UTILIZATION OF DUROC, HAMPSHIRE AND YORKSHIRE BREEDS OF SWINE IN VARIOUS MATING SYSTEMS

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CHAPTER I

INTRODUCTION

The advantage of crossbred dams and litters for increased pork production has been well documented by research. Crossbreeding of swine is currently employed by most producers who are involved in commercial production. Most recommendations to swine producers have been concerned with the relative merits of specific crosses and attempts to maximize individual and maternal heterosis. Additional considerations include ease of producing replacement females and simplicity of design.

Comparatively little research has considered the efficiency of different mating systems for pork productions, and these have dealt strictly with populations for which assumed breed values for production traits were used to make comparisons. Mating systems are defined herein to include all purebred and crossbred populations required to maintain breeding stock for a commercial operation. No research for efficiency of pork production could be found comparing mating systems which used actual breed performance and reproductive values based on experimental estimates.

There were two main objectives to this study. The first was to experimentally compare three-breed and backcross swine of Duroc, Hampshire and Yorkshire breeding for litter productivity and growth performance. These comparisons are an estimate of one-half individual heterosis and are important in making recommendations concerning mating systems to commercial producers. The backcross mating system may be preferred, inasmuch as only two purebred sources of breeding stock are required rather than three, and because this type of cross maintains 100 percent of the maternal heterosis.

The second objective was to compare the efficiency of swine production for different types of mating systems such as three-breed rotation, three-breed static and backcross systems, using the Duroc, Hampshire and Yorkshire breeds. These comparisons were based upon predicted cross performance obtained from eight years of crossbreeding research with those three breeds of swine at the Oklahoma Experiment Station. These comparisons should enable researchers and extention personnel to make more reliable recommendations to swine industry representatives and commercial producers concerning the types of mating systems which should be used to attain the specific objectives of the individual producer.

CHAPTER II

REVIEW OF LITERATURE

The four main objectives of the review of literature are to discuss: (1) methods of analyses for crossbreeding data, (2) efficiency of swine production and mating systems, (3) estimates of individual heterosis, and (4) estimates of differences between Duroc, Hampshire and Yorkshire breeds for reproductive and postweaning performance. The scope of this review is not to extensively review swine crossbreeding data, as this has been done by Sellier (1976) and Johnson (1973).

Analysis of Crossbred Performance

The analysis of crossbreeding experiments has received considerable attention in literature over the past 30 years. Several researchers have examined the genetic expectations which underlie crossbreeding experiments. Henderson (1952) presented a method of analysis which defined progeny of a two-line cross to have an effect due to the general combining ability of a line to have an effect (in addition to the additive genetic value) common to all progeny of the line used as a female parent, and to have an effect common to all progeny of the cross between two specific lines (specific combining ability).

Dickerson (1969) discussed the evaluation of breed crosses to identify those breeds which could be better utilized in certain mating systems. In most cases the number of breeds available and the number of purebred, two-breed, three-breed, and other combination crosses prohibits the experimental evaluation of all specific crosses. Dickerson (1969) proposed the analysis of breed and breed-cross means to estimate parameters used in estimating crossbred performance and in projecting which mating system or particular cross is better suited to the particular production or management schemes.

The genetic parameters are defined as:

g_A^I = deviation due to average direct effects of the individual's own genes, for breed A;

g_A^m = deviation due to average effects through maternal environment, for genes of breed A dams;

$g_A^{m'}$ = deviation due to average effects of genotype for breed A maternal granddams, through modification of direct maternal effects;

h_{AB}^I = deviation due to increased average heterozygosity of F_1 crossbreds from A males x B females, or their reciprocals;

h_{AB}^m = same as h_{AB}^I, but for crossbred maternal environment;

$h_{AB}^{m'}$ = same as h_{AB}^m, but through maternal environmental interaction effects of F_1 crossbred maternal granddams on the maternal influence of the dam;

r_{AB}^I = deviation due to change in non-allelic gene interaction effects in F_2 individuals, relative to those of the F_1, from gametic recombinations between chromosomes of the parent breeds A and B;

r_{AB}^m = same as r_{AB}^I, but for indirect maternal environmental effects;

$r_{AB}^{m'}$ = same as r_{AB}^m, but through maternal environmental interaction effects of maternal granddams on the maternal influence of the dams.

