THE INFLUENCE OF BREED AND OTHER FACTORS ON THE PROLIFICACY, LIVABILITY, AND WEANING WEIGHTS OF SWINE

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THE INFLUENCE OF BREED AND OTHER FACTORS ON THE PROLIFICACY, LIVABILITY, AND WEANING WEIGHTS OF SWINE

By

Charles Leslie Nickel

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THESIS

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INTRODUCTION

There is nothing inherent in any system of breeding which guarantees success or failure under all circumstances. The element of uncertainty which is constantly overshadowing the outcome of any breeding program requires the constant attention of the breeder for signs of the stimulating rewards of success or the depressing misery of failure.

Since 1900, considerable strides have been made in animal breeding. This is probably most particularly true in dairy cattle where individual variations in production can be measured. In more recent years progeny testing has appeared in other classes of livestock, including swine.

The history of the sow testing program began in this country in Minnesota in 1929, when purebred breeders were invited to send individual animals to the experiment station where rate and cost of gain as well as carcass yield were studied. In 1934, the sow testing program was expanded with the actual testing carried out at the farms and was found to stimulate more careful selection in swine herds. This type of project has since gained much popularity throughout the country and was introduced into Michigan in 1945.

Most of the purebred swine associations actively

promote progeny testing and have agreed upon requirements governing the tests. Although specific requirements vary between breed associations, their common goal is to recognize productive sows in order that their offspring may be used as herd replacements.

This study involves the swine litters entered in the Michigan Sow Testing Program and the relative merits of the various breeds of swine as well as the crossbreds entered therein. Inasmuch as the breeding of livestock is a specialized business with the economic well being of the operator often dependent upon its success, it is well for the participant to know all that he can about the product which he is producing.

Experienced operators are well aware that a successful swine enterprise can be based on good animals of any improved breed and that greater variations often exist between strains of one breed then between two different breeds. However, essential facts concerning the performance and improvement of individual breeds cannot easily be ignored and may well serve to direct the future progress and comparative status of a breed.

The writer is fully cognizant of the fact that much competition and rivalry exists between respective breeds of swine, as in all breeds of livestock. However, persons who contemplate the breeding of livestock should endeavor to acquaint themselves with the present attributes

and future possibilities of a breed. With these facts in mind it was felt that an opportunity presented itself in this study which could not be overlooked.

OBJECT OF THE STUDY

Although swine type has varied considerably in this country in recent decades, desirable market type swine have generally been developed by selection and breeding on the basis of pedigree and external appearance. The conformation and quality of several leading breeds have become remarkably similar due to uniform ideals held by most swine authorities and by various breeders working with different breeds. Although much agitation for a leaner hog has been forthcoming in recent years, it may be said in general, that satisfactory progress has been made in selection according to external characteristics.

It has been only in recent years however, that much study has been given to the factors which effect the prolificacy and the ability of sows to raise the pigs farrowed by them. Although most authorities agree that the commercial swine producer might better devote his time to providing adequate rations and keeping his herd healthy, there is great opportunity in the swine industry for increasing litter size and especially for controlling the various factors that might increase the size and number of pigs reaching weaning age. Some of these factors include the breed involved, the relative merits of sows and gilts and perhaps the season of year farrowed. It was the purpose of this study to find the effects of breeds and to study the merits of sows

and gilts within each breed. Also included were the effect of size of litter farrowed on the size of litter weaned along with the effect of litter size on the individual pig weights at weaning time. Other factors studied included, the effect of seasonal variation on the number of pigs farrowed, weaned, and the weaning weights of litters. The effects of various methods of crossbreeding on the above mentioned factors were also studied, although the data on this subject is somewhat limited.

A study of this nature becomes complicated by the fact that variations in feeding and management occuring between herds may mask or distort breed differences. Ideally, each breed should be kept under controlled conditions, but such a course is impossible under commercial production. Consequently it is necessary to deal with large samples selected at random which was the method followed in this study.

REVIEW OF LITERATURE

Inasmuch as this paper was concerned with several aspects of sow performance the review of literature was divided into various subjects directly concerned with the objects of this study.

In one of the earliest studies of breed differences on prolificacy of sows, Bitting (2) in 1898 reviewed the herd books of three popular breeds and reported that Chester Whites excelled both Berkshires and Poland Chinas by .14 and 1.5 pigs per litter respectively. He reported on 600 litters of Chester Whites, 400 litters of Berkshires and 1,086 litters of Poland Chinas.

Christenen, et al. (5) studied the records of breed prolificacy and mortality of pigs at the North Dakota Agricultural Experiment Station covering the period from 1909 to 1926. The average litter size for 393 sows was 9.6 pigs per litter farrowed. Yorkshires averaged 11.7 pigs per litter, Duroc Jerseys 10.7, Chester Whites 9.6, Berkshires 8.7, and Poland Chinas 8.2. No mention was made as to the number of sows of each breed farrowing. In the same study it was reported that the average weaning percentage for all breeds was 69.8%. In the individual breeds, Yorkshires weaned 74%, Duroc Jerseys 67%, Chester Whites 73%, Berkshires 69% and Poland Chinas 65%.

Surface, (28) in 1909 reviewed the herd books of

Poland Chinas and Duroc Jerseys. On 54,515 litters of Poland Chinas he found the average litter at birth to be 7.4 pigs, while on the 21,652 litters of Duroc Jerseys the average was 9.33 pigs farrowed per litter.

Rommel (23) also working on the herd books of the Poland China and Duroc Jersey breeds, found that in the Poland Chinas the average litter size during the preceding 20 years had increased by 0.5, while there was no change regarding the Durocs. The former breed had an average litter size of 7.52 and the latter 9.26.

Wentworth and Aubel (32) in a study conducted in 1916 on 3,540 litters, stated that 3 centers of deviation exist in swine fertility which may possibly correspond to genetic factors involved in its inheritance. They supported the contention that small litters were dominant to large ones.

Lush (13) in a statistical study at Iowa State College, found in the instructional herd (7 different breeds maintained), that the breed differences account for 5% of the variance in live pigs farrowed. Nearly 13% of the remaining variance was caused by permanent individual differences between sows within a breed. He further estimated that it would require 10-20 years to increase the average fertility by as much as one pig per litter.

Morris and Johnson (20) analyzed 1,035 litters taken at random from Poland China records made no mention of average litter size but reported an increase in the

average litter size of one pig during the period 1900-1921.

One of the most extensive American studies on breed differences which has been reported is that made by Lush and Molln (14) in connection with their study of inheritance in sows. Information was obtained on 7,296 litters from 2,560 different sows, covering the period from 1920 to 1937. The data used was collected from experiment station and college herds in eight states and in herds maintained by the United States Bureau of Animal Industry. A tabulation of pigs farrowed by breeds and the number of breeds reported on follows.

Table I

Breed	P.C.	D.J.	C.W.	Hamp.	York.	Berk.	Tam.	Landrace
Average	7.98	9.78	9.33	8.66	10.75	7.74	7.43	9.74
Number of Litters	1851	3,337	832	267	194	483	218	114

These workers concluded that breed differences were statistically significant and that a high degree of consistency existed regardless of station.

The same workers reported on the number of pigs weaned per litter and used data including 4,790 litters farrowed from 1634 different sows. The following table gives the breed, average number of pigs weaned per litter and the number of litters of each respective breed studied.

Table II

Breed	P.C.	D.J.	C.W.	Hamp.	York.	Berk.	Tam.	Landrace
Average Litter Size	5.18	5.62	6.10	6.25	7.08	5.30	4.02	5.09
Number of Litters	1492	2,104	607	101	143	83	146	114

Differences were found to be significantly different between breeds.

Weaver and Bogart (31) reported on 117 sows that weaned an average of 5.8 pigs. Only 24% of them raised as many as eight pigs.

Lush (13) indicates that selection for the number of pigs weaned would progress at about the same rate as selection for number of pigs farrowed (one pig increase every 10-20 years). He further states that about 9% of the variance in numbers of pigs weaned is due to permanent differences between sows. About 10% of the variance in weaning weight is similarly caused. This work was done on Iowa State College's instructional herd.

Many workers have studied the effects of age of the sow on prolificacy and mortality of pigs. Snyder (30), in a study concerning 72 mature sows and 87 first litter gilts, reported a farrowing average of 10.9 pigs per litter for sows against 8.2 pigs per litter for gilts. The sows weaned 6.56 pigs per litter while the gilts weaned 6.25

pigs per litter. Percentages of farrowed pigs weaned was 60% for the former and 76% for the latter. Johansson, as cited by Smith and Donald, (26) supports this in his observation of 1,671 litters of Swedish Large White Pigs. He indicated that first litter sows farrow fewer pigs than older sows but that they suffer lower mortality. Vestal (31) found yearling sows farrowing an average of about two pigs less than aged sows, which differed little regardless of age. He also showed that two year old sows weaned the maximum number of pigs with the yearlings weaning 1.62 pigs per litter less.

Lush (14) found that gilts averaged ½ pig smaller litters at weaning then did the average of four of the first six litters when consecutive records of the same individual sows were kept. He also reports that the two year old sow weaned ½ pig more than the average of the first six litters. He concluded his study of effect of age on prolificacy with the observation that size of litter rose slightly more than ½ pig from the first to the second litter, then one more pig per litter at two years of age, then varied only a little until the sows were four and one half years old at which point a gradual decline was observed.

Stewart (27) reported on the effects of age from the records of 749 inbred Poland China and Minnesota #1 gilts. He found that litter size increased with the age

of dam at farrowing. Gilts farrowing at 320 days of age averaged one pig less and those farrowing at 410 days, ½ pig more than those at one year. He further reported that on the average, gilts making the greatest gains during gestation farrow the largest litter but variations in gain may be an effect rather then a cause. He concluded that age and weight together account for four % of the variance in size of first litters and provide the most reliable criteria for use in fertility selection.

