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CONTENTS

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INTRODUCTION

HISTORY has often provided modern man with the conception of a new idea. The pitfalls of past generations as well as the achievements made in bygone years have aided scientist and statesman to plan the future in more profitable terms. Since Robert Bakewell, eminent English animal husbandman of the eighteenth century, set out those famous maxims of "like begets like" and "breed the best to the best," students of animal breeding have examined the genealogy of their herds and flocks, the herds and flocks of other great breeders, and the breeds of livestock subsequently developed, to discover the breeding methods used in evolving the domestic animals of pen and pasture.

In general, these breeding methods have been described in terms of the inbreeding and relationship used, the manner and effectiveness of the selection practiced, the length of generation used, and the importance of particular animals, such as the foundation animals, in the development of these herds and flocks. The earliest students were handicapped by a lack of some measuring stick by which these factors could be estimated. Sir Francis Galton made some of the first concrete advances in solving this problem with his attempts to measure the degrees of resemblance between different kinds of relatives. Other methods were forthcoming.

REVIEW OF LITERATURE

In 1917, Pearl *(20* and *21)* suggested that a separate coefficient of relationship and of inbreeding be used for each generation. He later proposed a total inbreeding coefficient based on a ratio

[1] The data on which this study is based were gathered in a project being conducted by the University of Minnesota in cooperation with the Regional Swine Breeding Laboratory, Ames, Iowa, Bureau of Animal Industry, U.S.D.A. This publication has been condensed from a thesis submitted by the senior author to the Graduate Faculty of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

of the sum of these individual coefficients compared with a summation of the maximum inbreeding which could be found in the higher orders of animals; namely, brother-sister matings, etc.

These coefficients were soon superseded by coefficients evolved by Wright *(32* and *33)* which avoided Pearl's failure to take into account the different systems of mating which might be used. The coefficient of inbreeding, as developed by Wright, measured the amount of departure from the homozygosis present under random matings toward complete homozygosity. Similarly, his coefficient of relationship measured the percentage of genes which were probably identical in the two related individuals because of their descent from some common ancestor.

Since Wright's formulae were first published, most genetic histories have been based on their use. Wright *(33)* himself conducted a study of the Duchess family of Shorthorns as bred by Thomas Bates. This family of cattle, which originated in about 1790, was found to be about 40 per cent less heterozygous than the foundation Shorthorns. Bates consistently maintained this level for eight generations, (40 years), by using bulls which bore a relationship of approximately 60 per cent to the matrons of the herd.

McPhee and Wright *(17)* found that the average percentage of inbreeding in the British Shorthorns had increased from 0 per cent in 1790 to 27.4 per cent in 1875, falling to 26 per cent by 1920. This 1920 figure was not appreciably different from that of 28 per cent inbreeding discovered by the same authors *(18)* in the British Dairy Shorthorns of 1920. A select group of high producers fell into the same category. These studies also revealed that the bull, Favourite, had influenced the Dairy Shorthorns no more than he had influenced the British Shorthorns as a whole. The same was true of Champion, noted Cruickshanks-bred bull of England.

Brockelbank and Winters *(2)* found that inbreeding had not been used to any extent in developing prize winners among the Shorthorns at the International Livestock Exposition from 1925 to 1928. Similar findings had been made by Winters in a study of the Hereford breed. There was a tendency, however, for show-ring winners to sire show-ring winners in both Shorthorns and Herefords. Fourteen per cent more Shorthorns and 95 per cent more Hereford show-ring winners could be found in the first ancestral generation of show-ring winners than could be found in random samples of the breeds.

In a study conducted by Willham *(29)*, the American Hereford of 1930 was found to be 8.1 per cent less heterozygous than the normal cattle population. This study disclosed a tendency towards family formation, as the inter se relationship was only 8.8 per cent. This would give a coefficient of inbreeding of 4.6 per cent, if purely random breeding had prevailed. This family formation was borne out as early as 1923 (Malin *16*) by the fairly high relationship (direct) of the bull, Anxiety 4th, and his first and second generation descendants to the breed.

A slight tendency towards family formation has also been observed in the Aberdeen Angus breed of 1939. Stonaker *(27)* found that since 1850, the inbreeding in this breed in America had increased at the rate of .3 per cent per generation of 5.4 years, reaching a peak of 16.1 per cent in 1930 and falling to 13.3 per cent in 1939. Some sires had influenced the breed more than others. Some of these animals were Hanton (80) and Black Prince of Tillyfour, which bore a relationship to the breed of 21.3 per cent and 24.1 per cent, respectively. Earl Marshall and Blackcap Revolution were more recent sires of less importance.

ANCESTRY OF THE POLAND CHINA BREED OF SWINE

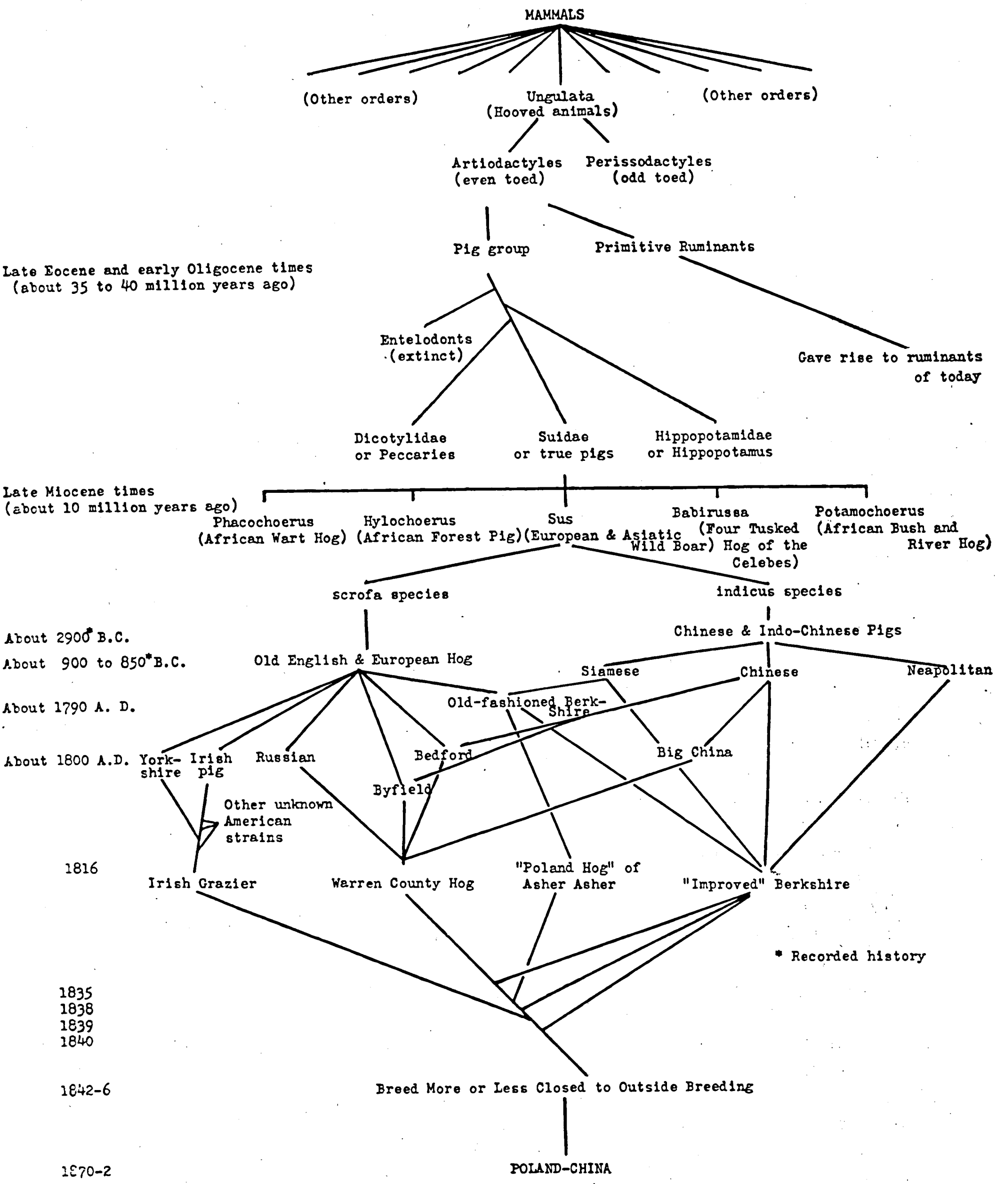

Fig. 1. Ancestry of the Poland China breed of swine

The dairy breeds of cattle have been developed with an almost complete lack of inbreeding. Fowler *(9)* was unable to support the contention that inbreeding, even to a very limited degree, was detrimental to high milk production in the Ayrshires. The rise of 5.3 per cent in homozygosity by 1927, relative to a base period of 1877, embraced the whole Ayrshire population on the average. The same could be said of the Brown Swiss Cattle of the United States studied by Yoder and Lush *(36)*. The sample of 1929 had a very low inbreeding coefficient. Show-ring winners did appear to be a slightly homogeneous lot genetically, as they had an inter se relationship of 7.4 per cent, compared with that of 4.3 per cent for random samples of the breed.

Holstein-Friesian breeding in America from 1881 to 1928 through 1931 has been marked by a 4 per cent decrease in heterozygosity (Lush, *et al. 12)*. A faint tendency toward family formation was observed, but on the whole, the popularity of certain blood lines has led to their almost immediate dispersion through the breed. De Kol 2nd has had the greatest influence on the breed, furnishing 10 per cent of the genes of the breed in 1931. Special samples of show-ring winners and "1,000 pounds plus" producers were found to resemble the random samples of the breed in almost every respect. Asdell *(1)* came to similar conclusions in studying the Guernsey breed in England. He stated that no particular system seemed especially noteworthy in the production of superior animals.

In describing the success of a certain animal, a horseman frequently denotes that his animal traces to so and so on both his sire's and dam's sides, etc. Smith *(24)* writes that the 1.9 per cent inbreeding found in the United Kingdom Clydesdales of 1885 and the 6.5 per cent in 1920 through 1925 suggest that close matings have been avoided. This is probably because a large number of defects, which were present in the foundation animals, are less harmful if kept in a heterozygous condition. However, some individual coefficients as high as 20 and 25.2 per cent were found.

According to Steele *(25)* Thoroughbred breeders have, as a whole, avoided inbreeding in the development of the breed. This is also true for subclasses within the breed, such as the leading "money winners" and those finishing last in popular American race meets. In spite of this, Eclipse, Herod, and Matchem had been outstanding sires of the breed and had contributed some 33 to 36 per cent of the genes present in the breed at that time. The same author, in comparing the breeding methods used in the top group (2:05 and better performers) of American Standardbreds with the American Saddle Horse, found that the inbreeding coefficient of the American Standardbred was only 4 per cent, and that of the American Saddle Horse only 3.2 per cent. Only in the American Saddle Horse has there been a tendency to form families.

The long length of generation must be considered an obstacle in a horse breeding program. Even so, Fletcher *(7)* reports that in samples of the American Quarter Horse taken from "before 1930" to 1941, the small amount of inbreeding (about 2 per cent) is above the expected and indicates some attention to a breeding program. One of the families of this breed is discussed by Rhoad and Kleberg *(22)*. Based on the extensive use of a stallion, Old Sorrel, and Standardbred and Thoroughbred mares, a band of Quarter Horses was established on the King Ranch. Thirty-five of the 86 pedigrees trace directly to Old Sorrel, while the band as a whole shows a relationship to him of 40.29 per cent. In spite of "line" breeding to Old Sorrel and his descendants, the inbreeding was 4.89 per cent, according to Fletcher *(7)*.

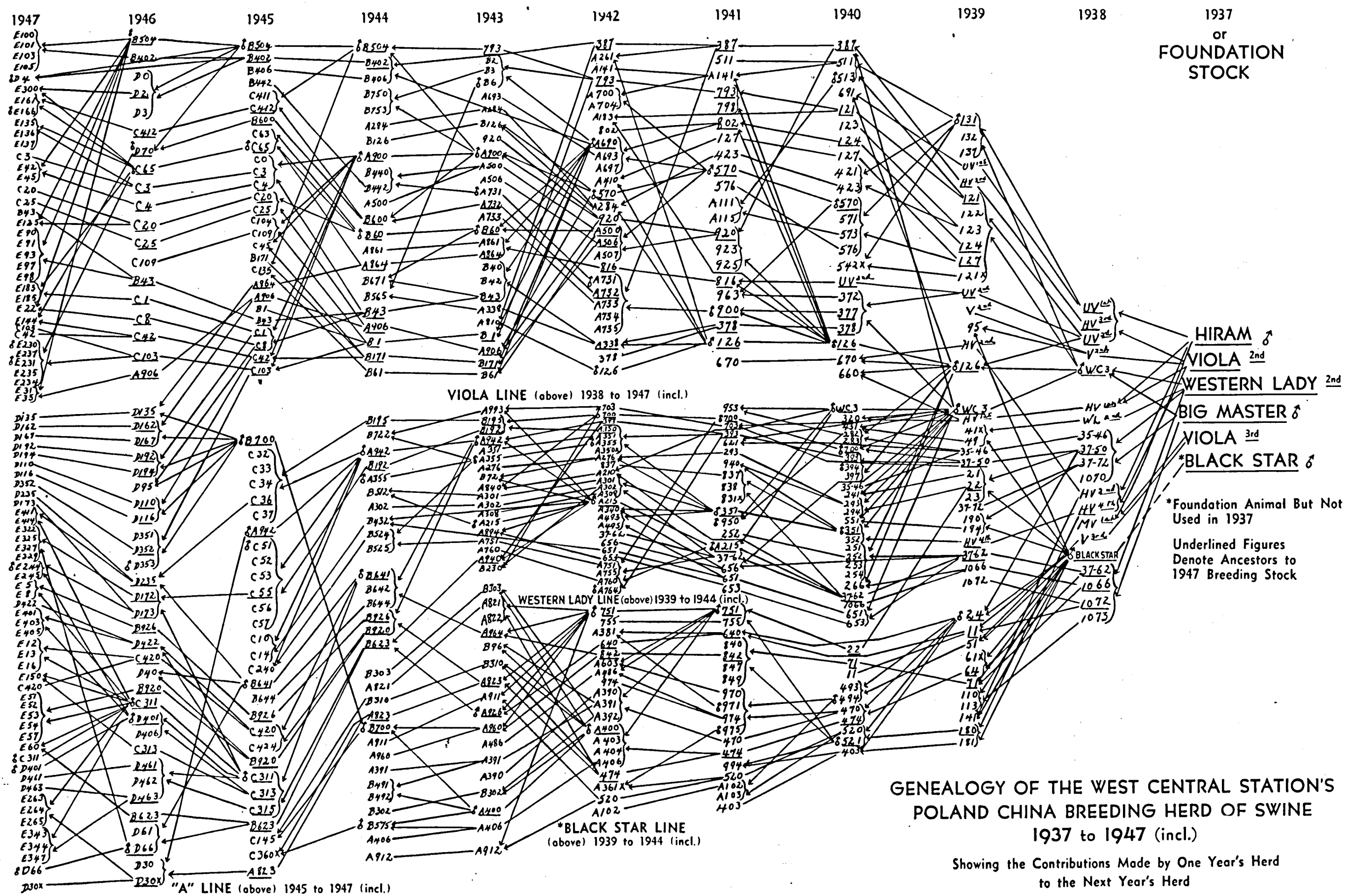

Fig. 2. Genealogy of the West Central Station's Poland China breeding herd of swine

The stress placed on outside "blood" (open stud book) has probably held the inbreeding low, even though it is higher than the average of the breed. Fletcher *(8)* mentions that the Tennessee Walking Horse also uses an open stud book and has continually added new material from the Standardbred and American Saddle Horse breeds. It is, however, a more closely knit group. The inbreeding in this breed rose from 1.24 per cent in 1900 to 3.6 per cent in 1940, quite a bit above that expected. This was accomplished in several generations of about 10.2 years per generation.

In the Rambouillet breed of sheep of the United States, family formation was found to be present. Dickinson and Lush *(6)* estimated the inbreeding coefficient in 1926 to be 5.5 per cent. This, if it is not deliberate, could have been due to geography. No particular ewe or ram seems to have influenced the breed excessively. Inbreeding was only slightly evident in the Hampshire breed of sheep, as studied by Carter *(3)*. From 1925 to 1935, about .7 to .9 per cent of the heterozygosis was lost per generation of 3.5 to 3.8 years, to reach an average inbreeding coefficient of 2.9 per cent in 1935.

The genealogy of the Poland China breed of swine offers an example of the evolution of our modern hog. The descent of this animal from the most primitive forms is shown graphically in figure 1. Samples from this breed between 1900 and 1929 examined by Lush and Anderson *(15)* gave a gradual increase in inbreeding from 2 to 9.8 per cent with respect to the foundation animals of 1886. These figures are not out of line with those expected. Some three animals had been important to the breed. Each of these contributed a little more than 12 per cent of the genes of the breed. The three were related. Danish Landrace breeders, according to Rottensten *(23)*, seemed to avoid inbreeding in developing their breed of swine prior to 1930, although a coefficient of 6.9 per cent was held by the breed in 1930. One family showed a relationship to the breed of 12 per cent, but no one individual seems to have had an overly large influence.

Although inbreeding was used effectively by the early founders of most of the breeds, it appears that most of the improvement made since that time, if there has been any, has been made largely through selection. In the past two decades many experimental projects have been instituted on the inbreeding of farm livestock.

Objects

The object of this study—a genealogy of the West Central Experiment Station's herd of Poland China swine—was to study the breeding methods employed in developing the inbred lines at that station and to express the results in terms familiar to the animal breeder.

METHODS OF STUDY

The swine herd at the West Central Experiment Station was established on three bred registered sows of the Poland China breed—Western Lady 2nd, bred to the boar, Big Master; and two daughters of Big Master, Viola 2nd and Viola 3rd, both bred to the boar, Hiram—and on the boar, Black Star, used on two of the inbred lines in the matings of 1937 through 1938. This adds up to six foundation animals.

The breeding methods were analyzed as to the manner in which inbred lines were formed; the amount of inbreeding used and its effects on the herd; the basis and effects of selection; the obvious changes in body form; and the importance of the foundation animals and various other individuals to the herd.

Inbreeding

Inbreeding is commonly defined as the mating of individuals more closely related than the average of the breed. In theory, it is a measure of the decrease in heterozygosity or heterogeneity. An individual having a coefficient of inbreeding of 20 per cent would be said to be 20 per cent less heterozygous than the average outbred population. Inbreeding in this study was calculated after the method described by Wright *(32, 33,* and *34)*. Three inbred lines were formed—one based on the sow, Viola 2nd, another on the sow, Western Lady 2nd, and a third on the boar, Black Star. The last two lines were converged, beginning with cross matings in 1942 through 1943, and a new inbred line, known as the "A" line, was developed. The two parent lines were discontinued. Further outcrosses of the "A" line (the original crosses were made to the Black Star portion of the "A" line) were made to the Viola line to improve this former line in the fall of 1944. This outcross was still in the process of incorporation into the "A" line in 1947. The fall mating list of 1946 was considered the breeding herd of 1947 and used as an end point in this study.

No fixed system of inbreeding could be observed, but only the best of each year's crop was retained and bred. The varying pattern followed is well illustrated in figure 2.

The average inbreeding rose fairly rapidly in each line to a figure close to 30 per cent (figure 3 and table 1). By 1947, the level of inbreeding in the Viola line, as a whole, was 35.6 per cent, the 30 per cent level having been maintained for some four years previous to that time. This represents an average decrease in heterozygosity of 5.63 per generation. The corresponding levels of inbreeding reached in the Western Lady and Black Star lines at the time of their elimination were 25.2 per cent and 29.2 per cent, respectively.

