
Litter weight at 42 days	114	0.827**

[a] Gilt litters only. Pooled across year, season, and age of dam.

**Significantly different from zero ($P < .01$).

CHAPTER V

SUMMARY

The objectives of this study were to determine the degree of stability in a genetic control population and to obtain estimates of various genetic parameters from this population. The data were collected from a zero-selection control line maintained in the Oklahoma swine breeding project herd and included 3860 individuals from 363 litters farrowed during the 14 seasons from 1962 spring through 1968 fall.

The preweaning traits studied were number of pigs farrowed per litter, pig birth weight, number of pigs per litter at 21 days, pig 21 day weight, number of pigs per litter at 42 days, pig 42 day weight, and total litter weight at birth, 21, and 42 days of age. Postweaning traits included average daily gain, age at 200 pounds, and probe backfat thickness. In determining the stability of the population, additive correction factors were used to correct for age of dam within season. Repeat matings were used to correct for season differences. One boar was used for each female in this study, which provided the basis for estimating heritabilities from the regression of individual offspring on sire, dam, and mid-parent and also from the regression of offspring mean on sire, dam, and mid-parent. Genetic correlations were estimated from parent-offspring covariances. For heritability estimates, genetic correlations and phenotypic correlations, the analyses were done on a within year, season, and age of dam basis.

The corrected season means for each variable studied were fairly consistent across all seasons. Two standard errors above or below each season mean represented intervals very similar to 95 percent confidence intervals. These intervals overlapped in all seasons for most traits studied. For intervals that did not overlap, the observed differences were small and were attributed to random drift. The overall selection differentials of the gilts retained for breeding were 0.037 for average daily gain and -.002 for probe backfat. The average litter inbreeding did not exceed two percent in any given season. In control populations it is difficult to determine if small fluctuations in the population mean represent true genetic changes. However, for the traits considered in this study, it was concluded that the population had remained fairly uniform across the 14 seasons and had served adequately as a genetic control population.

Heritability estimates obtained from regression of individual offspring on parent (or mid-parent) were similar to those obtained from regression of offspring mean on parent (or mid-parent). The results of this study verified most reports in the literature in that pig weight at birth, 21, and 42 days of age were lowly heritable traits ($h^2 \leq 0.20$) and average daily gain, age at 200 pounds, and probe backfat were moderately heritable traits ($0.20 \leq h^2 \leq 0.40$). Heritability of number of pigs per litter, based on daughter-dam regression, increased from 0.004 ± 0.144 at birth to 0.238 ± 0.152 at weaning. Total litter weight at birth, 21, and 42 days of age were found to be moderately heritable ($0.20 \leq h^2 \leq 0.40$).

Genetic correlations obtained from offspring-sire covariances revealed that pig birth weight was positively correlated with pig 21 day weight, pig 42 day weight, and average daily gain but negatively correlated with age at 200 pounds and probe backfat. Pig 21 day weight was also positively correlated with pig 42 day weight and average daily gain, and negatively correlated with age at 200 pounds and probe backfat. Pig weight at 42 days of age was positively correlated with average daily gain and probe backfat but negatively correlated with age at 200 pounds. These results would indicate that selection for heavier pig weights at birth, 21, or 42 days of age would increase average daily gain and decrease age at 200 pounds. However, the lack of additive genetic variance for pig weight at birth, 21, or 42 days would lead one to question the relative magnitude of these correlations. Average daily gain had a negative genetic relationship with age at 200 pounds and probe backfat. Age at 200 pounds was positively correlated with probe backfat thickness.

Genetic correlations obtained from offspring-dam covariances were generally quite different, both in magnitude and direction, from those calculated from offspring-sire covariances. Based on the results of this study, it was concluded that genetic correlations between traits influenced to a large degree by maternal environment, were subject to considerable bias and were, for the most part, meaningless.

Genetic correlations based on mid-parent values were intermediate between those based on the two parent values separately. These correlations would also be influenced by the maternal environment and would not reflect the true genetic relationship between any two traits.