Young (36) reports the following records on 308 sows and 270 gilts. The sows farrowed an average of 9.0 pigs compared to an average of 7.1 pigs from gilts. Sows lost 1/3 of their pigs prior to weaning compared to 1/4 lost by gilts. The average size of litter weaned by sows was 6.0 pigs and by gilts to 5.3 pigs. No mention was made as to the numbers studied.

McPhee (18) in determining the feasibility of using litter size as a selection index, examined 589 litters. He concluded that there is a significant correlation between a sow's first litter and her later litter but no such correlation existed between the size of litter a gilt was farrowed in and the size of litter produced by her. In contrast Weaver and Bogart (32) concluded that gilts from the higher producing dams make better sows than did gilts from poorer producers. Their work with

65 selected dams was rather conclusive although no statistical evidence was offered.

The review of literature on the effects of respective breeds on weaning weights of litters is rather limited. Lush and Molln (14) recognized that statistically significant differences did exist between breeds and that the differences appear consistently in all herds studied.

Russell and Hutton (24) studied the litter weights of 40 mature sows and 87 gilts. They found the pigs of mature sows to average 8 to 9 pounds heavier at 70 days of age than the pigs of 87 gilts. Menzies-Kitchin, (19) working with English breeds, found the litters of sows to be somewhat heavier at six weeks of age than the gilt litters. Smith and Donald (25) studying the records of sows and gilts farrowing the same numbers of pigs reported a slight difference in favor of the sows litters at the end of eight weeks. Hostetler, et al. (11) studied 167 individuals and indicated that no great difference existed between weights of sows and gilts at weaning, although the sows weaned slightly more pigs. McMeekan (17) also showed first litter gilts to wean litters comparable in weight to older sows.

The effect of litter size on the weaning weights of pigs has been a controversial issue among workers in the past.

Hostetler, et al. (11) indicated that the average weaning weight per pig decreases as the number of pigs in the litter increase. Menzie's-Kitchen (19) substantiates this, stating there was no significant difference at 6 weeks between the average weights of pigs from litters of different size at birth. He indicated that there is, however, a difference in average weight according to the number of pigs surviving at six weeks: the larger the number the lighter the pig. Further, Johansson, as cited by Smith and Donald (25) found a decrease in weight as the litter size increases. Murray (21), however studied the influence of size of litter on total litter weight at eight weeks and found that the litter weight increases with increase in litter size up to 12, after which the weight decreases. Alexsson, as cited by Smith, et al. (26), calculated the correlation between the number of pigs at birth and the litter weight and obtained $r = -0.815 \pm 0.0322$. The larger the average fertility, the stronger was the negative correlation between litter size and weight of individual animals at 3 weeks. Smith and Donald (25) concluded that no general relationship between weaning weight with respect to litter size existed. Carroll and Krider (4) express the view that the number of pigs nursing does not have a uniform influence on the average weaning weight of the pigs. They maintain that the evidence is not clear that a pig in a small

litter is any better nourished up to weaning than a pig in a reasonably large litter.

The effect of season or month of the year in which sows are farrowed has come under the scrutiny of several workers. Hostetler (11) states that more pigs were weaned per litter in the fall months than spring although no indication of the number of litters studies was advanced. Young (36) in a study of 180 Indiana farms states that the average death loss was 27% for fall pigs, while for the spring pigs it was 32%. Davidson (6) reports the most satisfactory months for farrowing two litters annually in England and Northwest Europe are March and September. He further states that litters farrowed in June give the best results in numbers and weight at weaning, while November litters were the poorest.

Vestal (31) reports March and September to have the heaviest losses of suckling pigs. Wilcox, et al. (34) report that in early farrowed pigs (before April 1) an average of 68% were alive at weaning. On an equal number of farms studied having pigs farrowed after April 1, 70% survived till weaning. In grouping of pigs farrowed into spring and fall litters the investigators found that only 66.2% of the spring pigs survived while fall litters saved an average of 68.1% of pigs farrowed. Hopkins (10) tabulated the effect of time of farrow on number of pigs weaned for 3 years. The months studied were March, April

and May. The 3 year average for March was 63.7% saved, for April 66.0% saved and for May 71.2% survived. Menzies-Kitchen (19) investigated English records, where sows are farrowed quite uniformly throughout the year, and concluded that approximately one more pig survived per litter during the summer than during the winter months.

The review of literature concerning the effect of litter size at birth on the number of pigs weaned is somewhat limited. Menzies-Kitchen states that there appears to be little advantage in producing more than 12 pigs at birth. In the case of more than 12 pigs the addition in number was more than offset by an increase in death rate.

A considerable amount of work has been done on the effects of crossbreeding on litter size and pig mortality. Lush, et al. (15) in a study comparing crossbred and purebred brood sows and involving 108 litters concluded that cross breds had a general superiority over purebreds in the percentage of pigs living till weaning. In weaning weights the crossbreds showed greater and more consistent gains. The workers further state that back cross and 3 breed crosses when sired by a purebred bear compare favorably to the first-cross pigs. McMeekan (16) compared purebreds and crossbreds up to 56 days of age and found the crossbreds superior. In his data 202 litters of purebred pigs of four breeds had a death loss of 21.2% up to weaning as compared to 12.8%

mortality for the 65 litters of crossbreds. The average birth weight of purebreds was slightly larger at birth but smaller at weaning than crossbreds.

Winters, et al., (35) at Minnesota reports first cross, 3 breed crosses and back crosses all superior to comparable purebreds. He further states that first cross and back cross groups were approximately equal in superiority to purebreds, but both were excelled by 3-breed crosses. The cross litters averaged 1/3 pig too 2 pigs larger at weaning. On the average each pig weighed from 5 to 7 pounds more than purebreds.

Carroll and Roberts (3) however, in reviewing the literature of 50,000 animals concluded that hybrid vigor cannot be expected in the majority of crosses between breeds of swine.

METHODS OF PROCEDURE

The data used in this study were obtained from the records of the Michigan Sow Testing Project carried on by the Animal Husbandry Extension Service of Michigan State College.

This project has been in effect for six years, from 1945 to date. In the six years 2296 litters with 19,825 pigs have been entered. Rules governing this project are simple and easily complied with. Each litter must be ear marked and weighed at birth or shortly after in the presence of an official witness. These weights must be recorded with the Extension Office before the pigs are four weeks of age. A second weighing of the litter occurs at or near 56 days of age. If pigs are not weighed exactly at 56 days, the weights are calculated to the 56 day basis using the conversion table below.

Table III

Days of Age	Factor	Days of Age	Factor	Days of Age	Factor
40	1.64	51	1.14	62	.87
41	1.58	52	1.11	63	.85
42	1.52	53	1.08	64	.84
43	1.46	54	1.05	65	.82
44	1.41	55	1.02	66	.80
45	1.37	56	1.00	67	.79
46	1.32	57	.98	68	.77
47	1.28	58	.95	69	.76
48	1.24	59	.93	70	.75
49	1.21	60	.91	71	.73
50	1.17	61	.89	72	.72

Awards are given to litters falling into predetermined weight groups. The results of the project were analyzed annually and circulars were distributed among cooperators in the project to stimulate more efficient production.

A total of 2,032 litters were available for this study. They were first grouped into straight breeds, cross breds, three breed crosses, back crosses, four breed crosses, and litters which were designated on entry blanks as grades. The straight breeds were not necessarily registered and should not be considered as such. Those litters falling into the straight breed classification were then regrouped into their specific breeds with the sows, second litter or above, being computed separately from the gilts, (first litter). A study was then conducted on breed prolificacy, number of pigs surviving at 56 days, and the 56 day weaning weights.

The second study made involved the comparison of performance by sows and gilts entered as straight breeds. No conversion factor designed to equalize gilt and sow litter weights was used in this study at any time.

A study of the effect of litter size on weaning weights was conducted using only a small portion of the available data. An analysis of covariance and correlation analysis was calculated in this portion of the study.

Since the farrowing date of the litter was listed

on each entry blank it was thought that a report of the numbers of litters farrowed by months would be of interest both from the standpoint of the livability of pigs in various seasons and to ascertain the popularity of individual months for farrowing pigs by the farmers of this state.

The number and percentage of pigs weaned according to size of litter at birth was also considered in this report.

The effects of various years reporting was carried out to reveal if any year was superior and whether the program was progressing towards its goal of "more pork from fewer sows".

A brief study of the comparison of various crossbreeding methods was conducted as a conclusion to this paper.

A statistical analysis of the data was made using the formula shown on page 18. An analysis of variance was calculated between the sows of each breed and the gilts of each breed for prolificacy, livability and weaning weights. An analysis was also carried out on the effects of season on the weaning weights of litters. The last analysis of variance was carried to study the effect of years on prolificacy, livability, and weaning weights of both sows and gilts of the straight breeds only. Other data are presented in table form.

Inasmuch as the analysis of variance was used extensively in this work a simplified explanation of its use is included.

In analyzing data certain results are obtained which are distinctly different from other results gathered, the object being to compare the two groups. The heterogeneity of the variation is the factor which is being tested, and the degree of its expression determines the significance of the findings of the experiment. Therefore in studies of variation it is necessary to be able to differentiate the variation according to causes or groups of causes, especially where such differentiation is an essential part of the analysis of the results.

The analysis of variance supplies the mechanism for this procedure and in addition supplies the results in a form to which tests of significance can be applied.