Table 1. Percentage of Inbreeding in the Lines and Crosses

	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
VIOLA											
Males	......	......	5.7	18.3	20.4	20.3	28.8	30.1	34.4	35.5	34.8
Females	......	.6	5.2	14.9	23.4	24.9	28.5	30.3	33.3	32.7	35.7
Herd	......	.4	5.3	15.3	22.9	24.2	28.5	30.3	33.4	33.2	35.6
BLACK STAR — VIOLA F_1											
Males	......	......	......	......	......	......	......	......	......	9.1	......
Females	......	......	......	......	......	......	......	......	......	9.0	......
Herd	......	......	......	......	......	......	......	......	......	9.0	......
WESTERN LADY											
Males	......	......*	4.3	12.6	21.4	23.5	23.0	22.0	......	......	......
Females	......	.2*	.4	13.5	19.2	20.5	24.3	26.1	......	......	......
Herd	......	.2*	.8	13.3	19.7	21.0	24.1	25.2	......	......	......
"A" LINE											
Males	......	......	......	......	......	......	......	12.0†	25.2¶	30.4	32.7
Females	......	......	......	......	......	......	......	13.0†	28.6¶	27.2	29.4‡
Herd	......	......	......	......	......	......	......	12.8†	28.0¶	27.6	29.7§
BLACK STAR											
Males	......	......*	.8	16.2	24.0	22.0	23.7	37.7	......	......	......
Females	......	.2*	1.1	11.0	20.3	22.5	28.3	27.8	......	......	......
Herd	......	.2*	1.1	12.1	20.9	22.4	27.7	29.2	......	......	......

* The same animals form the 1938 foundation of these two lines.
† The F_1 of the Black Star-Western Lady cross.
‡ 34.1 per cent if Black Star x Viola F_1 is omitted.
§ 34.0 per cent if Black Star x Viola F_1 is omitted.
¶ Includes remnants of Black Star and Western Lady lines as well as Black Star x Western Lady F_2, which formed the parentage of 1945 "A" line litters.

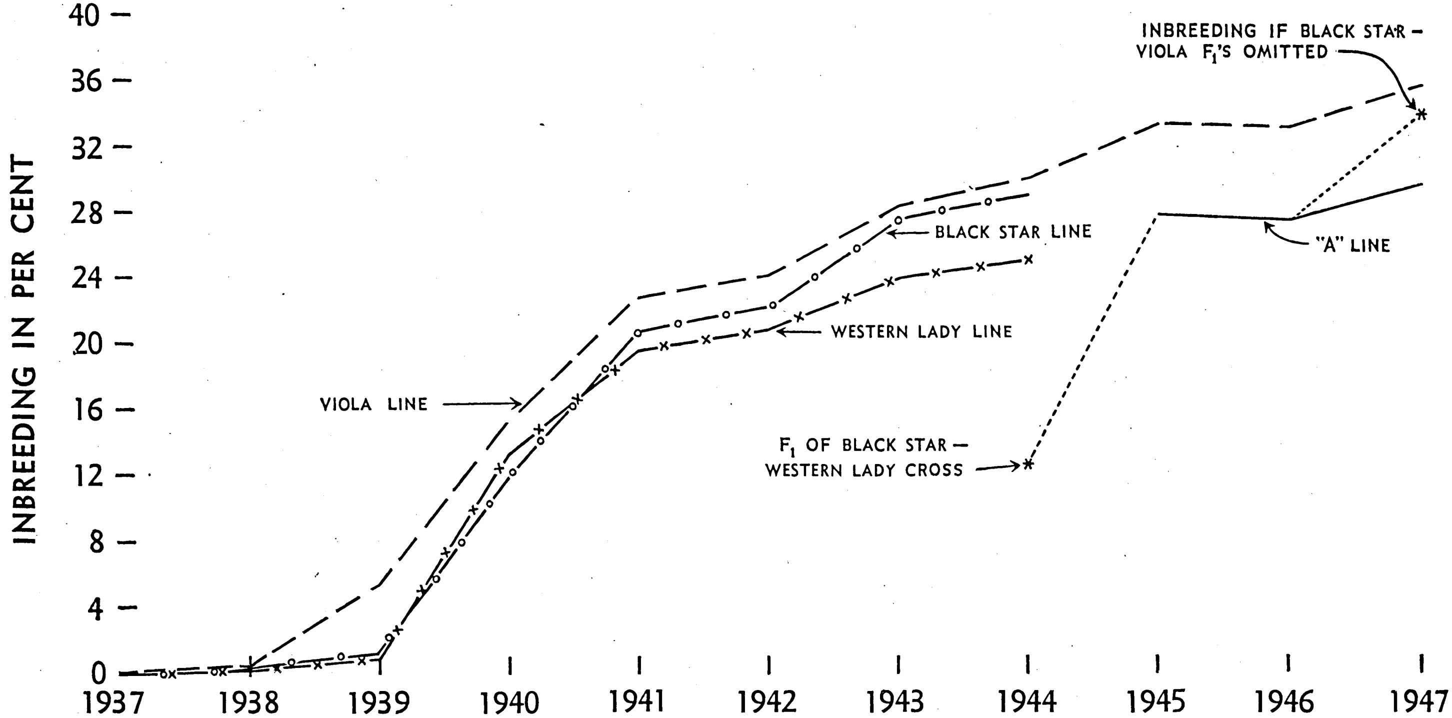

Fig. 3. Inbreeding of the herd by years

Although the cross of these two lines brought about a sudden and expected decrease in inbreeding, the level had risen again to 29.7 per cent in 1947. Neglecting the fact that the foundation began as two lines, and neglecting the rise and fall in inbreeding, this represents a decrease over the whole period of 4.18 per cent per generation.

Length of Generation

The average length of generation was calculated on the basis of the 1947 herd and the date when the foundation animals were first used. This would mean a count of ten years for all lines leading to Big Master, Western Lady 2nd, Hiram, and Viola 2nd, and nine years to the boar, Black Star. The average length of generation was 1.58 years for the Viola line and 1.38 years for the "A" line. These were based on 6.32 generations of breeding in the Viola line and 7.11 generations of breeding in the "A" line. (The "A" line included the Western Lady and Black Star lines from which it was formed).

Selection

Carefully kept records were available on the performance of the spring litters. These records provide information on five characteristics: fertility (number of pigs born per litter), survival (number of pigs weaned per litter), rate of gain or maturity, economy of gains (feed efficiency or feed costs), and live body score (an attempt to measure the utility value of the animal's body). Whole litters were placed in separate testing lots, providing enough pigs had survived to weaning age, and these were periodically weighed individually. In addition, a litter check was made on feed costs by measuring the grain (self-fed) required by each litter for a definite feeding period.

Replacements to the next year's breeding herd were chosen from these tested litters. Definite differentials were found to be in operation between the average of the group selected for breeding stock and the average of the tested pigs as a group (figures 4, 5, and 6). Smaller differentials were found between the "selected group" and the average of those members of this group which actually passed the genetic material down to the next generation and hence to the 1947 herd. This latter group could be termed the contributors.

Selection was rigorous. Tables 2, 3, 4, 5, and 6 show the number of litters farrowed per line each year, the number of pigs weaned, and the number and percentage of those tested and selected for breeding stock. These tables also give the percentages according to sex and, in addition, disclose the number and percentage of pigs of this tested group which finally contributed to the 1947 breeding herd.

A surplus of pigs over the capacity of the testing lots was farrowed each year. The fact that 85 per cent of the Viola line pigs weaned were tested as well as 78.5 per cent of those from the Western Lady line and 80.6 per cent from the Black Star line suggests that a fairly good percentage of litters survived the first two requirements (fertility and survival). A rigorous culling took place, however, before the next hurdle was completed. While it is true that the number selected for breeding stock might be limited because of small replacement demands, such does not seem to be the case in this instance. In many years suitable replacement stock was not available in the spring crop and recourse had to be made to the fall litters (table 7) for replacements.

Only 13.3 per cent of the pigs weaned in the Viola line, 10.1 per cent of those weaned in the Western Lady line, and 12.8 per cent of those surviving the

Table 2. Effects of Selection on the Numbers of Spring Pigs Farrowed Each Year — Viola Line

	1937*	1938	1939	1940	1941	1942	1943	1944	1945	1946	Total†	Av.†
Number, litters farrowed	3	3	16	17	18	19	17	20	17	16	143	15.9
Total pigs, weaned	23	24	94	124	136	123	110	126	94	109	940	104.4
Per cent, weaned pigs completing test	87.0	91.7	100.0	92.7	75.7	72.4	85.5	77.0	93.6	89.0	....	85.0
Per cent, weaned pigs selected for breeding stock	56.5	45.8	13.8	9.7	8.8	13.0	7.3	13.4	4.3	26.6	....	13.0
Per cent, weaned pigs which contributed	39.1	20.8	4.3	4.0	2.9	5.7	1.8	7.9	2.1	26.6	....	7.2
Number, females completing test	14	12	48	60	48	50	49	41	48	37	393	43.7
Number, males completing test	6	10	46	55	55	39	45	56	40	60	406	45.1
Number, females selected for breeding stock	12	9	11	11	11	13	7	16	3	26	107	11.9
Number, males selected for breeding stock	1	2	2	1	1	3	1	1	1	3	15	1.7
Per cent, tested females selected for breeding stock	85.7	75.0	22.9	18.3	22.9	26.0	14.3	39.0	6.3	70.3	....	27.2
Per cent, tested males selected for breeding stock	16.7	20.0	4.3	1.8	1.8	7.7	2.2	1.8	2.5	5.0	....	3.7
Number, females which contributed	8	3	3	4	3	5	1	9	1	2.6	55	6.1
Number, males which contributed	1	2	1	1	1	2	1	1	1	3	13	1.4
Per cent, tested females which contributed	57.1	25.0	6.2	6.7	6.2	10.0	2.0	22.0	2.1	70.3	....	14.0
Per cent, tested males which contributed	16.7	20.0	2.2	1.8	1.8	5.1	2.2	1.8	2.5	5.0	....	3.2
Per cent, breeding females which contributed	66.7	33.3	27.3	36.4	27.3	38.5	14.3	56.3	33.3	100.0	....	51.4
Per cent, breeding males which contributed	100.0	100.0	50.0	100.0	100.0	66.7	100.0	100.0	100.0	100.0	....	86.7
Per cent, all breeding stock which contributed	69.2	45.5	30.8	41.7	33.3	43.8	25.0	58.8	50.0	100.0	....	55.7

* All lines started from a common foundation in 1937.
† Based on 1939-43 average.

Table 3. Effects of Selection on the Numbers of Spring Pigs Farrowed Each Year Western Lady Line

	1937*	1938†	1939	1940	1941	1942	1943	Total‡	Average‡
Number, litters farrowed	3	14	13	19	14	18	12	76	15.2
Total pigs, weaned	23	91	85	116	109	105	59	474	9.5
Per cent, weaned pigs tested	87.0	89.0	98.8	68.1	83.5	64.8	84.7	......	78.5
Per cent, weaned pigs selected for breeding stock	56.5	19.8	21.2	5.2	10.1	8.6	6.8	......	10.1
Per cent, weaned pigs which contributed	39.1	6.6	2.4	......	0.9	3.8	......	......	1.5
Number, females tested	14	39	43	40	46	34	19	18.2	36.4
Number, males tested	6	42	41	39	45	34	31	19.0	38.0
Number, females selected for breeding stock	12	17	16	5	10	8	4	43	8.6
Number, males selected for breeding stock	1	1	2	1	1	1	......	5	1.0
Per cent, tested females selected for breeding stock	85.7	43.6	37.2	12.5	21.7	23.5	21.0	......	23.6
Per cent, tested males selected for breeding stock	16.7	2.4	4.9	2.6	2.2	2.9	......	......	2.6
Number, females which contributed	8	5	1	......	1	3	......	5	1.0
Number, males which contributed	1	1	1	......	......	1	......	2	0.4
Per cent, tested females which contributed	57.1	12.8	2.3	......	2.2	8.8	......	......	2.7
Per cent, tested males which contributed	16.7	2.4	2.4	......	......	2.9	......	......	1.1
Per cent, breeding females which contributed	66.7	29.4	6.2	......	10	37.5	......	......	11.6
Per cent, breeding males which contributed	100.0	100.0	50.0	......	......	100.0	......	......	40.0
Per cent, all breeding stock which contributed	69.2	33.3	11.1	......	9.1	44.4	......	......	14.6

* All lines started from a common foundation in 1937.
† The total group which the separate Black Star and Western Lady Lines emerged in 1939.
‡ Five year average (1939-43 inclusive).

first 8 weeks of life in the Black Star line were eventually chosen as breeding stock. Few animals seemed to possess a genotype that would enable them to survive as ancestry to the herd of 1947. Slightly less than half of those added each year to the breeding herd possessed this requirement.

Discussion

The level of homozygosity obtained through inbreeding in the lines described above, though lower than the 40 per cent inbreeding found in the Duchess, is much higher than that recorded for other families and breeds. It is considerably above that of 9.8 per cent reported for the Poland China breed as a whole by Lush and Anderson *(15)*.

Of more importance is the fact that these levels of inbreeding have been achieved and maintained without appreciable deterioration in any characteristic. In fact, some of the characteristics have shown improvement. This is most likely due to the system of inbreeding and the type of selection practiced. No fixed pattern of inbreeding (see figure 2) has been followed, except that the best performers (figures 4, 5, and 6) have been used. It has been truly a case of breeding "the best to the best", using inbreeding to promote segregation and selection based on performance to sift the

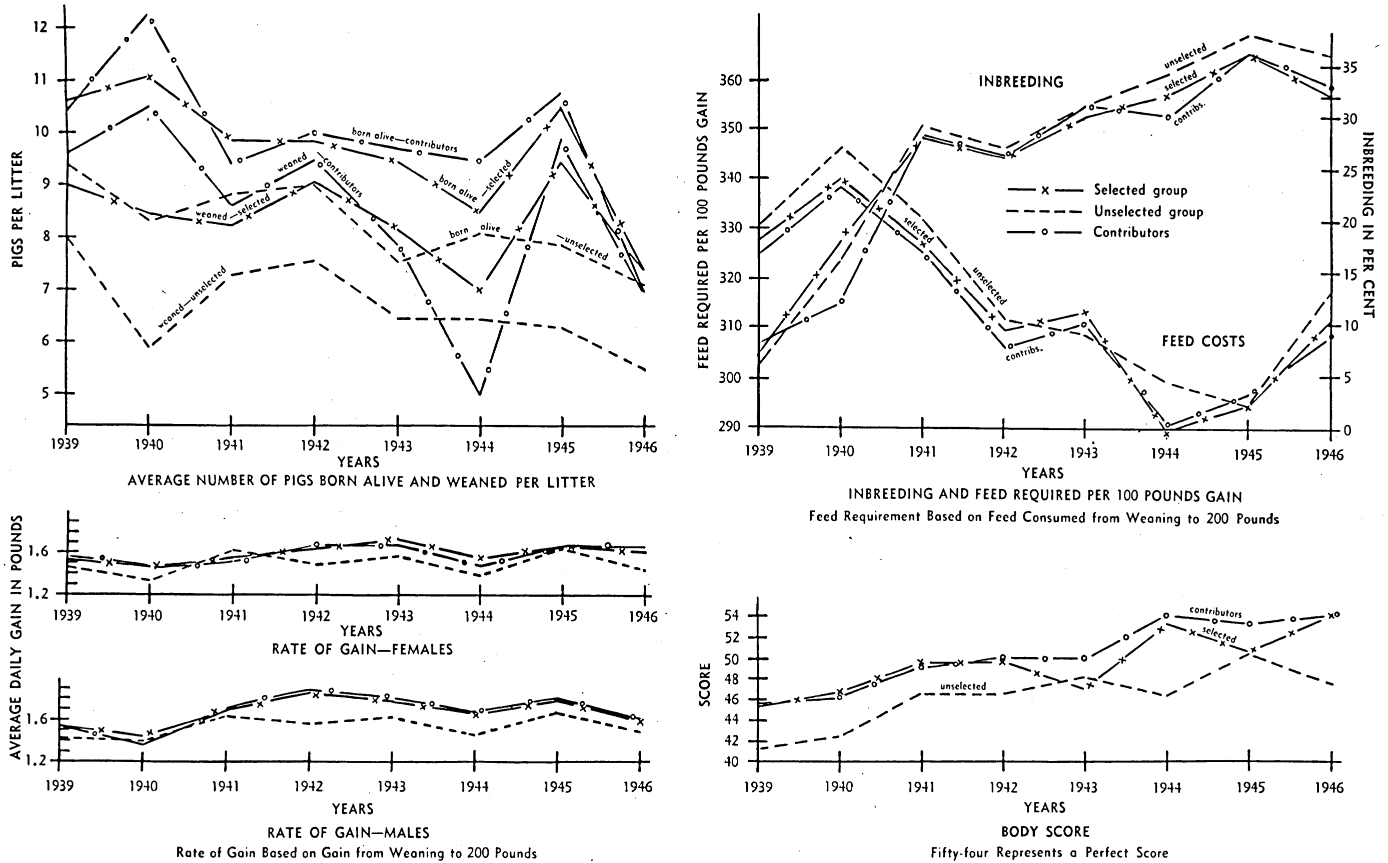

Fig. 4. Graphs illustrating the various factors of performance of the Viola line, by groups as to unselected, selected for the breeding herd, and contributors to the breeding herd

Table 4. Effects of Selection on the Numbers of Spring Pigs Farrowed Each Year Black Star Line

	1937*	1938†	1939	1940	1941	1942	1943	Total‡	Average‡
Number, litters farrowed	3	14	10	8	15	17	7	57	11.4
Total pigs, weaned	23	91	44	55	111	117	40	367	73.4
Per cent, weaned pigs tested	87.0	89.0	100.0	94.5	73.9	71.8	85.0	....	80.6
Per cent, weaned pigs selected for breeding stock	56.5	19.8	15.9	23.6	9.9	10.2	10.0	....	12.8
Per cent, weaned pigs which contributed	39.1	6.6	4.5	3.6	0.9	3.4	2.5	....	2.7
Number, females tested	14	39	20	22	44	50	19	155	31.0
Number, males tested	6	42	24	30	38	34	15	141	28.2
Number, females selected for breeding stock	12	17	5	10	10	11	2	38	7.6
Number, males selected for breeding stock	1	1	2	3	1	1	2	9	1.8
Per cent, tested females selected for breeding stock	85.7	43.6	25.0	45.4	22.7	22.0	10.5	....	24.5
Per cent, tested males selected for breeding stock	16.7	2.4	8.3	10.0	2.7	2.9	13.3	....	6.4
Number, females which contributed	8	5	1	1	....	3	....	5	1
Number, males which contributed	1	1	1	1	1	1	1	5	1
Per cent, tested females which contributed	57.1	12.8	5.0	4.5	....	6.0	....	....	3.2
Per cent, tested males which contributed	16.7	2.4	4.2	3.3	2.7	2.9	6.7	....	3.5
Per cent, breeding females which contributed	66.7	29.4	20.0	10.0	....	27.3	....	....	13.2
Per cent, breeding males which contributed	100.0	100.0	50.0	33.3	100.0	100.0	50.0	....	55.6
Per cent, all breeding stock which contributed	69.2	33.3	28.6	15.4	9.1	33.3	25.0	....	21.3

* All lines started from a common foundation in 1937.
† The total group from which the separate Black Star and Western Lady Lines emerged in 1939.
‡ Five Year Average (1939-43 inclusive).