Phenotypically, pig birth weight was correlated with pig weight at 21 days (0.45), pig weight at 42 days (0.51), average daily gain (0.27), age at 200 pounds (-.36), and probe backfat (-.18). Variation in pig weight at 21 days accounted for 49 percent of the variation in pig weight at 42 days and less than five percent of the variation in average daily gain. Fifteen percent of the variation in age at 200 pounds, and only two percent of the variation in probe backfat was accounted for by variation in pig 21 day weight.

Pig 42 day weight accounted for 10, 29, and one percent of the variation in average daily gain, age at 200 pounds, and probe backfat, respectively.

Average daily gain had a highly significant negative correlation (-.92) with age at 200 pounds but essentially no correlation with probe backfat. The correlation between age at 200 pounds and probe backfat was essentially zero.

Number of pigs born per litter could account for about 64 percent of the variation in number of pigs at 21 days and about 50 percent of the variation in number of pigs at 42 days. Variation in number of pigs born per litter also accounted for approximately 80, 14, and 41 percent of the variation in litter weight at birth, 21, and 42 days, respectively. Number of pigs at 21 days of age was positively correlated with number of pigs at 42 days, litter weight at birth, litter weight at 21 days, and litter weight at 42 days (0.99, 0.63, 0.78, and 0.84, respectively). Number of pigs at 42 days accounted for 55, 59, and 83 percent of the variation in litter weight at birth, 21, and 42 days, respectively.

Litter weight at birth had highly significant positive correlations of 0.71 and 0.75 with litter weight at 21 and 42 days, respectively. Variation in litter weight at 21 days of age accounted for 69 percent of the variation in litter weight at 42 days.

Results of this study indicated that the population in question had served adequately as a genetic control population. In general, heritability estimates and phenotypic correlations were in good agreement with estimates reported by other workers. Genetic correlations obtained from offspring-sire covariances were also in general agreement with other estimates in the literature. However, genetic correlations obtained from offspring-dam covariances were not in agreement with other estimates in the literature. The influence of maternal environment was considered the primary factor contributing to the unrealistic estimates of these correlations.

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APPENDIX

TABLE XXVII

UNCORRECTED MEANS AND STANDARD DEVIATIONS FOR TRAITS MEASURED ON INDIVIDUAL PIGS FROM GILT LITTERS BY YEAR AND SEASON

Year and Season[a]	No. Litters Farrowed	Pig Birth Wt. (lb.)		Pig 21 Day Wt. (lb.)		Pig 42 Day Wt. (lb.)		Average Daily Gain (lb./day)[b]		Age at 200 Pounds (days)[b]		Probe Backfat (in.)[b]	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
62S	16	3.0	0.5			24.2	4.6	1.36	0.16	177.4	16.0	1.49	0.12
62F	13	2.7	0.5			23.1	4.2	1.49	0.16	170.2	13.7	1.38	0.15
63S	12	2.6	0.5			21.1	3.1	1.48	0.14	167.3	10.8	1.46	0.15
63F	14	2.8	0.5			25.1	5.6	1.65	0.17	155.0	12.7	1.51	0.16
64S	8	2.7	0.5			31.1	5.1	1.56	0.13	152.8	12.6	1.52	0.13
64F	16	2.5	0.6			29.5	5.7	1.50	0.17	158.2	15.0	1.46	0.15
65S	14	2.6	0.5	11.6	1.9	28.4	5.3	1.50	0.18	157.7	17.4	1.50	0.16
65F	13	2.6	0.4	11.0	1.9	27.1	4.4	1.60	0.14	154.1	9.9	1.51	0.15
66S	21	2.6	0.4	10.6	1.8	24.1	4.5	1.52	0.19	163.7	13.3	1.46	0.14
66F	18	2.8	0.5	10.3	2.0	23.2	4.7	1.54	0.21	164.2	18.0	1.47	0.15
67S	19	2.8	0.4	12.1	2.1	28.3	4.8	1.57	0.16	156.9	12.6	1.57	0.13
67F	12	2.9	0.5	12.1	2.7	26.0	4.3	1.53	0.14	162.0	12.0	1.51	0.15
68S	21	2.8	0.6	11.6	2.4	27.0	4.8	1.46	0.13	166.5	11.5	1.57	0.17
68F	19	2.8	0.5	12.3	2.0	28.1	4.6	1.50	0.18	164.4	14.8	1.51	0.14
Spring	111	2.7		11.4		26.1		1.49		163.2		1.51	
Fall	105	2.7		11.4		26.1		1.54		161.2		1.48	
Overall	216	2.7		11.4		26.1		1.52		162.2		1.49	