Formulae Used In Statistical Analysis

Analysis of Variance:

$$Sx^2 - \frac{(Sx)^2}{n} = \text{Total Sum of Squares (29)}$$

$$\frac{(Sx)_1^2}{n_1} + \frac{(Sx)_2^2}{n_2} - - - - - \frac{(Sx)_n^2}{n_n} - \text{C. T.} = \text{Sum of Squares Between Breeds (29)}$$

Correlation Analysis:

$$b = \frac{Sxy}{Sx^2} = \text{Regression Coefficient (29)}$$

$$r = \frac{Sxy}{\sqrt{(Sx^2)}\sqrt{(Sy^2)}} = \text{Correlation Coefficient (29)}$$

$$\sigma_r = \frac{1 - r^2}{\sqrt{n - 2}} = \text{Standard error of Correlation Coefficient (12)}$$

$$\sigma_e = \sqrt{\frac{Sy^2 - (Sxy)^2/Sx^2}{\frac{n - 2}{Sx^2}}} = \text{Standard error of Regression Coefficient (31)}$$

$$s = \sqrt{Sx^2/n-1} = \text{Standard deviation}$$

$$s/\sqrt{n} = \text{Standard error of mean (1)}$$

RESULTS AND DISCUSSION

Breed as a Factor in Size of Litter Farrowed

The comparison of the various breeds in respect to prolificacy in this study was, of necessity, broken down into sows and gilts. It is quite evident that a breed having a majority of sow records would enjoy a distinct advantage over other breeds with a majority of gilt entries. The average litter size farrowed by the nine breeds studied of both sows and gilts are reported in Tables IV and V. Statistical treatment of the data compiled between breeds reveals that there is highly significant difference as shown in Tables IV-A and V-A. This is in agreement with Lush and Molln (14) who found significant differences existing in the prolificacy of various breeds in their inheritance study.

The exceptional prolificacy of the Yorkshire breed reported in this data is substantiated by Christensen, et al., who found the average Yorkshire litter size to be 11.7. The prolificacy table of Lush and Molln (14) also indicates that the Yorkshire and Duroc breeds are to be highly recommended in respect to prolificacy. A partial explanation of the Yorkshire prolificacy might be found on the basis of work by Zeller and Hetzer (37) on the effect of type on production efficiency. Working within a single breed, they concluded that sows

classified as large type were generally superior to those of intermediate or small type. The Yorkshire breed as a whole could be classified as "large" type. This is however, only an opinion of the writer.

Table IV

Breed Prolificacy of Sows

Breed	Number of Pigs	Number of Sows	Ave.	S.E
Duroc	3094	290	10.66#	.142
Hampshire	2328	229	10.17#	.088
Chester White	1143	105	10.88#	.223
Spotted P. C.	934	91	10.26#	.170
Poland China	582	59	9.86#	.275
Yorkshire	617	49	12.59#	.406
Berkshire	523	52	10.06#	.252
OIC	312	28	11.14#	.650
Minnesota #1	35	4	8.75#	2.79

Table IV-A

Analysis of Variance of Breed Prolificacy of Sows*

Source of Variation	D.F.	S.S.	M.S.	F
Total	906	4,961		
Between Breeds	8	403	50.38	9.92**
Within Breeds	898	4,558	5.08	

*Appendix A
**Highly Significant

Calculations to determine the percentage of the total variance between and within breeds were as follows:

$K = \frac{\text{Number of Sows}}{\text{Number of breeds}}$ ... Total Variance = Sum of Mean Square of Between Breeds and within breeds.

Between breeds variance = $A + KB = 50.38$

$A + 101B = 50.38 - 5.08$

$101B = 45.30$

$B = .45$

$45 \div 55.46 = 8.1\%$ of the total variance

$100\% - 8.1\% = 91.9\%$ of the total variance

From the above calculations it is apparent that differences between breeds are responsible for approximately 8.1% of the total variance.
Differences within breeds or between gilts of the same breed are responsible for 91.9% of the variance.

Table V

Breed Prolificacy of Gilts

Breed	Number of Pigs	Number of Sows	Average	S.E.
Duroc	3,853	402	9.58	± .096
Hampshire	1,820	199	9.15	± .129
Chester White	985	108	9.12	± .233
Spotted P.C.	581	64	9.08	± .195
Poland China	478	57	8.39	± .211
Yorkshire	649	59	10.64	± .272
Berkshire	209	24	8.71	± .252
OIC	262	29	9.03	± .384
Minnesota #1	23	3	7.67	± .913

Table V-A

Analysis of Variance of Breed Prolificacy of Gilts*

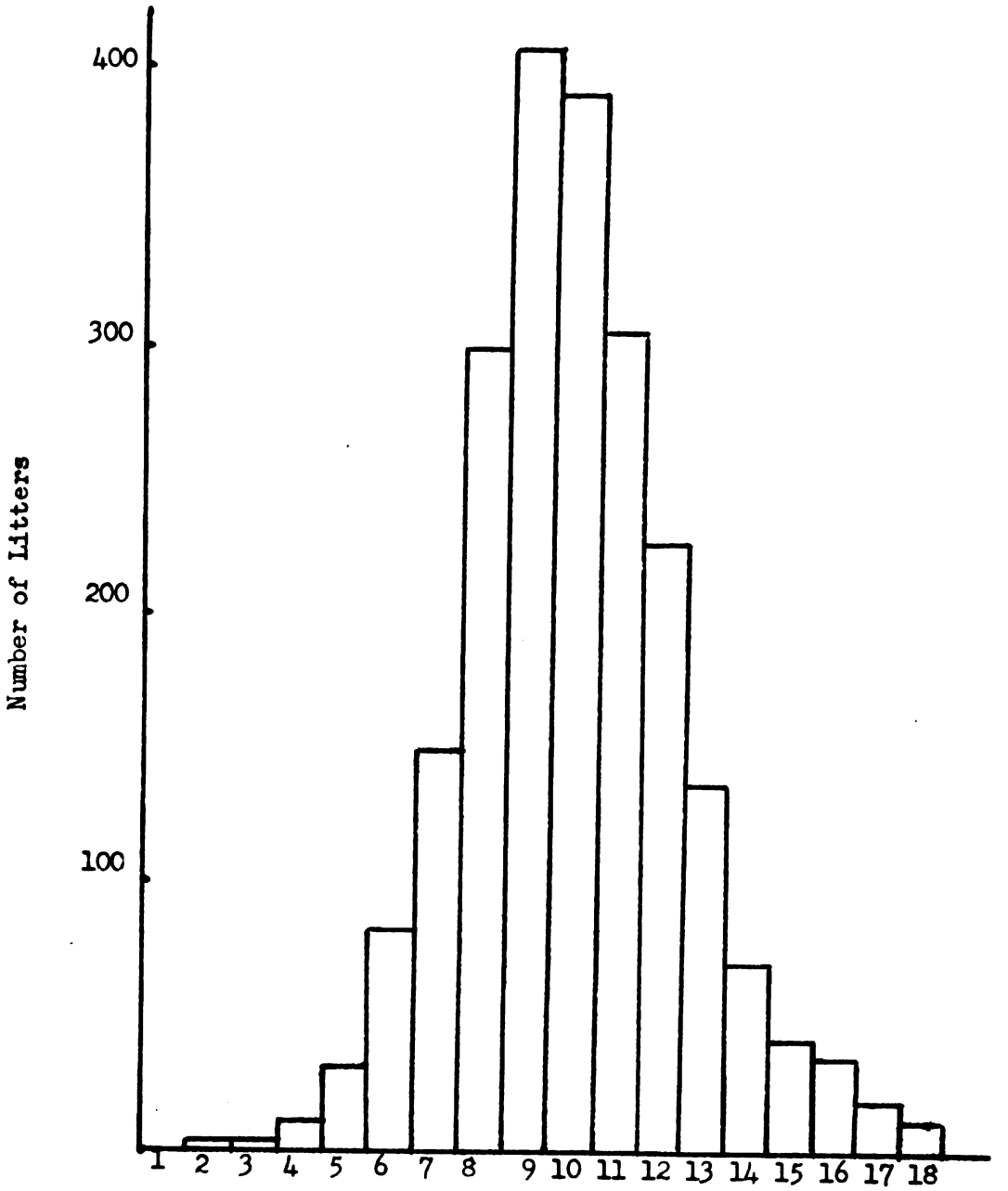
Source of Variation	D.F.	S.S.	M.S.	F
Total	944	3,660		
Between Breeds	8	92	11.50	3.02**
Within Breeds	936	3,568	3.81	

*Appendix B

**Highly Significant

Calculation of the estimate of variance shows that differences between breeds accounted for approximately 7.3% of variance. Differences within breeds or between gilts of the same breed accounted for approximately 92.7%.

F I G U R E I



L I T T E R F R E Q U E N C Y

Average litter size at birth= 9.96

Breed Influence on Number of Pigs Weaned

The term prolificacy is measured more directly by the number of pigs born alive than by the number reared. The former measure more nearly approaches the true fertility of a breed, inasmuch as the number of pigs weaned is probably influenced to a greater extent by management and other environmental factors than by the capacity of survival inherited from the sow.

Sows and gilts were again studied separately. Results are shown in Table VI and VI-A. The analysis of variance on this data, shown in Table VII and VII-A, revealed that significant differences at the 1% level existed. The same breeds which excelled in number of pigs farrowed were superior in number of pigs reared per litter.

Table VI

Breed Influence on Number of Pigs Reared by Sows

Breed	Number of Pigs	Number of Sows	Average	Standard Error
Duroc	2,591	290	8.93	± .089
Hampshire	2,044	229	8.93	± .168
Chester White	980	105	9.33	± .122
Spotted P.C.	782	91	8.59	± .111
Poland China	496	59	8.41	± .201
Yorkshire	492	49	10.06	± .247
Berkshire	453	52	8.71	± .214
OIC	284	28	10.14	± .238
Minnesota #1	33	4	8.25	± .240

Table VI-A

Analysis of Variance of Pigs Reared by Sows*

Source of Variation	D.F.	S.S.	M.S.	F
Total	906	3,585		
Between Breeds	8	155	19.38	5.07**
Within Breeds	898	3,430	3.82	

*Appendix C

**Highly Significant

Breed differences accounted for 4% of the total variance. Differences within breeds or between sows of the same breed accounted for 96% of the variance.