Table 5. Effects of Selection on the Numbers of Spring Pigs Farrowed Each Year Black Star — Viola Cross

	1945*	1946†	Total	Average
Number, litters farrowed	8	10	18	9
Total pigs, weaned	54	68	122	61
Per cent, weaned pigs tested	100.0	100	....	100.0
Per cent, weaned pigs selected for breeding stock	20.4	....	....	9.0
Per cent, weaned pigs which contributed	14.8	....	....	7.4
Number, females tested	26	27	53	26.5
Number, males tested	28	41	69	34.5
Number, females selected for breeding stock	10	....	10	5.0
Number, males selected for breeding stock	1	....	1	0.5
Per cent, tested females selected for breeding stock	38.5	....	....	18.9
Per cent, tested males selected for breeding stock	3.6	....	....	1.4
Number, females which contributed	8	....	8	4
Number, males which contributed	....	....	....	....
Per cent, tested females which contributed	38.8	....	....	15.1
Per cent, tested males which contributed	....	....	....	....
Per cent, breeding females which contributed	80.0	....	....	80.0
Per cent, breeding males which contributed	....	....	....	....
Per cent, all breeding stock which contributed	72.7	....	....	72.7

* F_1 litters.
† F_2 litters.

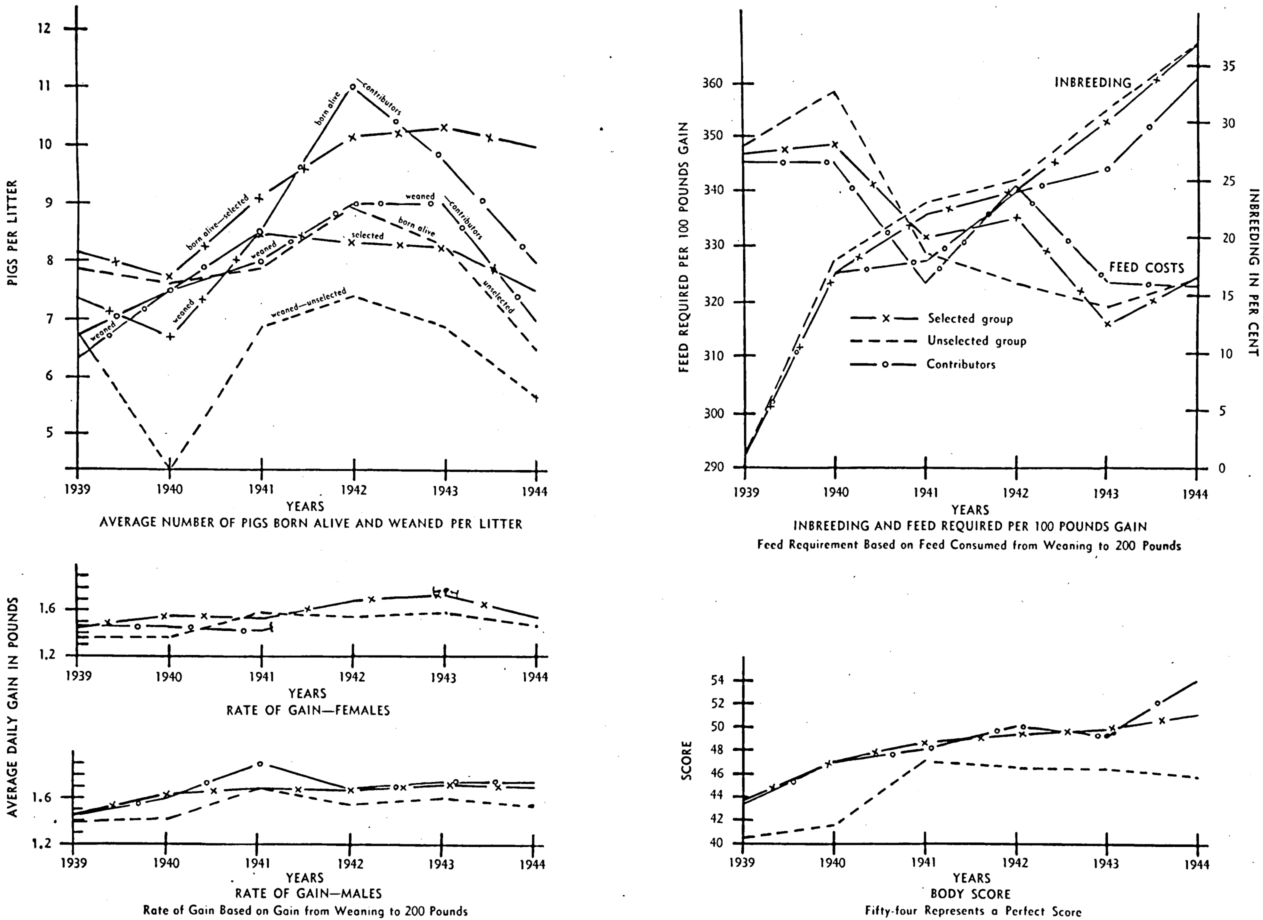

Fig. 5. Graphs illustrating the various factors of performance of the Black Star line, by groups as to unselected, selected, and contributors to the breeding herd

Table 6. Effects of Selection on the Numbers of Spring Pigs Farrowed Each Year "A" Line

	1943*	1944†	1945	1946	Total	Average
Number, litters farrowed	7	21	24	17	69	17.2
Total pigs, weaned	50	142	145	104	441	110.2
Per cent, weaned pigs tested	96.0	88.7	93.8	84.6	....	90.2
Per cent, weaned pigs selected for breeding stock	12.0	14.8	9.7	27.9	....	15.9
Per cent, weaned pigs which contributed	8.0	4.2	6.2	27.9	....	10.9
Number, females tested	24	58	61	46	189	47.2
Number, males tested	24	68	75	42	209	52.2
Number, females selected for breeding stock	5	19	12	28	64	16.0
Number, males selected for breeding stock	1	2	2	1	6	1.5
Per cent, tested females selected for breeding stock	20.8	32.8	19.7	60.9	....	33.9
Per cent, tested males selected for breeding stock	4.2	2.9	2.7	23.8	....	2.9
Number, females which contributed	3	5	7	28	43	10.8
Number, males which contributed	1	1	2	1	5	1.2
Per cent, tested females which contributed	12.5	8.6	11.5	60.9	....	22.8
Per cent, tested males which contributed	4.2	1.47	2.7	23.8	....	2.4
Per cent, breeding females which contributed	60.0	26.3	58.3	100.0	....	67.2
Per cent, breeding males which contributed	100.0	50.0	100.0	100.0	....	83.3
Per cent, all breeding stock which contributed	66.7	28.6	64.3	100.0	....	68.6

* The Black Star-Western Lady F_1 litters.

† Includes litters from the remnants of the Western Lady and Black Star lines.

Table 7. Summary of Selections from Fall Litters

		1939	1940	1941	1942	Total	Average
Viola	Number of litters	6	6	1	5	18	4.5
	Number weaned	37	41	6	28	112	28.0
	Number selected	3	1	5	2	11	3.8
	Number which contributed	......	......	1	1	2	0.5
Western Lady Line	Number of litters	6	5	5	4	20	5.0
	Number weaned	47	34	25	15	121	30.2
	Number selected	6	2	4	1	13	3.2
	Number which contributed	1	1	......	......	2	0.5
Black Star Line	Number of litters	1	......	2	1	4	1.0
	Number weaned	8	......	15	3	26	6.5
	Number selected	1	......	......	......	1	.2
	Number which contributed	1	......	......	......	1	.2

chaff from the good genes. To prevent retrogression this selection has had to be ruthless. Of the 2,458 spring pigs weaned, 84.9 per cent were tested but only 13.4 per cent were used for breeding stock. Only 6.3 per cent of those weaned have contributed to the breeding herd of 1947. It is of interest that selection here has been for characters denoting vigor, the item usually lost in inbreeding. It is also worthy of note that fertility and survival must be satisfactory in order to select that closely.

Not only has there been no serious retrogression observed in most characteristics of economic importance but there actually has been improvement in many over the period of time of the project. These trends can be observed

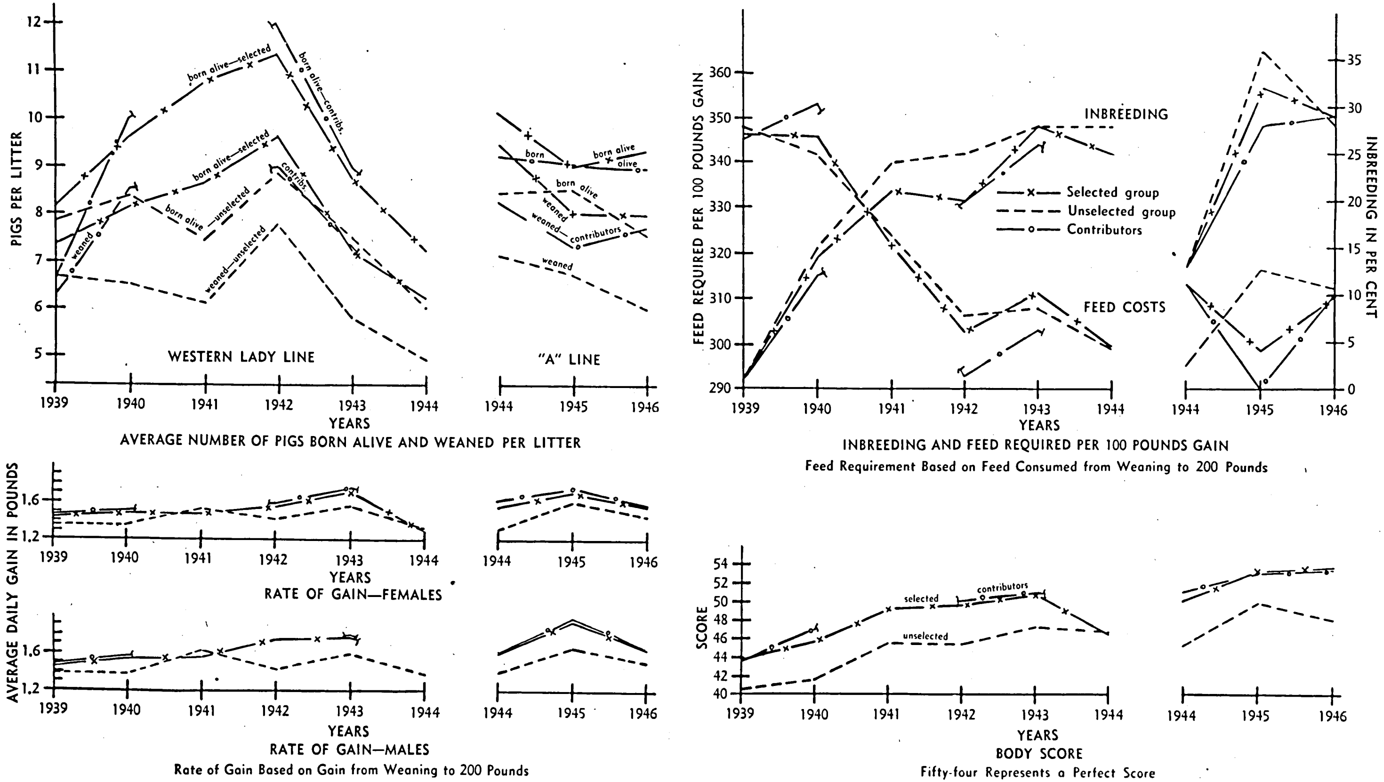

Fig. 6. Graphs illustrating the various factors of performance of the Western Lady and "A" lines, by groups as to unselected, selected, and contributors to the breeding herd. (Year refers to first year used in breeding herd. Animals were born in previous year.)

in figures 4, 5, and 6. It might be suggested that the degree of improvement is related to the heritability of the characteristic. Fertility has not, for example, been improved in any of the lines, and retrogression has actually been observed in two of the lines. The heritability of this figure has been estimated to be from 8.8 per cent to 17.6 per cent (Stewart *26*). At least two contradictions would appear to setting up such a theory as was previously mentioned. No decided improvement was obtained in rate of gain. Nordskog, *et al.* *(19)* estimated the heritability of this figure as 40 per cent. Feed efficiency was decidedly improved over the years and this has been estimated to be only about 8 per cent heritable (Lush *13*). There are several arguments which could be advanced as explanation of these contradictions. Most important among them would be that heritability estimates, which would be universally applicable, are difficult to compute because of the differing genetic constitutions, environmental conditions, etc.

The length of time needed to turn a generation has been shortened successfully below the breed average of 2.44 to 2.69 years, reported by Lush and Anderson *(15)*, and that of 2.2 per cent for the Danish Landrace (Rottensten *23)* has been shortened to an average of 1.44 years.

Changes in Body Form

According to observers, the only noticeable change in the body form which is suggested in the improvement in body score (a score based on utility of body form) was an improvement in uniformity (figures 4, 5, and 6). Each line, however, did possess distinguishing characteristics even though selection was made for the same utility characteristics in all lines. All lines came more or less from the same foundations.

IMPORTANT ANCESTORS

The importance of an ancestor can be measured in two ways. The first one is based on the number of his direct descendants of breeding ability, or, in short, on his posterity. This is called direct relationship, or "percentage blood." Percentage blood is an old term similar in name to the one by which old livestock breeders (and many modern ones) described their animals as being fifty per cent of the blood of such and such a grandsire or granddam. But these terms used by old stockmen were also used in describing the relationship of brother and sister as 100 per cent blood relationship. Direct relationship cannot describe, at least without reference to some common ancestor, the relationship between brother and sister. It is merely a halving of the gene number for each generation that the individual, or group, is removed from its ancestor.

On the other hand, total relationship, the second method of measuring an ancestor's importance, will give an estimate of both this direct relationship and relationship of the collateral nature, such as exists between brother and sister, or cousins. It measures the paths by which the duplicates of a gene may have come from some ancestor common to the animals between which a relationship is to be established. It is an estimate of the proportion of genes from this common descent which are the same. It differs from the old stockman's method in that full brother and sister are only 50 per cent related and not 100 per cent, as commonly thought. This is because of the matter of chance in Mendelian segregation. The total coefficient of relationship is computed in this study after the method of Wright *(32)*.

The lines were analyzed to determine which animals had contributed the most to each of the lines during the ten years studied. The importance of each of

Table 8. Relationship of Important Ancestors to the Viola Line

	1938		1939		1940		1941		1942		1943		1944		1945		1946		1947	
	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.
Hiram	37.5	38.5	28.1	29.2	28.1	29.2	26.4	27.5	26.2	27.4	25.7	26.9	25.6	26.8	25.6	26.7	25.2	26.4	25.6	26.7
Big Master	12.5	32.4	21.9	36.8	21.9	36.8	23.6	37.6	23.8	37.7	24.3	38.0	24.4	38.0	24.4	38.0	24.8	38.2	24.4	38.0
Viola 2nd	37.5	46.3	28.1	42.9	28.1	42.9	26.4	42.3	26.2	42.2	25.7	42.0	25.6	42.0	25.6	42.0	25.2	41.9	25.6	42.0
Western Lady 2nd	12.5	18.4	21.9	26.3	21.9	26.3	23.6	27.7	23.8	27.9	24.3	28.4	24.4	28.5	24.4	28.5	24.8	28.8	24.4	28.5
W. C. 3	......	......	43.8	53.4	43.8	53.4	47.2	56.3	48.8	56.5	50.0	57.4	49.4	57.6	49.6	57.6	50.0	58.3	49.0	57.7
University Viola 2nd	......	......	37.5	54.8	46.9	59.5	41.7	55.8	35.0	51.7	38.2	52.8	34.4	51.3	34.2	51.2	32.6	50.1	35.5	52.0
126	......	......	......	......	12.5	62.7	38.9	75.4	30.0	69.1	31.9	71.1	28.8	69.7	29.3	69.0	28.9	68.6	30.7	70.3
127	......	......	......	......	......	......	......	......	12.5	60.3	15.3	62.8	17.5	63.1	18.0	63.3	17.2	63.7	16.8	63.3
131	......	......	......	......	......	......	......	......	12.5	53.5	15.3	55.2	17.5	56.9	18.0	57.2	17.2	57.4	16.8	56.5
387	......	......	......	......	......	......	16.7	56.0	12.5	61.2	13.9	54.6	17.5	56.9	17.2	56.5	18.4	57.6	14.6	55.1
570	......	......	......	......	......	......	11.1	59.0	25.0	71.1	30.6	73.1	35.0	76.0	35.9	76.7	33.6	76.7	31.4	75.3
802	......	......	......	......	......	......	......	......	......	......	13.9	71.2	15.0	70.3	12.5	69.0	10.2	68.3	11.5	70.3
920	......	......	......	......	......	......	......	......	20.0	74.5	16.7	70.6	20.0	72.2	23.5	73.8	23.4	74.5	20.0	72.3
A690	......	......	......	......	......	......	......	......	......	......	27.8	82.4	30.0	84.2	25.0	82.0	23.5	81.1	26.4	82.5
A900	......	......	......	......	......	......	......	......	......	......	......	......	20.0	81.7	28.1	86.0	29.7	86.9	27.4	84.3
B43	......	......	......	......	......	......	......	......	......	......	......	......	10.0	76.5	18.8	81.4	18.8	80.8	16.7	81.0
B60	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12.5	84.0
B504	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	15.6	82.6	25.0	86.9
C65	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	18.1	86.1

the foundation animals to each year's contributor group and to the herd of 1947 was also studied line by line. As might be expected from the names attached to the lines, some lines leaned more heavily on the genes of certain animals than did others.

