AUGUST, 1952 RESEARCH BULLETIN 503

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Reproductive Development and Performance of Inbred and Crossbred Boars

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(Publication Authorized July 7, 1952)

COLUMBIA, MISSOURI

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INTRODUCTION

Good fertility and prolificacy are indispensible to the swine producer. In breeders' herds there is automatic selection against boars and sows of low fertility and those producing small litters, because they leave fewer progeny in the herd. In addition, the selection of breeding animals from the larger litters farrowed and weaned has been emphasized by both education agencies and breed organizations though the Registry of Merit, Ton-Litter contest, and the cooperative swine breeding projects at state experiment stations. Normal function of both parents is necessary for consistent fertility and large litters, but the relative importance of the boar and the sow influence has not been clearly defined.

Reports from projects of the cooperative Regional Swine Breeding Laboratory have indicated that inbred boars perform less satisfactorily on farms than non-inbred boars. Much of the dissatisfaction has been based on lack of mating desire by young inbred boars and the consequent delay in breeding.

It has generally been difficult to demonstrate real sire differences in the size of litters, when the boars are mated to similar groups of females, during the same season and under similar environmental conditions. However, when boar differences are associated with the degree of inbreeding of the litters, a definite increase in viability of the less inbred litters has been demonstrated. In spite of the general lack of evidence for a direct sire influence on litter size, the swine breeder often attributes returns to estrus and variation in number of pigs farrowed in some measure to the boar.

In 1947, Hazel reported that boars of various inbred lines from the Iowa Station project sired litters significantly smaller in size than litters from non-inbred boars when mated to similar groups of females under

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**The authors acknowledge gratefully the cooperation of C. D. Squiers, now Associate Animal Breeder, Alabama Polytechnic Institute, in collecting the data, and the support and counsel of Professor L. A. Weaver. This work was conducted in cooperation with the Missouri project of the Regional Swine Breeding Laboratory, Bureau of Animal Industry, U. S. Department of Agriculture, with the encouragement of Director W. A. Craft.

similar environmental conditions on Iowa farms. Later data failed to show the same trend, but some of the lines which gave poorer performance in the early tests were omitted in the later trials.

Boar influence on litter size could be caused by (1) failure of sperm to reach the ova due to physical or physiological incompatability of mates, (2) inability of sperm to fertilize the ova, (3) a transmitted influence on viability of zygotes. It seems reasonable to assume that litter size is influenced much less by the boar than by the sow, because the boar has no influence on the number of ova shed and the sow provides the uterine environment in which spermatozoa, ova, and embryos must function or develop.

It was the purpose of the present investigation to obtain added information on reproductive development and performance of inbred and crossbred boars. The study included the gross and histological development of the testis and epididymis, libido, semen characteristics, fertility, litter size and certain relationships between these components of reproduction.

The inbred lines of the Poland China and the Hampshire breeds established by the University of Missouri together with their crosses, seemed desirable as a source of experimental animals for two reasons: first, the effect of inbreeding on the reproductive development and function of boars could be estimated from comparison of crosses with parental inbred lines; second, the line differences arising from the inbreeding process should be representative of individual variations in non-bred stock, but could be studied more thoroughly because large numbers of boars were available in each of three fairly uniform groups.

This invesigation was divided into three parts: (1) the development of the testis and epididymis, (2) character of semen, (3) fertility and litter size.

DEVELOPMENT OF THE TESTIS AND EPIDIDYMIS

The gross anatomy of the testis and epididymis is of interest only as it is related to actual reproductive function. It was thought that the absolute and relative sizes of the testis and epididymis might serve to characterize the boars of inbred lines and their crosses and to explain differences in reproductive behavior.

The histological structure of the testis and epididymis indicates the stage of spermatogenesis and should be related directly to libido, semen production and fertility. These measures of testicular development presumably would be subject to less experimental error than would direct observations of libido, semen production and fertility, and hence should be useful in detecting real differences in rate of sexual development.

Phillips and Zeller (1943) in a study of three types of Poland Chinas found that testis size had increased only slightly between 5 and 10 weeks of age, but that growth was more rapid from 10 to 17.5 weeks and most rapid during the few weeks following initial increase in the size of the seminiferous tubules. Green and Winters (1944a) also reported a curvilinear increase in testis growth with age.

Phillips and Zeller showed that testis size relative to body weight declines from 5 to 10 weeks of age but increases thereafter, with a marked rise at about 20 weeks or at the age of first sperm production. According to Green and Winters testis weight in relation to body weight follows a curvilinear pattern and is more closely associated with body weight than with age. McKenzie, Miller and Bauguess (1938), working with sexually mature boars weighing 350 pounds, reported average testis weights of 312 grams and epididymides weighing about 108 grams.

Phillips and Zeller (1943) found differences in testis growth between the small type boars as compared to the medium and large types while Green and Winters report very real differences existed between inbred lines in rate of testis growth.

Phillips and Zeller (1943) and Green and Winters (1944a) found that the seminiferous tubules increase in diameter most rapidly from 70 to 150 days of age and then tend to level off, while Phillips and Andrews (1936) reported little increase up to the 105th day, but rapid increase thereafter. They also found sperm heads in the tubules of two boars at 126 and 147 days of age. Phillips and Zeller (1943) reported that no sperm were present in the tubules at 140 days of age, but sperm were present at the 157th day among boars of all three types. Green and Winters (1944a) state that spermatozoa were first found in the seminiferous tubules at ages between 147 to 175 days and that some lines showed no spermatogenic activity whatever when castrated at 112 or 161 days of age. They reported a time interval between the secondary spermatocyte stage and the sperm stage of spermatogenesis of 21, 28 and 52 days in three inbred lines. They also found a slightly concave curvilinear rise in the number of cells of Leydig as testis size increased. In another paper (1944b) they reported an association of the amount of 17-ketosterols in the urine with libido and masculinity. Phillips and Zeller (1943) observed that libido was less pronounced in small type boars.

The present study was undertaken to obtain additional information on the normal course of testicular development in boars as influenced by age, body weight, strain and particularly by degree of inbreeding.

Experimental Animals and Procedure

The boars used were from two Poland China lines, II and VI, about 45 and 30 per cent inbred, respectively; line V Hampshire, about 25 per cent inbred; Durocs from the non-inbred college herd, and all of the possible crosses between these four breeding groups.

The castration data were obtained from all male pigs of each breeding group that were not saved for breeding purposes. A sample of the boars was chosen from this group by number at random, for castration at ten-day intervals between 125 days and 175 days of age. The remainder of the group were bilaterally castrated at about three months of age. Only weights and measurements were obtained for the testes from the latter group. They make up the group designated as "early bilateral castration data."

In the study of testicular development, unilateral castrations were performed at the various ages in order to get as much information as possible from each boar and to measure the age changes on a within-boar basis.

All of the boars were weighed just prior to castration. After removal, testes were placed in a 0.9 per cent sodium chloride solution. Weight, measurements and tissue samples were taken from each testis and epididymis within 30 minutes after castration.

The measurements included gross length and width of the testis and epididymis. After these dimensions were recorded, the testis and epididymis were separated and the weights and measurements of each were taken.

The tissue pieces were cut from the end and middle of the testis and from the head and tail of the epididymis and placed in Bouin's solution. The paraffin method as outlined by Guyer (1936) was followed. Four or five sections six micra in thickness were cut and mounted on slides. Two slides were made from each of the four pieces of tissue from the testis and the epididymis. The staining technique involved the use of iron hematoxylin by the slow method and counter straining with eosin.

An ocular micrometer was used in measuring the diameter of the seminiferous tubules, the distance between tubules and the diameter of the tubule of the epididymis. For each seminiferous tubule measured, an estimate of the stage of spermatogenesis was made in terms of a numerical rating of 0 through 3. A zero rating indicated presence of only basement cells and spermatogonia. The rating was one when primary spermatocytes were present, two when secondary spermatocytes and spermatids were observed, and three if spermatozoa were observed.

The diameter of the seminiferous tubules and the distance between tubules were used as possible indicators of sexual maturity and of interstitial tissue, respectively. Five observations of these two dimensions were taken from each of the four slides, and the average of the 20 observations, in micra, was recorded as the tubular diameter and intertubular space for each boar. Only the most nearly round tubules were measured to avoid those that may have been cut on an angle. Each observation of the distance between tubules was the mean distance from one tubule to all the adjoining tubules. Those tubules near septums of connective tissue were not used in these measurements.

Five measurements of tubular diameter of the epididymis were also made from each of the four slides of the epididymis tissue. The presence or absence of sperm in the epididymis was recorded.

Fall of 1947.—Since only a few boars were available for this first experiment, it served mainly to develop procedure and technique. Table 1 gives the outline followed in castration.

TABLE 1 -- PLAN OF CASTRATION FOR BOARS FROM FALL OF 1947 (Herd Number and Order of Unilateral Castration).

Breeding Group	Age in Days 125	135	145	155	165	175
V	160(L)		160(R)			
V		246(R)		246(L)		
VI	215(L)			215(R)		
VI		210(R)			210(L)	
VI			213(R)			213(L)
II x V	5(L)				5(R)	
II x V		63(R)			63(L)	
II x V			69(L)			69(R)
II x V				7(R)		7(L)
II x V					64(L)(R)	
II x VI	84(L)		84(R)			
II x VI		176(R)		176(L)		
V x VI	41(L)			41(R)		
V x VI		43(R)			43(L)	
V x VI			99(L)			99(R)
Total	5(L)	5(R)	2(L) 3(R)	2(L) 3(R)	4(L) 1(R)	2(L) 2(R)

L = Left testis removed.
R = Right testis removed.

Castrations of the 15 boars were arranged to obtain as much information as possible within each breeding group concerning development of the testes between 125 and 175 days of age. Within each group, the right testis was removed first from alternate boars; the left first from the remainder. This permitted comparison of development of the second testis after the first was removed with testes development of intact boars during the same interval. The intervals between first and second castration varied from 20 to 40 days, and were arranged to overlap between boars within each group. Also, the plan permitted comparison between breeding groups castrated at the same ages and in the same order (right and left).

Spring of 1948.—The same techniques and procedures were followed with the boars farrowed in spring of 1948. Twelve boars of each of the three inbred lines were castrated according to the schedule in Table 2. The intervals between castration again were varied to study effect of time and of age at first unilateral castration on subsequent growth of the remaining testis. The outline gives only the procedure followed with the line II boars, but the same schedule was followed with the other two lines.

TABLE 2 -- PLAN OF CASTRATION FOR BOARS FROM SPRING OF 1948 (Herd Number and Order of Unilateral Castration).

Breeding Group	Age in Days 125	135	145	155	165	175
Line II	32(R)----	32(L)				
	100(L)----	----	100(R)			
	482(R)----	----	----	482(L)		
	452(L)----	----	----	----	452(R)	
		1(R)----	1(L)			
		265(L)----	----	265(R)		
		360(R)----	----	----	360(L)	
			480(R)----	480(L)		
			307(L)----	----	307(R)	
				30(R)----	30(L)	
				75(L)----	----	75(R)
					306(L)----	306(R)
All 1st	2L,2R	1L,2R	1L,1R	1L,1R	1L	---
All 2nd		1L	1L,1R	2L,1R	2L,2R	2R
Line V			Same			
Line VI			Same			

L = Left testis removed.
R = Right testis removed.

Fall of 1948.—The 1947 fall and 1948 spring data showed that the longer intervals between removal of the first and second testis resulted in some hypertrophy of the second testis. To avoid this increased rate of growth it was decided to keep the interval at ten days in castrating the boars farrowed in the fall of 1948. Five boars of each breeding group were castrated according to the outline given in Table 3. In order to equalize treatment between breeding groups, it was necessary within each group to remove a single left testis at 125 days from one boar and a single right testis at 175 days from another boar. For this reason, the mean testis weights obtained at 125 and at 175 days would be biased in opposite directions if a real difference in weight exists between the right and the left testis.

TABLE 3 -- PLAN OF CASTRATION FOR BOARS FROM FALL OF 1948 (Herd Number and Order of Unilateral Castration).

Breeding Group	Age in Days 125	135	145	155	165	175
II x D	44(L)	44(R)				
		318(L)	318(R)			
			45(L)	45(R)		
				47(L)	47(R)	
					647(L)	647(R)
Total II x D	1(L)	1(L) 1(R)	1(L) 1(R)	1(L) 1(R)	1(L) 1(R)	1(R)
II x V			Same			
II x VI			Same			
V x D			Same			
V x VI			Same			
VI x D			Same			
Duroc			Same			

L = Left testis removed.
R = Right testis removed.

Results

Gross Anatomy.—*Comparison of Left and Right Testes.*—The left testis was significantly heavier than the right testis for all seasons (Table 4), but the differences in weight of epididymis and in length-width ratio were negligible and non-significant. These differences, although slight, would bias the age differences in 1947 fall and in the 125 and 175 day age groups from 1948 fall. However, numbers of right and left testes were equalized between ages in 1948 spring and between other age groups in 1948 fall.

TABLE 4 -- COMPARISONS OF LEFT WITH RIGHT FOR TESTIS AND EPIDIDYMIS IN ALL SEASONS AND LINES

No. of Testes	Side	Wt. of Testis (grams)	Wt. of Epididymis (grams)	Testis Ratio: Length/Width
103	Left	17.7	9.5	1.54
106	Right	15.7	9.1	1.51

Hypertrophy Following Unilateral Castration. —It was realized that the removal of one testis might influence subsequent changes in both body and testis weight. The influence of the first unilateral castration was measured by the difference between means for second and for first testis, within each age and breeding group (Table 5).

The first operation probably did check gain in body weight of the boar, but its effect was too small for statistical significance and did not vary significantly between lines or ages.

A second testis removed at a particular age was significantly heavier than first testis removed at that age. The difference between first and second testis at 165 days was very large, and was significant when analyz-

TABLE 5 -- EFFECT OF UNILATERAL CASTRATION ON SUBSEQUENT CHANGES IN WEIGHT OF BODY, TESTIS AND EPIDIDYMIS FOR BOARS FROM SPRING OF 1948

Mean Difference (2nd Minus 1st) Within Each Age and Line					
Age 2nd Castration	135	145	155	165	Mean
Interval in Days	10	15	20	25	17.5
	Number of Testes Per Line				
1st	1L,2R	1L,1R	1L,1R	1L	4L,4R
2nd	1L	1L,1R	2L,1R	2L,2R	6L,4R
	Body Weight in Pounds				
Line II	-17.3	-15.5	-9.2	-.8	-10.7
Line V	15.3	-8.0	-28.0	-3.8	-6.1
Line VI	19.0	-14.5	-7.5	-8.0	-2.8
Mean	5.7	-12.7	-14.9	-4.2	-6.5
	Testis Weight in Grams				
Line II	-.9	32.9	.4	30.8	15.8
Line V	7.1	-12.8	-11.3	67.5	12.6
Line VI	-.8	-15.7	36.5	67.1	21.8
Mean	1.8	1.5	8.6	55.1*	16.7*
	Epididymis Weight in Grams				
Line II	1.7	7.1	-1.4	7.4	3.7
Line V	9.9	-4.4	-8.6	14.0	2.7
Line VI	6.2	.5	5.8	7.8	5.1
Mean	6.0	1.1	-1.4	9.7	3.8

* Indicates $P < .05$ for deviation from zero

ed separately. No important hypertrophy was evident at earlier ages. Although line differences in the average hypertrophy at all ages were minor, there were very large variations between lines within ages due to individual variation within line, age, and order of castration.

Unilateral castration had a similar but smaller effect on epididymal growth, but the increase in weight was not significant.