Under the assumption of linearity between degree of heterozygosity and dominance and recombination effects, breed or breed-cross means can be written in the following manner:

$$A \times A = g_A^I + g_A^m + g_A^{m'} + \text{joint effects}$$

$$A \times B = \frac{g_A^I}{2} + \frac{g_B^I}{2} + g_B^m + g_B^{m'} + h_{AB}^I + \text{joint effects}$$

$$C \times (AB) = \frac{g_C^I}{2} + \frac{g_A^I}{4} + \frac{g_B^I}{4} + \frac{g_A^m}{2} + \frac{g_B^m}{2} + g_B^{m'} + \frac{h_{CA}^I}{2} + \frac{h_{CB}^I}{2} + h_{AB}^m + \frac{r_{AB}^I}{2} + \text{joint effects.}$$

Dickerson (1973) has extended these comparisons to the expected average gain in performance over the weighted mean of the purebred parents as follows:

$$\text{2-Breed or } F_1 \text{ (A male x B female)} = h_{AB}^I + \frac{1}{2}(g_B^m - g_A^m + g_A^p - g_B^p);$$

$$\text{3-Breed, C male x (AB female)} = \frac{1}{2}(h_{CA}^I + h_{CB}^I) + h_{AB}^m + \frac{1}{2} r_{AB}^I + \frac{1}{2}(g_{A,B}^m - g_C^m + g_C^p - g_{A,B}^p);$$

$$\text{4-Breed (CD male) x (AB female)} = h^I + h_{AB}^m + h_{CD}^p + \frac{1}{2}(r_{CD}^I + r_{AB}^I) + \frac{1}{2}(g_{A,B}^m - g_{C,D}^m + g_{C,D}^p - g_{A,B}^p);$$

$$\text{Rotation, n sire breeds} = \frac{(2^n - 2)}{(2^n - 1)} h^I + h^m + \frac{1}{3}(r^I + r^m);$$

$$\text{C male x Rotation female} = h^I_{C(Rot)} + \frac{(2^n - 2)}{(2^n - 1)} h^m + \frac{1}{3}(r^I + r^m)_{Rot} + \frac{1}{2}(g^m_{Rot} - g^m_C + g^p_C - g^p_{Rot}); \text{ and}$$

$$\text{Synthetic, n breeds} = \frac{(n-1)}{n}(h^I + h^m + h^p + r^I + r^m + r^p) \text{ or } (1 - \sum_{i=1}^{n} q_i^2)(h^I + h^m + h^p + r^I + r^m + r^p);$$

where q_i = fraction of each n breeds in parentage. The g^I, g^p and g^m are defined to be the breed differences in individual and paternal performance compared to maternal performances for the purebreds.

Carmon et al. (1956) derived the prediction equation for prediction of rotational crossbreeding based on purebred and single-cross mean performance. The equation for predicting two-breed rotation performance was $R_2 = S_2 - (S_2 - \bar{X}_2)/3$, where R_2 is the predicted rotation performance, S_2 is the phenotypic mean of the two-single crosses, and $\bar{X}_2$ is the mean performance for the two purebreds. These were also extended to crosses with additional breeds.

If heterosis is linear with percentage of heterozygosity, then these parameters and equations can readily be adapted to estimating breed cross reproductive rates, growth performance and carcass characteristics of different breed combinations.

Moav (1966a) outlined the procedures for an economic analysis for sire and dam breeds when heterosis is present. A profit curve was derived producing a profit contour for different crosses. The following equation applies for the case where genetic additivity and independence of the component traits are assumed.

$$\text{Profit} = \text{Constant} - \frac{G}{2}(y_s + y_d) - \frac{N}{X_d}$$

where G is the economic value for a production trait such as feed efficiency, y_s and y_d are the genetic values of the sire and dam lines for feed efficiency, N is an economic constant for the cost of reproduction, and X_d is the reproductive rate of the female line. This was extended to include values for heterosis, or non-additivity, for production traits, along with maternal and paternal heterosis for reproduction (Moav, 1966b). Profit contours for different breeds can then be calculated once the economic constants have been derived. Although these procedures are not easily adapted to more than two traits, they do aid in understanding the problem of comparing and economically evaluating different lines as sources of sires and dams. The model used for heterosis and genetic additivity assumes that individual and maternal heterosis is constant for all lines and is linear with degree of heterozygosity in the crossbred individual and dam. This method does allow for the ranking of specific breed crosses or comparison of these to expected performance for crossbred combinations which have not been tested. Then a few likely crosses may be identified and experimentally tested.