Table VII

Breed Influence on Number of Pigs Reared by Gilts

Breed	Number of Pigs	Number of Gilts	Average	Standard Error
Duroc	3346	402	8.33	± .092
Hampshire	1676	199	8.42	± .104
Chester White	902	108	8.35	± .168
Spotted P.C.	521	64	8.14	± .243
Poland China	414	57	7.26	± .258
Yorkshire	558	59	9.46	± .258
Berkshire	194	24	8.08	± .264
OIC	238	29	8.21	± .395
Minnesota #1	19	3	6.33	± .664

Table VII-A

Analysis of Variance of Pigs Reared by Gilts**

Source of Variation	D.F.	S.S.	M.S.	F
Total	944	3284		
Between Breeds	8	104	13.00	3.82**
Within Breeds	936	3180	3.40	

*Appendix D

**Highly Significant

The breakdown of the total variance shows that 3% was due to breed differences while differences within breeds or between gilts of the same breed accounted for 97%.

Effects of Breed on Weaning Weights of Pigs

All litter weights were adjusted to exactly eight weeks after birth. The sows were again calculated separately from the gilt averages. Management plays an important role in the weaning weights of litters reported in this study because of the doubtless attempts to encourage high litter weight through supplemental feeding. However there is no reason to assume that any one breed has been pushed more than any other.

Table VIII shows the average litter weight by breeds of sows. Table VIII-A, the analysis of variance of weaning weights, reveals that significant differences to exist between breeds. This is in accordance with Lush and Molln (14) who reported significance differences on 56 day litter weights.

Tables IX and IX-A show the effect of breeds on the litter weight of gilts.

Table VIII

Effect of Breed on 56 day Weaning Weights (Sows)

Breed	Total Weight	Number	Average	Standard Error
Duroc	82,829	290	285.53	± 9.05
Hampshire	69,061	229	301.58	± 6.28
Chester White	32,889	105	313.23	± 6.09
Spotted P.C.	24.914	91	273.78	± 15.25
Poland China	18,583	59	314.96	± 11.00
Yorkshire	17,348	49	354.04	± 14.64
Berkshire	14,909	52	286.71	± 9.38
OIC	10,141	28	362.17	± 16.54
Minnesota #1	1,158	4	289.50	± 36.67

Table VIII-A

Analysis of Variance of 56 day Weaning Weights (Sows)*

Source of Variation	D.F.	S.S.	M.S.	F.
Total	906	12,999,815		
Between Breeds	8	415,605	51,961	3.71**
Within Breeds	898	12,584,210	14,013	

*Appendix E

**Highly Significant

Effect of breed on the 56 day weaning weights of litters farrowed by sows accounted for 2.6% of the total variance. The remaining 97.4% of the variance is found within breeds or between the sows of the same breed.

Table IX

Effect of Breed on 56 day Weaning Weights (Gilts)

Breed	Total Weight	Number	Average	Standard Error
Duroc	109,257	402	271.78	± 3.95
Hampshire	49,943	199	250.97	± 5.66
Chester White	27,101	108	250.94	± 6.93
Spotted P.C.	16,814	64	262.71	± 9.74
Poland China	14,027	57	246.09	± 10.41
Yorkshire	16,389	59	277.77	± 5.62
Berkshire	5,698	24	237.42	± 13.41
OIC	8,481	29	292.45	± 16.18
Minnesota #1	759	3	253.00	± 27.10

Table IX-A

Analysis of Variance of 56 day Weaning Weights (Gilts)*

Source of Variation	D.F.	S.S.	M.S.	F
Total	944	4,312,428		
Between Breeds	8	464,361	58,045	14.12**
Within Breeds	936	3,848,067	4,111	

*Appendix F

**Highly Significant

Breed effect accounted for 12% of the variance on the weaning weights of gilts. 88% of the variance was caused by differences within breeds or between gilts of the same breed.

Comparative Performance of Sows and Gilts

The comparative performance of sows and gilts on the basis of prolificacy, rearing ability, and weaning weight of litter is summarized in Table X. This data includes 907 sows and 945 gilts.

Table X

Comparative Performance of Sows and Gilts

	Farrow Average	Weaning Average	Percentage Raised	Average Litter Wt.
Sows	10.55	8.99	85.23	311.74
Gilts	9.38	8.33	88.80	264.77

The results listed in this table are generally in accordance with those obtained in other studies. The sows farrowed 1.17 more pigs per litter than did the gilts. Usually an efficient producer eliminates those gilts from his herd whose initial litter is below average, thus the sows remaining in the herd have been retained on a partial selection basis for prolificacy. Another theory concerning prolificacy of sows and gilts is that a larger number of eggs are ovulated by a sow during the estrus period than in gilts. However, this is complicated somewhat by the plane of nutrition of the individual animals at breeding.

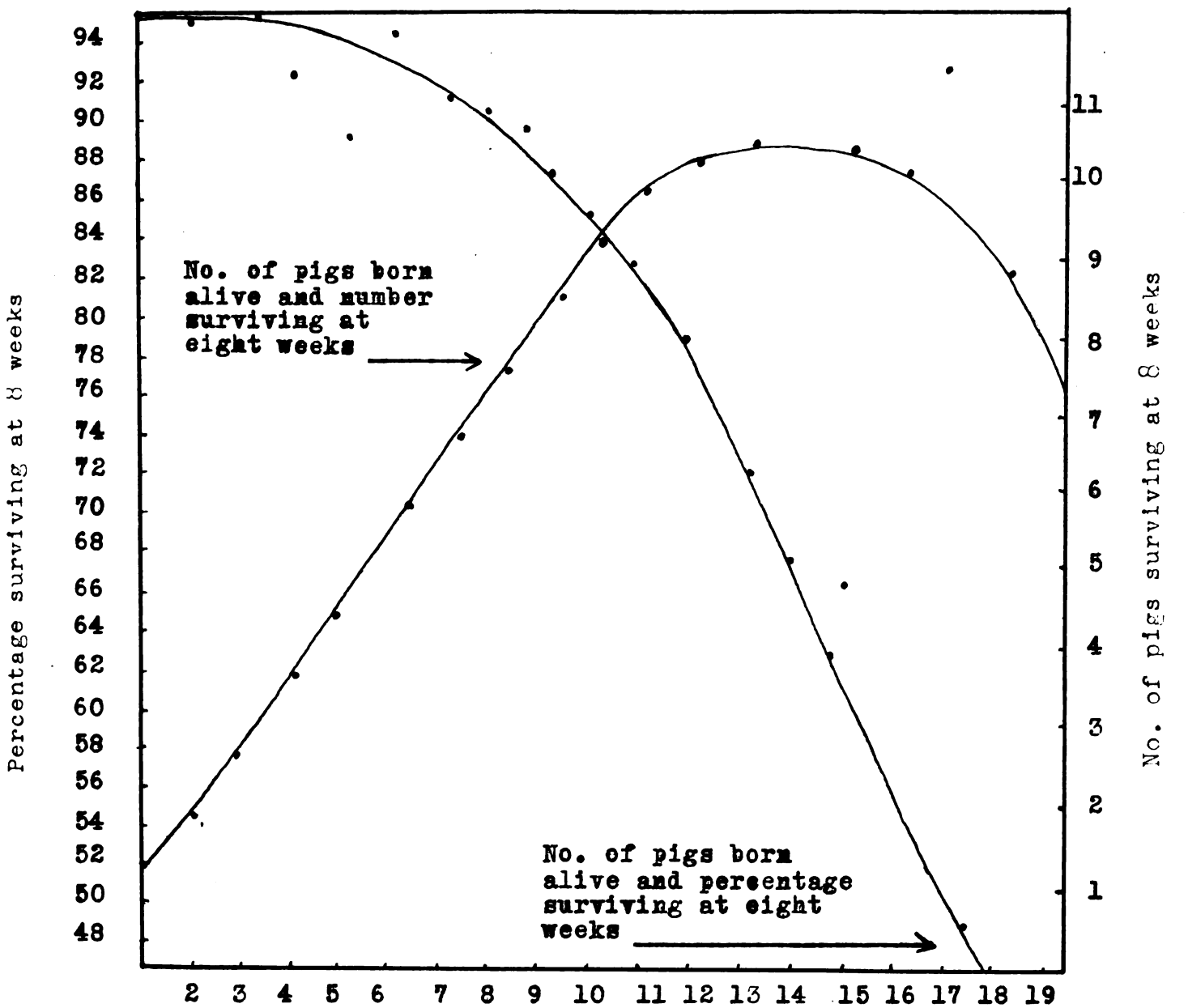
The percentage of pigs raised of those farrowed indicates that the advantage distinctly rests with the gilts. This is in line with other reports as previously mentioned in the review of literature. There are many apparent reasons why this is true.

Figure 2 shows that the advantage of larger litters is partially offset by increased death loss. Usually extremely large litters are handicapped by the presence of small, weak pigs at birth which jeopardize there chances of survival. Inasmuch as most gilts are smaller than mature sows, the possibility of pig losses through crushing, pinning and general carelessness on the part of the mother is somewhat smaller. Wilcox (34) et al., report that 44% of all losses of suckling pigs was attributed to crushing.

The heavier litter weights at weaning recorded by sows is substantiated by Russel and Hutton (24) and Menzies-Kitchen (19) who found slightly heavier litter weights in sows than gilts at six weeks. This may be explained in part of the increased number of pigs weaned per litter but this point is open to debate. The added maturity of the sow over the gilt may also allow for increase milk production by sows, consequently resulting in higher litter weights.