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[a] S = Spring, F = Fall.

[b] Female offspring only.

TABLE XXVIII

UNCORRECTED MEANS AND STANDARD DEVIATIONS FOR TRAITS MEASURED ON INDIVIDUAL PIGS FROM SOW LITTERS BY YEAR AND SEASON

Year and Season[a]	No. Litters Farrowed	Pig Birth Wt. (lb.)		Pig 21 Day Wt. (lb.)		Pig 42 Day Wt. (lb.)		Average Daily Gain (lb./day)[b]		Age at 200 Pounds (days)[b]		Probe Backfat (in.)[b]	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
62S	6	3.4	0.6			27.9	5.1	1.40	0.15	172.7	13.1	1.41	0.14
62F	13	3.1	0.6			25.9	5.4	1.57	0.17	162.3	15.3	1.44	0.14
63S	12	2.8	0.7			26.8	4.9	1.59	0.14	155.9	11.3	1.41	0.16
63F	10	3.1	0.6			28.1	4.0	1.63	0.21	154.9	15.1	1.45	0.14
64S	14	3.1	0.6			32.5	5.9	1.52	0.22	157.2	21.0	1.56	0.14
64F	5	2.6	0.5			27.8	4.9	1.53	0.14	155.9	12.0	1.44	0.13
65S	12	3.2	0.6	13.6	2.0	32.9	5.8	1.55	0.14	150.6	13.0	1.47	0.13
65F	14	3.1	0.7	12.4	1.9	29.7	6.5	1.65	0.19	149.7	14.6	1.45	0.18
66S	9	2.9	0.4	11.8	2.1	27.8	4.0	1.53	0.17	165.7	13.5	1.46	0.13
66F	11	3.0	0.5	10.7	2.9	27.1	7.1	1.61	0.19	161.3	17.8	1.50	0.12
67S	11	3.3	0.5	12.5	1.9	30.0	4.2	1.58	0.16	153.5	11.7	1.53	0.12
67F	11	3.1	0.5	12.7	2.3	29.4	4.6	1.50	0.19	163.7	14.6	1.53	0.15
68S	10	3.2	0.6	14.9	1.9	33.6	4.0	1.51	0.18	155.6	14.8	1.47	0.16
68F	9	2.8	0.4	12.8	1.9	28.3	4.6	1.42	0.15	170.6	11.6	1.52	0.16
Spring	74	3.1		13.2		30.5		1.52		158.7		1.47	
Fall	73	3.0		12.1		28.1		1.56		159.8		1.47	
Overall	147	3.0		12.7		29.1		1.54		159.3		1.47	

[a] S = Spring, F = Fall.

[b] Female offspring only.