Viola Line

The most important ancestors to the Viola line are listed in table 8, together with their direct relationship to each year's "contributors" and to the line herd of 1947. The relationship

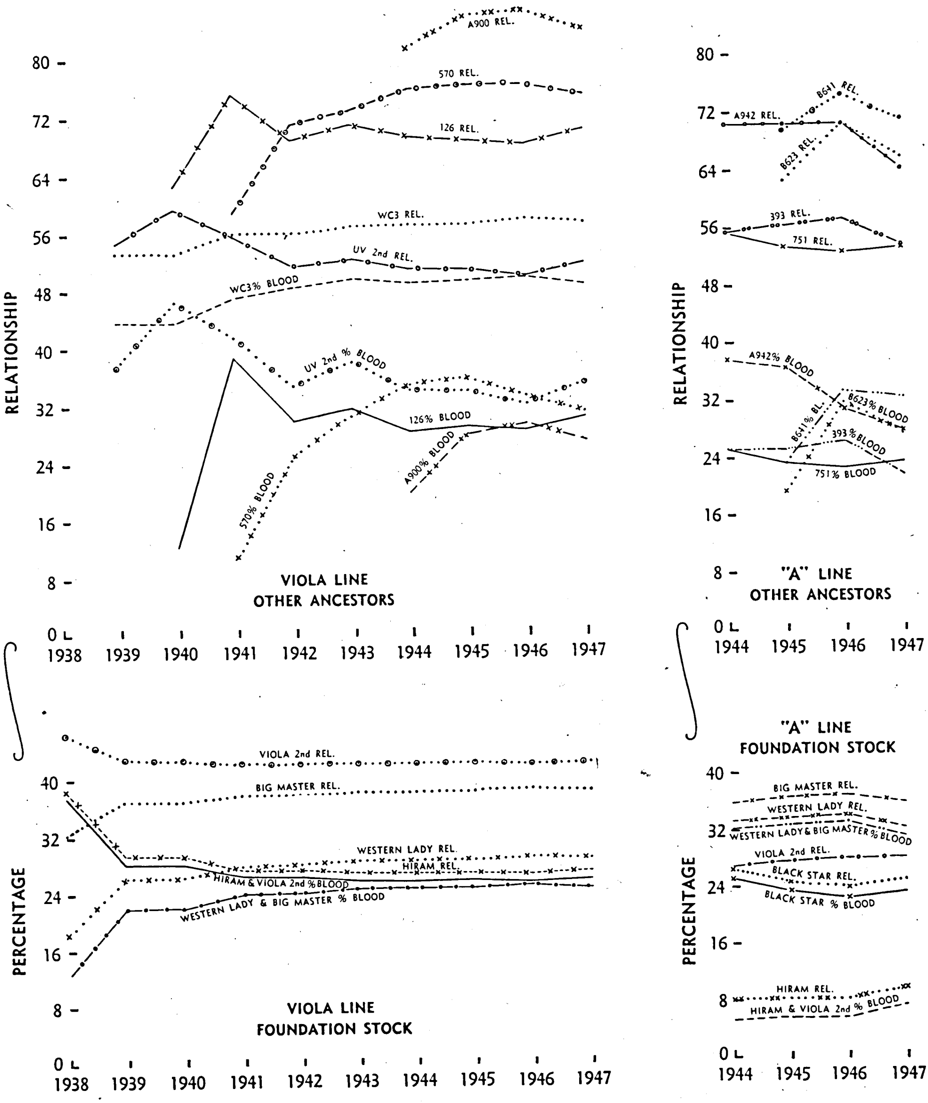

Fig. 7. Relationship of important ancestors to the Viola and "A" lines

of the foundation animals and a few outstanding individuals in the group are shown graphically in figure 7. The four members of the foundation pigs contributing (Black Star was never used as a sire in this line and the last descendants of Viola 3rd were culled from all lines in 1943) have been the approximate equivalents of grandparents to this line. The frequency of Big Master and Viola 2nd genes has been increased in the herd, as can be seen by the rising total relationship figures. This is no doubt due to the

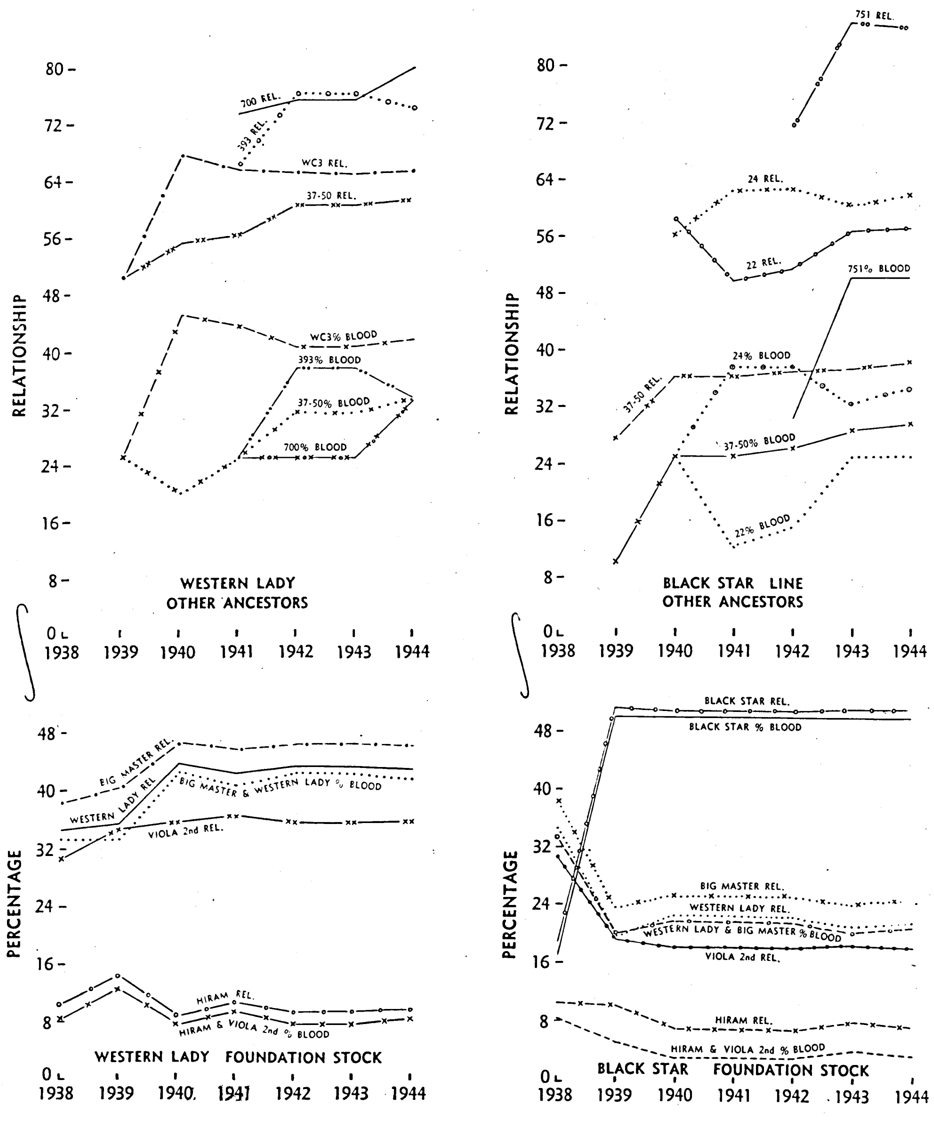

Fig. 8. Relationship of important ancestors to Black Star and Western Lady lines

Table 9. Relationship of Important Ancestors to the Western Lady Line

	1938		1939		1940		1941		1942		1943		1944	
	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.
Hiram	8.3	10.5	12.5	14.3	7.5	8.9	9.4	10.8	7.8	9.3	7.8	9.3	8.3	9.8
Big Master	33.3	38.3	33.3	40.2	42.5	46.5	40.6	45.6	42.2	46.3	42.2	46.3	41.7	46.1
Viola 2nd	8.3	30.6	12.5	34.7	7.5	35.5	9.4	36.2	7.8	35.6	7.8	35.6	8.3	35.8
Western Lady 2nd	33.3	34.6	33.3	35.3	42.5	43.7	40.6	42.1	42.2	43.4	42.2	43.4	41.7	43.0
W. C. 3	....	....	25.0	50.3	45.0	67.6	43.8	65.7	40.6	65.2	40.6	65.0	41.7	65.4
37-50	....	....	25.0	50.3	20.0	55.1	25.0	56.4	31.2	60.6	31.2	60.6	33.3	61.3
126	....	....	....	....	10.0	51.1	12.5	52.4	18.8	55.5	18.8	55.5	16.7	54.5
351	....	....	....	....	....	....	25.0	61.7	12.5	51.9	12.5	51.9	16.7	54.9
393	....	....	....	....	....	....	25.0	66.4	37.5	76.3	37.5	76.3	33.3	74.2
700	....	....	....	....	....	....	25.0	73.6	25.0	75.4	25.0	75.4	33.3	80.0
A215	....	....	....	....	....	....	....	....	25.0	70.7	25.0	70.7	16.7	65.4
A350	....	....	....	....	....	....	....	....	....	....	25.0	75.0	33.3	78.9
B192	....	....	....	....	....	....	....	....	....	....	....	....	33.3	92.4
B195	....	....	....	....	....	....	....	....	....	....	....	....	33.3	92.4

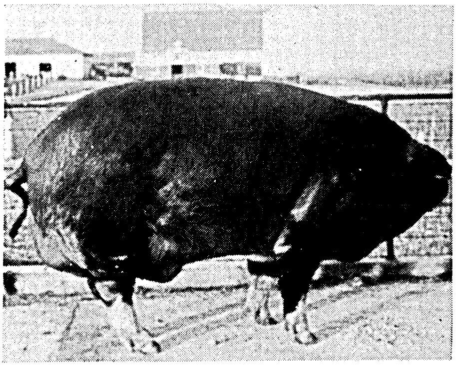

Fig. 9. The boar W. C. 3 as a two-year-old

influence of W.C. 3, a son of Big Master who has almost consistently been the equivalent of a parent to the line, and to the contributions of University Viola 2nd, a daughter of Viola 2nd who bears the highest direct relationship to the line of all the females used.

The heavy use of boar 126, a son of W.C. 3 and University Viola 2nd, and the use made of boar 570, a double grandson of W.C. 3, give further indication of the emphasis placed on the genes of Big Master and Viola 2nd. More recent animals figuring in the passage of the inheritance from the foundation sires to the herd of 1947 are boars A690, A900, and B504.

Western Lady Line

As its name implies, the Western Lady line was built primarily on the sow Western Lady 2nd. She held a direct relationship of over 40 per cent to the line (table 9 and figure 8), a contribution unequaled by any other female. The sire, Big Master, had an equal direct relationship and a higher total relationship to the herd, because of the use of offspring of Viola 2nd in this line (Viola 2nd was a daughter of Big Master). W.C. 3 has also made a greater contribution to this line than any other animal. Sow 37-50 was the only other female establishing a 25 per cent or higher direct relationship to the line.

Black Star Line

From the establishment of the Black Star family in 1939 until it was converged with the Western Lady line, no animal has influenced the line as greatly as has the sire whose name it carries. He has been virtually a sire to the group during this time. Boar 751 has held a similar figure of direct relationship but for a much shorter time. Over 30 per cent of the genes of the 1947 herd have been passed down through boar 24 (table 10 and figure 8).

"A" Line

As the "A" line is made from the convergence of the Black Star and Western Lady lines, it might be expected that the important animals of these two converging lines would share their importance in the new family. This is approximately true. Figure 7 and table 11 present the importance of the various ancestors to the line. More emphasis has been placed on the use of descendants of Big Master and Western

Fig. 10. The boar 126 as a yearling

Table 10. Relationship of Important Ancestors to the Black Star Line

	1938		1939		1940		1941		1942		1943		1944	
	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.
Hiram	8.3	10.5	5.0	10.1	3.1	7.0	3.1	7.0	3.1	7.0	4.4	8.2	3.9	7.8
Big Master	33.3	38.3	20.0	23.6	21.9	25.1	21.9	25.1	21.9	25.1	20.6	24.5	21.1	24.7
Black Star	16.7	18.4	50.0	51.1	50.0	50.9	50.0	50.9	50.0	50.9	50.0	51.0	50.0	51.0
Viola 2nd	8.3	30.6	5.0	19.4	3.1	18.3	3.1	18.3	3.1	18.3	4.4	18.8	3.9	18.6
Western Lady 2nd	33.3	34.6	20.0	19.7	21.9	22.4	21.9	22.4	21.9	22.4	20.6	21.3	21.1	21.7
37-50	....	....	10.0	27.5	25.0	36.2	25.0	36.2	26.2	36.9	28.8	37.3	29.7	38.1
22	....	....	....	....	25.0	58.6	12.5	49.8	15.0	51.4	25.0	56.6	25.0	57.0
24	....	....	....	....	25.0	56.1	37.5	62.3	37.5	62.4	32.5	60.4	34.4	61.7
64	....	....	....	....	12.5	45.1	12.5	45.1	15.0	46.7	10.0	43.2	18.8	48.8
180	....	....	....	....	12.5	39.6	12.5	39.6	12.5	39.6	17.5	43.1	15.6	41.8
474	....	....	....	....	....	....	25.0	66.1	30.0	69.5	20.0	61.7	37.5	74.1
521	....	....	....	....	....	....	25.0	63.3	25.0	63.4	35.0	69.0	31.2	67.2
751	....	....	....	....	....	....	....	....	30.0	71.2	50.0	85.8	50.0	85.1
842	....	....	....	....	....	....	....	....	20.0	60.3	20.0	65.3	12.5	59.8
A400	....	....	....	....	....	....	....	....	....	....	20.0	61.8	25.0	89.5
A823	....	....	....	....	....	....	....	....	....	....	....	....	50.0	99.5
A960	....	....	....	....	....	....	....	....	....	....	....	....	25.0	82.6

Table 11. Relationship of Important Ancestors to the "A" Line

	1944		1945		1946		1947*		1947†	
	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.	Per cent blood	Total rel.
Hiram	5.1	7.7	5.5	8.1	5.5	8.1	5.5	8.1	7.2	9.7
Big Master	32.4	35.9	32.9	36.6	33.3	36.9	32.9	36.6	31.1	35.7
Black Star	25.0	26.4	23.1	24.5	22.5	24.0	23.1	24.5	23.4	25.0
Viola 2nd	5.1	26.8	5.5	27.6	5.5	27.8	5.5	27.6	7.2	28.1
Western Lady 2nd	32.4	33.1	32.9	33.8	33.3	34.1	32.9	33.8	31.1	32.2
W. C. 3	18.8	43.9	20.7	45.5	20.9	45.9	20.4	45.4	21.1	44.5
37-50	24.2	48.3	25.5	49.2	24.0	49.2	23.0	48.8	21.5	47.4
37-62	15.6	42.4	14.2	42.3	14.5	42.5	13.8	42.1	11.9	39.9
24	17.2	45.9	15.4	44.5	15.0	44.0	14.9	44.1	15.0	43.2
126	12.5	38.4	12.5	39.5	13.1	40.1	13.0	39.7	13.2	40.3
393	25.0	55.3	25.0	56.3	26.2	57.2	26.0	56.7	21.5	53.7
521	15.6	44.0	15.4	43.0	15.0	42.5	16.4	43.4	16.8	43.5
751	25.0	55.3	23.1	53.4	22.5	52.7	23.1	53.5	23.4	53.4
A215	25.0	55.7	23.1	55.4	25.0	56.7	25.0	56.3	20.7	52.6
A926	12.5	53.8	9.6	50.7	15.8	53.7	16.3	54.5	13.7	52.5
A940	12.5	60.4	9.6	59.7	15.8	63.2	16.3	63.0	13.7	58.6
A942	37.5	70.3	36.5	70.3	30.8	70.5	33.5	69.7	27.8	64.1
A964	12.5	50.8	11.5	52.0	16.7	53.8	19.6	56.0	16.2	54.6
B623	....	....	19.2	62.5	31.7	70.5	33.0	71.2	27.4	65.9
B641	....	....	23.1	69.6	33.3	74.4	39.1	77.3	32.4	71.3
C311	....	....	....	....	26.7	84.1	43.6	93.4	36.2	84.5

* If Black Star-Viola F_1 excluded.
† If Black Star-Viola F_1 included.

Lady 2nd than on the boar, Black Star. Black Star shows consistently lower direct and total relationship (approximately 8 per cent) to the line than the other two. W.C. 3 has been of less importance as a contributor, but the frequency of his genes in the herd is higher than that of either of his parents. The same can be said of his sisters, sows 37-50 and 37-62.

Discussion

Frequent reference is made in breed journals to line breeding because a certain family is descended in one female or male line from an illustrious ancestor. In studying five-generation pedigrees of one of our well-known breeds of beef cattle, the authors have found many cases where so-called "line-bred" females (of a certain family) possessed no more than one ancestor of that family in the fifth or any one of the intervening generations. The breeder looking at such an animal and examining only one generation back would be sadly misled if he felt his beast was the culmination of generations of line breeding within this family. Less than 3 per cent of the genes of this animal were contributed by the family whose name it bears.

The lines developed at the West Central Station have, on the other hand, been definitely developed from the animals which bear their name and/or their descendants. Black Star, for example, contributed 50 per cent of the genes to the line which bore his name. The frequency of his genes in the herd, that is his total relationship to the breed, is only slightly higher. This is to be expected, as he was not related to Western Lady and only slightly related to Big Master and Viola 2nd—6.2 and 1.6 per cent respectively. Therefore, the frequency of his genes in his own family could not increase greatly beyond his actual contribution through his descendants.

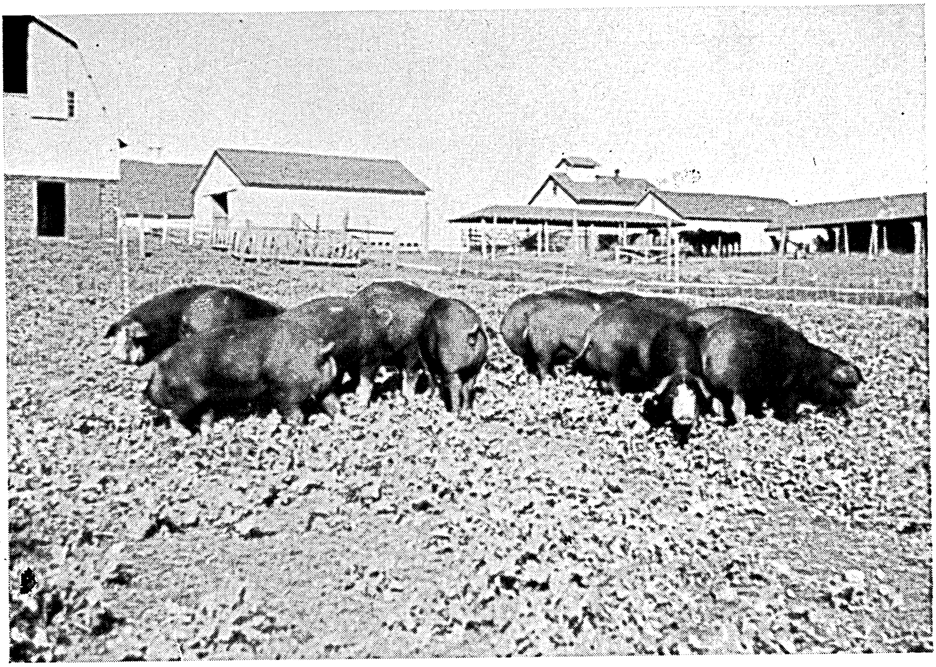

Fig. 11. A group of Viola gilts

More recent ancestors to the 1947 herd in the various lines can be found where the difference between direct and total relationship is great. In fact, this total discrepancy increases with each year as the frequency of the genes is increased and the series of genes present for each characteristic is narrowed.

The contributions and total relationship of the animals to the contributors and the herd of 1947 are greater than those of any animal in another breed or family, with the exception of the bull, Favourite, progenitor of the Duchess family of Shorthorns (Wright 34).

The total relationship of animals to the herd is important, particularly of sires to females, as it gives one an idea of the degree of increase in homozygosity to be expected. It does not, however, indicate the contribution this animal has made to the herd. An animal could have a fairly high relationship to the herd through its collateral relatives used therein and yet have no descendants present. Viola 3rd, a full sister of Viola 2nd, held a coefficient of relationship of 29.2 per cent to the breeding herd of 1947 even though her last descendants were culled from all lines in 1943. This figure of 29.2 per cent is entirely collateral relationship. Total relationship of the female members of a line to a sire or of a female to be brought into the herd to a sire is of value in estimating the inbreeding to be expected. It is also of value in trying to estimate the value of an animal through a knowledge of his relatives, and the higher this total relationship is in this case the more reliable the estimate will be. In estimating what an animal has actually done in a line, however, the percentage of genes he has contributed to the line, or, in other words, his direct relationship to the animals present, must be taken into consideration.

SUMMARY

Two highly inbred lines of Poland China swine have been developed at the West Central Experiment Station at Morris. The methods used in developing these lines are described.

Animals which appeared to have the desired genetic constitution were selected as foundation animals. The station herd was then closed to outside breeding. Three inbred lines were formed, each line centering around a particular animal (Viola 2nd, Western Lady 2nd, and Black Star). Convergence of two of these inbred lines has been used in the production of the "A" line.

Line improvement has also been made through outcrosses ("A" line to Viola line). Inbreeding, to sort the genes and fix desired characters through combinations and gene groupings both before and after the crosses, has been flexible but deliberate. It has been flexible in that a system of mating the "best to the best," regardless of relationship, has been followed.

The level of inbreeding achieved has been high compared to the average of livestock breeds in general—34.8 per cent for the Viola line and 29.7 per cent for the "A" line in 1947.

No disastrous effects have been observed from the inbreeding. A slight loss in fertility was noted in the Viola and Western Lady lines. In all other factors there has been stability or improvement. Improvement has been noticeable in all lines in economy of gains and body score.