FIGURE 2

A STUDY OF THE NUMBER OF PIGS WEANED BY THE NUMBER FARROWED



The number of pigs raised to eight weeks of age increased up to 17 in this study. However the advantage of larger litters is mostly offset by the increased death losses in the larger litters.

(Based on 2,114 litters)

Effect of Litter Size on Individual Weaning Weights

A study of the effect of litter size on individual weaning weight at 56 days of age was carried out for the purpose of finding the relationship between litter size and weaning weight of individual pigs.

In order that the environmental factor be kept as neglible as possible, four herds were selected from the available data, each herd representing a different breed. Although these litters were farrowed in different years it is assumed that the treatment within each herd accorded the sows and their litters by the operator was consistent from year to year.

An analysis of variance was calculated between the four herds to see if breed alone might induce significant differences on the weight of litter weaned. Results of the analysis of variance are shown in Table XI.

Table XI

Analysis of Variance of Individual Weaning Weight Between Four Breeds*

Source of Variation	D.F.	S.S.	M.S.	F
Total	61	3885		
Between Breeds	3	172	57.33	.895
Within Breeds	58	3713	64.02	

*Appendix G

Table XI-A

Mean and Standard Error of Individual Weaning Weights

Breed	Number of Litters	Mean Weight	Standard Error
Spotted P.C.	15	34.67	2.26
Duroc Jersey	22	35.68	2.35
Chester White	10	32.00	1.12
Hampshire	15	35.00	1.26

Since no significance was found, breed apparently had no effect upon litter weight in this portion of the study.

To obtain the effect of litter size upon pig weight using the combined results of the four herds, and analysis of covariance was calculated. Results are shown in Table XII.

Table XII

Analysis of Covariance of the Effects of Letter Size on Individual Weaning Weights*

Source of Variation	D.F.	SX^2	SXY	SY^2
Total	61	256	54	3885
Between Herds	3	26	-40	172
Within Herds	58	230	94	3713

*Appendix G

From the above table the correlation coefficient was calculated as follows:

a. $$r = \frac{Sxy}{\sqrt{(SX^2)\ (SY^2)}}$$

$$r = \frac{94}{\sqrt{(230)(3713)}} = \frac{94}{\sqrt{853990}} = \frac{94}{924} = 0.10$$

b. Standard error of correlation coefficient was calculated from the following formula:

$$\frac{1 - r^2}{\sqrt{n - 2}} = \frac{.99}{\sqrt{60}} = \frac{.99}{7.74} = 1.27$$

Inasmuch as the error term exceeds the correlation coefficient it was concluded that little correlation existed between these two variables. It would have taken a sample approximately seven times as large as the one used in this study to give a significant value.

These results disagree with those obtained by Alexson, as cited by Smith and Donald (25) who found a negative correlation of r = -0.815 ± 0.0722.

Although little correlation was obtained the regression coefficient was calculated as follows:

a. $$b = \frac{Sxy}{Sx^2} = \frac{.94}{270} = .41$$

b. The Standard Error of Regression Coefficient:

$$e = \sqrt{\frac{\frac{Sy^2 - bSxy}{n - 2}}{Sx^2}} = \sqrt{\frac{\frac{3713 - 38.54}{60}}{270}} = \sqrt{\frac{63}{270}} = \sqrt{.27} = 0.519$$

These results again show that the error term exceeds the regression coefficient and cannot be considered a reliable measure of the effect of litter size on weaning weight of the individual pig.

The interpretation of the results obtained in this study indicates that a small correlation may exist between size of litter and the weight of individual pigs at 56 days in the four herds studied. Hammond, as cited by Smith and Donald, (85) has pointed out that sows which are very fertile usually have a good milk supply. This may mean simply that as the litter size increases, the number of teats used and the total quantity of milk produced rise. This view is supported by Carroll and Krider,

(3) who state that the amount of milk produced by a sow is closely related to the number of pigs which she suckles. Smith and Donald (25) advance the theory that both fertility and milk yield are closely related with the function of the pituitary gland, and it may well be that large litters and heavy milking are associated because of the possession of an active pituitary.

Further interpretation of such studies and this study in particular, might proceed along the line of thought that there is a special feeding of sows with large litters with the production of heavy litters as a specific goal. The supplemental feeding of the pigs themselves to produce extraordinarily high 56 day weights would, of course, give a bias picture of this study. More instructive results could be obtained by raising large and small litters on sows of known high fertility and sows of known low fertility and recording 3-week weights which would eliminate the effects of supplemental pig feeding to a large extent.

Effect of Season on Size of Litter

Season, or month of farrow also appears to exercise some influence on pre-weaning mortality. Results given in Table XIII show little seasonal variation in the number of pigs born alive. Not a great deal more variation is encountered in pigs surviving at eight weeks. However, this variation would undoubtedly appear larger if equal

numbers were farrowed in both seasons. The survival percentage reported here does not agree with studies of other workers, most of whom report fall litters excelling spring litters in the number of pigs raised to weaning.

Effect of Season on Litter Weight

The effect of season on weight of litter was studied and is summarized in Table XIV. Analysis of variance of the data is given in Table XIV-A. It was found that a significant difference existed between the seasons. This can be explained to a large extent by weather conditions. Management methods might also improve the weights of fall farrowed litters. Inadequate housing, dry lot confinement, etc., might effect late fall farrowed litters. However, it is undeniable that early spring litters face the same problems in this state.

Table XIII

Month of Farrow and Survival Rate at 8 Weeks

	Jan.	Feb.	Mar.	Apr.	May	June
Pigs farrowed per litter	11.50	10.18	9.96	10.31	9.95	9.83
Pigs weaned per litter	9.87	8.23	8.65	9.50	8.67	8.96
Survival rate (percentage)	85.87	80.84	86.86	92.04	87.13	91.15
No. of litters	8	103	1,028	632	203	46

Table XIII-A

Season of Farrow and Survival Rate at 8 Weeks

	SPRING (Mar., Apr., May)	FALL (Aug., Sept., Oct.)
Pigs farrowed per litter	10.08	10.04
Pigs weaned per litter	8.94	8.86
Survival Rate (percentage)	88.69	87.34
No. of litters	1863	127

uly	Aug.	Sept.	Oct.	Nov.	Dec.	Total
.85	9.43	10.40	10.64	10.84	10.00	10.09
.55	8.63	8.95	9.00	8.60	9.33	8.99
.80	91.11	86.05	84.59	79.14	93.33	88.19
20	40	62	25	15	3	2185

Table XIV

Spring and Fall Variations in Litter Weight

	Total weight per month	Number of Litters	Average
Spring			
Mar.	289,192	1,028	281.32
Apr.	185,859	632	294.08
May	61,482	203	286.09
Total	536,533	1,863	287.99
Fall			
Aug.	8,275	40	206.88
Sept.	18,859	62	300.66
Oct.	7,220	25	288.80
Total	34,136	127	268.79

Table XIV-A

Analysis of Variance of Seasonal Variation in Litter Weight*

Source of Variation	D.F.	S.S.	M.S.	F
Total	1989	17,982,532		
Between Seasons	1	43,858	43,858	4.86**
Within Seasons	1988	17,938,674	9,023	

*Appendix H

**Highly Significant

Effect of Year on Prolificacy, Livability and Weaning Weight.

One of the purposes of a progeny testing program is to stimulate efficiency of production. This is especially true in swine where so many variables enter into efficient production. In an effort to find out whether more efficient production was developing, a study of yearly differences was made.

This study also assists in clarifying breed differences which have already been reported. It is manifest that if any one year excelled others and one breed recorded many entries in that particular year, their overall average might give a biased picture of the breeds actual performance.

The yearly performance of sows and gilts was calculated separately. Analysis of variances were run on each table to test the statistical significance of the differences. Table headings on the following pages are self-explanatory.

Table XV

Yearly Averages of the Prolificacy of Sows

	1945	1946	1947	1948	1949	1950	Total
Number of pigs farrowed	1,011	1,796	1,023	1,320	2,385	2,025	9,560
Number of Sows	102	185	98	121	214	187	907
Average	9.91	9.71	10.43	10.91	11.14	10.82	10.54

Table XV-A

Analysis of Variance of Yearly Differences in Prolificacy of Sows*

Source of Variation	D.F.	S.S.	M.S.	F
Total	906	1915		
Between Years	5	279	55.80	30.66**
Within Years	901	1636	1.82	

*Appendix J

**Highly Significant

Table XVI

Yearly Averages of the Prolificacy of Gilts

	1945	1946	1947	1948	1949	1950	Total
Number of pigs farrowed	710	1,064	962	1,467	2,249	2,415	8,867
Number of gilts	79	116	104	158	235	253	945
Average	8.99	9.17	9.25	9.28	9.57	9.55	9.38

Table XVI-A

Analysis of Variance of Yearly Differences in Prolificacy of Gilts*

Source of Variation	D.F.	S.S.	M.S.	F
Total	944	3490		
Between Years	5	38	7.60	2.07
Within Years	939	3452	3.68	

*Appendix J.