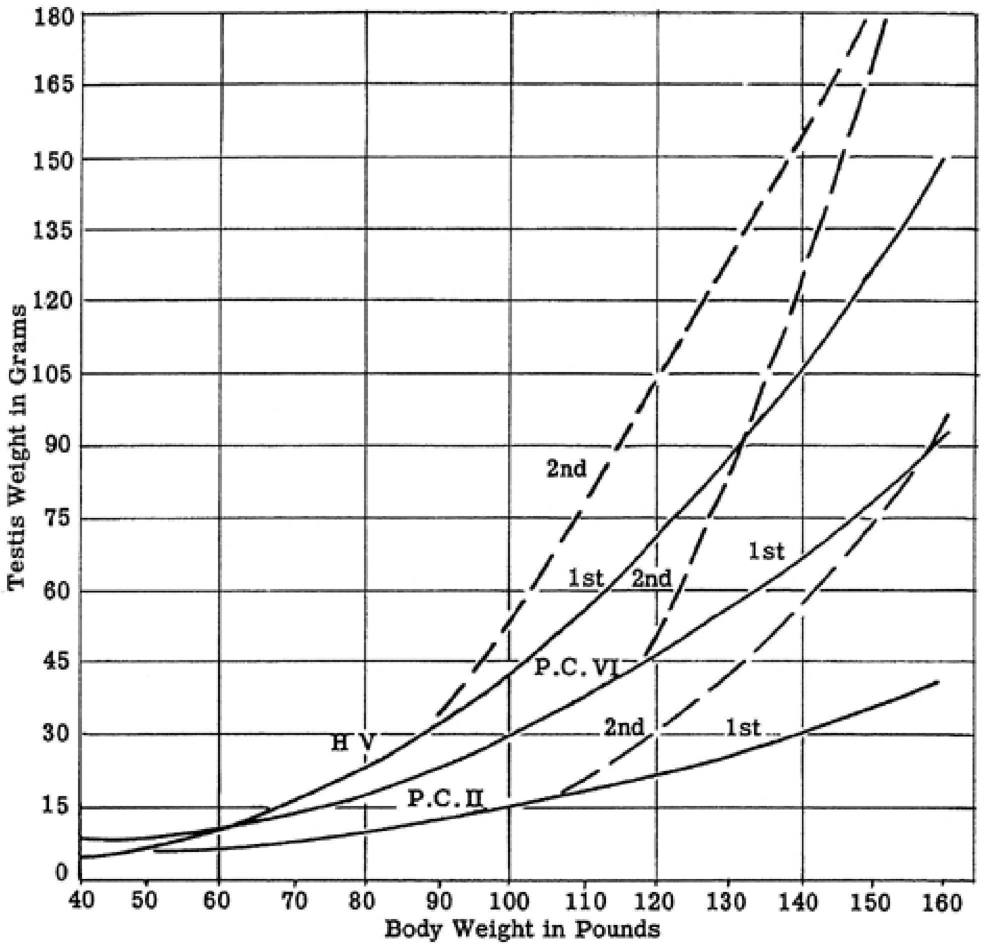


Fig. 1.—Curvilinear regression of testis weight on body weight for first and second unilateral castrations of inbred boars from 1948 Spring farrow.

The curvilinear regression of testis weight on body weight presented in Figure 1. shows the combined effect of reduction in body weight and increase in testis weight due to unilateral castration. Lines V and VI show the greatest effect of previous castration.

The effect of unilateral castrations at 10 day intervals for the crossbred boars in 1948 fall is shown in Table 6. None of the differences are significant. Castration at ten day intervals seemed to eliminate the hypertrophy found in the previous season.

TABLE 6 -- EFFECT OF UNILATERAL CASTRATION ON CHANGES IN WEIGHT OF BODY, TESTIS AND EPIDIDYMIS DURING SUBSEQUENT 10-DAY INTERVAL FOR BOARS FROM FALL OF 1948

	Mean Difference (2nd Minus 1st)* for 7 Breeding Groups			
Age in Days	No. Testes	Body Weight (lbs.)	Testis Weight (grams)	Epid. Weight (grams)
		A. By Ages		
135	7L,7R	-1.6	11.2	3.0
145	7L,7R	-6.1	-9.6	1.2
155	7L,7R	-6.3	22.7	0.6
165	7L,7R	-8.3	-28.3	0.7
Mean	28L,28R	-5.6	-1.0	1.4
		B. By Breeding Groups		
II x V	4L,4R	-20.2	-21.6	-5.4
II x VI	4L,4R	2.2	14.2	1.9
II x D	4L,4R	-11.5	19.9	5.8
V x VI	4L,4R	3.0	-9.9	0.6
V x D	4L,4R	0.8	-19.4	0.1
VI x D	4L,4R	-8.0	-11.7	2.6
D	4L,4R	-5.2	21.3	4.1
Mean	28L,28R	-5.6	-1.0	1.4

* The 2nd testis was always the right and the 1st testis the left.

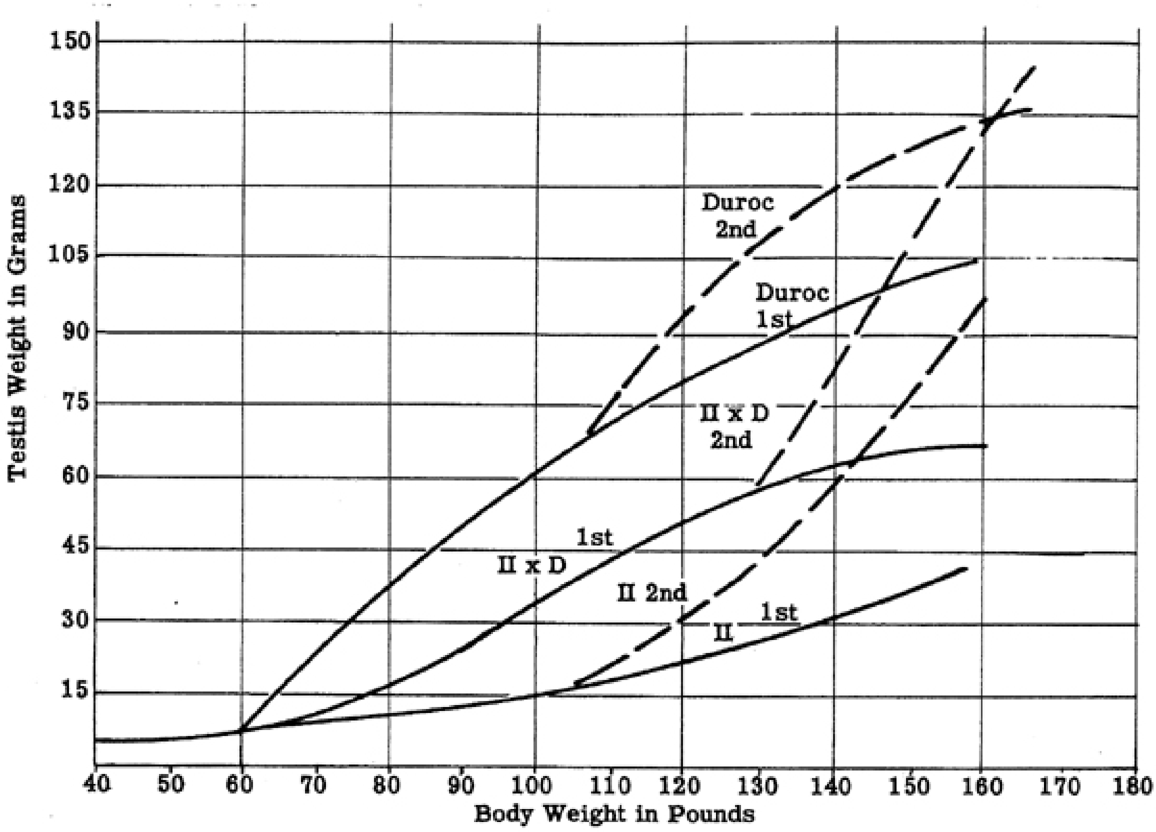


Fig. 2.—Curvilinear regression of first and second testis weights on body weight for Line II, Duroc and the II x D Crossbreds from Spring and Fall of 1948.

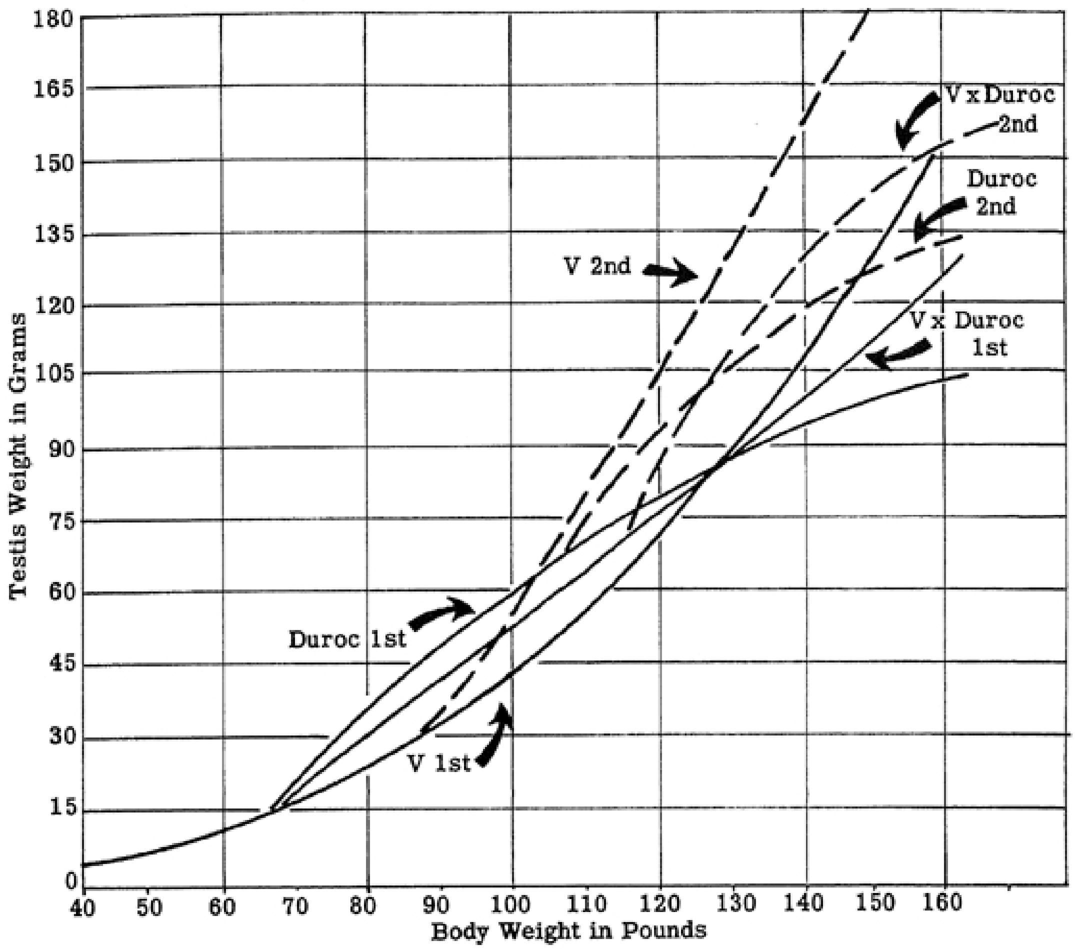


Fig. 3.—Curvilinear regression of first and second testis weights on body weight for Line V, Duroc and the V x D Crossbreds from Spring and Fall of 1948.

It would appear from Figures 2, 3, and 4 that there was some hypertrophy of the second testis during the ten day interval. This apparent hypertrophy when testes weight is plotted against body weight merely reflects the slower gain in body weight due to operational effect of the first castration.

Tables 7 through 12 give the means for testicular and epididymal development of the various age and breeding groups of boars.

Influence of Age.—As was expected, all measures of size of the testis and epididymis increased significantly with age (Tables 7, 10, 12). There was no change with age in the length-width ratio of the testis, indicating that shape of the testis remained the same as it increased in size.

The testis increased in size with age more rapidly than the epididymis among both inbred and non-inbred boars as shown by the testis-epididymis weight ratios at the various ages. At average ages of about 150 days the testis-epididymis ratio for inbred boars and crossline boars

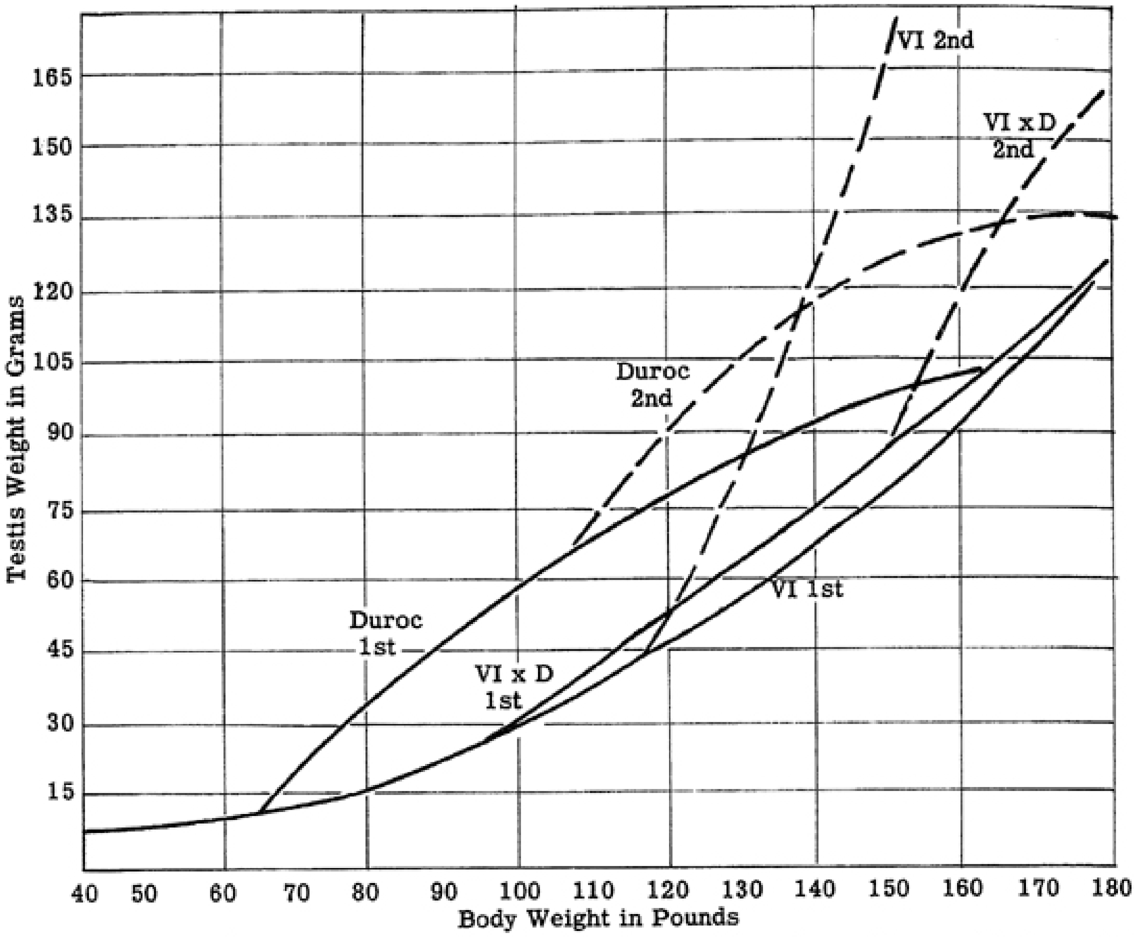


Fig. 4.—Curvilinear regression of first and second testis weights on body weight for Line VI, Duroc and the VI x D Crossbreds from Spring and Fall of 1948.

TABLE 7 -- CHANGES IN TESTIS AND EPIDIDYMIS WITH AGE FOR BOARS FROM FALL OF 1947

Age in Days	No. Testes	Body Weight (lbs.)	Weight (grams) Testis	Weight (grams) Epid.	Ratio of: Length/Width Testis	Testis/Epid. Weight
125	5	113	34.4	18.2	1.44	1.89
135	5	116	33.6	18.9	1.48	1.78
145	5	106	49.6	22.0	1.49	2.25
155	5	153	79.4	26.6	1.52	2.98
165	6	180	119.3	33.2	1.48	3.59
175	3*	128	66.7	23.2	1.56	2.87
Mean 148.8	29	134.8	70.37	24.21	1.49	2.56

* One boar died after first unilateral castration.

averaged 2.52 and 3.20, respectively. During the two seasons when groups of young boars were castrated bilaterally (Tables 9, 11), the mean testis-epididymis ratio was 1.50 when the average age was about 100 days.

TABLE 8 -- MEANS OF BREEDING GROUPS FOR TESTIS AND EPIDIDYMIS OF BOARS FROM FALL 1947

Boar Line	No. Testes	Age in Days	Body Wt. (lbs.)	Weight (grams) Testis	Weight (grams) Epid.	Ratio of: Length/Width Testis	Testis/Epid. Weight
V	4	140	117	61.6	26.7	1.38	2.31
VI	6	150	107	57.0	19.7	1.53	2.89
II x V	9	156	145	61.4	23.3	1.46	2.64
II x VI	4	140	133	57.6	22.1	1.55	2.61
V x VI	6	148	160	88.3	29.8	1.35	2.96
Mean	29	148.8	134.8	70.4	24.2	1.49	2.56

TABLE 9 -- LINE DIFFERENCES IN CHARACTERS OF TESTIS AND EPIDIDYMIS AT EARLY BILATERAL CASTRATION FOR 1948 SPRING

Line	No. Boars	Age in Days	Body Wt. (lbs.)	Weight (grams) Testis	Weight (grams) Epid.	Ratio of: Length/Width Testis	Testis/Epid. Weight
II	3	110	53	7.3	6.3	1.66	1.16
V	13	105	43	8.4	7.2	1.40	1.17
VI	25	101	58	12.8	5.9	1.56	2.17
Mean	41	103	53	11.0	6.6	1.52	1.50

In comparison with McKenzie's data for mature boars, the weight of testis and epididymis appears to reach about 25 per cent of mature size at 150 days of age. Since the epididymis is smaller than the testis and mature weights of the epididymis include sperm and epididymal secretions, the epididymis is closer to its mature size at 150 days of age than is the testis.