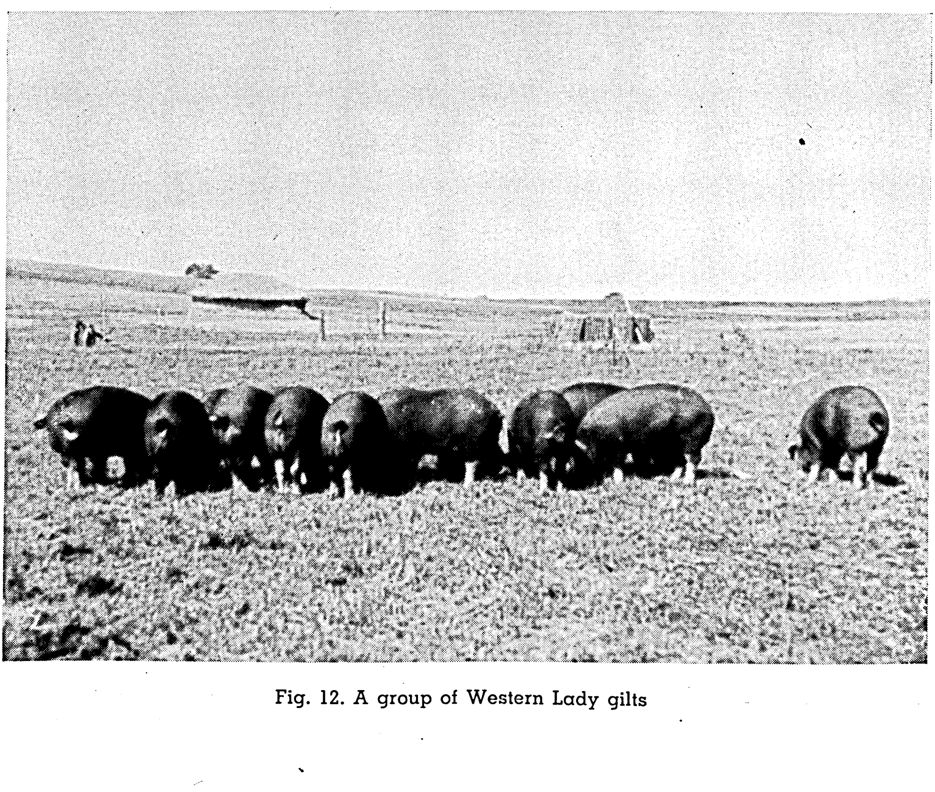

Fig. 12. A group of Western Lady gilts

The inbreeding and improvement in the lines has been accomplished in a shorter than average length of generation—1.58 years in the Viola line and 1.38 years in the "A" line, or 1.44 years in the station herd as a whole.

Selection has been pointed definitely at increased vigor in characters affecting utility. The five characters for which animals were selected were: fertility, survival, rate of gain, economy of gains, and body score. Selection has also been rigorous. Only 13.4 per cent of the spring pigs weaned have been used for breeding stock and less than 50 per cent of these have contributed to the 1947 breeding herd. The system practiced has been somewhat of a combination of the "total score" and "independent culling levels" methods.

While more emphasis has been placed on some individuals than on others, in the breeding program followed, a large number of ancestors show high direct and higher total relationship figures to the breeding herd of each year. As inbreeding increases, the difference between these two figures also increases. Both are important in assessing the value of a particular ancestor.

Some improvement in body form has been observed and this has been due mostly to an increase in uniformity within the lines.

In general, the study reveals that inbred lines can be developed from a few individuals and maintained with about 15 to 20 sows. These lines can be developed rapidly by shortening the length of generation. The study also shows that disaster can be avoided by selecting rigorously on the basis of performance for utility characters and by the ruthless culling of undesirable individuals. It appears that there is an advantage in avoiding rigid systems of mating.

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A Genealogical Study of the Minnesota No. 2 Hog

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CONTENTS

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INTRODUCTION

THE OBJECTIVE in the development of the Minnesota No. 2 breed was the development of a lean type of hog that would cross well with the Minnesota No. 1 *(25)*[2]. The general plan was to use the "flexible system" of inbreeding; that is, no definite system or pattern of mating was used. Those animals that were most desirable for breeding stock were retained and mated to other selected animals regardless of relationship. The program proved successful and on September 12, 1948, the Minnesota No. 2 breed was dedicated at Crookston, Minnesota.

The object of this study is to analyze the various phases of the breeding program used in the development of the Minnesota No. 2 breed. Pertinent data are examined in an attempt to evaluate the results of methods used in developing the breed.

LITERATURE REVIEW

The genetic histories of many of the popular breeds of livestock have been studied by various workers during the past several years. These studies are chiefly concerned with the application of inbreeding and relationship formulas developed by Wright *(26, 27)* and Wright and McPhee *(30)*.

Some of the results showing inbreeding and inter se relationship are summarized in table 1.

Some of the studies do not stress the inbreeding or inter se relationship of the breed, but are more concerned with the effect on more prominent individuals in the breed *(12, 20)*. The breed-

[1] This paper is condensed from a thesis submitted by the senior author to the Graduate Faculty of the University of Minnesota in partial fulfillment of the requirements for the degree of doctor of philosophy.

The research on which this paper is based was conducted in cooperation with the Regional Swine Breeding Laboratory, Ames, Iowa, Bureau of Animal Industry, U. S. Department of Agriculture.

[2] Numbers in parentheses refer to Literature Cited, page 30.

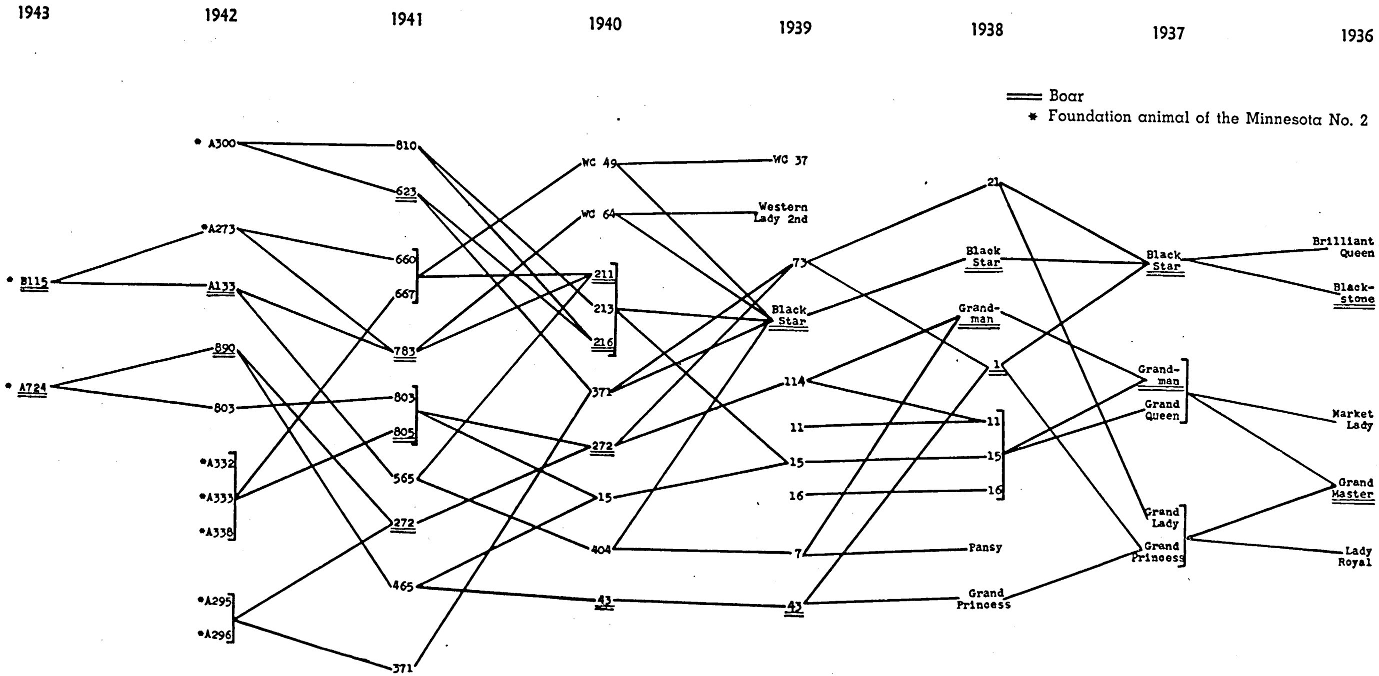


Fig. 1. Genealogy of the contributing foundation Poland Chinas of the Minnesota No. 2 herd at Crookston, Minnesota

Table 1. Results Showing Inbreeding and Inter se Relationship of Stock

Breed	Year	Fx	Inter se	Author*
Shorthorn	1920	.26	.25	(17)
Dairy Shorthorn	1920	.26	.25	(18)
Ayrshire	1927	.05	—	(10)
Holstein Friesian	1931	.04	.03	(16)
Hereford	1930	.08	.09	(23)
Aberdeen Angus	1939	.11	—	(21)
Rambouillet	1926	.06	.03	(6)
Hampshire Sheep	1935	.03	.005	(4)
American Quarter Horse	1945	.02	.04	(8)
Tennessee Walking Horse	1940	.04	.06	(9)
Minnesota No. 1	1947	.34	—	(3)
Poland China	1939	.10	.14	(14)
Hamprace	1948	.32	—	(11)
Viola Line Poland China	1947	.36	—	(22)
Western Lady Poland China	1944	.25	—	(22)
"A" Line Poland China	1947	.30	—	(22)

* Numbers in parentheses refer to Literature Cited, page 30.

ing systems used to produce higher performing individuals have also been given some study *(1, 2)*. The results tend to show that no particular system of breeding is used to produce better performing individuals, but that selection in a broad sense, including pedigree and individuality, is practiced.

METHOD OF DEVELOPMENT

Foundation Stock

One of the primary reasons for establishing the Minnesota No. 2 breed was to have a breed that would cross well with the Minnesota No. 1. Since it has been shown that genetic diversity is desirable in obtaining maximum hybrid vigor in cross breeding, an attempt was made to select breeds for foundation stock that were not similar to the breeds used in the development of the Minnesota No. 1. Tests at the Minnesota stations indicated that pigs of the Poland China, Market Lady, and Black Star lines gained weight on low feed requirements and produced satisfactory carcasses. However, the fertility was not high and the sows were poor milkers. In an attempt to improve the carcass, raise the fertility, and improve the sows' milking abilities, the Canadian Yorkshire was combined with the Poland China foundation stock.

The genealogical chart of the contributing foundation of Poland Chinas is shown in figure 1, and the genealogical chart of the Minnesota No. 2 line at the Northwest Station is shown in figure 2. Nine of the animals are indicated as foundation stock, although it will be noted that they in turn rest on a foundation stock of only five animals. In other words, the Minnesota No. 2 breed may be said to trace back to a foundation stock of five Poland Chinas and one Yorkshire. The computed inter se relationship of the Poland China contributors is .59, the average coefficient of the inbreeding of these gilts is .24.

Early Breed Development

In 1941, the Canadian Yorkshire boar (figure 3), 7V, was mated to 13 Poland China gilts. The F_1 animals were all white (figure 4), later generations were segregated for color (figure 5).

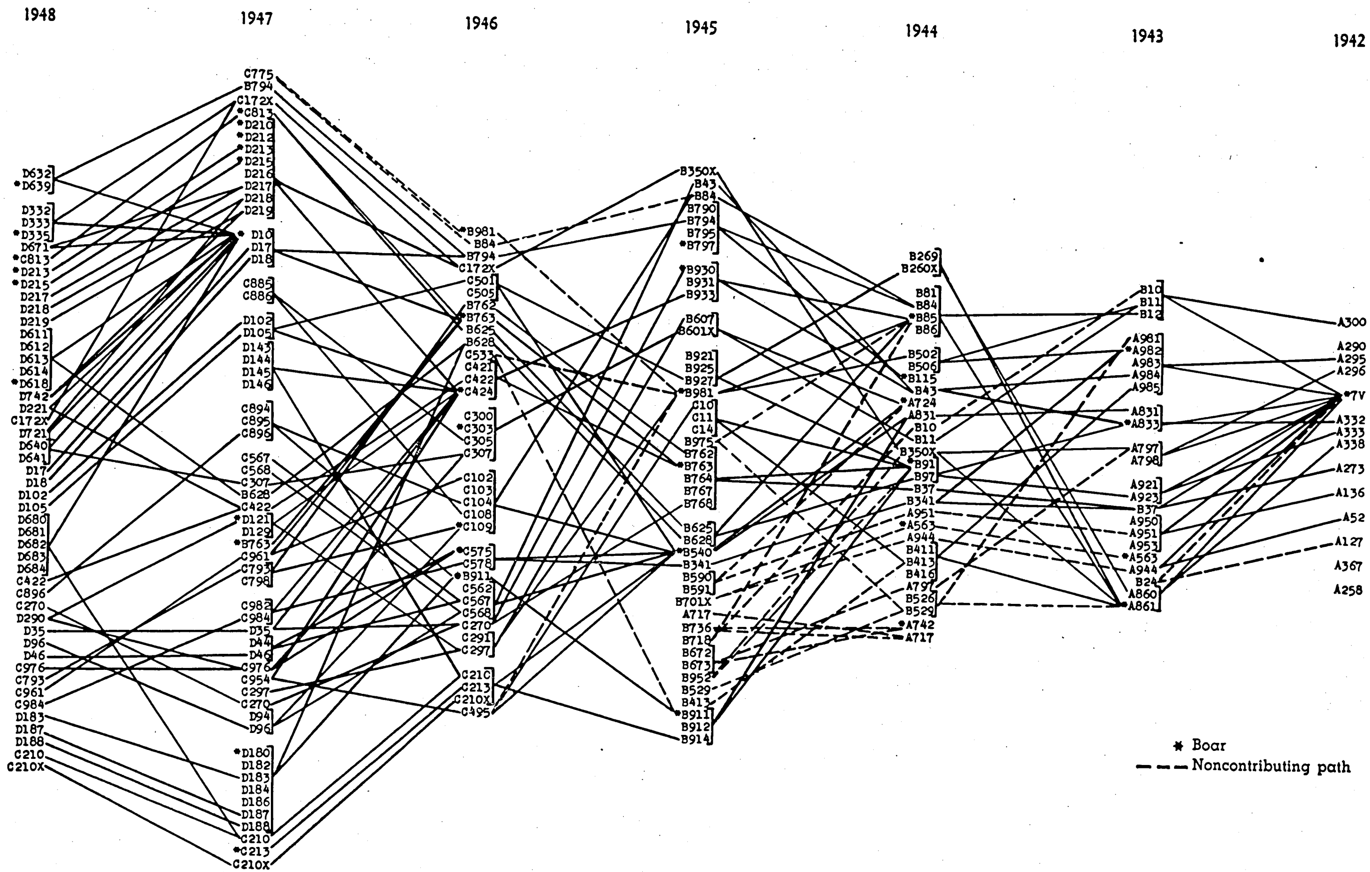


Fig. 2. Genealogy of the Minnesota No. 2 herd at the Northwest Experiment Station, Crookston, Minnesota

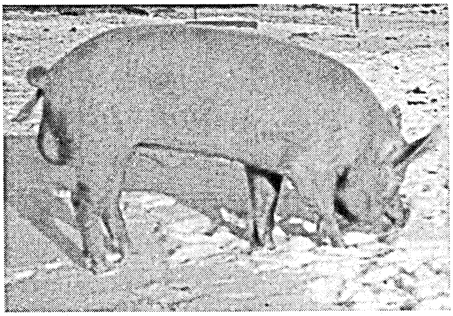


Fig. 3. The foundation Yorkshire boar

Winters *et al (25)* state that neither the performance nor the type of the F_1 and F_2 pigs was quite what was desired, so in the fall of 1943, one half of the F_2 females were backcrossed to Market Lady and Black Star boars. The results of this backcross are presented in some detail in the discussion.

Selection of breeding stock during the early generations included many animals that proved to be noncontributors. That is, the animals were selected on the basis of their performance, but if they were not able to produce progeny with desirable performance they were quickly eliminated from the breeding herd. The elimination of noncontributors was particularly evident during the early years of the breed development (figure 6). Table 3 contains information regarding the number of years the noncontributing animals or their progeny remained in the breeding herd. It will be noted that the peak was reached about 1945; since then the number of noncontributing animals has rapidly declined.

The number of foundation animals which have contributed to the Minnesota No. 2 herd has also been established since 1945 (figure 7). The ten foundation animals are shown as contributors, although, as has been noted previously, the nine Poland China hogs rest on a common foundation stock of five ancestors (figure 1).

Fig. 4. An F_1 litter farrowed in 1942

Table 2. Breeding Herd Components of the Minnesota No. 2 Herd by Years

	1942	1943	1944	1945	1946	1947	1948
Total population, breeding herd	14	23	30	43	36	52	48
Number of gilts	13	19	18	30	23	35	18
Number of sows	......	......	6	7	5	9	24
Number of young boars	1	4	3	6	5	7	3
Number of aged boars	......	......	3	......	3	1	3
Number of litters represented	10	11	20	24	18	28	27
Number of noncontributing females present	6	10	13	22	9	6	......
Number of noncontributing males present	......	1	2	1	1	3	......

Table 3. Number of Years and Number of Noncontributing Animals or their Progeny Remaining in the Breeding Herd for One or More Years

Base year	1942	1943	1944	1945	1946	1947	1948
years in breeding herd				number of animals			
1	3	6	7	22	8	9	45
2	1	......	8	1	2	......	12
3		5	......	......	......	......	5
4	2	......	......	......	......	......	2
Number of noncontributing animals in the breeding herd each year	6	11	15	23	10	9	74
Per cent noncontributing animals in the breeding herd each year	42.9	47.8	50.0	68.3	27.8	17.3	......

Average Length of Generation

The breeding stock in the early generations consisted almost entirely of replacement stock. During the latter years of the program there has been a tendency to retain individuals for more than one year. The average ages are given in table 4.

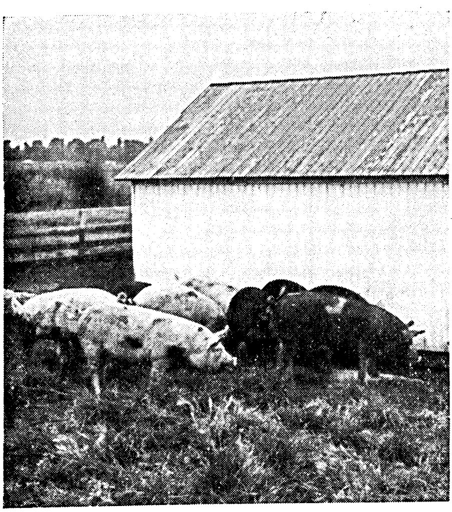


Fig. 5. A Minnesota No. 2 litter in the early stages of segregation

As shown in figure 8, the average age of the females used does not exceed 15 months previous to the 1948 breeding herd. The 19-month average age of the males in 1944 is due to three aged boars that were used for the backcrossing.

The computed average length of generation was found to be 1.68 years. This is comparable to that in the Minnesota No. 1 which was reported to be 1.56 *(3)*, while in the Minnesota inbred Poland China lines the average was 1.48 years *(22)*.