Table XVII

Number of Pigs Reared by Sows in the Different Years

	1945	1946	1947	1948	1949	1950	Total
Number of pigs weaned	881	1,553	868	1,076	1,963	1,730	8,071
Number of Sows	102	185	98	121	214	187	907
Average	8.64	8.39	8.86	8.89	9.17	9.25	8.89

Table XVII-A

Analysis of Variance of Yearly Differences in Number of Pigs Reared by Sows*

Source of Variation	D.F.	S.S.	M.S.	F
Total	906	4,478		
Between Years	5	93	18.60	3.82**
Within Years	901	4,385	4.87	

*Appendix K

**Highly Significant

Table XVIII

Number of Pigs Reared by Gilts in the Different Years

	1945	1946	1947	1948	1949	1950	Total
Number of pigs weaned	597	944	804	1,321	1,989	2,129	7,784
Number of Gilts	79	116	104	158	235	253	945
Average	7.56	8.14	7.73	8.36	8.46	8.42	8.24

Table XVIII-A

Analysis of Variance of Yearly Differences in Number of Pigs Reared by Gilts*

Source of Variation	D.F.	S.S.	M.S.	F
Total	944	4,448		
Between Years	5	89	17.80	3.84**
Within Years	939	4,359	4.64	

*Appendix K

**Highly Significant

Table XIX

Weaning Weights of Pigs Farrowed by Sows in the Different Years

	1945	1946	1947	1948	1949	1950	Total
Total Weight of Litters	30,404	54,173	29,647	39,195	69,108	60,211	282,748
Number of Litters	102	105	98	121	214	187	907
Average	298.07	292.83	302.53	323.93	322.93	321.98	311.73

Table XIX-A

Analysis of Variance of Yearly Differences in Weaning Weights of Pigs Farrowed by Sows*

Source of Variation	D.F.	S.S.	M.S.	F
Total	906	12,117,225		
Between Years	5	668,269	133,654	10.52**
Within Years	901	11,448,956	12,707	

*Appendix L

**Highly Significant

Table XX

Weaning Weights of Pigs Farrowed by Gilts in the Different Years

	1945	1946	1947	1948	1949	1950	Total
Total Weight of Litters	20,892	30,436	24,271	43,086	64,451	67,064	250,200
Number of Litters	79	116	104	158	235	253	265
Average	264.46	262.38	233.37	272.70	274.26	265.08	264.76

Table XX-A

Analysis of Variance of Yearly Differences in Weaning Weights of Pigs Farrowed by Gilts*

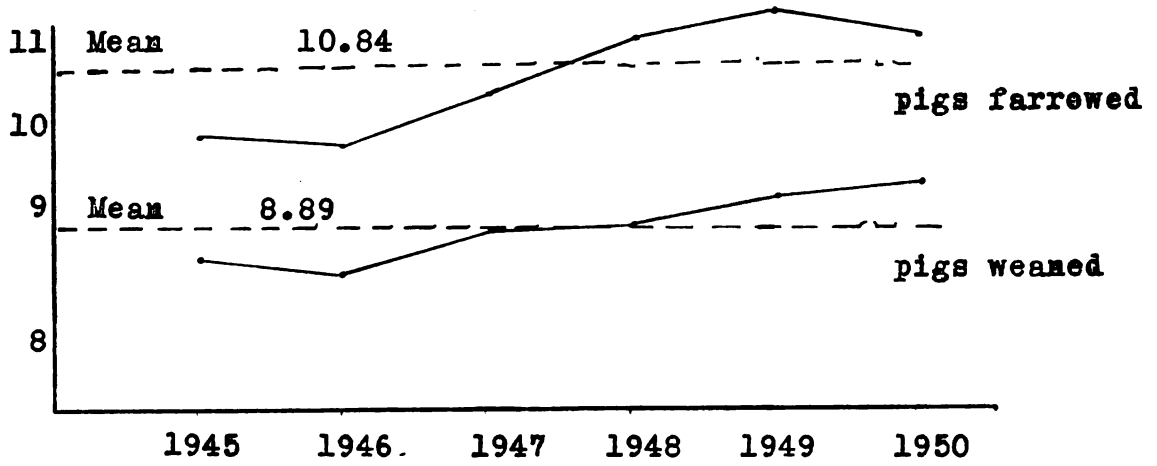
Source of Variation	D.F.	S.S.	M.S.	F
Total	944	9,023,183		
Between Years	5	330,861	166,172	714**
Within Years	939	8,701,322	9,267	

*Appendix L

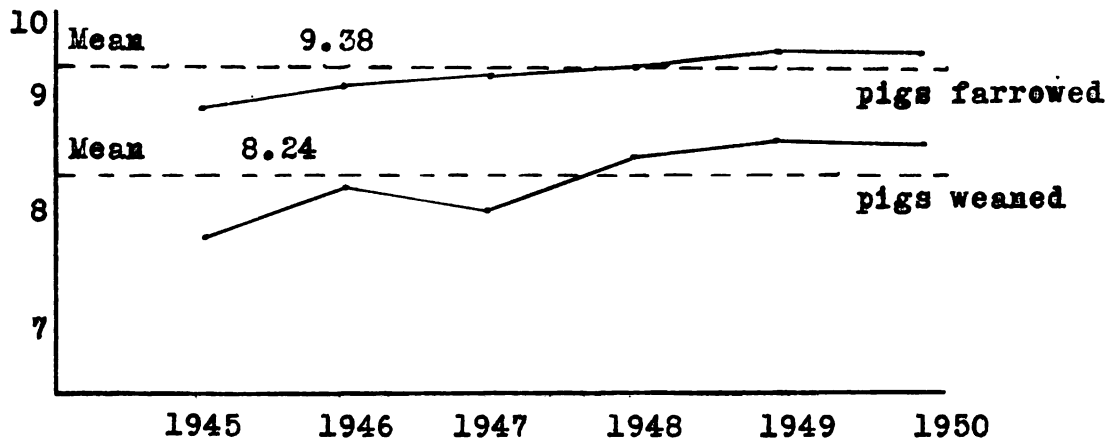
**Highly Significant

Figure 3

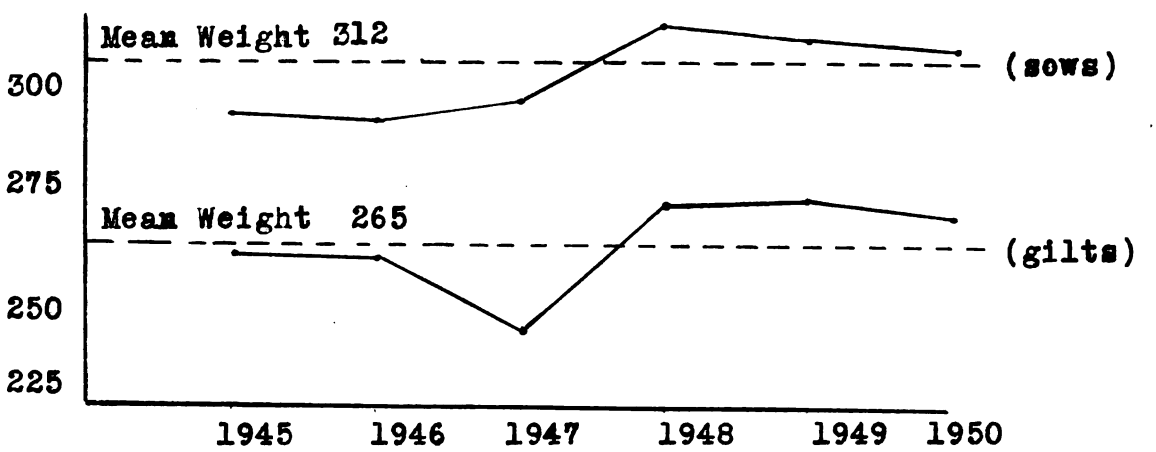
YEARLY EFFECTS ON THE RECORD OF PERFORMANCE OF SOWS AND GILTS



YEARLY AVERAGES OF FARROWING AND WEANING NUMBERS (SOWS)



YEARLY AVERAGES OF FARROWING AND WEANING NUMBERS (GILTS)



Yearly Averages of Weaning Weights of Sows and Gilts

A study of the graphs in Figure 3 reveals that, with minor exceptions, the trend covering the six years has been upward. There has been a tendency, during the past three years, for the number of pigs farrowed to level out. This may indicate that prolificacy was reaching a maximum or practical level in this project. This might in turn lead to a similar level in weaning numbers and weaning weights. It may be said in general, since the trend is upward, that the project over the six years has proved successful.

Since only one sharp drop appeared on the entire graph, it may be concluded that no particular breed suffered severe yearly effects to their overall average. The sharp drop of weaning weights of the litters farrowed by gilts in 1947 may have had a slight effect on the weights of the more popular breeds.

Effects of Various Crossbreeding in Study

Crossbreds, as interpreted in this study, are the progeny resulting from the matings of different breeds. Probably the commonest use of crossbreeding, at least in the animal kingdom, has been with swine. Crossbred animals usually exhibit an increase in vigor and growth over either of their purebred parents. The exact cause of this occur-

ence, which is known as heterosis, or hybrid vigor, is not clearly understood. Some authorities suggest that the inhibiting genes, which are carried in the germ plasm with desirable genes, are neutralized by genes from the other species or breed.

There were several methods of crossbreeding reported in these data. They include (1) first cross pigs, which were produced by crossing a purebred sow with a purebred boar of another breed, (2) three-breed cross pigs, produced by breeding first cross gilts or sows to a purebred boar of a third breed, (3) backcross pigs, produced by breeding first-cross gilts or sows to a purebred boar of one of the two original parent stocks and (4) four-breed cross, by breeding a first cross sow to a first cross boar.

Although many experiments have shown that crossbred pigs are somewhat superior in the feed-lot to purebred pigs, it has generally been accepted that they should not be used for breeding purposes. However, in the recent Minnesota experiment reported by Winter, et al., (35) the crossbreds excelled the purebreds in prolificacy, rearing ability and weaning weights.

Although a rather small number of the various crossbreds were entered in this project the results of their performance were tabulated and are compared with the purebreds in Table XXI.