TABLE XXIX

UNCORRECTED MEANS AND STANDARD DEVIATIONS FOR LITTER TRAITS FROM GILT LITTERS BY YEAR AND SEASON

Year and Season[a]	No. Litters Farrowed	Farrowing Data				21 Day Data				Weaning Data			
		No. Pigs		Litter Weight (lb.)		No. Pigs		Litter Weight (lb.)		No. Pigs		Litter Weight (lb.)	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
62S	16	9.9	3.2	30.2	9.8					9.0	2.7	218.5	72.6
62F	13	11.2	2.2	30.1	5.6					8.5	1.5	197.3	29.9
63S	12	11.3	2.0	29.9	4.4					8.3	1.9	176.2	40.3
63F	14	9.1	3.6	26.0	7.6					7.2	2.7	181.6	51.6
64S	8	11.0	2.7	29.3	4.1					9.1	1.9	284.4	34.4
64F	16	6.7	4.3	17.0	9.9					5.0	3.2	147.4	88.8
65S	14	10.5	2.6	27.3	5.8	8.1	2.6	93.7	28.7	8.1	2.6	229.0	71.6
65F	13	8.8	3.5	23.2	9.0	6.7	3.2	73.3	34.2	6.7	3.2	180.5	87.5
66S	21	11.8	1.9	30.7	6.9	8.9	2.8	94.4	29.6	8.9	2.7	213.5	60.3
66F	18	10.4	2.2	28.6	5.9	9.2	1.5	94.3	17.8	9.2	1.5	212.9	38.4
67S	19	10.6	1.6	29.0	4.8	9.4	1.8	113.1	17.6	9.3	1.8	262.5	44.4
67F	12	9.4	3.0	27.1	9.8	7.6	2.6	91.9	30.9	7.6	2.6	196.9	64.5
68S	21	10.2	2.1	29.1	6.9	8.9	2.4	103.1	27.9	8.3	2.2	223.6	64.3
68F	19	9.4	2.1	26.4	6.8	8.2	2.0	100.9	28.7	8.2	2.0	230.4	57.5
Spring	111	10.7		29.4		8.8		101.4		8.7		227.55	
Fall	105	9.3		25.4		8.0		91.8		7.5		196.45	
Overall	216	10.0		27.4		8.4		95.6		8.1		211.06	

[a] S = Spring, F = Fall.

TABLE XXX

UNCORRECTED MEANS AND STANDARD DEVIATIONS FOR LITTER TRAITS FROM SOW LITTERS BY YEAR AND SEASON

Year and Season[a]	No. Litters Farrowed	Farrowing Data				21 Day Data				Weaning Data			
		No. Pigs		Litter Weight (lb.)		No. Pigs		Litter Weight (lb.)		No. Pigs		Litter Weight (lb.)	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
62S	6	10.2	1.6	34.8	4.0					8.5	1.0	237.5	32.1
62F	13	12.1	2.5	37.6	8.4					8.9	2.2	230.9	49.4
63S	12	11.1	2.4	31.1	7.8					8.0	2.2	214.8	53.9
63F	10	10.7	3.0	33.1	6.4					8.5	1.9	239.2	43.8
64S	14	10.4	3.4	32.1	9.4					8.1	3.5	262.3	91.8
64F	5	14.2	1.3	37.2	4.0					11.4	0.9	316.3	18.8
65S	12	9.9	3.3	31.3	9.3	7.9	2.5	107.4	23.1	7.9	2.5	260.2	60.3
65F	14	11.1	3.5	33.7	8.6	8.5	3.1	105.0	28.7	8.4	3.1	250.8	70.1
66S	9	12.8	1.9	36.9	5.4	11.1	2.2	131.5	30.3	11.1	2.2	308.8	67.9
66F	11	11.4	3.2	33.9	9.6	8.0	3.0	85.8	29.2	7.7	2.8	209.2	77.5
67S	11	12.2	1.9	39.9	5.6	11.1	1.3	139.0	18.7	11.1	1.3	332.2	38.7
67F	11	11.4	2.5	34.9	7.5	8.4	2.2	107.2	24.0	8.4	2.2	246.2	63.1
68S	10	9.9	3.1	31.7	11.0	8.7	3.3	129.5	49.0	8.7	3.3	292.7	110.2
68F	9	11.7	3.0	33.3	7.7	9.2	2.5	118.0	26.0	9.1	2.5	257.7	61.4
Spring	74	10.9		33.7		9.6		127.4		9.0		273.4	
Fall	73	11.8		35.3		8.5		103.2		8.9		248.7	
Overall	147	11.4		34.4		9.1		115.4		8.9		261.3	

[a] S = Spring, F = Fall.

VITA

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