Litter Selection

Not all litters farrowed are placed on a litter test. The procedure and policy of selecting litters for testing is to test the largest litters, since it is obvious that the small litters are not wanted for herd replacements. Since replacement breeding stock is selected only from the

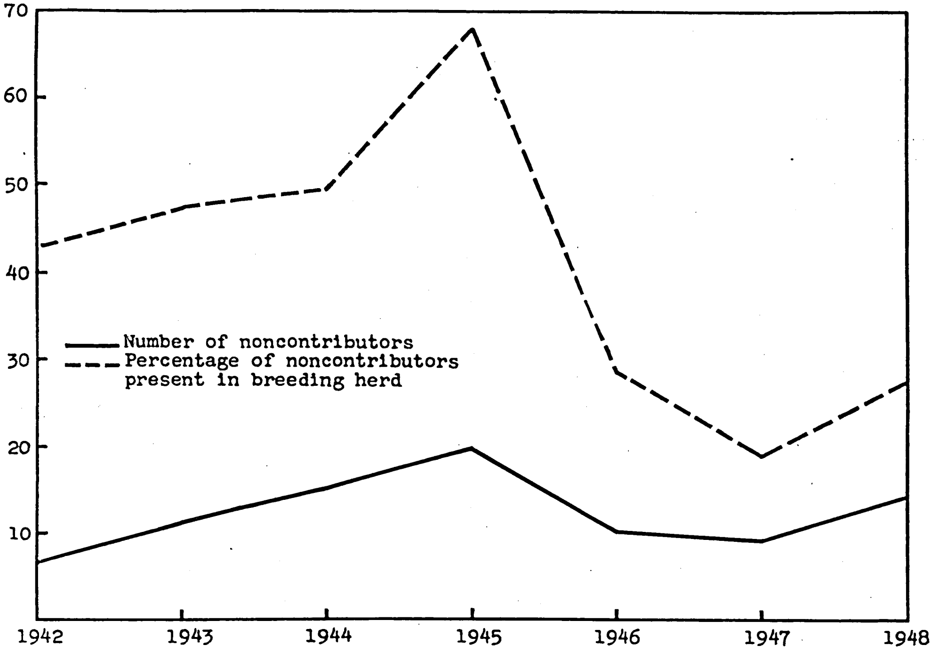


Fig. 6. Noncontributors in the Minnesota No. 2 herd at Crookston, Minnesota

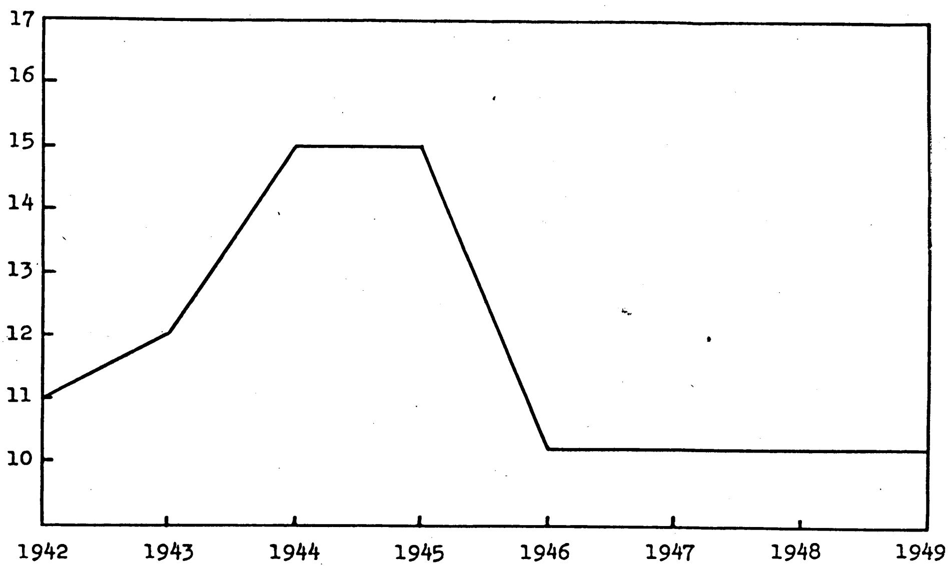


Fig. 7. Number of foundation animals contributing to the breeding herd of the Minnesota No. 2

Table 4. Average Age in Months at Time of Farrow of the Male and Female Breeding Stock of the Minnesota No. 2 Herd at Crookston, Minnesota

	1942	1943	1944	1945	1946	1947	1948
Selected females	11.4	11.8	14.6	14.0	14.1	14.7	19.1
Contributing females	11.4	11.8	15.6	15.6	14.5	15.0	....
Selected males	15.0	12.0	18.5	13.2	16.5	16.6	15.3
Contributing males	15.0	12.3	14.0	13.6	16.0	18.3	....

Table 5. Litter Selection for the Breeding Herd of the Minnesota No. 2 Swine

	1942	1943	1944	1945	1946	1947	1948
Total number of litters farrowed	13	19	18	41	28	42	40
Number of litters tested	13	15	13	18	26	23	18
Per cent of litters farrowed that were tested	100	78.9	72.2	43.9	92.9	54.8	45.0
Number of litters selected for replacement stock for the breeding herd	10	9	11	12	18	10	16
Per cent of farrowed litters represented in breeding herd	76.9	37.4	61.1	29.3	64.3	23.9	40.0

tested litters, this serves to limit initially the number of animals available for the breeding herd. The data concerning litter selection are summarized in table 5. As shown in figures 9 and 10, the per cent of farrowed litters selected for the breeding herd follows closely the per cent of farrowed litters tested.

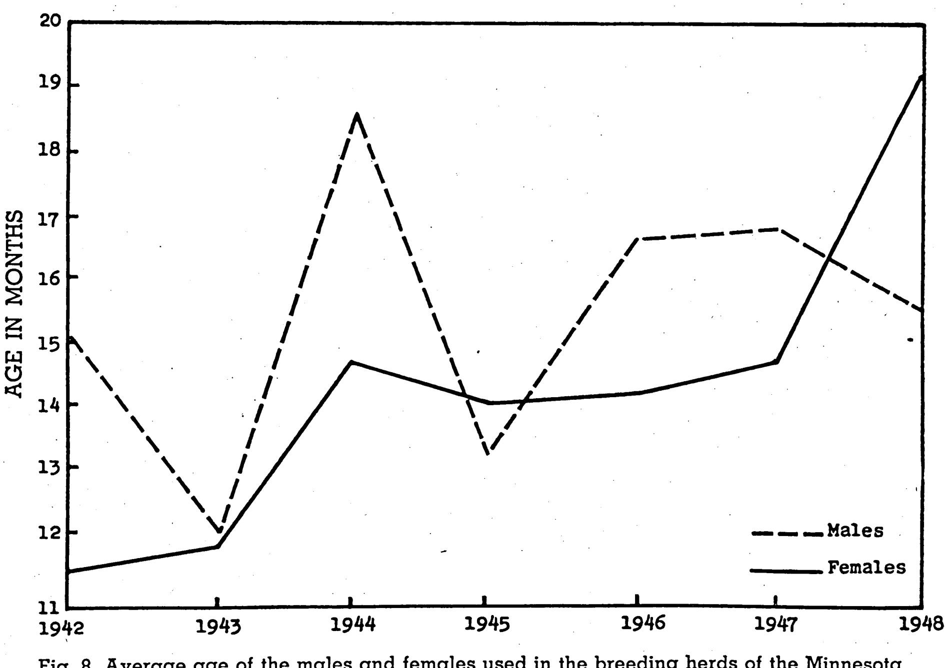


Fig. 8. Average age of the males and females used in the breeding herds of the Minnesota No. 2 line of swine at Crookston, Minnesota

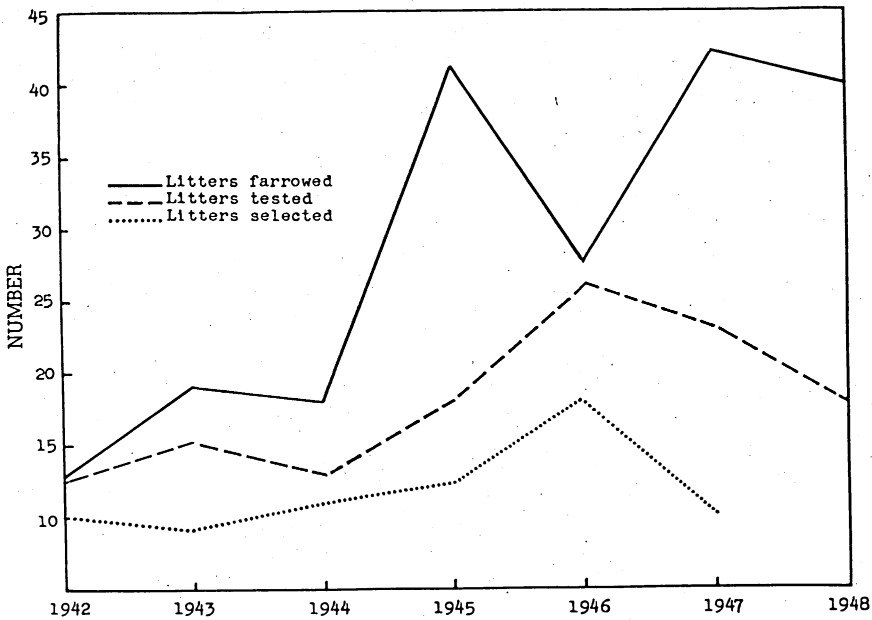


Fig. 9. Litter selection in the Minnesota No. 2 herd at Crookston, Minnesota

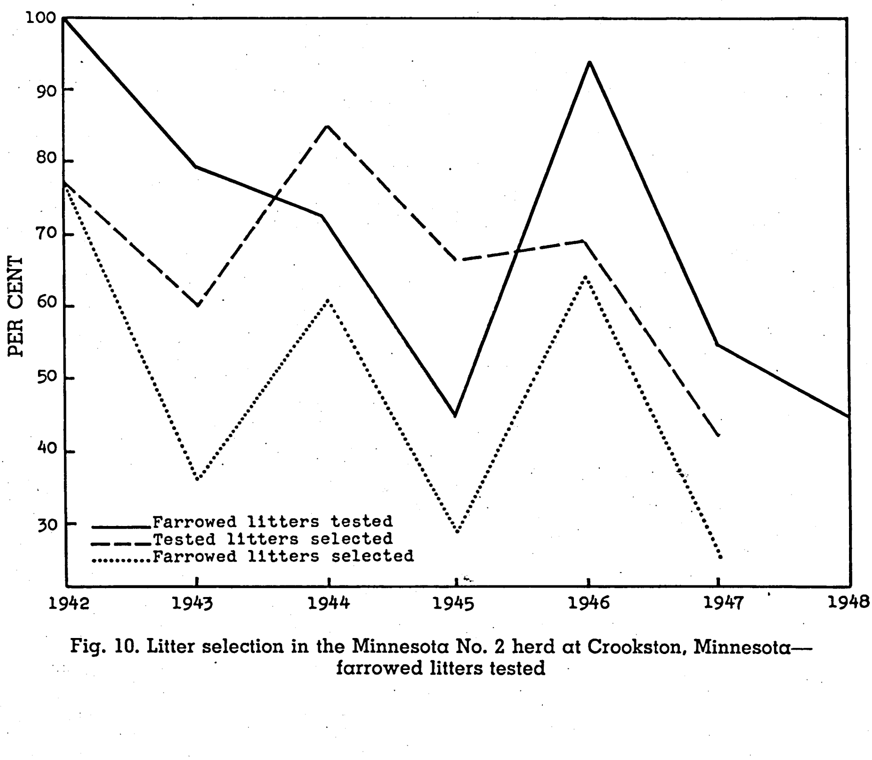


Fig. 10. Litter selection in the Minnesota No. 2 herd at Crookston, Minnesota—farrowed litters tested

Table 6. Selection of Male and Female Breeding Stock for the Minnesota No. 2 Herd at Crookston, Minnesota

	1942		1943		1944‡		1945		1946		1947		1948	
	M*	F†	M	F	M	F	M	F	M	F	M	F	M	F
Number farrowed	32	49	95	91	108	110	172	177	109	116	167	150	152	145
Number tested	24	46	43	48	37	41	64	70	72	85	77	72	75	65
Number selected for breeding stock	3	19	2	16	6	27	5	23	7	35	3	18	4	19
Number contributing	3	9	2	8	5	11	5	15	6	30	2	7	......	......
Per cent of total tested	75	94	45	53	34	37	37	39	67	73	46	48	49	45
Per cent tested selected	13	41	5	33	16	66	8	33	10	42	4	25	......	......
Per cent tested contributing	13	19	5	17	14	27	8	21	8	35	3	10	......	......
Per cent selected contributing	100	47	100	50	83	41	100	65	57	83	67	39	......	......
Per cent total selected	9	39	2	18	6	25	3	13	6	31	2	12	......	......
Per cent total contributing	9	18	2	9	5	10	3	9	4	26	1	7	......	......

* Male
† Female
‡ Includes backcross litters

Breeding Stock Selection

Selection of the male and female breeding stock used in the Crookston herd is summarized in table 6. The selection of the female breeding stock is shown graphically in figure 11. It will be noted that there is a relatively constant difference in the number of females contributing to the 1948 breeding herd compared to the number of females selected for the breeding herd each

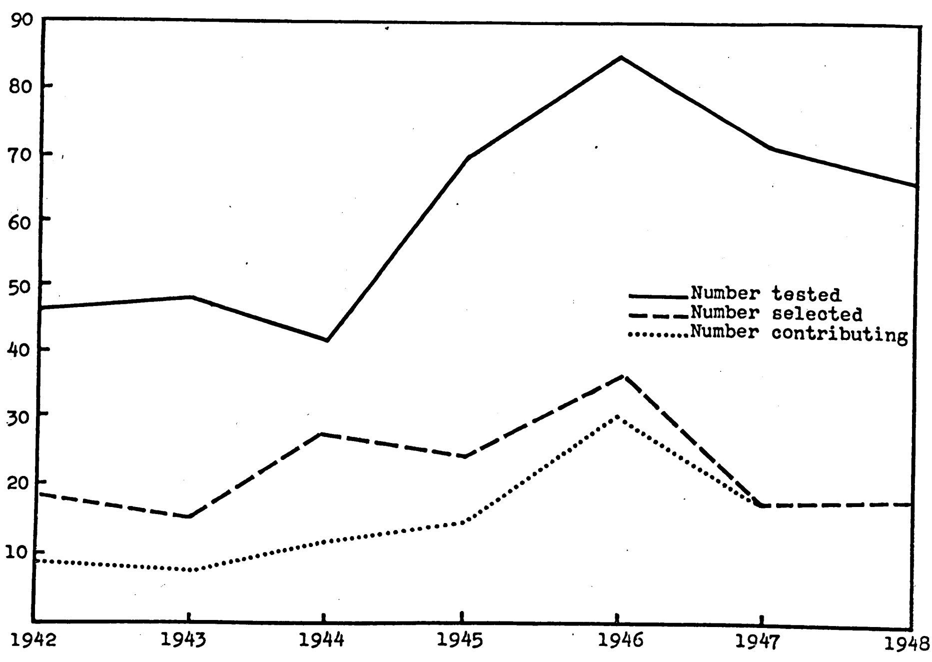


Fig. 11. Selection of female breeding stock for the Minnesota No. 2 herd at Crookston, Minnesota

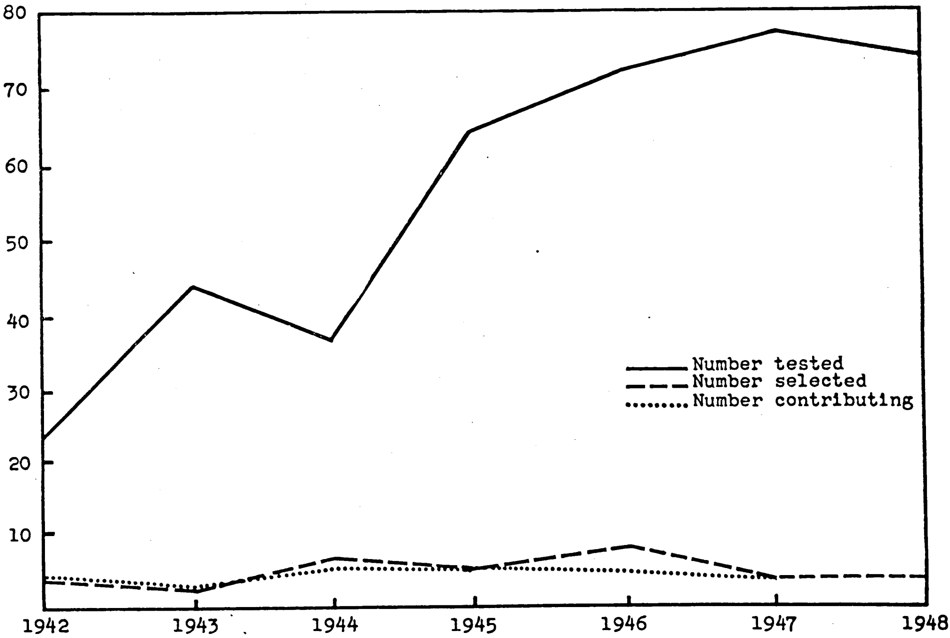


Fig. 12. Selection of male breeding stock for the Minnesota No. 2 herd at Crookston, Minnesota

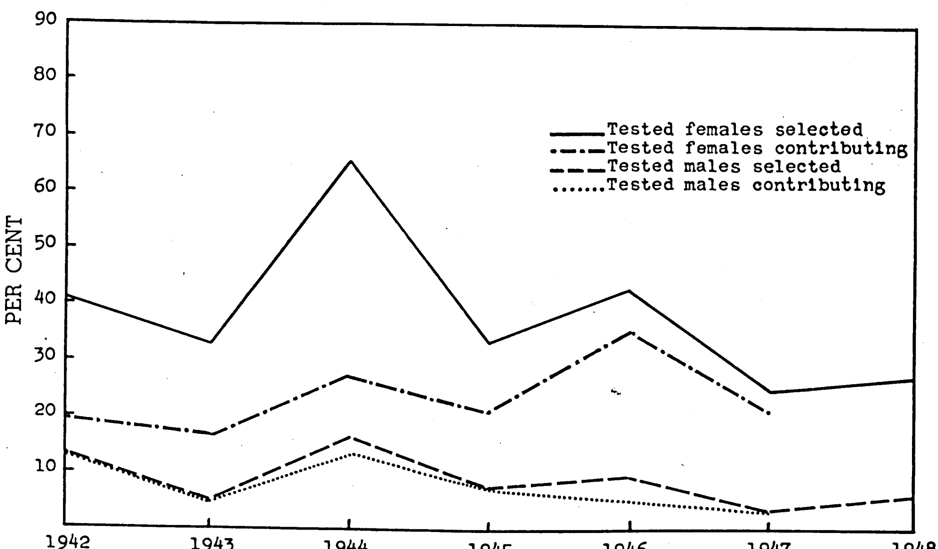


Fig. 13. Selection of male and female breeding stock of the Minnesota No. 2 herd at Crookston, Minnesota—tested animals selected

year. The initial selection of male breeding stock is of utmost importance since it is only occasionally that a male proves to be a noncontributor (figure 12). The relative per cent of male and female noncontributors is directly compared in figure 13.

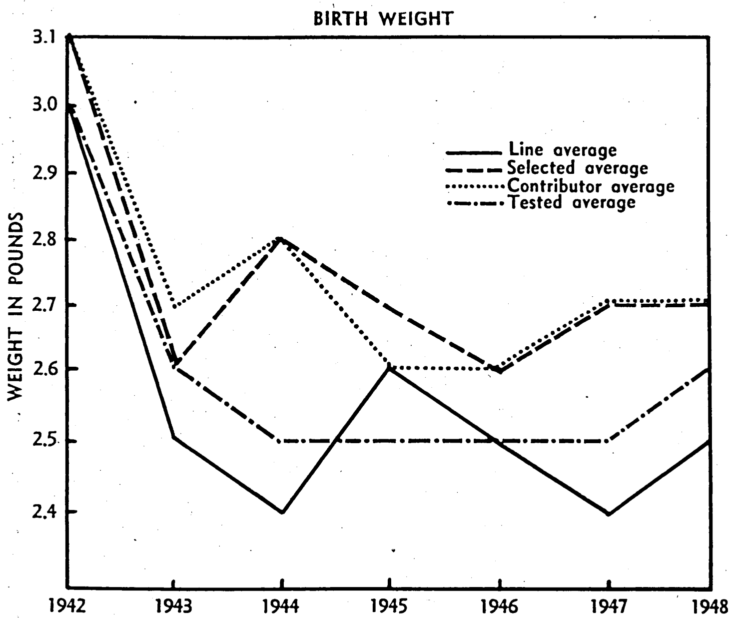
Performance

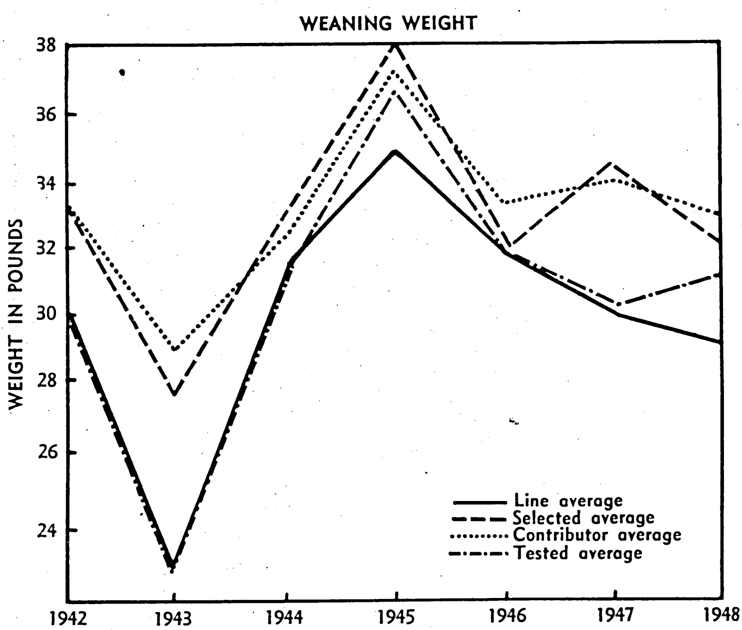
The procedure used in establishing the performance of the animals has been described by Winters *et al (24)*. The number of litters tested and consequently the number of individuals tested varies considerably for each year (tables 5 and 6). The performance data for the various factors are given in table 7. The tested average refers to the average performance of all litters placed on test, while the selected average includes the average of all animals subsequently used in the breeding herd. The contributor average includes only those animals selected for the breeding herd that contributed to the 1948 herd.