Genetic Variation.—There were no significant differences in body weight between the inbred lines in the 1948 spring season (Table 10). The lines, however, can be characterized by differences in body conformation and in fattening tendencies. The line II Poland Chinas were longer, leaner and trimmer than the line VI and the Duroc boars. Compared with other lines, the line V boars tended to be longer in legs, leàner, and more active, especially after they had begun to rant. The line VI and the Duroc boars had a tendency to fatten more rapidly, and the Durocs were shorter in body and leg length than the other two lines.

Differences between crosses in body weight for the 1948 fall boars (Table 12) were significant. The VI x D boars were the heaviest and the II x D were lightest at the average age of 150 days. Body weight averaged 20 to 30 per cent heavier for crosses than for the mean of the two parent strains.

TABLE 10 -- AGE AND LINE DIFFERENCES IN CHARACTERS OF TESTIS AND EPIDIDYMIS IN CASTRATION EXPERIMENT OF 1948 SPRING

Age:	125	135	145	155	165	175	Mean
No.:*	4	4	4	5	5	2	24
			Mean Body Weight in Pounds				
II	88.2	91.0	116.2	133.0	134.4	158.0	118.1
V	89.0	89.5	103.5	119.2	128.0	144.5	110.5
VI	99.2	96.8	114.8	130.0	134.0	146.5	118.3
Mean	92.2	92.4	111.5	127.4	132.0	149.7	115.7
			Mean Testis Weight in Grams				
II	13.9	17.8	33.7	31.9	58.1	78.5	36.3
V	26.9	28.2	64.6	94.5	130.7	134.8	78.1
VI	26.2	26.5	58.2	83.5	105.1	123.2	66.4
Mean	22.4	24.1	52.2	70.0	97.5	112.2	60.2
			Mean Epididymis Weight in Grams				
II	12.5	13.3	18.2	21.0	23.0	25.9	18.7
V	17.6	17.7	25.4	33.2	43.4	44.7	29.8
VI	12.6	12.0	16.7	20.2	20.9	25.0	17.4
Mean	14.2	14.3	19.6	24.8	29.7	31.9	22.0
			Mean Ratio of Length to Width of Testis				
II	1.58	1.54	1.59	1.48	1.58	1.50	1.54
V	1.32	1.30	1.36	1.36	1.34	1.34	1.34
VI	1.47	1.59	1.65	1.62	1.54	1.55	1.57
Mean	1.46	1.48	1.53	1.49	1.49	1.46	1.48
			Mean Ratio: Testis Weight to Epididymis Weight				
II	1.11	1.29	1.75	1.51	2.30	2.97	1.72
V	1.61	1.59	2.42	2.84	3.00	3.00	2.40
VI	2.04	2.11	3.32	4.28	4.35	4.90	3.45
Mean	1.59	1.67	2.50	2.88	3.22	3.62	2.52

* Number testes per line.

TABLE 11 -- LINE DIFFERENCES IN CHARACTER OF TESTIS AND EPIDIDYMIS AT EARLY BILATERAL CASTRATION FOR 1948 FALL

Line	No. Boars	Age in Days	Body Weight (lbs.)	Weight (grams) Testis	Weight (grams) Epid.	Ratio of: Length / Width Testis	Testis / Epid. Weight
II	2	94	44	8.6	6.3	1.51	1.37
V	1	105	47	7.2	7.1	1.26	1.01
D	8	94	64	14.1	7.6	1.63	1.86
II x D	6	93	78	11.7	8.2	1.49	1.43
II x V	6	100	82	13.7	10.9	1.48	1.26
II x VI	6	98	77	12.0	8.4	1.64	1.43
V x D	5	93	67	15.5	10.3	1.52	1.50
V x VI	3	98	97	18.9	13.8	1.55	1.37
VI x D	10	97	85	20.2	8.8	1.60	2.30
Mean	47	97	71	13.5	9.0	1.52	1.50

Testis weight for line II boars was only about half as great as that for the other two lines, and the line V boars had the largest testis at the average age of 150 days (Table 10). Line differences in the rate of testis growth were not statistically significant in the data from 125 to 175 days of age alone. However, data from the bilaterally castrated boars in Table 9 show that the young line V boars have a lighter testis than the line VI boars, but the difference is zero at 125 days of age and the line V testes were heavier at 175 days.

TABLE 12 -- AGE AND BREEDING GROUP DIFFERENCES IN DEVELOPMENT OF TESTIS AND EPIDIDYMIS FOR 1948 FALL BOARS

Age in Days	No. Testes	Body Weight (lbs.)	Testis Weight (grams)	Epid. Weight (grams)	Ratio of: Length/Width Testis	Testis/Epid. Weight
			A. By Ages			
125	7	111.1	40.7	16.9	1.57	2.20
135	14	120.9	54.1	18.7	1.50	2.66
145	14	137.5	76.9	22.9	1.53	3.29
155	14	158.7	95.4	26.6	1.49	3.49
165	14	175.1	114.1	33.6	1.48	3.41
175	7	190.6	164.3	40.2	1.48	4.09
			B. By Breeding Groups			
II x V	10	153.4	77.7	28.0	1.50	2.38
II x VI	10	165.1	71.9	21.4	1.48	3.18
II x D	10	130.3	58.1	19.2	1.54	2.85
V x VI	10	140.5	83.8	24.6	1.37	3.09
V x D	10	140.5	108.9	32.3	1.49	3.14
VI x D	10	182.4	133.9	33.2	1.54	4.18
Duroc	10	130.2	87.6	24.8	1.62	3.58
Total	70	148.9	88.8	26.2	1.51	3.20

Differences between crosses in testis weight at the mean age of 150 days were significant among the crossbred and linecross boars from the 1948 fall farrowing (Table 12). The II x D boars had the lightest testes and the VI x D the heaviest testes, paralleling the difference in body weight. The crosses with line II as one of the parent strains had the lightest testes, again indicating that small testis size was characteristic of line II. Testis weight of crosses in 1948 fall averaged about 25 per cent above that for the corresponding parent lines in 1948 spring.

There were distinct differences between the four parent lines in shape of testes (Tables 7 to 12). The average length-width ratio for all crosses was the same as the mean for all parent lines. Only two crosses closely resembled one of the parent lines in this respect (II x V like II; V x VI like V).

There were marked differences between lines in epididymal growth and in the relative growth of testis and epididymis. Boars of lines II and VI had lighter epididymal weights than the line V boars, but testis weight was large in line VI and small in line II. The crossbred boars with line VI as one of the parent strains possessed the same small epididymis relative to testis size that was characteristic of line VI.

The testis proper developed more rapidly than the epididymis. Also, line differences in the testis-epididymis ratio changed with age. In boars of lines V and VI, the testis grew proportionally much faster than the epididymis from 135 to 155 days of age, whereas this ratio widened most rapidly in line II boars from 155 to 175 days. The small number of boars castrated per cross at each age in 1948 fall made impossible detection of any real differences between crosses in the age change in testis-epididymis ratio. In general, the crosses exceeded the parent lines in weight of epididymis and in ratio of testis to epididymis size, since the crosses were more nearly mature sexually.

Relationship of Testes Characters with Body Weight.—Body weight at a given age is one of the major considerations in selection of breeding animals and rapid gains indicate favorable environmental influences. From both the breeding and management viewpoints, therefore, the association of testicular development with body weight is of interest. Figures 2, 3, 4 and 5 show that the regression of testis weight on body weight is curvilinear for the various lines and their crosses. All of the inbred lines exhibited the same type of concave curve, indicating an accelerated rate of testicular development relative to gain body weight during the period immediately preceding puberty. The convex curve of the Duroc represents a slowing down of testis growth relative to body weight. The line V and VI boars show a rapid increase in testis weight relative to body weight. In all cases the fitted curves for the crossbred boars are between the curves for the parent inbred lines.

The crossbred boars were above the corresponding parent strains in body, testis and epididymis weight, but the increase in testis weight relative to body weight is intermediate to the two parent strains. This suggests that precocious testicular development of crosses is merely part of the general growth stimulus from crossing.

The relative importance of the linear association of testis weight (Y) with body weight (X_1) and with age (X_2) is indicated by the standard partial regressions, $YX_1 . X_2 = .59$ and $YX_2 . X_1 = .31$, and by the corresponding simple correlations, $^{r}YX_1 = .82$ and $^{r}YX_2 = .74$. Rate of testicular development appears to be more closely associated with body size than with age. Of course, much of the variability in body weight

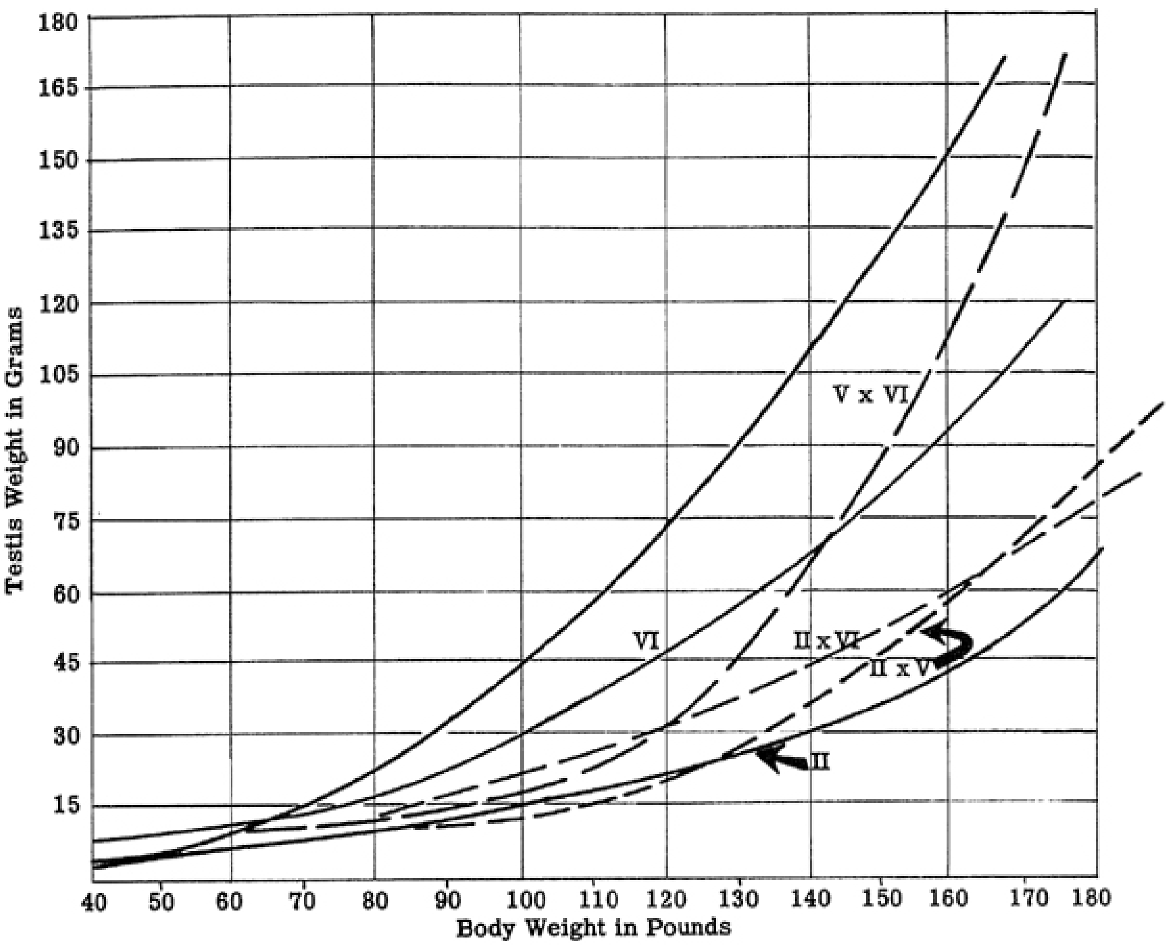


Fig. 5—Curvilinear regression of testis weight on body weight for Lines II, V, VI, and the possible crosses (first testis, 1948 Spring and Fall).

was associated with age ($^{r}X_1\ X_2 = .72$), but these were wide variations in weight at any given age.

These data included 212 boars castrated at various ages from 85 to 175 days. The pooled intra-group multiple regression equation for all 10 groups was $Y = -81.98 + .597\ X_1 + .503\ X_2$.

Histology.—Tables 14, 15, and 16 give the means of microscopic measurements and stage of spermatogenesis from histological study of the testes and epididymides. All dimensions are in micra.

Hypertrophy from Unilateral Castration.—There was no hypertrophy following unilateral castration in any of the indicators of histological development of the testes (Table 13). Apparently, the hypertrophy of the testis was due to extension in length of the seminiferous tubules.

Influence of Age.—The age changes for the 1947 fall castrations are not presented (Table 14), as they were confounded with breeding group differences. However, in the last two seasons (Tables 15 and 16) it can be seen that seminiferous tubule diameter increased with age. An ac-

TABLE 13 -- EFFECTS OF UNILATERAL CASTRATION ON SUBSEQUENT CHANGES IN HISTOLOGY OF REMAINING TESTIS (2nd Minus 1st Within Age and Breeding Group)

Season	Age	No. Testes	Diam. Tubule (micra) Testis	Epid.	Inter-Tubal Distance (micra)	Stage of Spermatogenesis (0 to 3)
1948 S	135	9 - 3	-.07	+22.96	-5.48	-.78
	145	6 - 6	-8.90	-.08	-1.77	-.33
	155	6 - 9	+19.42	+13.12	+2.52	0.00
	165	3 -12	+30.42	+16.58	+4.59	+.27
	All	24-30	+10.22	+1.67	-.04	-.24
1948 F	135	7 - 7	+1.77	+3.11	+6.93	-.10
	145	7 - 7	-4.16	+7.05	+.34	-.10
	155	7 - 7	-11.78	-15.67	-.34	-.60
	165	7 - 7	+5.87	+10.98	-4.62	+.30
	All	28-28	-2.08	+1.44	+.58	-.12

TABLE 14 -- MEAN HISTOLOGICAL DEVELOPMENT OF THE TESTIS AND EPIDIDYMIS BY LINES FOR BOARS FROM FALL 1947

Line	No. Testes	Age in Days	Diam. Tube Testis (in micra)	Inter Tubal Space (in micra)	Diam. Tube Epid.	Stage *	% Sperm in Epid.
V	4	140	138.9	45.5	220.3	2.0	0
VI	6	150	117.3	12.1	239.6	2.2	33
II x V	9	156	104.7	40.3	240.0	1.4	11
II x VI	4	140	144.0	22.4	267.3	2.2	50
V x VI	6	148	113.8	22.5	239.0	2.3	17

* of spermatogenesis, scale of 0 to 3. See text.

celeration in tubule growth occurred between 135 and 165 days of age among inbreds, but at least 10 days earlier in the crosses. In both cases, the spurt in tubule diameter occurred when the average stage of spermatogenesis was between one and two, or when secondary spermatocytes and spermatids were being formed. The diameter of the seminiferous tubules seemed to reach a maximum at the time sperm appeared in the tubules. Increased growth of the testis at later ages must result largely from extension of the tubules, as the distance between tubules changes very little with age. The maximum tubule diameter for all lines seemed to be reached between 155 and 165 days of age, but varied between lines.

Among inbred lines in 1948 Spring, primary spermatocytes were present by mean age of 135 days, secondary spermatocytes and spermatids at 155 days and sperm were found at 175 days or later. Each stage of spermatogenic development occurred about 10 days earlier on the average

TABLE 15 -- AGE AND LINE DIFFERENCES IN THE HISTOLOGICAL DEVELOPMENT OF THE TESTIS AND EPIDIDYMIS FOR INBRED BOARS 1948 SPRING

Age	125	135	145	155	165	175	Mean
No.:*	4	4	4	5	5	2	24
	Mean Diameter of Seminiferous Tubules in Micra						
II	62.4	72.6	84.8	81.7	97.3	103.6	82.2
V	97.0	85.3	135.3	143.1	166.2	151.2	130.0
VI	93.2	98.8	134.8	140.6	129.8	153.0	123.3
Mean	84.2	85.6	118.3	121.8	131.2	136.0	111.5
	Mean Stage of Spermatogenesis (Scored 0 to 3)						
II	0	.25	.75	1.00	1.40	2.50	.88
V	.75	1.25	2.00	2.60	3.00	3.00	2.08
VI	1.75	1.25	2.75	2.40	2.25	3.00	2.08
Mean	.83	.92	1.83	2.00	2.21	2.83	1.68
	Mean Distance Between Tubules in Micra						
II	21.4	20.4	23.9	22.6	17.7	18.2	20.8
V	35.8	37.6	37.9	29.3	27.4	29.0	32.8
VI	14.0	15.5	14.3	12.6	12.1	11.6	13.5
Mean	23.8	24.5	26.2	21.5	18.6	19.6	22.4
	Mean Diameter of Epididymal Tube in Micra						
II	193.3	213.8	218.1	216.7	207.0	200.6	209.2
V	222.6	224.5	262.7	266.2	288.6	318.2	260.4
VI	197.7	198.5	216.2	236.1	263.8	272.1	227.4
Mean	204.6	212.3	226.2	241.3	251.5	263.6	232.2
	Mean Percentage of Testes with Sperm in Epididymus						
II	0	0	0	0	0	50	4
V	0	0	0	60	100	50	38
VI	0	25	50	40	20	0	25
Mean	0	8	17	33	40	33	22

* Number testes per line.

among the crosses from the 1948 Fall farrow. The method of rating stage of spermatogenic development from zero to three made the mean rating of any group asymptote toward a maximum of three, since variation in numbers of spermatozoa present was ignored.