An example using poultry broilers demonstrated crossing four unrelated lines which had different levels of production. The most profitable cross in this case was a three-breed cross $S_1(S_2D_1)$. In this example a four-way cross $(S_1S_2)(D_1D_2)$ is not as profitable as the three-breed cross. In the case of four breeds with sire and dam lines of equal value, the most profitable combination is $S_2S_1(S_1D_1)$ but is only slightly more profitable than $S_2(S_1D)$. From that work is was apparent that various crosses may have similar economic value for commercial production. Since the profit contours were for terminal crosses only, the crossbred progeny which were most profitable may not be most profitable when the purebred and crossbred populations which are needed to produce the terminal crossbred progeny are evaluated as a breeding system.

Efficiency of Swine Production and Mating Systems

Dickerson (1973) compared the number of sows required per 1000 market pigs for mating systems with five theoretical breeds comprising the purebreds which were potential breeds for use in the mating systems. A static three-breed cross was used as a standard in comparing numbers of sow years per 1000 market pigs. The assumptions of 7 percent heterosis in crossbred litters from purebred sows, 25 percent heterosis in crossbred litters from crossbred sows, and 10 percent increase in growth efficiency of crossbred pigs were used. The sire lines raised 6.0 pigs per sow and had a net value of 108 percent while the other lines had either 8.0 or 8.5 pigs per litter with a net value of 95 percent or 100 percent.

With these assumptions, two-breed crosses required 15 percent more sow years per 1000 pigs than the static three-breed cross. A synthetic male line crossed with an F_1 of two synthetic female lines had 1 percent fewer sows if recombination effects were zero. If recombination effects were equal to heterosis values, 18 percent more sows were required. A synthetic male line crossed with a four-breed rotation female was equal to the three-breed cross for production. A rotation cross of the four female lines had 6 percent more sow years per 1000 market pigs than the three-breed static system.

The efficiency of meat production with different mating systems has been studied in beef cattle and sheep. Cartwright et al. (1975) studied beef cattle systems consisting of three mature cow body sizes and two management regimes. Returns were compared on a fixed amount of input. Two-breed crosses were similar in returns to crisscross breeding schemes; however, single crosses utilizing complementarity did exceed the best crisscross patterns. Three-breed crosses utilizing large body size sires on either F_1 cows or crisscross cows gave an increased amount of efficiency and higher returns per fixed amount of input.

Nitter (1978) compared the number of ewes which were required to produce a given amount of lamb. When there was no superiority in growth rate for the terminal sire line, three-breed rotation, three-breed static, and the terminal sire on a two-breed rotation female were of similar efficiency. As the superiority for growth potential of the terminal sire line increased to 20 and 40 percent, the terminal sire crosses became the most efficient for lamb production.

In studying these mating systems, some method of comparison based on an economic or relative economic basis must be developed to know which mating systems are most efficient. Figure 1 depicts the expense and income equations for individual swine as defined by Harris (1970, p. 861).

There are several economic values which can be considered as constants when comparing mating systems using different breeds and crossbreds. These constants would be slaughter costs, cost per unit feed, labor and facilities costs per unit of time for finishing and farrowing.