Some of the performance factors are shown graphically (figures 14, 15, 16, 17, 18, and 19). The fertility of the line is shown in figure 18. It will be noted that the average number born per litter decreased from nine in 1943 to 7.5

Table 7. Performance of the Selected and Contributing Breeding Stock as Compared to the Line Average of the Minnesota No. 2 Herd at Crookston, Minnesota

	1942	1943	1944	1945	1946	1947	1948
Fx							
Line average	.....	.20	.16	.19	.23	.24	.28
Selected average	.....	.20	.17	.19	.22	.23	.25
Contributor average	.....	.20	.19	.19	.22	.23	.25
Number born							
Line average	6.2	9.1	8.5	8.5	8.0	7.6	7.5
Tested average	6.2	10.0	9.9	9.6	8.1	8.4	9.1
Selected average	6.9	8.8	10.6	9.5	9.6	10.1	9.6
Contributor average	6.9	8.5	10.4	10.0	9.5	10.7	9.6
Number weaned							
Line average	5.5	6.1	4.4	4.7	5.8	4.1	6.1
Tested average	5.5	6.1	6.0	7.5	6.0	6.5	7.8
Selected average	6.6	7.2	8.3	8.3	9.5	9.7	8.4
Contributor average	6.1	6.8	8.5	8.8	8.1	9.7	8.4
Birth weight							
Line average	3.0	2.5	2.4	2.6	2.5	2.4	2.5
Tested average	3.0	2.6	2.5	2.5	2.5	2.5	2.6
Selected average	3.1	2.6	2.8	2.7	2.6	2.7	2.7
Contributor average	3.1	2.7	2.8	2.6	2.6	2.7	2.7
Weaning weight							
Line average	30.0	23.5	31.7	34.8	31.8	30.0	29.2
Tested average	30.0	23.5	31.7	36.7	31.8	30.8	31.0
Selected average	32.6	27.6	33.2	38.0	32.0	34.6	32.2
Contributor average	32.8	28.9	32.7	37.2	33.5	34.1	33.0
154 day weight							
Line average	167	136	178	187	170	153	163
Selected average	178	149	175	195	168	180	176
Contributor average	176	153	173	189	173	177	180
Feed per 100 pounds gain							
Line average	308	281	335	311	336	316	294
Selected average	317	298	312	332	329	310	322
Contributor average	309	308	310	328	328	317	318
Score							
Line average	.....	6.3	6.8	6.4	8.1	7.0	8.1
Selected average	.....	.....	6.8	7.1	8.2	8.3	8.4
Contributor average	.....	.....	7.0	7.2	8.2	8.3	8.4





Figs. 14 and 15. Performance of the animals tested and those selected for the breeding herd compared to the line average for the Minnesota No. 2 herd in 1948. During this period those who were directly associated with the herd had stated that they were not satisfied with the type of ration being fed to the pregnant sows. In 1948 a change was made in the ration in an attempt to eliminate any existing deficiencies. Data for the 1949 farrow, which became available just prior to publication, are included to show that the fertility of the line is still equal to that of the 1943 farrow. The tested litters have always averaged a larger number born than has the average for the line. The selection advantage of the breeding stock to the line has been maintained at over one pig per litter.

Survival, as measured by number of pigs weaned per litter has shown an increase during the period of development of the line (figure 19). The sharp drop in the line average for 1944, 1945, and 1947 is due to the serious outbreak of "baby pig sickness" during those years. The tested litters have always been considerably larger than the line average while the animals selected for breeding stock have been from litters that averaged over three pigs per litter larger than the line average. This indicates that much emphasis has been placed on selection of breeding stock from only the larger litters weaned.

As indicated in figure 14, the line average for birth weight has remained practically constant throughout the period 1943 through 1948.

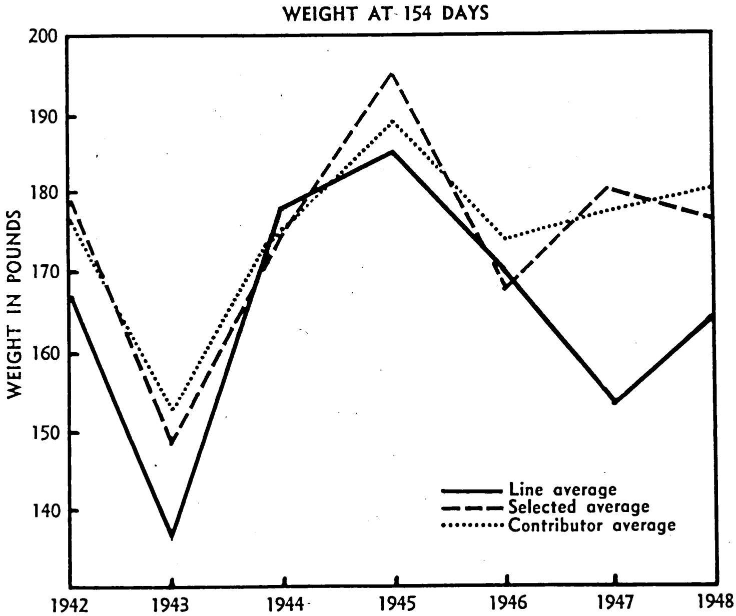
The birth weight of the selected and contributor animals has been consistantly heavier than the line average. A consistent selective differential is also noted for weaning weight (figure 15). The selected and contributor groups are approximately equal and average about two pounds heavier at weaning than the average of the entire line.

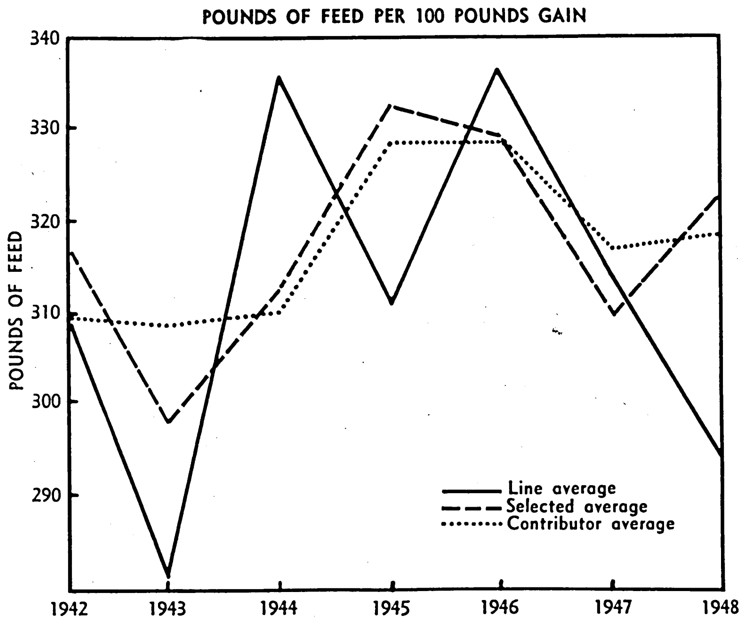
The graph of 154-day weight (figure 16) bears a striking similarity to that of weaning weight (figure 15). The selected and contributor groups average about ten pounds heavier at 154 days than does the line as a whole. It appears, therefore, that selection of the heavier animals at 154 days automatically selects those animals that were heavier at the time of weaning.

The pounds of feed used per 100 pounds gain in weight, as shown in figure 17, indicate that an effort has been made to select for breeding stock animals from those litters that were more efficient in feed utilization. Also, since the figures are not corrected for final weight, they may actually underestimate the difference between the selected group and the line.

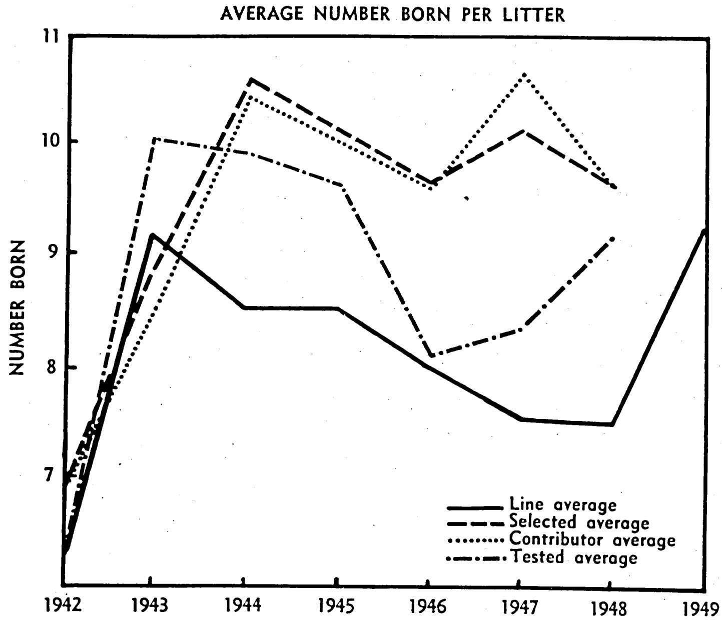
INBREEDING AND RELATIONSHIP

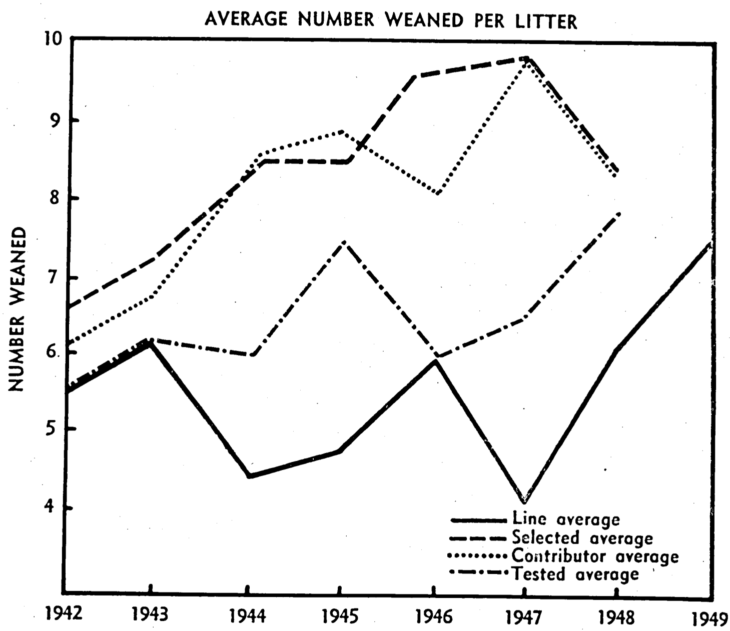
Formulas for calculating the coefficient of inbreeding and the coefficient of relationship have been presented by Wright *(26, 27,* and *28)*. The importance and application of these formulas have been discussed by Wright *(27)*, Wright and McPhee *(30)* and by other authors *(3* and *13)*. The method of calculating coefficients at the University of Minnesota involves the use of relationship tables for all of the animals of a particular line. The animal numbers are listed in order, boars first followed by females, along the top of the table and repeated in the same order on the left hand margin. The spaces to be used to record the relationship of two animals is found at the intersection of the respective row and column. The breeding herd for each farrow is listed separately. Thus, the average coefficient of inbreeding of a particular farrow may be readily computed without resorting to sampling.





Figs. 16 and 17. Performance of the animals selected for the breeding herd compared to the line average for the Minnesota No. 2 herd





Figs. 18 and 19. Average litter size of the tested litters and those selected for breeding stock compared to the line average for the Minnesota No. 2 herd

Table 8. Inbreeding and Relationship of the Minnesota No. 2 Breeding Herd

	1942	1943	1944	1945	1946	1947	1948
Breeding herd							
Average Fx boars	—	.06	.29	.20	.19	.22	.23
Average Fx females	.24	......	.18	.17	.19	.22	.22
Average relationship between sire and dam	......	.40	.32	.38	.46	.48	.56

Breeding Herd

The inbreeding and relationship of the breeding herd is presented in table 8. The high average relationship of the F_1 animals selected for breeding stock is due to the close relationship of the original foundation Poland China stock. This is also evident in the inbreeding coefficient of .24 for these animals (figure 20). The decrease in the relationship in 1944 is due to the backcross individuals that were used the preceding year. The fact that they were closely related to the original Poland China foundation stock (figure 1) prevented a further decline in the relationship. The sharp increase of inbreeding in 1944 for the breeding males is also explained by the backcross since inbred Poland China males were used. Since 1945 the inbreeding of the male and female breeding animals has been approximately equal.

Inbreeding

Table 9 includes the actual and expected coefficient of inbreeding of the Minnesota No. 2 herd. The expected inbreeding was computed according to the method of Wright and McPhee *(30)* which is based on the number of males and females used in the breeding herd.

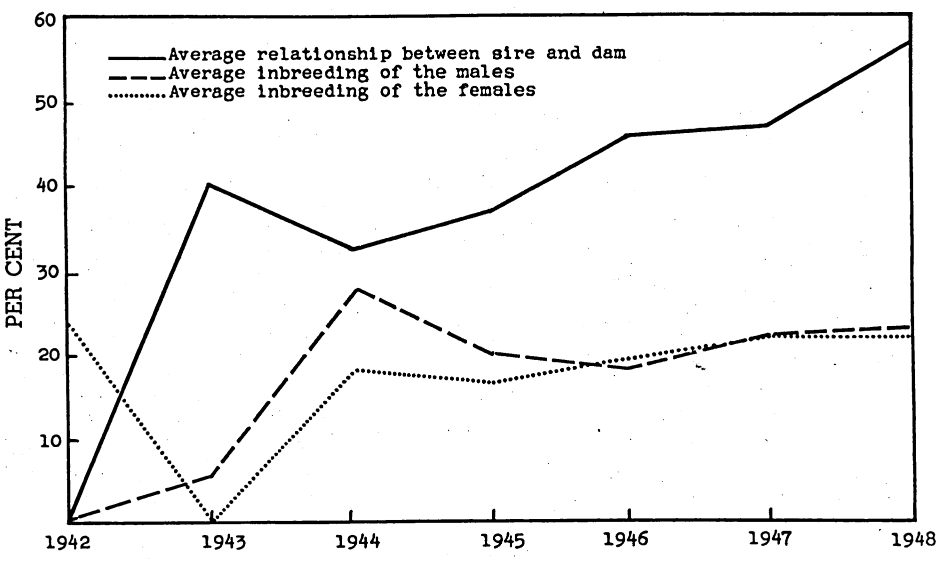


Fig. 20. Inbreeding of the Minnesota No. 2 breeding herd at Crookston, Minnesota

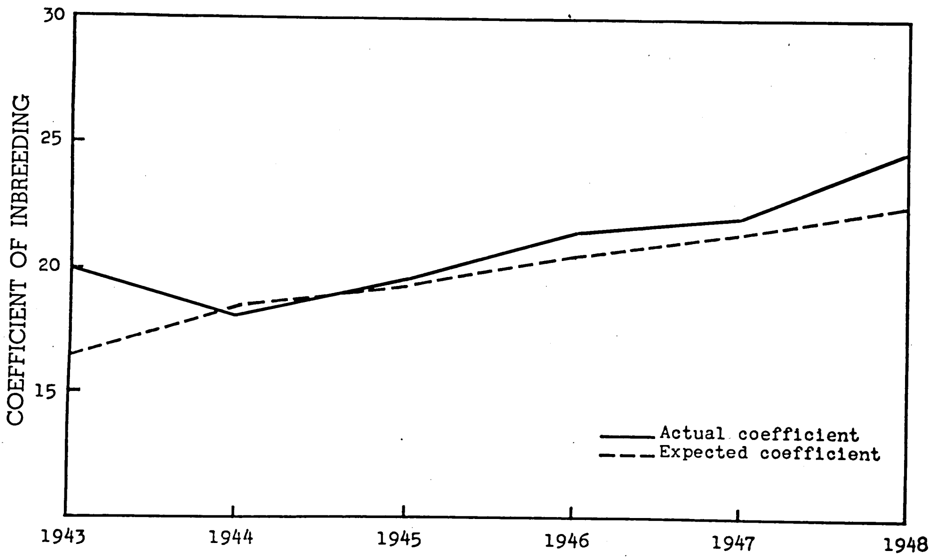


Fig. 21. Actual and expected coefficient of inbreeding of the Minnesota No. 2 herd

The standard error of the inbreeding coefficient is based on the formula by Lush *(13)*.

A significant difference between the actual and expected inbreeding is present for three separate years. Figure 21 indicates that the actual inbreeding may be increasing more rapidly than the expected inbreeding.

The decreased coefficient of inbreeding of the 1944 farrow is due to the backcross that was used previously. The following generation did not quite regain the inbreeding that was present prior to the backcross. Thus the backcross resulted in a delay of over two years in increasing the coefficient of inbreeding of the herd. The fact that animals used in the backcross were quite highly related to the original stock undoubtedly served to prevent an even more marked effect.

Table 9. The Actual and Expected Inbreeding of the Minnesota No. 2 Herd at Crookston, Minnesota

Year	Actual Inbreeding	S.E.	Expected Inbreeding
	per cent		per cent
1942	......	......	......
1943	20	.26	13*
1944	16	.21	17
1945	19	.19	19
1946	23	.22	21*
1947	24	.19	23
1948	28	.21	25*

* Highly significant difference.

Inter se Relationship

McPhee and Wright *(17)* point out that a very important question connected with a breed is the degree of homogeneity. That is, is the breed a well knit unit or is it a collection of diverse tribes? The coefficient of inbreeding does not answer this question since a breed might become split into several such tribes each closely inbred within itself but having little relationship to each other. Thus, a group such as this may show well a rather high coefficient of inbreeding but the inter

Table 10. Inter se Relationship and Inbreeding of the Minnesota No. 2 Herd at Crookston, Minnesota

	1942	1943	1944	1945	1946	1947	1948
Inter se	.44	.39	.41	.46	.48	.52	.56
Average Fx	......	.20	.16	.19	.23	.24	.28

se relationship will be very low. On the other hand, if all inbreeding resulted solely from the fact that members of the breed were all related to each other the inter se relationship coefficient would be approximately twice as large as the coefficient of inbreeding for the particular breed.

The inter se relationship for the contributing animals of the Minnesota No. 2 breeding herd at Crookston, Minnesota, is shown in table 10 and figure 22. The inter se relationship was computed by establishing the relationship of each contributing animal to every other contributing animal used the same year, and then averaging the relationships.

The high inter se relationship in the early years of the breeding program is due to the high inter se relationship of the foundation Poland China animals, which was .59.