Tubule diameter in the epididymis increased slowly but significantly from 125 to 175 days of age in both inbred and non-inbred boars, but averaged larger for the latter. Only measurements of tubule diameter from the head of the epididymis were used, because of the great variation in the diameter of the tubules in the tail of the epididymis. There tended to be a rather rapid increase in size as the tubule sections were taken closer to the vas deferens.

Among inbred boars from 1948 spring the proportion having sperm in the epdidymis ranged from 1/12 at 135 days to 6/15 at 165 days of age and

TABLE 16 -- AGE AND BREEDING GROUP DIFFERENCES IN HISTOLOGICAL DEVELOPMENT OF THE TESTIS AND EPIDIDYMIS OF NON-INBRED BOARS FROM FALL OF 1948

Age in Days	No. Testes	Diam. Tube Testis	Inter Tubal Space (In micra)	Diam. Tube Epid.	Stage*	% Sperm in Epid.
			A. By Ages			
125	7	89	28.4	211	1.28	14
135	14	111	29.6	214	1.64	14
145	13	126	30.6	242	2.08	31
155	15	132	31.0	260	2.27	33
165	14	141	39.1	285	2.36	50
175	7	141	37.6	274	2.86	57
		B. By Breeding Groups				
II x V	10	101	30.5	214	1.4	0
II x VI	10	121	19.4	238	2.2	40
II x D	10	105	32.0	224	1.4	0
V x VI	10	114	20.2	219	1.9	20
V x D	10	142	44.3	240	2.6	50
VI x D	10	152	41.3	303	2.7	80
D	10	137	42.2	267	2.0	40
Total	70	124	32.8	244	2.0	33

* of spermatogenesis, scale of 0 to 3. See text.

averaged 22 per cent for all ages. Among non-inbred boars from 1948 Fall, the proportion ranged from 1/7 at 125 days to 7/14 at 165 days of age and averaged 33 per cent for all ages.

Genetic Variation.—Differences between the three inbred lines in mean seminiferous tubule diameter were significant (Table 15). Line II had the smallest and line V the largest tubular diameter. Because of the relative immaturity of testes in line II, tubular diameter continued to increase to 175 days of age and later. However, in line V, particularly, and in line VI, tubule diameter was already approaching maximum at 155 to 165 days of age. The same tendency existed among the non-inbred groups of boars from the 1948 fall farrow (Table 16). Tubular diameter of testes was significantly smaller in crosses having line II as one of the parent strains than in the other non-inbred groups of boars.

Differences between lines in stage of spermatogenesis were associated with those in diameter of seminiferous tubules. The line II boars were less advanced in the spermatogenic process at all ages studied and transmitted the characteristic to their progeny in the crosses. There was considerable variation among the line VI boars. However, their crosses were superior in sexual maturity.

Figure 6 shows the curvilinear regression of stage of spermatogenesis on age and the square of age for the three inbred lines separately and for data from all lines. The method used to score stage of spermatogenesis puts a ceiling on stage three so there is a tendency for the curves to flat-

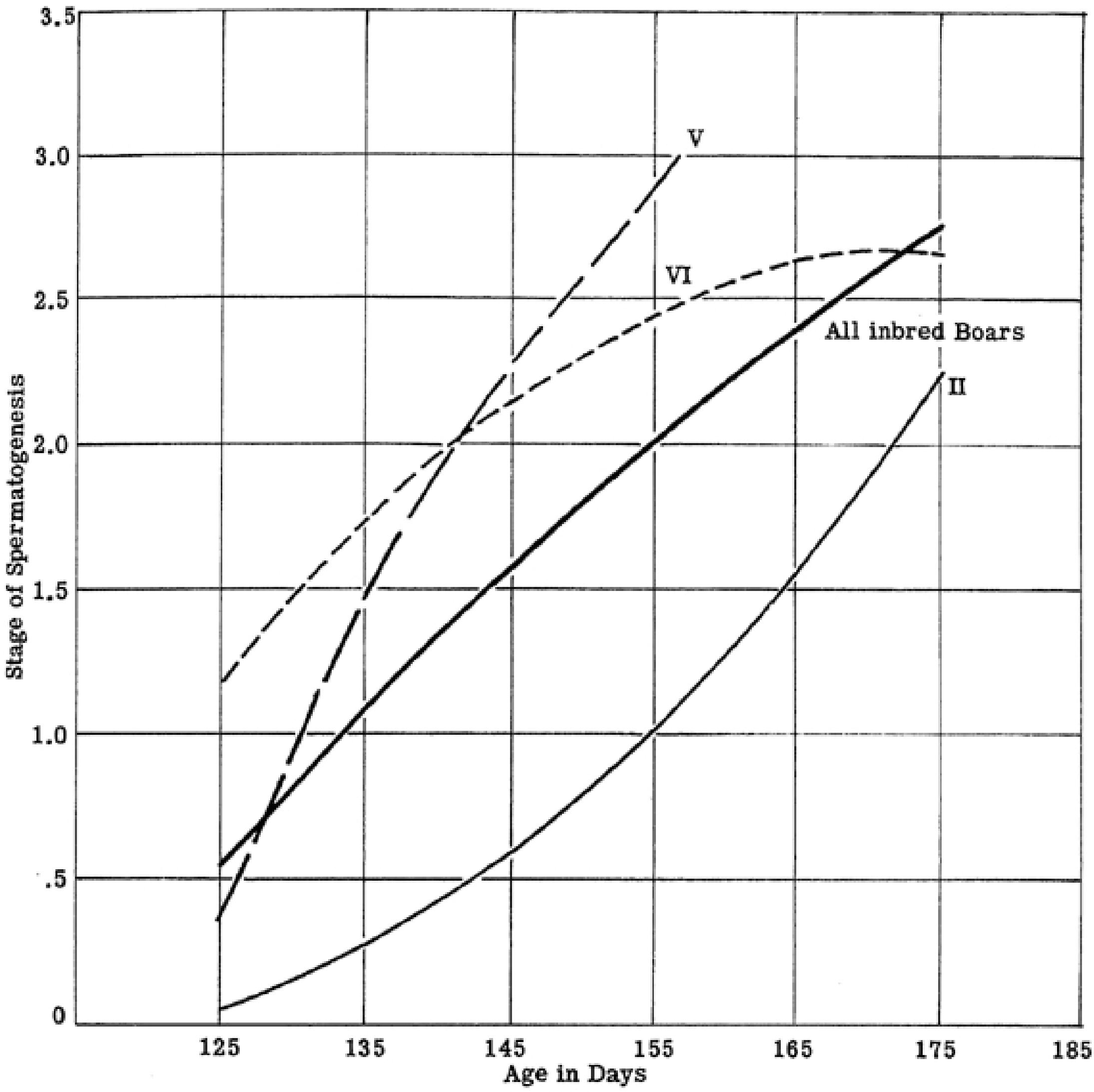


Fig. 6.—Curvilinear regression of stage of spermatogenesis on age for the three lines of Inbred boars from 1948 Spring farrow.

ten out just below that upper limit. Using the nearly linear regression curve for all inbred boars, the age at initial sperm production can be estimated from the mean age and stage of spermatogenesis for each line. These estimates (Table 17) ranged from 5 1/2 months for lines V and VI to 6 1/2 months for line II.

TABLE 17 -- SUMMARY OF REPRODUCTIVE DEVELOPMENT OF BOARS FROM FOUR STRAINS AND THEIR CROSSES (ALL SEASONS)

A. Gross Development

Line	No. Testes	Age in Days	Body Weight (lbs.)	Testis Weight (grams)	Epid. Weight (grams)	Testis / Epid. Weight
II	24	150.0	120	39.1	19.0	2.06
II x V	19	158.1	158	70.0	25.8	2.71
II x VI	14	147.1	156	67.8	21.6	3.14
II x D	10	150.0	130	58.1	19.2	3.03
V	28	147.5	111	75.7	29.4	2.57
V x VI	16	149.1	148	85.5	26.5	3.23
V x D	10	150.0	140	108.9	46.7	2.33
VI	29	148.4	116	64.5	17.9	3.60
D	10	150.0	130	87.6	24.8	3.53
VI x D	10	150.0	182	133.9	33.2	4.03
Deviation of Cross from Mean of Two Parent Lines						
II x V		9.4	42	12.6	1.6	.39
II x VI		-2.1	38	16.0	3.2	.31
II x D		0	5	-5.3	-2.7	.23
V x VI		1.2	34	15.4	2.9	.15
V x D		1.3	20	27.3	19.6	-.72
VI x D		.8	59	57.9	11.9	.47

B. Shape and Histological Development

Line	Length / Width Testis	Diam. Tube (micra)	Inter Tubal Space (micra)	Stage of Spermato-genesis	Est. Age Sperm Prod. (days)*
II	1.54	81.5	20.9	.88	196
II x V	1.47	102.6	35.1	1.42	180
II x VI	1.51	128.2	21.1	2.79	160
II x D	1.54	105.2	32.0	1.40	184
V	1.35	131.3	34.6	2.07	171
V x VI	1.36	113.8	21.1	2.06	165
V x D	1.49	141.6	44.3	2.60	156
VI	1.56	122.2	13.2	2.17	170
D	1.62	136.8	42.2	2.20	162
VI x D	1.54	151.9	41.3	2.60	156
Deviation of Cross from Mean of Two Parent Lines					
II x V	.03	-3.8	7.3	-.06	-4
II x VI	-.04	26.4	4.1	1.27	-13
II x D	-.04	-4.0	0.4	-.14	5
V x VI	.10	-13.0	-2.8	-.06	-5
V x D	.01	7.6	5.9	.46	-10
VI x D	-.05	22.4	13.6	.42	-10

* Estimated from fitted curve plotting stage of spermatogenesis against age. See Figures 8 and 9.

Figure 7 presents the same sort of curves for the crossbred, line cross, and Duroc boars. Again it is difficult to predict the age at initial sperm production for each breeding group based on its own regression curve. The small numbers and variation among boars within each breeding group make the pooled regression curve more reliable for this purpose (Table 16). Among these non-inbred groups, sperm production began at mean ages of from 5 to 6 months.

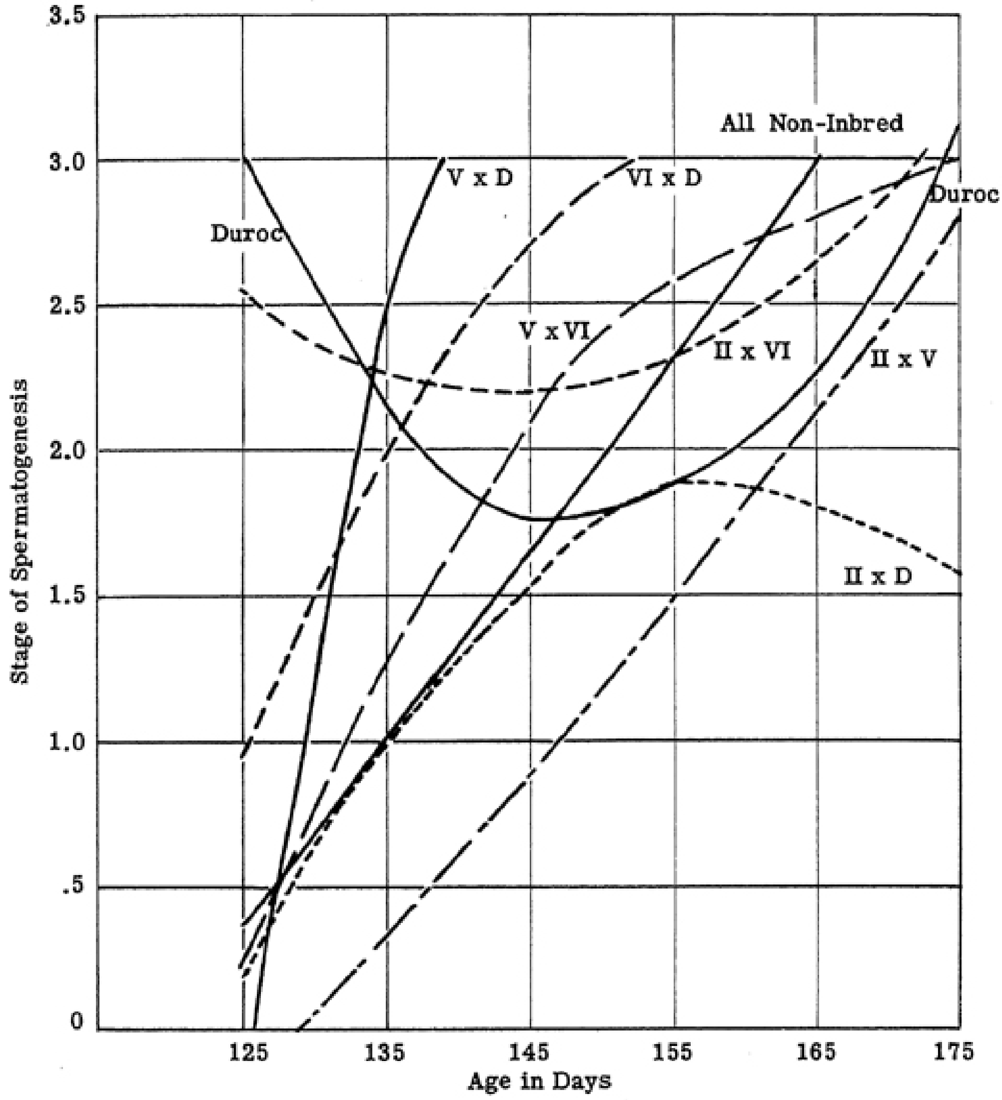


Fig. 7.—Curvilinear regression of stage of spermatogenesis on age for the Crossbred and Duroc boars from 1948 Fall farrow.

The testes of the line VI boars had considerably less intertubular space than the other two inbred lines, as well as a smaller epididymis. The II x VI and Vx VI boars had the same trait to a lesser degree, but the VI x D boars tended to be more like the Duroc parent in distance between tubules.

Tubular diameter of the epididymis was smallest for line II and for their crosses with other lines, as might have been expected from the generally slower testicular development for these groups. There was no age increase in tubal diameter of epididymides among line II boars.

Difference between lines and crosses in proportion of boars found with sperm in their epididymides agreed well with the differences in stage of spermatogenesis in the tubules. Generally, more of the boars in a given age and group were classified as stage three of spermatogenesis than showed sperm in the epididymis. Such a lag would be expected between testis and epididymis.

Evidence for Heterosis.—In Table 17, the data from the controlled experiments of all three seasons are combined to facilitate comparison of lines with their possible crosses. It is recognized that seasonal environmental influence may have biased this comparison, since inbred boars were farrowed in the Spring of 1948 and the non-bred boars in the Fall of 1948. However, supplemental intra-season comparisons of these same lines and crosses were made in the Fall of 1949. These indicated an advantage of crosses over parental lines of about 15 per cent in daily gain from weaning to final weight of 200 pounds. In the present comparison, advantage of crosses over mean of parental strains in weight for age averaged 25 to 30 per cent, indicating that environmental influences probably favored the non-inbred boars from the fall farrow. However, the advantage of crosses over parental mean was of the same order for both testis and epididymis weights. This would be expected if testicular development follows general growth impulse closely.

In testis weight, all crosses except II x D were above the average of the parent stock, and the II x VI, V x VI, V x D and VI x D crosses were above either of the two parent lines. In epididymis weight, all except II x D were above the average of the parent lines and II x VI, V x D and VI x D were above both of the parent lines. The percentage increase of crosses over parent lines averaged 25 to 35 for testis weight and 12 to 39 per cent of epididymis weight. The increase was larger for top crosses on Duroc than for the line crosses. The seasonal bias would have favored topcrosses less than line crosses over parent lines, because the Durocs were from the same season as the crosses.