Table XXI

Comparison of Performance by Various Methods of Crossbreeding

	Purebreds	first-cross	3-breed cross	back-cross	4-breed cross
Farrowing average of sows	10.54	10.32	10.67	10.75	11.30
Weaning average of sows	9.00	9.13	9.51	9.50	11.00
Litter weight of sows	311.74	343.4	301.9	351.0	391.0
Number of sow litters studied	907	104	23	16	3
Farrowing average of gilts	9.38	9.13	9.51	9.50	11.00
Weaning average of gilts	8.33	8.42	9.40	8.56	9.30
Litter weight of gilts	264.77	276.1	322.5	300.7	255.0
Number of gilt litters studied	945	56	23	16	3

Interpretation of the above results is complicated somewhat by the inequality of numbers. The 4-breed cross litters could be discounted entirely because of their extreme minority. Comparing the purebreds and first cross litters, the advantage in prolificacy distinctly rests with the purebreds for both sows and gilts, although more first cross pigs were raised to weaning. The 3-breed cross and back cross litters had superior records to purebreds and first crosses. This is substantiated in part by Winters et al., (36) who reports that 3-breed crosses averaged 1/3 to 2 pigs larger at weaning.

Although crossbreeding in swine is a common practice it should be remembered that the haphazard crossing of various breeds may quickly result in a nondescript swine herd which would be uneconomical and certainly without pride to the owner.

SUMMARY AND CONCLUSIONS

1. A study was made of 1852 litters of purebred swine representing nine breeds on the prolificacy, livability and 56 day weaning weights of each breed.
2. The study on prolificacy revealed that some differences did occur between breeds in this respect, and that these differences were statistically significant. They varied from a low of 7.67 to a high of 12.59 pigs per litter.
3. The number of pigs weaned per litter by the various breeds differed. This difference was statistically significant. The same breeds which excelled in prolificacy raised the most pigs to weaning. They varied from a low of 6.33 to a high of 10.14 pigs per litter.
4. Breed differences existed in weaning weights which were statistically significant. The range in this study was from 362 pounds to 237 pounds per litter.
5. The comparative performance of sows and gilts showed that sows farrowed 1.17 pigs more per litter than gilts. However gilts weaned 88.80 per cent of their pigs while sows weaned 85.23 per cent. The sow litters weighed 53 pounds more per litter than did gilt litters at eight weeks.
6. The correlation coefficient between litter size and

weight of individual pigs at weaning was found to be 0.10 ± .0165. The regression coefficient was found to be 0.41 ± 0.519. This data was calculated on 62 litters from four different herds.

7. Size of litters farrowed in spring and fall were very similar and 88.69% of the spring pigs survived till weaning compared with 87.34% of the fall pigs.
8. Spring farrowed litters were 19.2 pounds heavier at weaning than were the fall litters. These differences were statistically significant.
9. Studies of the effect of the yearly differences on prolificacy, livability and weaning weights were found to be statistically significant with one exception. Improvement in all three factors over a period of six years was noted.
10. A study of the effects of crossbreeding revealed that backcrosses and 3-breed crosses were superior to first-crosses and purebreds in prolificacy and number of pigs weaned. These averages are unreliable because of the small number of crossbred litters studied.

BIBLIOGRAPHY

1. Baten, W. D.
   1938 Elementary Mathematical Statistics. First edition. John Wiley and Sons, Inc., New York. 338 pp.

2. Bitting, A. W.
   1898 The Fecundity of Swine. Tenth Annual Report of the Indiana Agricultural Experiment Station. 42-46.

3. Carroll, W. E. and Roberts, E.
   1942 Crossbreeding In Swine. Illinois Agricultural Experiment Station Bulletin. 489.

4. _____ and Krider, J. L.
   1950 Swine Production. First edition. McGraw-Hill Book Company Inc., New York. 498 pp.

5. Christensen, F. W., Thompson, O.A., and Jorgenson, L.
   1926 Prolificacy of Sows and Mortality of Pigs. North Dakota Agricultural Experiment Station Bulletin 194. p. 83.

6. Davidson, H. R.
   1948 The Production and Marketing of Pigs. First edition. Longsmans, Green and Company, London. 413 pp.

7. Ferrin, E. F.
   1932 Production Tests for the Selection of Breeding Hogs. Proceedings of the American Society of Animal Production. 1933. 134-137.

8. Goulden, C. H.
   1939 Methods of Statistical Analysis. First edition, John Wiley and Sons, Inc., New York. 277 pp.

9. Henke, L. A.
   1935 Is Fecundity in Swine Inherited. Journal of Heredity. 26. 455-56.

10. Hopkins, J. A., Jr.
    1928 An Economic Study of the Hog Enterprise in Humbolt County. Iowa Agricultural Experiment Station Bulletin. 225.

11. Hostetler, E. H., Nance, R. E. and Foster, J. E.
    1930 Cost of Raising Pigs to Weaning Age. North Carolina Agricultural Experiment Station Bulletin. 272.

12. Lindquist, E. F.
1940 Statistical Analysis in Educational Research. First Edition. Houghton Mifflin Company, Boston. 210 pp.

13. Lush, J. L., Anderson, A. L., Culbertson, C. C. and Hammond, W. E.
1934 The Reliability of Some Measures of Production in Brood Sows. Procedures of the American Society of Animal Production: 1933. 282-287.

14. _____, and Molln, A. E.
1942 Litter Size and Weight as Permanent Characteristics of Sows. United States Department of Agriculture Technical Bulletin 836.

15. _____, Shearer, J. L. and Culbertson, C. C.
Crossbreeding Hogs for Pork Production. Iowa State College Agricultural Experiment Station Bulletin. 380.

16. McMeekan, C. P.
1941 Growth and Development of the Pig. Journal of Agricultural Science: 31. pp. 17-31.

17. _____
1936 Critical Study of Important Factors in Successful Swinekeeping. New Zealand Journal of Agriculture: 52. 278-289.

18. McPhee, H. C.
1931 Size of Litter as a Selection Index in Swine. Proceedings of the American Society of Animal Production: 1932. 262-264.

19. Menzies-Kitchen, A. W.
1937 Fertility, Mortality, and Growth Rate in Pigs. Journal of Agricultural Science: 27 611-624.

20. Morris, H. P. and Johnson, D. W.
1932 Effects of Nutrition and Heredity upon Litter Size in Swine and Rats. Journal of Agricultural Research: 44. 511-521.

21. Murray, G. N.
1934 A Statistical Analysis of Growth and Carcass Measurements of Baconers. Onderstepoort Journal of Veterinary Science: 2. 301-360.

22. Rice, V. A.
1942 Breeding and Improvement of Farm Animals. Third Edition. McGraw-Hill Book Company, Inc., New York. 750 pp.

23. Rommel, G. M.
1906 The Fecundity of Poland-China and Duroc-Jersey Sows. United States Department of Agriculture Circular 95. 12 pp.

24. Russell, E. Z. and Hutton, R. E.
1938 Comparative values of Mature Sows and Gilts for Producing Market Hogs. United States Department of Agriculture Circular 472.

25. Smith, A. D. B., and Donald, H. P.
1937 Weaning Weights of Pigs and Litter Sampling of Pigs. Journal of Agricultural Science: 27. 485-502.

26. _____, Robinson, O. J., and Bryant, D. M.
1935 The Genetic of the Pig. First Reprint. Reprinted from the Bibliographia Genetica VII. The Hague, Martinus Nijhoff. 160.

27. Stewart, H. A.
1945 An Appraisal of Factors Affecting Prolificacy in Swine. Journal of Animal Science: 3. 250-259.

28. Surface, F. M.
1909 Fecundity In Swine. Biometricka: 6. 433-436.

29. Snedecor, George W.
1946 Statistical Methods. Fourth edition. Iowa State College Press, Ames, Iowa. 485 pp.

30. Snyder, W. P.
1915 Pork Production. Nebraska Agricultural Experiment Station Bulletin. 147.

31. Venkatachalam, Ganapathy
1949 Estimates of Heritability of Birth Weight and Weaning Weight of Lambs. Michigan State College, Ph. D. Thesis. 69 pp.

32. Vestal, C. M.
1936 Feeding and Management Experiments with Brood Sows and Litters. Indiana Agricultural Experiment Station Bulletin. 413.

33. Weaver, L. A. and Bogart, Ralph
1943 Some Factors Influencing Efficient Production of Sows. Missouri Agricultural Experiment Station Bulletin. 461.

34. Wentworth, E. N. and Aubel, C. E.
1916 Inheritance of Fertility in Swine. Journal of Agricultural Research: 5. 1145-1160.

35. Wilcox, R. H., Carroll, W. E., and Harnung, T. G.
1933 Some Important Factors Effecting Costs in Hog Production. Illinois Agricultural Experiment Station Bulletin. 390.

36. Winters, L. M., Kiser, O. M., Jordan, P. S. and Peters, W. H.
1935 A Six Years' Study of Crossbreeding Swine. Minnesota Agricultural Experiment Station Bulletin. 320.

37. Young, G. E.
1930 The Two-Litter Hog System on Indiana Farms. Indiana Agricultural Experiment Station Bulletin. 338.

38. Zeller, J. H. and Hetzer, H. O.
1944 Influence of Type of Hog on Production Efficiency. United States Department of Agriculture Circular. No. 698.