Individual Relationship

Direct relationship, also called "per cent of blood," measures the per cent of genes which may theoretically have been contributed by an ancestor to a particular individual or group of individuals. It is computed by establishing the relationship of the ancestor to those animals which contain the particular ancestor in their pedigree. Direct relationship as used here is a measure of

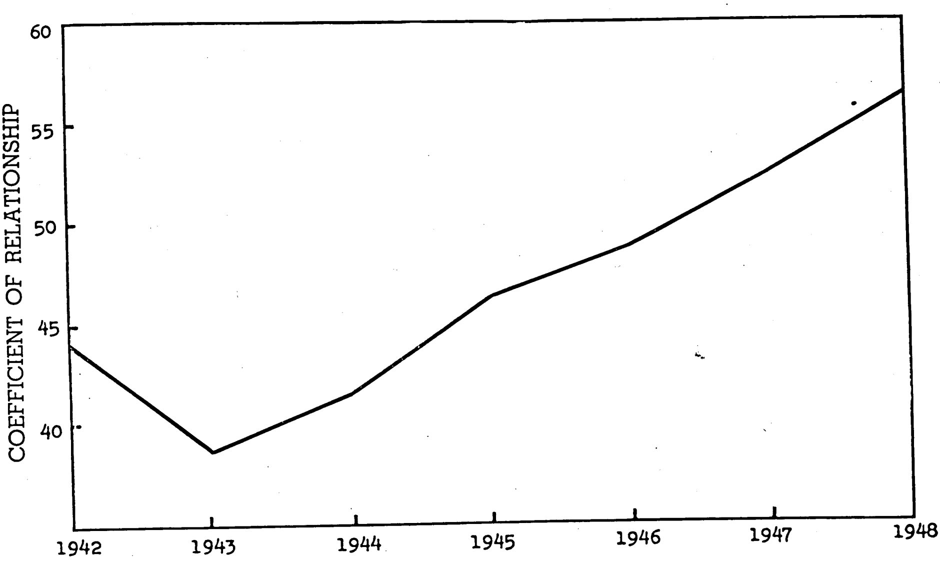


Fig. 22. Inter se relationship of the contributor breeding stock of the Minnesota No. 2 herd at Crookston, Minnesota

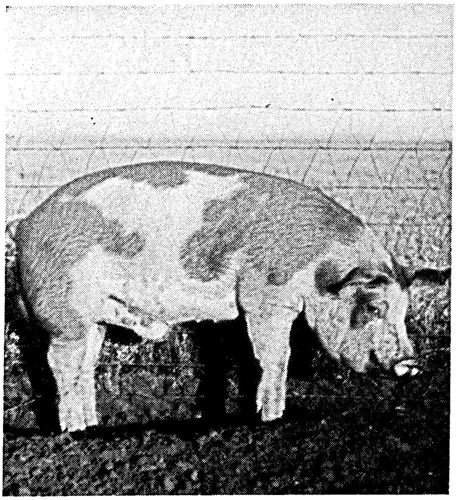


Fig. 23. Herd boar B763 at 6 months

the theoretical genetic contribution of an ancestor to the present herd.

Total relationship, also called collateral relationship, is equal to the sum of all possible paths by which duplicates of a gene in a common ancestor may have reached the respective individuals. The formula and method are presented by Wright *(26)* and are also discussed by Lush *(13)*. The direct and total relationships of the contributing foundation animals and other important ancestors to the Minnesota No. 2 breeding herd are shown in table 11. The figures show that the Yorkshire boar, 7V, has contributed 40 per cent of the heredity of the 1948 breeding herd.

The direct relationship of the contributing female foundation animals to the 1948 breeding herd is fairly well distributed, no single individual having made an outstanding contribution. The high total relationship of the individuals to the respective breeding herds is due primarily to the high initial inter se relationship of the foundation stock. Generally there has been very little change in the total relationship of the foundation animals to the breeding herds during the program. Most of the relationships do fluctuate somewhat,

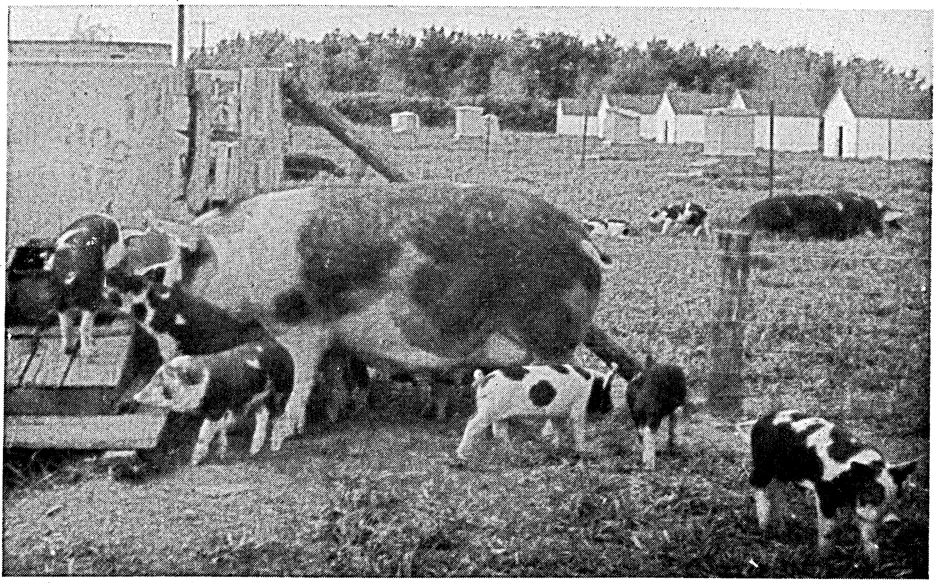


Fig. 24. Sow and litter, 1948 farrow

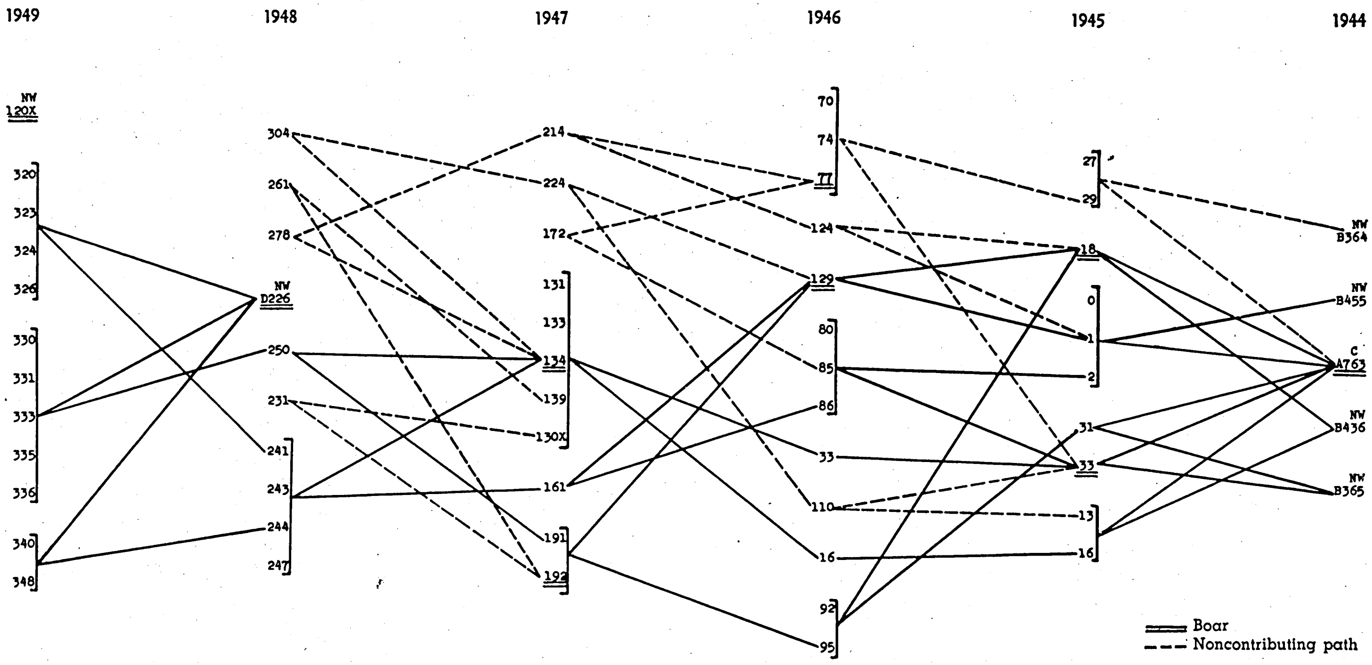


Fig. 25. Genealogy of the Minnesota No. 2 herd at the Northeast Experiment Station, Duluth, Minnesota

especially in 1945 and 1946 when they were generally decreased due to the backcross which had been previously introduced.

The most important individual that was selected from the backcross animals was the boar, B540, used in the 1945 breeding herd. His total relationship has increased from 50.0 in 1946 to 53.0 in 1948. However, a straight F_3 boar, B763, (figure 23) used the same year, has shown an increase in total relationship from 35.0 to 60.0 during the same period.

THE HERD OF MINNESOTA NO. 2 SWINE AT THE NORTHEAST EXPERIMENT STATION

In 1943, four females were taken from Minnesota No. 2 herd at Crookston to the Northeast Experiment Station at Duluth, Minnesota. A "C" line Poland China boar from the Central Station at St. Paul, Minnesota, was mated with these females. The genealogy of the Duluth line is shown in figure 25. It was maintained as a closed population until 1947 when a boar from the Minnesota No. 2 herd at Crookston was used for the 1948 farrow. Another Crookston boar was used for the 1949 farrow.

Since it was not practicable to handle litter testing at the Duluth Station, performance data do not include efficiency of feed utilization or rate of gain.

However, on the basis of the data that have been measured, the performance of the Duluth line has compared very favorably with the herd at Crookston (table 12).

Since 1948 the Duluth herd has been incorporated into the Minnesota No. 2 herd proper. Figure 26 illustrates animals of the Duluth herd.

Table 11. Direct and Total Relationship of the Contributing Foundation Animals and Other Important Ancestors to the Minnesota No. 2 Breeding Herd at Crookston, Minnesota

	1943		1944		1945		1946		1947		1948	
	direct	total	direct	total	direct	total	direct	total	direct	total	direct	total
*7V	50.0	50.0	43.3	42.9	43.8	44.1	43.7	40.9	40.0	42.8	40.0	41.3
*A295	12.5	34.5	5.0	34.5	5.0	30.6	3.1	27.2	3.2	32.1	3.0	32.0
*A296	4.2	31.4	1.7	33.2	1.3	30.4	0.5	26.7	0.9	30.0	0.9	31.8
*A273	4.2	24.2	5.0	36.0	7.5	27.5	7.7	23.1	6.0	33.5	2.5	38.0
*A332	8.3	37.4	3.8	39.2	7.5	41.7	9.1	34.3	9.1	43.0	9.1	43.1
*A333	4.2	34.0	3.3	37.0	3.8	39.3	2.9	30.2	7.6	38.9	7.6	40.0
*A338	8.3	35.7	10.0	39.1	7.5	40.0	7.2	31.3	6.1	39.3	3.1	40.3
*A300	8.3	34.5	8.3	36.4	7.5	38.5	7.2	34.0	5.0	33.3	9.2	36.0
A861	....	....	20.0	47.4	15.0	48.6	14.4	34.7	12.2	46.2	6.3	46.7
B12	....	....	6.5	41.4	8.8	45.8	11.1	32.1	9.6	43.0	5.0	42.6
*†A724	....	....	....	....	7.5	34.9	16.4	37.5	11.3	38.4	8.7	36.1
*B115	....	....	....	....	2.5	34.6	1.9	24.4	2.8	34.4	7.3	34.2
B85	....	....	....	....	12.5	54.9	8.7	36.4	11.9	51.0	6.4	49.8
B91	....	....	....	....	10.0	58.6	7.7	37.9	7.1	56.0	7.8	61.2
‡B540	....	....	....	....	....	....	26.9	50.0	19.2	52.0	14.9	53.1
B763	....	....	....	....	....	....	3.9	35.0	16.9	56.5	20.3	60.1
C172X	....	....	....	....	....	....	....	....	4.8	50.5	9.9	53.1
C424	....	....	....	....	....	....	....	....	19.8	63.2	12.5	59.8
D10	....	....	....	....	....	....	....	....	....	....	22.9	64.7

_______ Boars.
* Foundation animals.
† Used for backcross.
‡ Selected from backcross.

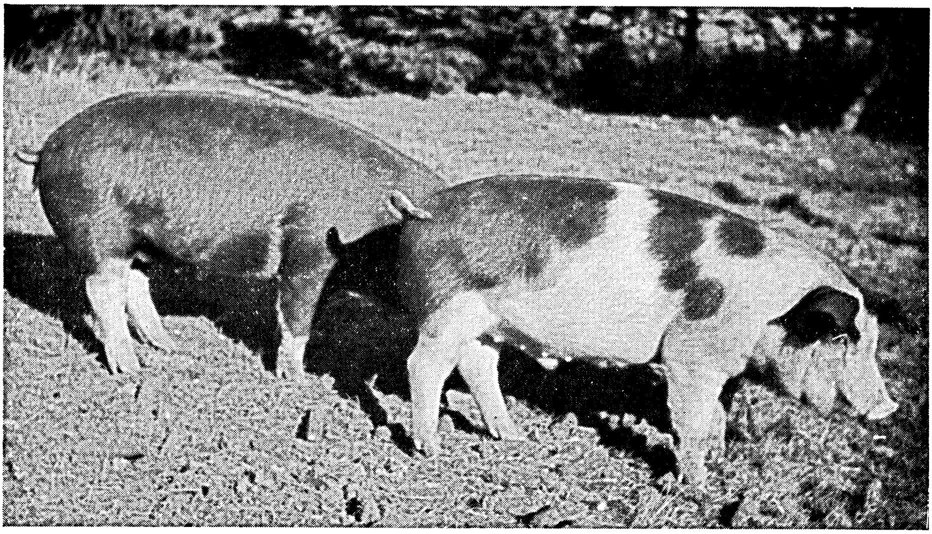


Fig. 26. Animals of 1946 farrow at the Northeast Experiment Station

DISCUSSION

It has been demonstrated that superior foundation stock is essential to the development of an inbred line *(24)*. The Poland China foundation stock used in the development of the Minnesota No. 2 breed had been selected and tested at the Minnesota stations primarily on the basis of performance. The animals were derived from common foundation stock (figure 2) and maintained as inbred lines. The relatively high inter se relationship of these animals has proved to be an important factor in the development of the Minnesota No. 2 breed. That is, when considering the performing ability of a line or breed, the average per cent of homozygosis is important in a number of ways *(26)*. It measures the permanency of the change effected by the system of mating. Thus, no matter how high the correlation between parents and offspring, random mating among the descendents of even a carefully selected group will be followed by the loss of uniformity unless the group consists of individuals homozygous for the same factors.

The inter se relationship, which measures the gene similarity, is rela-

Table 12. Performance of the Minnesota No. 2 Herd at Duluth, Minnesota

	1944	1945	1946	1947	1948
Average Fx litters	.02	.25	.28	.29	.30
Average number of pigs born alive per litter	9.0	7.8	9.4	6.4	8.9
Average birth weight	2.7	2.9	2.6	2.7	2.4
Average number weaned per litter	8.3	6.7	7.3	4.1*	8.0
Average weaning weight	33.3	34.6	35.1	31.7	30.0

* Baby pig sickness.

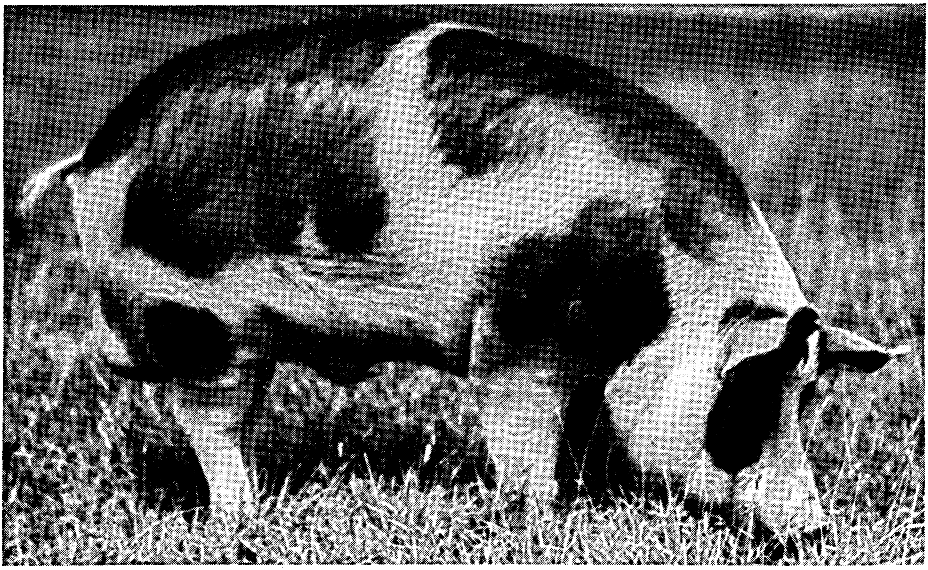


Fig. 27. Boar C401, a prominent herd boar born in 1947

tively high in the Minnesota No. 2 breed. The high initial inter se relationship of the foundation Poland China animals has been the important factor in establishing the high inter se relationship of the breed, which has risen steadily from .40 to .56. This means that the breed as a whole is as related as full litter mates in a non-inbred line. Also, since the animals used in the backcross were from the same Poland China lines as the original foundation stock, the backcross did not seriously affect the inter se relationship nor the inbreeding of the line. In addition, the fact that the foundation animals were closely related has likely been an important factor in establishing the relative similarity and constancy of the individual relationships to the various breeding herds (table 11).

Selection of breeding stock during development of the breed has been very stringent, as demonstrated by the continuing high performance during the period of continued inbreeding. Survival and weaning weight have been improved during the period of development of the line, while the other factors have been at least maintained.

The relatively short generation interval, 1.68 years, indicates that there has been a rapid turnover of breeding stock. This was especially true during the early years of the program when the breeding herds were composed solely of replacement stock.

Except for the original Yorkshire boar, no single individual has made an outstanding contribution to the breed. The Yorkshire boar has contributed 40 per cent of the heredity of the 1948 herd, the original foundation females range from 0.9 to 9.2 per cent. The contribution of the animals brought in for backcrossing also appears to be relatively low. The most important individual, the boar A724, has a direct relationship of 8.7 per cent to the 1948 herd. The relationship of many of these animals is not final however, since they do not appear in the pedigrees of all the present animals. The trend appears to be for a decline in the contribution made by the backcross individuals. This tendency may be observed in a study of relationship and an increase in the contribution of the F_2 and F_3 animals used at the time the backcrosses were made.

The F_1 pigs were all white, later generations segregated for color. Eventually a black and white spotted type became the standard for the breed. During the development of the line no pronounced abnormalities were observed.

SUMMARY

1. The development of the Minnesota No. 2 breed has been studied with special consideration given to the methods of breeding employed.
2. Foundation animals consisted of a Canadian Yorkshire boar and 13 Poland China gilts of the Black Star and Market Lady lines.
3. The Minnesota No. 2 breed theoretically consists of 40 per cent Yorkshire and 60 per cent Poland China genes.
4. A total of 246 animals was used in the breeding herd during the seven year period, 1942 to 1948. This included 207 females and 39 boars.
5. Selection of breeding animals was especially severe during the initial years of the development of the breed.
6. On the average about one half of the females selected for the breeding herd actually proved to be contributors. Very few selected males proved to be noncontributors. In general, males fail to be contributors because they sire litters that do not become test litters. Therefore their progeny cannot be selected as breeding stock.
7. An average coefficient of inbreeding of 28 per cent has been attained in the Minnesota No. 2 breed. The inter se relationship is 56 per cent.
8. Performance of the breed has been maintained or increased during the development of the breed.

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