Crossing seemed to have little consistent effect on the length-width ratio of the testis. In general, crosses were intermediate in this respect. The line V boars had a much shorter, thicker testis than the other lines, but their crosses varied from one extreme (V x VI) to the other (V x II) depending on the cross. In the diameter of the seminiferous tubules only three of the six crosses were above the average of the two parent strains, the average increase amounting to only about 5 per cent. The V x D and VI x D were above the means of either parent strain.

Mean distance between tubules averaged about 18 per cent higher for crosses than for parent lines. Only one cross, V x VI, was below parental mean and II x V, II x VI and V x D crosses averaged above either of the parent strains. The advantage of crosses over parent strains in testis size apparently consisted of longer tubules and increased intertubular space, since tubule diameter was increased little by crossing. All but one cross exceeded the parent lines in testis-epididymis weight ratio. This might have been expected, since testis-epididymis ratio normally widens as stage of sexual development advances.

In stage of spermatogenesis, only three crosses, II x VI, V x D and VI x D are above the average of the two lines crossed, but they are each above the highest of the parent lines.

On the average, crosses exceeded parent lines by 28 per cent in body weight, 30 per cent in testis weight, 27 per cent in epididymis weight and 20 per cent in the stage of spermatogenesis. In estimated age of first sperm production, all crosses except II x D were superior to the average of the two parent strains. The II x V and II x D were between the two parent strains while II x VI, V x VI, VI x D and V x D were above.

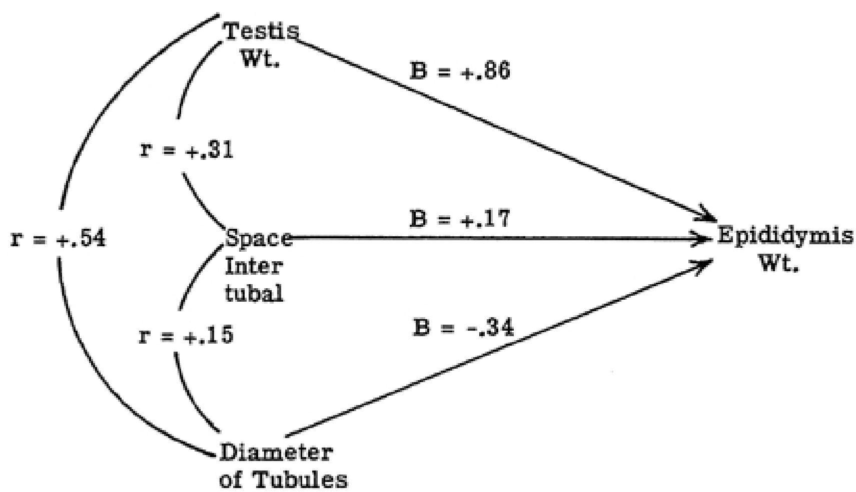
Line VI boars transmitted early sexual maturity when crossed with the other lines, while the line II boars seemed to transmit their own slow sexual development to their crosses except when crossed with line VI, the other Poland China line.

As shown earlier, rate of sexual development was closely associated with rate of gain in body weight. The curves of testis weight plotted against body weight for the various crosses fall between those of the two parent lines (Figures 2 to 5).

Association of Epididymis Weight with Testis Characters.—To compare the association of testis weight, seminiferous tubule diameter and distance between tubules with epididymis weight, a multiple regression analysis was made within line and age groups. These relations were of interest because the interstitial cells presumably secrete the hormone that stimulates development of the epididymis.

The numbers of degrees of freedom within any age were too small (7 for non-inbreds and 9 or 12 inbreds) to attach any significance to differences between ages in the correlations. The pooled simple correlations and standard partial regressions are presented in Figure 8, treating epididymis weight (E) as dependent upon testis weight (T), tubule diameter (D) and mean distance between tubules (S). The pooled simple correlations show rather close association of testis weight both with epididymis weight ($r = .71$ and $.81$ for inbreds and crosses, respectively) and with tubal diameter ($r = .54$ and $.68$) and less association between epididymis weight and tubal diameter ($r = .19$ and $.54$). However, association of distance between tubules was slight with any of the other three variables. The multiple regression analysis shows that neither intertubular space (S) or tubular diameter have much association with epididymis weight (E) that is independent of testis weight (T). This analysis is rather unsatisfactory as a measure of relation between interstitial cell volume and epididymis weight, because intertubal distance ignores total tubule length, and hence does not reflect total volume of intertubal tissue. However, it was noteworthy that line VI boars and their crosses tended to have small intertubal distance and large ratios of testis to epididymis weight, compared with other lines and crosses.

A. Among Non-Inbred Boars (28 degrees of freedom)



B. Among Inbred Boars (51 degrees of freedom)

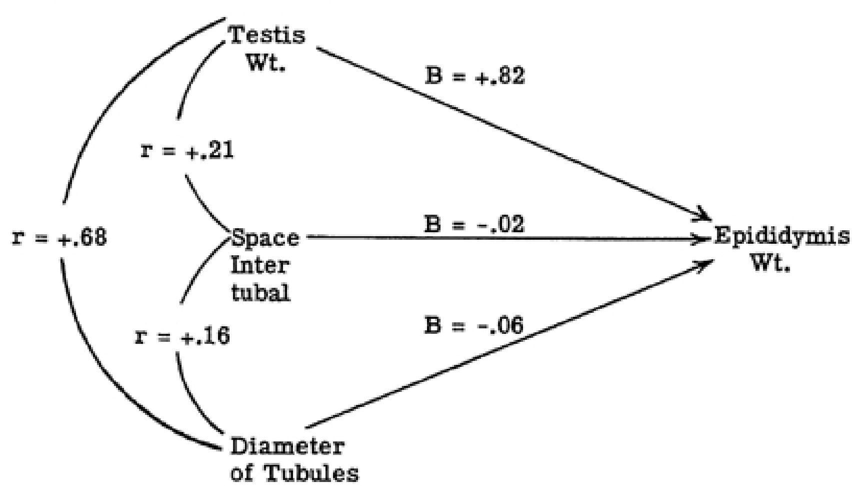


Fig. 8.—Multiple regression of epididymis weight on the weight, diameter of tubules and intertubal space of the testis proper, within ages and breeding groups.

CHARACTER OF SEMEN PRODUCED

There is little concrete evidence of association between semen characteristics and fertility in boars. Phillips (1935) reported that percentage of abnormal sperm in semen samples was associated with the proportion of sows settled. However, his grouping of boars apparently was based on characters other than abnormal sperm because most of the association with fertility disappears if the boars are grouped directly on the basis of per cent abnormal sperm.

McKenzie, Miller and Bauguess (1938) have done most of the work reported on semen characteristics of the boar. However, they used these characteristics only as measures of sexual activity, and did not study them in relation to fertility. They obtained a range of 425-500 c.c. per ejaculate, a concentration range of 25,000 to 1,000,000 sperm per mm^3 or 2.7 to 300 billion sperm per ejaculate. Frequency of ejaculation was an important factor in influencing volume of semen, sperm number, and motility. They reported that heavy service caused boars to lose mating desire. Rodolfo and Timofeeva (1933) reported 254.8 c.c. and 70 billion sperm as the average per ejaculate. The second ejaculate collected from the same boar in one day was smaller in volume.

In the present study, onset of libido and initial sperm production were used to measure inbreeding and strain differences in sexual maturity and these were related to the corresponding differences in testicular development and in initial fertility. Also, the relationship of various semen characters to actual fertility was studied.

Experimental Animals and Procedure

A study of semen production and fertility was conducted each fall and spring from 1947 through 1949 spring. The same boars were used in both phases of the experiment. During the intervals between collections of semen with an artificial vagina, the boars were mated with sows and gilts of the various breeding groups as will be described later.

Initial motility estimates were made on a 0-5 scale, 0 indicating absence of motility and 5 indicating maximum motility. They were recorded in tenths rather than plus and minus, in order to facilitate quantitative analysis.

The number of sperm per cubic mm. of semen was determined by diluting the semen in a blood dilution pipette and counting the number of sperm in the field of the hemacytometer.

Fall of 1947.—Three boars of each of the three inbred lines II, V and VI were bred to gilts of the same inbred lines.

Spring of 1948.—Two yearling (1947 Spring) boars of each of the three inbred lines were retained to produce crossbred litters and six noninbred boars farrowed in 1947 fall (two II x V, one II x VI, two V x VI and one Duroc) were added to the experiment. The same procedure was followed as in the previous season, but volume of semen was recorded in addition to estimates of the motility.

Fall of 1948.—The four line cross boars used in the Spring of 1948 were retained for service. Also, four 1948 Spring boars from each of lines II, V and VI, and two mature Duroc boars from the college herd were added. Weekly collections were made from October 2 until November 27. Initial motility, volume and concentration were measured. In addition, during this season methylene blue reduction time was recorded for each sample. The technique as outlined by Salisbury (1944) for bull semen was followed in determining the methylene blue reduction time except that it was necessary to prepare more concentrated samples of boar spermatozoa than existed in the semen as collected.

The semen was filtered through cheese cloth and an 18 c.c. sample of semen poured into a test tube. The sample was centrifuged for 5 minutes and the clear fluid portion drawn off. To the residue was added enough egg yolk-phosphate-glucose diluter to bring the volume to 6 c.c. Motility, concentration and methylene blue reduction time were recorded for the concentrated sample.

In previous seasons, most of the boars were sexually mature (7 or 8 months old) when semen collections began. In order to measure age at sexual maturity more accurately, libido and fertility data were collected on inbred, linecross, topcross and non-inbred Duroc boars from the 1948 Fall farrow beginning at 5 to 6 months of age. If boars refused to mount the gilts in heat on first trial they were tried again later in the same morning. It was found impossible to standardize satisfactorily the handling of boars in the check of libido. Collections were made at irregular intervals and only motility rating, semen volume and sperm concentration were recorded.

Frequency of Service.—In all seasons there were wide differences between boars and between breeding groups in the frequency of matings or collections of semen. This occurred primarily because the boars were used in the breeding project or for studies of actual fertility and litter size during the same period when the studies of semen character were conducted. The number of sows mated to a boar in the interval between collections and the interval between last mating and the next collection depended on when the sows assigned to the boar came into estrus. These factors undoubtly influenced volume and concentration of the samples collected. The effect of frequent service was most clearly demonstrated in the Fall of 1947. Frequent service or collection markedly reduced the concentration of sperm, although fertility as measured by litter size at birth was not influenced. Frequent service also reduced sex drive, causing the boars to refuse opportunity to mate before fertility was impaired.

In the study of onset of semen production in very young boars in the Spring of 1949, variation in frequency of service undoubtedly influenced the time of first fertile mating.

Results

Data concerning the influence of age and of breeding groups on libido and on character of semen produced are summarized in Tables 18 through 22. The age changes studied included the onset of libido and semen production in young boars as well as those between the first and second year. Both inbreeding or linecrossing effects and strain differences were studied.

TABLE 18 -- SUMMARY OF SEMEN COLLECTION DATA FOR YOUNG BOARS

Line	Year	No. Boars	No. Coll.	Age 1st Att. Collection in Days	Age 1st Succ. Collection in Days	Mean Succ. Coll.	Incr. Sp. Prod. Days	Mean Succ. Coll. Motility	Conc. (In M)	Vol. c.c.
II	1947F	3	13	227.3	232.0	252.4		3.6	195	
II	1948F	4	17	205.2	214.0	230.7		3.2	297	58.0
II	1949S	1	6	196.0	210.0	227.5	231	.52	19	77.5
Mean		8	37	212.3	220.2	238.4		3.0	213	63.1
V	1947F	3	15	231.3	231.3	253.7		3.9	229	
V	1948F	4	29	208.8	208.8	231.6		3.0	187	78.4
Mean		7	44	220.0	220.0	239.1		3.3	201	78.4
VI	1947F	4	16	234.0	238.7	260.8		3.2	155	
VI	1948F	4	16	207.5	228.5	236.8		3.2	317	79.8
Mean		8	32	220.8	233.6	248.8		3.2	236	79.8
II x V	1948S	2	14	193.0	193.0	214.0		2.0	85	112.8
II x V	1949S	3	15	169.6	188.0	214.9	221	.35	16	108.0
Mean		5	29	180.9	190.4	214.5		1.1	49	110.3
II x VI	1948S	1	5	200.0	200.0	264.0			302	
II x VI	1949S	4	20	174.7	188.5	208.3	208	.5	27	79.8
Mean		5	25	179.7	191.0	209.4		.5	82	79.8
V xVI	1948S	2	13	204.0	211.0	227.2		2.6	141	141.5
V x VI	1949S	2	10	165.0	165.0	194.5	192	1.6	97	83.2
Mean		4	23	184.5	188.0	213.0		2.2	122	116.1
D	1949S	5	14	177.2	177.2	190.2	187	1.0	119	38.9
VI x D	1949S	3	12	153.0	153.0	173.2	168	1.2	131	57.1
V x D	1949S	3	15	161.0	161.0	191.6	183	1.3	88	87.6
II x D	1949S	1	6	151.0	151.0	174.3	166	1.6	83	56.7

Influence of Age.—The influence of age first became noticeably apparent during the second season, 1948 spring, when yearling boars and boars about eight months old were used on the experiment (Tables 21 and 22). The older inbred boars (13 months) produced a much greater

TABLE 19 -- ONSET OF SPERM PRODUCTION FOR YOUNG BOARS DURING SPRING OF 1949
CONCENTRATION IN THOUSANDS PER CUBIC MM

Line	Boar	Age	February					March:					April:					May:	
		2/8	8	15	18	22	26	1	5	12	19	26	2	9	16	23	30	7	14
II	363	150										NL	NL		1	2	1	28	80
II x V	79	166	NL							2				1		4	28	90	
	164	163		NL		0	2			1	70								
	457	150						NL	NL	NL	2		2	2	4	0	12	34	
II x VI	87	166		7		7			30		35		75						
	266	161					NL	NL	5		6		4	85	80				
	469-4	148							NL	NL	NL	NL	NL	1	2		22		62
	488	148							NL	NL	1		2	6	28	30	45		
V x VI	207	162			1			4		2		110		395			390		
	296	158	0					0		4	62								
II x D	534	144		20		40		5		60									360
V x D	19	170		7	2		5		8		23								175
	345	152	0		2				9		135								
	603	139					1				9		180				450		320
VI x D	256	160	200					240			145								
	499	146			2		45		9		225								
	659	129				0			1		9		200				570		
Dur.	6	173		40	100				350										
	217	163	0					0		0		110							
	407	150						7		3		60					840		
	439	149								5			100						
	515	145										50							
Means		154	50	18	21	12	14	62	59	10	59	66	81	82	19	9	262	51	199
Cum. % of Boars																			
Collected from			80	80	83	92	87	82	79	85	95	91	91	96	100				
Sperm in Coll.			25	62	80	67	77	78	87	94	95	100	100	100	100				

NL indicates "no libido" or failure to make a collection of semen.

volume of semen per ejaculate with a higher concentration of sperm and greater motility than did the younger (6-7 months) non-inbred boars. Among the young boars there was a rapid rise in sperm concentration and volume of semen as the boars grew older. Several matings between collections or immediately preceding a collection lowered the concentration markedly, making the increases in volume and concentration rather irregular. The same results were obtained in the fall of 1948, when the young boars were the inbreds and the more mature boars were the crossbred and linecross boars.

TABLE 20 -- MATING BEHAVIOR AND CHARACTER OF SEMEN FOR YOUNG BOARS USED IN 1949 SPRING

Line	Boar	% Inbreeding	No. Collections	Age in Days: 1st Coll. Attempted	1st Coll. Successful	1st Sperm	Mean All Success. Coll.	Mean Conc. in M	Mean Motility	Mean Vol. c.c.
II	363	49	6	196	210	210	228	19	0.5	78
V	503	29								
II x V	79	0	5	166	200	200	235	25	0.8	121
	164	0	3	170	177	181	189	18	0.1	98
	457	0	7	165	189	189	216	8	0.3	99
	Mean	0	15	167	189	190	213	17	0.4	106
II x VI	87	9	5	173	173	173	193	31	0.9	90
	266	9	5	160	185	185	209	36	0.4	71
	469-4	9	4	173	208	208	224	22	0.5	92
	488	9	6	173	188	188	209	18	0.2	68
	Mean	9	20	170	188	188	209	27	0.5	80
V x VI	207	0	6	172	172	172	204	150	2.4	87
	296	0	4	158	158	190	181	17	0.4	78
	Mean	0	10	165	165	181	192	83	1.4	82
II x D	534	0	5	151	151	151	174	97	1.6	57
V x D	19	0	6	174	177	177	202	37	1.2	119
	345	0	4	152	152	162	170	36	0.3	51
	603	0	5	157	157	157	196	192	2.1	79
	Mean	0	15	161	162	165	189	88	1.2	83
VI x D	256	0	3	160	160	160	179	172	1.8	67
	499	0	4	156	156	156	169	70	0.9	59
	659	0	5	143	143	154	171	56	1.0	50
	Mean	0	12	153	153	157	173	99	1.2	59
Dur.	6	0	3	180	180	180	187	163	1.7	28
	217	0	4	163	163	208	187	28	0.4	52
	407	0	4	170	170	170	195	228	1.3	27
	439	0	2	170	182	181	191	55	0.6	40
	515	0	1	191	191	191	191	50	1.3	65
	Mean	0	14	175	177	186	189	105	1.1	42

In most instances in all seasons the older boars exhibited more libido than the younger boars. A very rapid increase in willingness to mate was observed after the first mating or collection from young boars, indicating that experience as well as age was a factor causing increased libido.