Appendix A

Analysis of Variance of Litter Size of Sows

Breed	EX^2	N	EX
Duroc	34,663	290	3,094
Hampshire	27,734	229	2,328
Chester White	13,037	105	1,143
Spotted P. C.	9,824	91	934
Poland China	6,000	59	582
Yorkshire	8,183	49	617
Berkshire	5,429	52	523
O.I.C.	3,362	28	312
Minnesota #1	418	4	36
	105,650	907	9,569

$$C.\ T. = \frac{(9,569)^2}{N} = 100,954$$

$$\text{Total SS} = EX^2 - C.T. = 4,961$$

$$\text{SS Between Breeds} = 100,852 - 100,449 = 403$$

Appendix B

Analysis of Variance of Litter Size of Gilts

Breed	EX^2	N	EX
Duroc	38,423	402	3,853
Hampshire	17,306	199	1,820
Chester White	9,614	108	985
Spotted P. C.	5,429	64	581
Poland China	4,148	57	478
Yorkshire	7,328	59	646
Berkshire	1,855	24	209
O.I.C.	2,488	29	262
Minnesota #1	181	3	23
	86,672	945	8,857

C. T. $= \frac{(8857)^2}{943} = 83,188$

Total $SS = 86,672 - 83,188 = 3,484$

Between Breeds = 83,104 - 83,102 = 92

Appendix C

Analysis of Variance of Litter Size at Weaning (Sows)

Breed	EX^2	N	EX
Duroc	23,787	290	2591
Hampshire	19,718	229	2044
Chester White	9,310	105	980
Spotted P. C.	6,821	91	782
Poland China	4,308	59	496
Yorkshire	5,084	49	492
Berkshire	4,067	52	453
O.I.C.	2,924	28	284
Minnesota #1	279	4	33
	76,298	907	8121

C. T. = $\frac{(8121)^2}{907}$ = 72,713

Total SS = EX^2 - C.T. = 3,585

Between Breeds SS = 72868 - 72713 = 155

Appendix D

Analysis of Variance of Litter Size at Weaning (Gilts)

Breed	EX^2	N	EX
Duroc	29,203	402	3,346
Hampshire	14,541	199	1,676
Chester White	7,862	108	902
Spotted P. C.	4,479	64	521
Poland China	2,770	57	414
Yorkshire	5,500	59	558
Berkshire	1,608	24	194
O.I.C.	2,080	29	238
Minnesota #1	119	3	19
	68,062	945	7,824

$$C.\ T. = \frac{(7824)^2}{945} = 64,778$$

$$\text{Total SS} = EX^2 - C.T. = 3,284$$

$$\text{Between Breeds SS} = 64,882 - 64,778 = 104$$

Appendix E

Breed as a Factor on 56 Day Weaning Weights (Sows)

Breed	EX^2	N	EX
Duroc	30,491,295	290	82,829
Hampshire	22,884,911	229	69,061
Chester White	10,707,432	105	32,889
Spotted P. C.	8,727,522	91	24,914
Poland China	6,267,171	59	18,583
Yorkshire	6,646,378	49	17,348
Berkshire	4,503,282	52	14,909
O.I.C.	3,889,721	28	10,141
Minnesota #1	351,382	4	1,158
	94,469,094	907	271,832

$$C.\ T. = \frac{(271,832)^2}{907} = 81,469,279$$

$$\text{Total SS} = EX^2 - C.T. = 12,999,815$$

$$\text{Between Breed SS} = 81,884,884 - 81,469,279 = 415,605$$

Appendix F

Breed as a Factor on 56 Day Weaning Weights (Gilts)

Breed	EX^2	N	EX
Duroc	32,207,739	402	109,257
Hampshire	13,794,423	199	49,943
Chester White	7,361,109	108	27,101
Spotted P. C.	4,799,824	64	16,814
Poland China	3,797,669	57	14,027
Yorkshire	4,660,683	59	16,389
Berkshire	1,452,204	24	5,698
O.I.C.	2,693,391	29	8,481
Minnesota #1	194,949	3	759
	70,956,250	945	250,955

$$C.\ T. = \frac{(250,955)^2}{945} = 66,643,822$$

$$\text{Total SS} = EX^2 - C.T. = 4,312,428$$

SS Between Breeds = 464,361

Appendix G

Analysis of Variance and Covariance of Effect of Litter Size on Weaning Weight

Spotted P. C.		Duroc		Hampshire		Chester White	
Pigs weaned per litter	Ave. pig wt. lbs.	pigs weaned per litter	Ave. pig wt. lbs.	pigs weaned per litter	Ave. pig wt. lbs.	Pigs weaned per litter	Ave. pig wt. lbs.
x	y	x	y	x	y	x	y
10	46	6	47	9	31	9	34
11	40	7	27	7	31	10	29
9	46	9	44	12	38	12	29
9	29	4	47	13	39	11	32
5	28	7	47	11	33	10	23
2	38	9	53	10	34	9	37
6	24	11	40	10	37	10	31
8	26	10	40	9	34	8	33
6	29	7	27	8	23	8	33
11	20	8	19	8	35	12	31
8	31	10	30	8	45		
8	34	8	33	11	34		
9	48	8	23	10	38		
12	40	6	19	9	39		
9	41	12	23	9	34		
		10	34				
		11	46				
		10	43				
		10	47				
		10	34				
		8	41				
		9	32				
Sum 123	520	190	796	144	525	99	312
Sx^2 1103		1720		1420		999	
Sy^2	19096		30990		18713		9860
Sxy 4338		6882		5073		3096	

Correction terms:

For x $(556)^2/62 = 4,986$

For y $(2153)^2/62 = 74,774$

For xy $(556)(2153)/62 = 19,307$

Sums of Squares:

Sx^2 $5242-4986.256$

Sy^2 $78659-74774=3885$

Sxy $19353-19307 = 54$

Between Herds:

$$\frac{(123)^2}{15} + \ldots\ldots\ldots\ldots + \frac{(99)^2}{10} = \text{C.T.}$$

Appendix H

Computation of Sums of Squares and Products characterizing the regression of the pig weights on the number of pigs weaned per litter.

$$\text{Breed Weights} = \frac{(520)^2}{15} + \frac{(796)^2}{22} + \frac{(525)^2}{15} + \frac{(312)^2}{10} - \text{C.T.} = 172$$

$$\text{Pig Numbers} = \frac{(123)^2}{15} + \frac{(190)^2}{22} + \frac{(144)^2}{15} + \frac{(99)^2}{10} - 4986 = 26$$

$$\text{Products} = \frac{(520)(123)}{15} + \frac{(796)(190)}{22} + \frac{(525)(144)}{15} + \frac{(312)(99)}{10}$$

$$- 19{,}308 = 40$$

Appendix I

Analysis of Variance of Seasonal Variation in Litter Weight

	EX^2	N	EX
Spring	170,799,552	1863	536,533
Fall	10,832,783	127	34,136
Total	181,632,335	1990	570,669

$$C.T. = \frac{(570,669)^2}{1990} = 163,649,803$$

$$\text{Total SS} = EX^2 - C.T. = 17,982,532$$

$$\text{SS Between Breeds} = 163,693,661 - 163,649,803 = 43,858$$

Appendix J

Analysis of Variance of Yearly Effects on Prolificacy of Sows

Year	EX^2	N	EX
1945	10,303	102	1011
1946	18,228	185	1796
1947	11,101	98	1023
1948	14,981	121	1320
1949	24,953	214	2385
1950	23,114	187	2025
	102,680	907	9560

$C.T. = \frac{(9,560)^2}{907} = 100,765$

Total SS = EX^2 - C.T. = 1,915

SS Between Years = 101,044 - 100,765 = 279

Analysis of Variance of Yearly Effects on Prolificacy of Gilts

Year	EX^2	N	EX
1945	6,672	79	710
1946	10,252	116	1064
1947	9,362	104	962
1948	14,301	158	1467
1949	22,271	235	2249
1950	23,829	253	2415
	88,687	945	8867

$C.T. = \frac{(8867)^2}{945} = 83,197$

SS Between Years = 83,235-83,197 = 38

Total SS = EX^2 - C.T. = 3,490

Appendix K

Analysis of Variance of Yearly Effect on Number of Pigs Reared by Sows

Year	EX^2	N	EX
1945	7,865	102	881
1946	14,396	185	1553
1947	7,964	98	868
1948	10,046	121	1076
1949	19,481	214	1963
1950	16,546	187	1730
	76,298	907	8071

C.T. = $(8071)^2$ = 71,820 SS Between Years =

Total SS = EX^2-C.T. = 4,478 71,913 - 71,820 = 93

Analysis of Variance of Yearly Effect on Number of Pigs Reared by Gilts

Year	EX^2	N	EX
1945	5,427	79	597
1946	8,058	116	944
1947	6,692	104	804
1948	11,712	158	1321
1949	17,961	235	1989
1950	18,715	253	2129
	68,565	945	7784

C.T. = $\frac{(7784)^2}{945}$ = 64,117 SS Between Years =

64,206-64,117 = 89

Total SS = EX^2 - C.T. = 4,448

Appendix L

Analysis of Variance of Yearly Effect on Weaning Weights of Pigs Farrowed by Sows

Year	EX^2	N	EX
1945	9,641,016	102	30,404
1946	16,957,114	185	54,173
1947	9,671,141	98	29,647
1948	13,673,112	121	39,108
1949	26,475,522	214	69,108
1950	20,810,259	187	60,211
	97,228,164	907	282,748

C.T. = $\frac{(282,748)^2}{907}$ = 85,110,939

Between years SS = 85,779,208 - 85,110,939=668,269

Total SS = EX^2 - C.T. = 12,117,225

Analysis of Variance of Yearly Effects on Weaning Weights of Pigs Farrowed by Gilts

Year	EX^2	N	EX
1945	5,893,071	79	20,892.30
1946	8,570,928	116	30,435.82
1947	6,571,497	104	24,271.00
1948	12,162,545	158	43,086.00
1949	18,771,227	235	64,451.00
1950	18,939,211	253	67,064.18
	70,908,419	945	250,200.50

C.T. = $\frac{(250,200)^2}{945}$ = 61,876,236

Between Years SS = 62,207,097-61,876,236 = 330,861

Total SS = EX^2 - C.T. = 9,032,183

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