In Spring of 1949, first collections were attempted at an earlier age (5 to 6 months) in order to study age at sexual maturity more critically (Tables 19 and 20). Collections could be attempted on only part of the boars on a given day. Beginning at an average of 154 days, collections were obtained from at least 80 per cent of the boars tried up to any date (Table 19). However, the proportion of boars whose semen contained sperm started at 25 per cent for the boars tried at 160 days of age, and increased rapidly from two-thirds at 170 days to nearly 100 per cent at 190 days and thereafter.

Of 23 boars, 7 showed no sex drive at the first attempted collection when these 7 boars averaged 175 days of age. The average age of these 7 boars was 187 days at first successful collection. The boars successfully collected from on the first attempt averaged about 166 days of age at the first collection. The slower gaining boars were released from the feeding trial at an older age. These were the boars that developed libido and sperm production at the later ages.

Five of the boars showed no sperm in the semen from the first collection. Nine more had only one or two thousand sperm per mm^3. All of these 14 boars were infertile at first mating; the gilts either returned to heat or showed no cleaved eggs when slaughtered 24 hours after the end of heat.

The concentration of sperm in the semen increases rather rapidly for each boar soon after the first sperm are found (Table 19). However, the mean concentrations shown in Tables 19 and 20 are underestimates because boars that had already shown concentrations in the normal range on a given date were omitted from most subsequent data.

The entire experiment included 49 young boars from which 236 collections were made during their first breeding season (Table 21). The average volume per collection was about 83 c.c., the sperm concentration 150 thousand per mm^3 and the average motility rating 2.2. Fourteen of these boars were carried over to be used a second season as yearlings. Fifty-eight collections were made from these more mature boars (Table 22), and the average ejaculate collected was 188 c.c. in volume, the sperm concentration 300 thousand per mm^3 and the motility rating 3.6. The rapid increase in motility and concentration between 7 and 9 months of age probably would account for most of the difference between yearling and young boars and between seasons among the young boars.

Inbreeding and Strain Differences. —In the 1947 Fall season (Table 18), collections were not attempted until the boars were 7 to 8 months of age. One boar of line II and one of line VI lacked sufficient sex drive on the first attempted collection but all boars of line V worked well.

In 1948 Fall (Table 18), first collections were attempted at about 7 months of age. None of the boars of line II and VI would mount females

TABLE 21 -- MEANS FOR SEMEN FROM YOUNG BOARS

Season	Breeding	No. Boars	No. Collections	Age in Days 1st Att. Coll.	1st Succ. Coll.	Mean All	Motility	Conc. Sperm (M's)	Vol. c.c.
1947F	Inbreds	10	45	231.2	234.5	255.8	3.56	192	
1948S	Crosses*	5(4)	32(27)	198.4	201.6	219.1	2.27	141	126.0
1948F	Inbreds	12	62	207.2	217.1	232.7	3.10	250	73.1
1949S	Crosses	21	92	167.5	172.7	196.1	.95	73	75.3
1949S	Inbreds	1	6	196.0	210.0	227.5	.52	19	77.5
Young Boars		49	236			220.7	2.18	150	82.9‡

* Motility and volume missing for one boar with a sheath adhesion preventing normal collection.
‡ Does not include 1947F.

TABLE 22 -- MEANS FOR SEMEN FROM YEARLING AND OLDER BOARS

Season	Breeding	No. Boars	No. Collections	Age Days	Motility	Conc. Sperm (M's)	Vol. c.c.
1948S*	Inbreds	8	45	414.29	3.47	244	186.9
1948F	Crossline	6	13	403.95	4.16	494	190.8
Old Boars		14	58	412.0	3.62	300	187.8

* Does not include 369 (VI) whose semen contained no sperm.

in heat at the first attempted collection, but again all boars of line V exhibited sufficient sex drive.

First collections from linecross boars in the spring of 1948 were attempted at 6 to 7 months of age, nine days earlier than for inbreds in 1948 fall (Tables 18 and 21). All but one boar of the V x VI cross showed sex drive at the first attempted collection.

In the Spring of 1949, the linecross boars were started on the experiment at about 5 months of age (Tables 19 and 20). The volume, concentrations and motility rating are necessarily low for all groups because collections from each boar were discontinued as soon as the initial rise in concentration had been observed.

The means for all young boars used are presented by seasons in Table 18. The line II Poland boars averaged 220 days of age before they had sufficient sex drive for service. In the regular breeding program temporary delay was experienced in getting some of these 7 and 8 months old line II boars to mate. The line VI Poland boars also were rather slow in developing libido (234 days). This characteristic may be associated with the small amount of interstitial tissue found in the testes of these boars. During the 1948 fall season when collections were attempted early, the average age at first collection was 214 days for 4 line II boars, and 225 days for 4 line VI boars. The line V boars were never tried soon enough to determine the earliest age at which they would serve a sow, but it is safe that it was before they were 209 days of age. No consistent differences in volume, concentration and motility were noted between the three inbred lines. The average age at first collection for the II x VI and II x V boars was about 188 days, 26 days before line II boars and 40 days earlier than line VI boars. Since the first attempted collection was succesful, the VI x V boars must have reached sexual activity prior to 165 days of age, the Durocs before 177 days, the VI x D before 153 days, V x D before 161 days and II x D before 151 days. The cross of the line II and line VI Poland China seemed to correct many of the reproductive deficiencies of the two lines. The age when first successful collections were obtained from all crosses averaged 39 days earlier than for the mean of the parent lines. The actual difference may not be quite this large because collections were obtained from all line V and Duroc boars at the first attempt; however, this was also true for 4 of the 6 crosses. Of course, the fact that inbred and linecrossed boars were farrowed in different seasons weakens the comparison between crosses and inbreds. However, the earlier sexual maturity of the crosses is strongly indicated.

For most crosses in the Spring of 1949, age when sperm first were found in the semen lagged only a few days behind first successful collection; the longest periods were 32 days for boar 296 of the V x VI cross and 45 days for Duroc boar 217. In all other seasons sperm were always present at the time of first collection.

The age at increased sperm production (Table 18) was estimated roughly from Table 19 as the point at which sperm concentrations increased sharply. The differences between breeding groups are significant. Crossbred boars from matings between the Durocs and inbred lines VI, V and II showed a pronounced increase in sperm production at the earliest ages, at 168, 183 and 166 days, respectively. Line II and II x V crosses reach the point of increase at 231 and 221 days of age, respectively. These are intra-season comparisons.

The average motility and concentration figures in Table 21 indicate that young inbred boars performed satisfactorily compared with the linecrossed boars. However, the linecrossed boars were used when about one month younger (at about 7 months of age) than the inbred boars. The apparent advantage of older crossline boars over inbred boars (Table 22) in motility and concentration may have been due partly to less frequent collections.

FERTILITY AND LITTER SIZE

Nearly all of the evidence to date concerning the boar influence on fertility has been based on size of litters farrowed and proportion of sows returning to estrus. Such results are complicated by the variation in the sows influence on number of ova produced and on viability of sperm and ova in the female tract, and by variation in the inherited ability of the new zygotic combination to survive from fertilization to farrowing. Because of these factors, pregnancy and litter size are better indicators of sow than of boar feritility. The boar could influence fertility either through failure of fertilization or through his transmitted influence on viability of embryos. Fertilization failure arising from the character of the semen itself, or from faulty timing of mating in relation to ovulation may be important. If so, it might be minimized by eliminating boars with poor semen and by mating several times during estrus.

According to Rodin and Lipatov (1936), Haring (1938), and Lewis (1911), ovulation usually takes place about 36 hours after the onset of heat and sows should be bred on the second day or on both the first and second day of heat.

McKenzie and Miller (1930) mated each of 15 sows to three boars of different breeds so that the pigs by each boar could be identified. The matings were made when the sows first came in heat, 20 hours after the onset of heat and at the last sign of heat. In four of the litters farrowed, there were no pigs sired by the boar used first in the estrus period. Three of the triple-mated litters were sired by the first and second boars used.

Later, McKenzie (1932) double-mated 13 Hampshire gilts to different boars at 12 and 36 hours after the onset of heat. Eight of the litters were sired by the first boar used, two litters by the second boar and three were mixed. These results suggest that there is considerable variation in the time of ovulation after onset of estrus. Such variation presumably would favor either boars whose semen retained its fertilizing capacity in the female tract for longer periods, or repeated matings.

McKenzie, Lasley and Phillips (1939) bred gilts artificially with stored semen and obtained six pregnancies from 29 gilts inseminated once, and 18 pregnancies from 34 gilts inseminated twice at 24-hour intervals. The fact that stored semen was used and fertility was low suggests that sperm life might have been shorter and that two services might have been more advantageous here than it would be for natural services.

Krallinger and Schott (1933) found no significant effect on number of pigs farrowed due to time of mating during estrus in an experiment using 394 females. One group was bred a few hours after the onset of heat and the other group the day following the beginning of estrus. Sixty-three per cent of the early matings were successful compared to 65.8 per cent for later matings. There were 10.0 pigs per litter as a result of the late breeding and 9.8 pigs for those bred early. The same authors (1934) maintain that there are no differences between boars that are fertile in the size of litters produced. Seventy-five pairs of boars were used on similar groups of sows and no real differences between boars were found in litter size.

McMeekan (1936) bred boars of four breeds to grade sows and got the following results:

	No. Litters	Average Pigs Born	Average No. Weaned	Mortality
Tamworth sire	104	9.1	7.6	16.4
Large White sire	7	11.1	9.3	16.7
Large Black sire	13	10.4	9.0	13.4
Berkshire sire	21	9.0	8.1	9.0

No analysis of the data is presented. However, the differences obtained between boars could easily have been due to chance, assuming that the error standard deviation in litter size was 2.5 to 3 pigs, as is usually the case.

Corner (1922-1923) determined gestation losses at various periods after breeding by comparing the number of corpora with the number of fetuses in the horn. He found 26.6 per cent missing and 4.7 per cent abnormal at 13-21 days gestation. Degenerate blastocysts that died a few days after beginning development accounted for 14.4 per cent. He states that "Embryonic morbidity arises in part from internal defects of the germ cells and embryos."

The purpose of this portion of the experiment was to measure the influence of age, inbreeding and line of boar on fertility and on litter size and to relate these influences on fertility to those on testicular development and character of semen. Also, use of inbred and non-inbred matings permitted estimates of the inbreeding effect on survival of embryos, which is a special type of boar influence on litter size.

Experimental Animals and Procedure

The same boars were used in the fertility and in the semen production experiments. The females used for the fertility trials were divided into two groups: (1) those slaughtered 24 hours after the end of the estrus period and (2) the group slaughtered 25 days after breeding.

The gilts and sows bred for slaughter at 24 hours and at 25 days included all surplus females from the breeding project. Females of each line and age were distributed by number between the boars of the various lines or crosses, (Tables 23, 24 and 25). An attempt was made after the 1948 spring season to slaughter alternate females within each breeding group and boar at 24 hours and 25 days after service. This program could not be followed exactly because of the irregular slaughtering schedule of the local packing plant. As a consequence, more animals were slaughtered at 25 days after breeding than at 24 hours.

The gilts and sows intended for early slaughter were bred once as early as possible in the estrus period. They were checked for estrus twice daily with boars. It was thought that a single service early in the heat period would be the most severe test of a boar's fertility. If gilts ovulate late in the estrus period, and ovulation was not instantaneous, early matings would be more likely to expose any differences in fertility between individual boars or breeding groups of boars than would mating late in estrus.

The reproductive organs of the two groups of females were examined for gross abnormalities. The number of ovulation points on ovaries of the gilts slaughtered at 24 hours after the end of heat were counted. The

TABLE 23 -- ALLOTMENT OF FEMALES TO BOARS FOR SPRING OF 1948 MATINGS

No. Boar	Line	Age of Sow	Number of Females, by Lines for 25-Day Slaughter				
			II	V	VI	D	All
211	II	G				1	1
		S	1	1	1	1	4
253	II	G				1	1
		S	1				1
101	V	G				1	1
		S		1	1		2
261	V	G				2	2
		S	2				2
176	VI	G				2	2
		S		1			1
201	VI	G				1	1
		S	1	1			2
68	II x V	G		1		2	3
		S	1		1		2
256	II x V	G				2	2
		S			1		1
44	V x VI	G				2	3*
		S		1	2		3
111	V x VI	G	1			3	5*
		S		1	2		3
Mean	All	G	1	1		17	21
		S	6	6	8	1	21

* 1 II x VI gilt added.

TABLE 24 -- ALLOTMENT OF FEMALES TO BOARS FOR THE FALL OF 1948 MATINGS

Number of Boars by Lines		Age of Sow	Number of Females by Lines Slaughtered at: 24 Hours After Estrus					25 Days After Breeding				
			II	V	VI	D	All	II	V	VI	D	All
4	II	G		1	1	2	4	4	2	2	1	9
		S	1				1		1	1	1	3
5	V	G		3		1	4	1	4	3	2	10
		S						1	1		1	3
4	VI	G		1	1	2	4	1		6	1	8
		S				1	1		1			1
2	V x VI	G		2	2		4		1		2	3
		S									2	2
2	II x V	G			2	1	3		1	2		3
		S								1	1	2
2	D	G		3	1	1	5	1		1	2	4
		S							1		3	4
19	All	G		10	7	7	24	7	8	14	8	37
		S	1			1	2	1	4	2	8	15

TABLE 25 -- PLAN OF MATINGS DURING SPRING OF 1949 FOR FERTILITY DETERMINATIONS AT 24 HOURS AND AT 25 DAYS POST ESTRUS

No. Boars by Lines	No. of Females* by Lines and Crosses: II	VI	V	D	II x VI	II x V	VI x V	II x D	VI x D	V x D	Total
					24-Hour Slaughter						
1 II									1		1
5 D	1				2			1	2	2	8
4 II x VI		1S		1	1						3
3 II x V									1	1	2
2 VI x V				1							1
1 II x D										1	1
3 VI x D				1+1S	1	1	1				5
3 V x D							1	1			2
All 24 Hr.	1	1	0	4	4	1	2	2	4	4	23
					25-Day Slaughter						
1 II						2					2
5 D	1				2	1	1			1	6
4 II x VI			1S	1+1S						1	4
3 II x V	1		1			1		1			4
2 VI x V					1	2	1	1			5
1 II x D							1	1	1		3
3 VI x D			1	1	1	2		1	1	1	8
3 V x D				2			1		1	1	5
All 25 Da.	2	0	3	5	4	8	4	4	3	4	37

*Gilts from 1948 fall farrow unless marked "S" for Sow.

oviduct was freed from its supporting tissue and straightened out. It was separated from the uterine horn at the junction of the two. A physiological salt solution was injected into the tube at the ovarian end and forced through the length of the tube by slight pressure of the thumb and forefinger. The expressed fluid was streaked on several microscope slides and examined under low power for eggs. Both low and high power objectives were used to determine the stage of cleavage as evidence of fertilization.

If few eggs were found in the oviduct, a three-inch segment of the anterior end of the uterine horn was removed and the same procedure was followed. By this procedure, an average of 80 per cent of the eggs shed were recovered. The percentage would have been higher except for the attempt to keep the 24-hour group as large as possible by slaughtering gilts in this group up to 48 hours after breeding. In such cases, many of the eggs were already in the uterine horn where they were difficult to recover. Because of the pressure used in expressing the fluid from the oviduct some of the eggs in the later washings were crushed. Stage of cleavage could not be determined for these ova. They were classified as unfertilized in part of the data from Fall of 1948, but as undetermined, thereafter.

For the 25-day group the corpora lutea and the embryos were counted for each uterine horn. The apparently normal and the atrophied embryos were recorded separately. The total number of embryos per female was used as the measure of 25-day fertility.

Results

Fertility at 24 Hours After Estrus.—Fertility of boars from the several lines and crosses, as determined by proportion of ova cleaved when the females were sacrificed 24 hours after estrus, is shown in Table 26. The time between end of heat and slaughter ranged from 18 to 48 hours. When females were slaughtered as soon as 18 hours after the end of estrus, some eggs may have been fertilized but still uncleaved. In some cases, cleavage had progressed only to the two-cell stage in part of the eggs with no cleavage in the others. Sperm could be clearly seen in the *zona pellucida* of many of these uncleaved eggs. Because of this uncertainty of the fertility determinations, such cases were eliminated from the data.

Among the 49 fertile matings in the 24-hour data, ova recovered represented 84 per cent of the corpora counted in the Fall of 1948, but the percentage was reduced to 73 in the Spring of 1949, because of unpredictable changes in the days when gilts could be slaughtered. In calculating fertility at 24 hours, it was assumed that the proportion of cleavage among ova recovered was representative of the proportion among all ova shed.

TABLE 26 -- FERTILITY AT 24 HOURS AFTER END OF ESTRUS

Season	Line	No. Boars	No. Preg-nancies	Avg. No. Corpora	Ova Re-covered	Ova Fert-ilized	Per Cent Fertility
1948	II	4	5	12.6	11.4	10.8	95
Fall	V	2*	4	12.5	10.5	10.0	95
	VI	2**	5	12.6	11.2	10.6	95
	D	2	5	11.8	8.0	7.6	95
	VI x V	2	4	11.2	9.8	8.8	90
	II x V	2	3	11.3	8.7	8.0	92
Mean		14	26	12.0	10.0‡	9.4	94
1949	II	1	1	11.0	6.0	6.0	100
Spring	D	5	8	11.5	9.1	8.3	90
	II x VI	3	3	11.0	6.0	5.0	83
II x V	II x V	2	2	13.0	9.5	8.5	90
	VI x V	1	1	9.0	6.0	6.0	100
	II x D	1	1	16.0	16.0	16.0	100
	VI x D	3	5	11.4	7.4	7.0	95
	V x D	3	2	10.5	10.0	10.0	100
Mean		19	23	11.5	8.5‡‡	7.9	93
All Mean		33	49	11.8	9.3	8.7	93

* Three boars omitted: 1 infertile, 1 with no 24-hour data, and 1 with mating in which gilt's ovary indicated very recent ovulation and only 1 4-cell and 5 uncleaved ova were recovered.

** Two boars omitted: 1 infertile and 1 with no 24-hour data.

‡ 84% ova recovered

‡‡ 73% ova recovered

The proportion of recovered ova showing normal cleavage was 94 in the Fall and 93 in the Spring. This indicates little opportunity for a boar influence on litter size, unless there are differences in the effectiveness of fertilization not reflected in early cleavage.

In the fall of 1948, only three of 18 boars failed to fertilize any ova in a 24-hour test mating after previous fertile matings. One line V boar showed 17 to 75 per cent fertilized ova in five matings and one return prior to the mating from which 18 uncleaved ova were recovered at 24 hours. However, these 18 ova were peculiarly elongate and irregular, possibly beginning to fragment. Another line V boar showed no fertility of 40 ova recovered from four gilts and had two returns to estrus before his first (and last) fertile mating; in his next mating none of 11 ova recovered were cleaved. A line II boar had three partially fertile matings (25 to 77 per cent) and two returns before a mating from which only one uncleaved ova was recovered. Among the 20 very young boars that were used in the Spring of 1949 until a fertile mating was obtained, none failed to show fertility in subsequent 24-hour test matings. However, matings usually were discontinued for each boar in 1949 Spring after his fertility had been demonstrated in two or three matings.

Among matings showing any cleaved ova at 24 hours post-estrus, the differences between boars within a line or between lines in the percentage of ova fertilized were little larger than would be expected from the differences between matings of the same boar. The mean proportion of ova unfertilized was so small (6 per cent) that failure of fertilization could account for only a very small portion of the wide variation in litter size at farrowing.

Fertility at 25 Days After Mating (Table 27).—During the three seasons a total of 131 pregnant females were slaughtered approximately 25 days after mating. The number of corpora averaged 12.8, 13.0 and 11.3, respectively, being fewer in the last season because the gilts were younger when mated. The proportion of corpora represented by embryos re-

TABLE 27 -- FERTILITY AT 25 DAYS AFTER MATING IN THREE SEASONS

Season	Line	No. Boars	No. Pregnancies	No. Corpora	No. Embryos Total	No. Embryos Normal	% Fertility Total	% Fertility Normal	Returns * to Estrus	
1948 Spr.	II	2	7	11.3	7.3	7.0	64.6	62.0		
	V	2	7	15.1	11.4	11.1	75.5	73.6		
	VI	2	6	12.5	10.4	9.7	82.6	77.3		
	II x V	2	8	14.9	11.3	10.5	75.6	70.6		
	V x VI	2	14	11.4	8.4	7.6	74.2	67.3		
	Mean	10	42	12.8	9.4	8.8	73.3	68.3	12	
1948 Fall	II	4	12	12.0	7.5	7.2	62.0	60.0	7	
	V	5	13	12.3	9.3	7.5	77.0	62.0	4	
	VI	3	9	10.3	8.9	8.1	86.0	78.0	3	
	D	2	8	16.6	10.4	8.8	62.0	53.0	1	
	II x V	2	5	14.0	9.8	9.4	70.0	67.0	0	
	V x VI	2	5	15.2	10.2	9.2	67.0	60.0	2	
	Mean	18	52	13.0	9.1	8.1	70.0	63.0	17	Total*
1949 Spr.	II	1	2	11.5	9.0	9.0	78.0	78.0	0	4
	D	5	6	10.8	9.2	8.7	85.0	80.0	1	3
	II x VI	4	4	14.8	11.8	10.6	80.0	71.0	1	11
	II x V	3	4	12.0	10.0	8.5	83.0	71.0	0	4
	V x VI	2	5	11.6	9.8	8.6	84.0	74.0	1	4
	II x D	1	3	10.7	7.3	5.3	69.0	50.0	1	5
	VI x D	3	8	10.4	6.2	5.5	60.0	53.0	0	3
	V x D	3	5	10.0	7.4	5.8	74.0	58.0	0	9
	Mean	22	37	11.3	8.6	7.5	76.0	66.0	4	45
All	Mean	50	131	12.5	9.2	8.2	73.0	66.0	33	

* Including all matings to boars shown to be fertile in previous matings. "Total" in 1949 spring includes returns to matings with very young boars (5-6 months old) with no previous fertile mating.

covered varied little between seasons: 70 to 76 per cent for all embryos and 63 to 68 per cent for the apparently normal embryos. There were no significant differences between boars or lines of boars in the percentage of corpora represented by either total or normal embryos, except that the lower fertility for line II compared with line V and VI boars approached significance.

It is shown in Table 28 that there were more inbred matings for line II boars and that inbreeding of both litter and dam averaged higher in matings of line II boars. Comparison of inbred and crossline litters from dams of the same inbred line indicates a mean advantage in percentage fertility for the crossline litters of about 5 per cent from total embryos and of 10 per cent from normal embryos, for a difference of about 20 per

TABLE 28 -- COMPARISON OF INBRED AND LINECROSS LITTERS AT 25th DAY OF GESTATION FROM SPRING AND FALL OF 1948 BREEDING

Mating*	Season	No. Sows	% Inbreeding of: Dam	Litter	Number /Sow Corpora	Embryos Total	Normal	% Fertility Total	Normal
II x II	S	2	36.8	45.3	11.0	6.5	6.5	59.1	59.1
	F	4	42.2	43.3	11.2	5.2	5.2	46.7	46.7
II x Other	S	5	10.5	1.8	11.4	7.6	7.4	66.7	64.9
	F	8	27.6	3.4	12.4	8.6	8.1	69.7	65.7
Other x II	S	5	46.5	6.1	12.8	8.4	8.4	65.6	65.6
	F	4	42.4	2.2	10.0	7.0	6.2	70.0	62.5
VI x VI	S								
	F	6	30.2	18.3	10.0	8.2	7.5	81.7	75.0
VI x Other	S	6	16.0	1.5	12.3	9.5	8.8	77.0	71.6
	F	3	19.3	3.0	11.0	10.0	9.0	90.9	81.8
Other x VI	S	8	16.8	6.4	14.8	12.1	10.6	82.2	72.0
	F	10	35.8	4.0	11.9	7.9	6.7	66.4	56.3
V x V	S	1	1.2	11.9	23.0	18.0	18.0	78.3	78.3
	F	5	26.5	36.5	12.6	9.6	7.2	76.2	57.1
V x Other	S	6	18.1	0	13.8	10.3	10.0	74.7	72.3
	F	8	22.0	0	12.0	9.4	8.1	78.1	67.7
Other x V	S	6	19.2	3.9	13.0	7.8	7.0	60.3	53.8
	F	7	26.8	3.0	12.6	10.3	9.9	81.8	78.4
D x D	S								
	F	5	0	0	19.6	12.6	10.2	64.3	52.0
D x Other	S								
	F	3	37.9	0	11.7	6.7	6.3	57.1	54.3
Other x D	S	17	0	0	11.9	9.2	8.7	77.3	72.9
	F	11	0	0	13.8	10.5	9.8	75.7	71.1

* Line of boar always given first.

cent in the inbreeding of the litters. Comparison of crossline litters from dams of one line with those by sires of the same line showed an advantage for the less inbred group of dams in all except the line II comparison.

The correlations of inbreeding of dam and of litter with the components of fertility are shown in Table 29. Among litters from inbred sows of the same line, the sow's inbreeding was correlated with fewer ova shed (r = —.40), fewer embryos (—.48) and lower fertility (—.27). Inbreeding of dam within line of sow is confounded with age of sow to some extent, because the gilts tended to be more highly inbred than the older sows. This is indicated by the large regressions on inbreeding of dam, which amounted to —1.7 ova, —2.7 embryos and —10.9 per cent fertility

TABLE 29 -- CORRELATIONS (r) AND REGRESSIONS (b) FOR ASSOCIATION OF INBREEDING OF SOW AND LITTER WITH COMPONENTS OF FERTILITY AT 25 DAYS

Components of Fertility (Y)	Within Line of Sow (39 D/F)				Within Line of Boar (50 D/F)			
	Inbr. of Sow (X_1)		Inbr. of Litter (X_2)		Inbr. of Sow (X_1)		Inbr. of Litter (X_2)	
	r_{X_1Y}	b_{YX_1}	r_{X_2Y}	b_{YX_2}	r_{X_1Y}	b_{YX_1}	r_{X_2Y}	b_{YX_2}
No. Corpora	-.40*	-.17			-.17	-.04		
No. Normal Embryos	-.48*	-.27	-.24	-.06	-.27**	-.06	-.26**	-.06
Per Cent Fertility	-.27	-1.09	-.18	-.33	-.23	-.38	-.19	-.31
	$r_{X_1Y_2}$ = -.07				$r_{X_1Y_2}$ = .42*			
	σX_1 = 7.6		σX_2 = 16.9		σX_1 = 17.1		σX_2 = 16.7	

* = $P \leq .01$ ** = $P \leq .05$

for a 10 per cent increase in the sow's inbreeding, even though variability in dam's inbreeding was small (standard deviation of 7.6 per cent) and uncorrelated with inbreeding of the litter produced (r = —.07). The indicated decline of .6 embryos and of 3.3 per cent fertility at 25 days for each increase of 10 per cent inbreeding of litter was not significant, but, if real, was large enough to be highly important.

Among litters by the same line of sire, both inbreeding of sow and of litter were associated with smaller litters (—.6 embryos per 10 per cent greater inbreeding of dam or litter) and lower percentage fertility at 25 days. The influence of the sows inbreeding appears to be partly a reduced rate of ovulation and partly poorer survival of ova. Variation among sows mated to boars of a given line includes strain differences among II, VI, V and non-inbred Duroc sows. Since the non-inbred Duroc could be used only to produce non-inbred litters, inbreeding of sow and of litter were confounded for differences between Duroc and other sows, ($^rX_1 X_2 = .42$ within line of sire).

From the evidence presented, it seems entirely reasonable to attribute the smaller litters from line II boars to the higher inbreeding of the line II sows and of the inbred II litters, rather than to impaired fertility of the line VI boars.

In two cases, the number of embryos recovered was larger than the number of corpora on the ovaries. Corpora were carefully dissected to detect septa undiscernable from the surface. Perhaps multiple ovulation from a single follicle may be a rare occurrence. Also, identical twinning may occur occasionally. In one case, 10 normal and 2 atrophic embryos were recovered when only 11 corpora could be found, and two of the embryos were found in a single placenta.

In the Fall of 1948, the number of sows returning to heat seemed rather large (17 of 95 matings, or 18 per cent), but these results are much the same as those obtained in the 1947 Fall season (12 returns from 71 matings, or 17 per cent). The data from females bred to fertile boars and slaughtered at 24 hours post-estrus showed very few cases of complete fertilization failure. The same boars were mated to the females slaughtered 25 days after estrus. The boars were watched closely at the time of mating and no abnormal services were observed. It seems likely that most returns to heat after matings with previously fertile boars were due to mortality of all of the ova during very early pregnancy. The higher proportion of returns from matings with the young inbred boars may have occurred because they were mated to larger numbers of inbred II, V and VI females and because of the higher proportion of inbred matings for these boars (Table 28).

Among returns to matings with fertile boars in all seasons, the average interval from mating to subsequent estrus was 23.6 days, slightly longer than normal. This interval might have been still longer, except for the experimental procedure of slaughtering all gilts that had not returned to estrus at about 25 days after breeding. In 15 of the gilts slaughtered no pigs were found in the uterine horns. In six of these cases, fresh ovulation points were found on the ovary, indicating that the gilts had been in heat, but unobserved. Evidently these matings were either infertile or fertilization was so abnormal that the ova failed to develop. Six others had developing follicles on the ovary and the corpora lutea were regressed. Active corpora were still present in the remaining three gilts, with no new follicular growth. Examination of the ovaries and uteri of these nine females indicated that pregnancy had existed for a short time but failed to persist.

Age at First Fertile Mating (Table 30).—In the 1949 season, collection of a semen sample from each boar was attempted as soon after 5 months of age as the boar would mate, in order to obtain information on sexual maturity. Often the first collection contained no sperm. To be sure that absence of sperm in semen collected meant that there were no sperm in the ejaculate of a natural service, many boars were mated before sperm had been found in their semen. No cleaved ova were recovered from gilts sacrificed 24 hours after such matings, and the gilts held until 25 days after such matings returned to estrus. Therefore, the total number of returns to heat for each boar is largely determined by the number of gilts bred to him before his semen contained sperm in appreciable numbers.

TABLE 30 -- ESTIMATES OF AGE AT SEXUAL MATURITY FOR YOUNG BOARS IN SPRING OF 1949

Line	No. Boars	Age in Days at Increased Sperm Production	First Fertile Mating: Age in Days	First Fertile Mating: Sperm Concentration at Nearest Collection in M's Per mm^3
II	1	231	242	28
D	5	187	207	72
II x VI	4	208	229	56
II x V	3	222	235	65
V x VI	2	192	208	228
II x D	1	166	164	22
VI x D	3	167	176	136
V x D	3	183	190	70
Total or Average	22	193	208	86.5

There were very few returns to boars proved fertile in earlier matings. These easily could have been due to aberrant function of the female or to early embryonic mortality. All boars except one line V boar with an adhesion within the sheath and one (V x D) linecross were used until fertile matings were obtained, either at 24 hours or at 25 days. The V x D boar had sufficient number of sperm in semen to be fertile, but for some unknown reason 4 of the 5 gilts bred to him returned to estrus and the other one had no embryos when killed at 25 days, although she had not returned to estrus. None of the semen characteristics studied on this boar suggested a possible reason for his infertility.

A major objective in the 1949 Fall matings was to study differences among the lines and crosses in the age when boars first showed fertility in mating. Evidence for significant differences between lines in age of boars at increased sperm was presented in the previous section (p. 34.) In Table 30, the mean ages at increased sperm production and at first fertile mating are given with the mean concentrations of sperm in the semen collection taken nearest the date of first fertile mating, by breeding groups.

The VI x D boars began rapid sperm production long before line II or II x V. The breeding group differences in age at first fertile mating were not statistically significant, but they were in the same direction as the significant differences in age at increased sperm production. Some of the boars were fertile at first attempted mating. Some matings classed as infertile were based on returns to heat, and thus could have been due to the female. It was impossible to mate each boar at regular intervals; hence a boar may have been capable of fertile mating a week or more before his first fertile mating occurred.

Estimates of sperm concentration at the semen collection nearest the first fertile mating are subject to errors similar to those for age at first fertile mating. There was much variation between boars in the concentration of sperm per mm^3 at which he was fertile. Two boars had fertile matings when the concentration was only 5 and 9 thousand sperm per mm^3, respectively. These estimates for age and concentration of sperm at first fertile mating are only rough approximations and are higher than the actual ages and concentrations when the boars were capable of fertile matings.

DISCUSSION OF RESULTS

This experiment was initiated to determine how the normal pattern of reproductive development and function in boars is modified by inbreeding and by strain differences. The two inbred lines of Poland China (II and VI), the inbred Hampshire line (V), the non-inbred Durocs and the crosses between these strains provided suitable variation for study of inbreeding and strain influences.

Testicular Development and Sexual Maturity

The most highly inbred line II boars were much slower to develop than boars of the other two lines in all measures relating to testicular growth and sperm production. Associated with their small testis and epididymis size were small seminferous tubule diameter, delayed libido, sperm production, and first fertile matings. The line VI boars were characterized by rapid testis growth, but by a small epididymis, small intertubular space and delayed development of libido and semen production. The line V Hampshire boars began to rant as early as four months of age. They exhibited precocious testis development in relation to body weight and were advanced in epididymal development and intertubular space compared with other inbred lines.

The nature of the age changes in testis size, tubule diameter and stage of spermatogenesis agree with the results of Green and Winters (1944a). The weight of the testis proper increased with age more rapidly than that of epididymis, and total weight of the testis increased more rapidly than body weight. The diameters of the seminiferous tubules were correlated with testis size at all ages. However, the increase in testis weight at later stages of development seemed to be due more largely to tubular extension than to increased diameter of tubules or intertubal space.

First appearance of sperm in the seminiferous tubules occurred at a mean age of 180 days among boars of the three inbred lines and at 165 days among the non-inbreed or linecross boars. Sperm were in the testes of some boars as early as 125 days of age and in most boars at 175 days of age. Spermatozoa were recovered from the epididymis of one non-inbred boar at 125 days of age. Only about half of the non-inbred boars examined at 165 to 175 days of age had sperm in the epididymis, and the proportion was smaller among boars of the inbred lines. Much variation in age at sexual maturity between strains and crosses and between individuals within groups was the rule.

The hypertrophy of the remaining testis after unilateral castration was greatest in line V and VI, at 165 days of age or older, and when the interval between first and second castration was 20 days or longer. These results would be expected if the androgens from the testes tend to depress the output of hormones, presumably from the pituitary, that stimulate testicular growth. In the older boars, more testicular tissue was removed at the first unilateral castration and a larger testis remained to respond to gonadotrophic hormone.

The partial regressions of epididymis weight on various characteristics within lines and within crosses indicated that epididymis weight was more closely associated with testis weight than with intertubal space or with diameter of the seminiferous tubules. The space between tubules was associated with epididymal weight only at the younger ages, possibly because the increase in total volume of interstitial cells varied more directly with the size than with the cross-section composition of the testis. The association between small interval space and low epididymal weight in line VI is in harmony with the supposition that the interstitial cells secrete a hormone that influences epididymis size.

The crossbred boars from all line combinations were above the mean of the two parent strains in body weight and in all measures of sexual maturity. The curvilinear regression of testicular weight on body weight for the crossline boars was intermediate to the two parent strains both in height and shape of the curve. Apparently, heterosis in testicular growth and function is an integral part of heterosis in general growth.

There were distinct strain differences in testicular development in relation to body weight that were characteristic of the line rather than due to inbreeding. For example, line II boars grew as rapidly as line VI or line V boars, but their testes were only one-half to two-thirds as large. The slower testicular development characteristic of line II inbred boars also was noticeable in the line II crossline boars. The small epididymis of line VI and the testis shape of line V boars also are assumed to be characteristics fixed in these lines due to the random effects of inbreeding. No direct selection for or against these characters was practiced, nor will it be until they become of such magnitude that they affect the fertility of boars from these lines. The slow sexual development of line II has not become a problem, because the boars did produce sperm by the usual age (8 months) for the first breeding season and they exhibited enough libido to breed sows if handled patiently.

The greatest number of reproductive abnormalities were noted in line VI, among both boars and sows. Two boars saved for breeding purposes in line VI did not persist in sperm production, two were cryptorchids, four had hernias. One sow in the line had only a single right uterine horn, and one gilt had only a segment of the left uterine horn. A litter mate to this gilt had an obstructed cervix and juvenile reproductive organs. The fact that these abnormalities were found mainly in one line led to the conclusion that predisposition to such irregularities is inherited. Many of the cases of abnormal genitalia occurred in one subline of line VI, later discarded, although the cryptorchids and herniated pigs were scattered throughout the line.

Significance of Semen Character

The data from semen collection agrees fairly well with that from histological examination of testes. There should be some time lag between first observation of sperm in the testes and in the semen. The histological data from the testes is more accurate than the collection data because it is less influenced by previous treatment. The effect of frequent matings or collection from the very young boars probably delayed the age at which markedly increased concentration of sperm in the semen was observed.

Much variation existed between boars and within boars from week to week in all semen characteristics studied. However, in all but the most extreme cases semen production was above the threshold necessary to insure fertility from natural service. Examinations of semen apparently can detect only those boars likely to be entirely infertile.

The behavior of semen samples during storage yielded no information on the potential fertility of the various boars. The presence of contaminants in the samples made the measures unreliable from boar to boar and between weekly samples from the same boar. Centrifugation and redilution did not remove the great amount of variability between samples, although it did make possible the storage of sperm. Best viability of sperm during storage was obtained when the centrifuged samples were rediluted to one-third of the original volume, using an egg yolk-glucose-phosphate diluter with a pH of 7.4. After storage for 32 hours at 5 to 10° C, the mean motility ranged from 1.4 to 3.7 for the weekly collections in the fall of 1949. A storage procedure of this sort may prove of value in any application of artificial insemination in swine husbandry.

Frequency of service or of collection of semen had a great influence on the volume and character of semen samples obtained. Frequent service reduced the number of sperm mm^3 of ejaculate to a marked degree. However, the frequency of service in this experiment was not enough to impair fertility, except possibly in young boars that were just beginning to produce sperm.

Semen collections were obtained from immature boars during the last season before sperm were present in the semen. It could be argued that such ejaculations did not represent natural or complete semen from these boars. However, aspermatic ejaculates did persist in some boars longer than in others, and no fertilized ova were found when gilts bred by such boars were slaughtered 24 hours after end of estrus. These same boars became fertile after sperm were found in their ejaculates.

The first fertile matings of some young boars resulted when the concentration of sperm in the semen was at a low level, below 10,000 sperm per mm^3, and when the volume of semen produced was small, in agreement with earlier results by Lasley (1940).

It was difficult to determine the age at puberty or sexual maturity for individual boars, since first expression of libido depended to a great extent upon the handling of the boar. In strains where the mating urge was rather weakly expressed, the boars were easily dissuaded from mounting sows by the method of handling. After the first collection or service the boars generally showed a marked increase in libido. The strain differences in mating desire were real, but perhaps not as exaggerated as the mean differences in age of first collection would suggest.

Although the differences between breeding groups of boars in age at first fertile mating were large and agreed well with other observations of sexual maturity, they were not significant, very probably because of (1) the relatively few gilts that could be mated to each boar, (2) the rather long interval between matings, and (3) the large number of gilts that were not checked until 25 days after mating, allowing variation in the sows influence to affect results more than in the 24 hour data.

There was little correlation between the semen characteristic studied and fertility in boars that were once proven fertile. In the absence of sperm or when concentration was below 10,000 sperm per mm^3, fertilization seldom occurred. In most cases, fertility seemed to be either 0 or 100 per cent. Among gilts showing any cleaved ova, an average of about 95 per cent of all ova were cleaved. The occasional uncleaved eggs recovered could be attributed either to failure of the sperm to fertilize the egg or to abnormality of the fertilized egg. In some cases sperm could be seen in the *zona pellucida* of uncleaved eggs, indicating that spermatozoa had reached the egg and possibly that the egg had been fertilized. Each season there were gilts that returned to heat, but in the last three seasons only three females slaughtered at 24 hours after breeding to previously fertile boars showed no cleavage of the eggs. In one case the ova were abnormal in morphology. In the other two cases, presence of sperm in the *zona pellucida* indicated that sperm had reached the ova. Fertilization failure apparently was rare.

In many sows slaughtered at 25 days, stimulated areas on the uterine horn indicated the recent presence of embryos of which no trace could be found. The presence of atrophied fetuses and stillborn pigs indicated that prenatal death continued throughout gestation. The smaller size of the inbred litters as compared to non-inbred litters indicated that the genotype of the pig influences the death rate.

The frequency distribution of litter size at 25 days from mating with fertile boars would fit the "normal" fairly well except for a rather large group with no embryos (15 of 146 cases). Such cases would appear as late returns to estrus and hence would reduce conception rate but not the size of litters farrowed. They were due to failure of fertilization and to early uterine mortality of whole litters. Genetic constitution of the embryos is unlikely to account for loss of entire litters and the 24-hour data on cleaved ova indicated that previously fertile boars almost never failed to initiate cleavage of ova. This leaves only variation in normality of the ova when fertilized or in the sow's influence on survival of fertile ova to explain most of the returns to estrus.

Repeat Mating

Results obtained here indicate that the practice of mating sows twice during the heat period, at intervals of 24 hours, would be unlikely to cause any important increase in the size of the litters farrowed. Boars that are fertile at all apparently fertilize at least 95 per cent of the ova shed, when allowed to mate only once early in estrus.

Squiers, *et al.* (1952) set up an experiment in the 1949 breeding season in which every other gilt of a particular line of breeding was given a second service 24 hours after the first. A total of 50 gilts were bred once and 48 were bred twice. Seventy of these gilts farrowed. The percentage of matings resulting in litters farrowed was 89 for the two-service and 66 for the single service matings, a highly significant gain of 23 per cent. Size of litters farrowed was only .51 pigs larger for the two-service matings, and this large a difference would be expected about once in six experiments of this size due to sampling error alone. The advantage in conception rate may have been over-estimated, since there were no checks of fertility of the boars 24 hours after mating, and since two of the boars accounted for seven (of the thirteen) returns to heat, of which six were in the single service group. The first three services to one of these boars were infertile, and they were in the single service group because the boar would not serve twice.

Much of the evidence presented in the work of others concerning the optimum time for mating during estrus has been based on matings of each sow to several different boars at intervals during estrus. Such evidence does not prove that sperm of the first service lose their fertilizing capacity before all ova are shed but only that as the result of chance some fertilization by sperm from the second service does occur, and that some ova are not shed until sperm from the second service are present. The extensive experiment of Krallinger and Schott (1933) indicated no difference in either conception rate or in litter size between sows bred once soon after onset of estrus and those bred once on the second day of estrus. Results from slaughter 24 hours after estrus in the present experiment show that no difference would be expected, considering the 94 per cent of the ova were cleaved from fertile matings, and that previously fertile boars almost never became infertile in later matings. The major problem in fertility and prolificacy of swine appears to be variation in female rather than male reproductive behavior. Results obtained by Tanabe and Casida (1949) and by Laing (1949) indicate that this was true in cattle. Cases of infertility in the boar do occur, but such boars make up a very small percentage, 8 per cent of the entire population in this work.

General

There were definite differences among the inbred lines and their crosses in sexual development and behavior. However, late sexual maturity and lack of libido were the only boar characters which approached a level low enough to affect reproduction of any line. Inbred boars were inferior to non-inbred boars in these respects, but some strains were definitely superior to others independent of their levels of inbreeding.

SUMMARY AND CONCLUSIONS

1. During three seasons a total of 174 boars from four strains and their crosses were used to determine normal age-changes in the gross and histological development of the testis and the influence of inbreeding and strain of breeding on testicular development.

a. Unilatered castrations of 86 boars at 10-day intervals from 125 to 175 days of age indicated that the second testis developed at a sharply accelerated rate when the interval between castrations was 20 days or longer and when the boars were 165 days old or older at the second castration, although gain in body weight was reduced slightly by the first castration. This hypertrophy was limited to extension of tubules, since none occurred in diameter of tubules or in intertubular space.

b. Between 125 and 175 days of age, the testis proper increased in weight by 4 to 5 times, the epididymis by 2.3 times and body weight by only 1.6 to 1.7 times, diameter of seminiferous tubules by 1.5 to 1.6 times, diameter of epididymal tubules by 1.3 times; but distance between seminiferous tubules increased only slightly and shape of the testis remained unchanged. Extension of tubules accounted for a major part of the growth in testes. Size of testis was more closely associated with body weight ($r = .82$) than with age ($r = .74$); although much of the variation in weight due to age ($r = .72$). Within age and breeding groups, the weight of the epididymis was closely correlated with weight of testis proper ($r = .71$ and .81 among inbreds and crosses, respectively), but had little association with diameter of seminiferous tubules or with distance between tubules.

c. Among 36 inbred boars in one season, primary spermatocytes appeared at a mean age of 135 days, secondary spermatocytes and spermatids at 155 days and spermatozoa at about 180 days; among 35 crossline boars in another season secondary spermatocytes and spermatids appeared 5 days earlier. Sperm were found in both the testis and the epididymis of one boar at 125 days, but sperm were found in the epididymis in only one-half of the crossline boars and in less than one-half of the inbred boars at 165 to 175 days of age.

d. On the average, the 45 crosses exceeded the 41 boars of the parent lines by 28 per cent in body weight, 30 per cent in testis weight, 27 per cent in weight of epididymis and 20 per cent in stage of spermatogenesis. The larger testes from crosses had 18 per cent greater distance between tubules but only 5 per cent greater diameter of tubules, indicating that extension of tubules accounted for much of the difference. Part of the superiority of crosses may have been due to seasonal factors. Heterosis in testicular development appears closely associated with heterosis in general growth, since crosses were definitely intermediate to parent lines in the curvilinear regression of testes weight on body weight.

e. Bilateral castration of 88 boars at a mean age of 100 days, and the unilateral castrations of 86 boars from 125 to 175 days of age indicated distinct line differences in rate and nature of testicular development in relation to body weight that were unrelated to level of inbreeding and were transmitted to crosses of the lines.

2. A total of 216 collections of semen were obtained from 23 inbred and from 26 non-inbred and crossline boars at 5 to 8 months of age during four seasons. Also, 52 collections were taken from 7 inbred and 5 non-inbred yearling boars. It was found that:

a. Yearling boars exhibited greater libido and produced about twice as large a volume of semen per collection as boars 7 to 8 months of age (150-225 ml. *vs.* 50-125 ml.), with nearly twice the concentration of spermatozoa (200,000 to 600,000/mm^3 *vs.* 100,000 to 300,000/mm^3) and with approximately 50 per cent higher scores for motility of spermatozoa. The rapid rise in concentration and motility between 7 and 9 months of age accounted for much of the advantage for yearling boars.

b. Age at first successful collection of semen ranged from 143 to 253 days. However, the first attempted collection was successful for 13 of 21 non-inbred boars at an average age of 166 days and the mean age when collections could have been obtained was less than 174 days for the non-inbred boars. Among inbred boars, age at first successful collection averaged 211 or more for 7 line II Poland boars, 214 or more for 8 line VI Poland boars, but considerably less than 209 days for 7 line V Hampshire boars.

c. The proportion of boars whose collections contained spermatozoa increased steadily from 25 per cent (1 in 4) at 158 days of age to practically 100 per cent at 190 days of age or later. The sharp rise in concentration of sperm usually occurred 2 to 3 weeks after first successful collection from a boar, and 1 to 2 weeks after sperm were first found in the semen. The line and inbreeding differences in age at sexual maturity and in sperm production corresponded closely with those found in testicular development.

3. Fertitility was determined in 254 matings during three seasons, either by recovery of ova 24 hours after end of estrus, by return to estrus, or by recovery of embryos at 25 days after mating, for 14 inbred and 26 non-inbred or crossline boars that were 5 to 8 months old and for 6 inbred and 6 crossline yearling boars.

a. No fertility was obtained in 14 matings adjacent to collections in which none or only one or two thousand spermatozoa per mm^3 were found. The mean concentration of spermatozoa in collections nearest the age of first fertile mating was 86,500 per mm^3, but two boars were fertile at concentrations of only 5 and 9 thousands per mm^3, and 10 to 20 thousand was usually sufficient for initial fertility. In matings subsequent to the first fertile mating, infertility 24 hours after mating was very rare (2 of 34 boars) and no association could be demonstrated between fertility and semen characters other than aspermia. Frequent service reduced concentration and volume of semen per collection but boars refused to mate before fertility was impaired.

b. Among 49 fertile females slaughtered 24 hours post-estrus, 9.5 or 81 per cent of the 11.8 corpora counted per sow were represented by ova recovered. Of these 8.9 or 94 per cent showed normal cleavage, indicating fertilization.

c. The 131 females that were pregnant when slaughtered 25 days after mating averaged 12.5 corpora and 9.2 embryos, of which 1.0 was abnormal or partly resorbed. This indicates about 6 per cent of unfertilized ova, 21 per cent very early complete disapppearance of fertile ova and 8 per cent partially resorbed ova, leaving 66 per cent of normal embryos at 25 days.

d. Only 3 of 40 young boars were regularly infertile; two had normal semen but one was very low in concentration of sperm.

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