$$\text{Expenses} = \begin{matrix}\text{Slaughter}\\ \text{Costs}\end{matrix} + \begin{pmatrix}\text{Cost Per}\\ \text{Unit Feed}\end{pmatrix} \begin{pmatrix}\text{Feed}\\ \text{Consumed}\end{pmatrix} + \begin{pmatrix}\text{Labor and}\\ \text{Facilities}\\ \text{Cost Per}\\ \text{Unit Time}\end{pmatrix} \begin{pmatrix}\text{Time to}\\ \text{Slaughter}\\ \text{Weight}\end{pmatrix}$$

$$+ \frac{\begin{matrix}\text{Cost of Gilt}\\ \text{Production}\end{matrix} + \begin{pmatrix}\text{No. of}\\ \text{Litters}\end{pmatrix} \begin{pmatrix}\text{Sow Herd Labor}\\ \text{and Facilities}\\ \text{Cost Per Litter}\end{pmatrix} + \begin{matrix}\text{Sow and}\\ \text{Litter Feed}\\ \text{Cost}\end{matrix} + \begin{matrix}\text{Boar}\\ \text{Cost Per}\\ \text{Litter}\end{matrix} - \begin{matrix}\text{Salvage}\\ \text{Value for}\\ \text{Old Sow}\end{matrix}}{\begin{pmatrix}\text{No. of}\\ \text{Litters}\end{pmatrix} \begin{pmatrix}\text{Avg. Litter}\\ \text{Size}\end{pmatrix} \begin{pmatrix}\text{Pig}\\ \text{Survival}\end{pmatrix}} .$$

$$\text{Income} = \begin{pmatrix}\text{Carcass}\\ \text{Weight}\end{pmatrix} \begin{pmatrix}\text{Carcass}\\ \text{Quality}\end{pmatrix}$$

Figure 1. Expense and Income Equations

Cunningham (personal communcation, 1978) has given an estimate for labor and facilities cost of \$.10 per day for finishing swine. Total gestation and lactation costs for a sow and her litter to an average pig weight of 18 kg were estimated to be \$260 per litter. Feed costs were approximated to be \$.11 per kg for finishing rations and \$.23 per kg for sow rations. In calculating the value of reduced backfat, \$2.75 per 100 kg of carcass weight was assumed to be the economic difference between a No. 2 and No. 3 carcass with an average difference of .89 cm of backfat (Cunningham, personal communication). This difference gives a value of \$2.16 for each cm that backfat is reduced.

Dickerson (1970, p. 849) defined an equation for the ratio of expenses per year to produce value per year. His equation, similar to the one described above by Harris, follows:

$$\frac{\text{Expense/Year}}{\text{Produce/Year}} = \frac{(A/Y) + (I_d + B_d \cdot \bar{F}_{md} + F_{pd})}{N \cdot P_o \cdot V_o} + \frac{D(I_o + B_o \cdot \bar{F}_{mo} + \bar{F}_{po}) + S_o}{P_o \cdot V_o}$$

where

A/Y = (cost, young female - value, old female) per years in production;

I_d = yearly fixed costs per female, for labor, housing, etc.;

B_d = metabolic body size of female, relative to population mean;

$\bar{F}_{md}$ = average maintenance feed costs per female per year for population;

$\bar{F}_{pd}$ = feed costs above maintenance per female per year;

N = number progeny marketed per female per year;

P_o = line weight of meat animal when marketed;

V_o = value per unit of live weight;

D = days from weaning to market weight for individuals;

I_o = average fixed costs per animal-day;

B_o = average postweaning metabolic body size for individual, relative to population mean;

$\bar{F}_{mo}$ = average maintenance feed cost per animal-day for population;

$\bar{F}_{po}$ = average feed costs above maintenance per day individual;

S_o = fixed costs per animal for slaughter, marketing, vaccines, etc.

From both equations it can be seen that rate of reproduction, time and feed to market weight for offspring, and product value are important in evaluation of mating systems or defining objectives for selection within swine populations. Sow cost per pig is determined by (total reproductive cost per sow ÷ number of progeny); thus at higher rates of reproduction the economic advantage of increasing the number of progeny per sow becomes less (Moav and Hill, 1966).

Fahmy et al. (1976) used an index to evaluate different crossbreds for production traits. The index was as follows:

$$I = \frac{(\bar{Y}_{1i} - \bar{Y}_1)}{\sigma_1} - C_1 \frac{(Y_{2i} - \bar{Y}_2)}{\sigma_2} + \frac{C_2(Y_{3i} - \bar{Y}_3)}{\sigma_3}$$

where C_1 and C_2 are economic constants, $(Y_i - \bar{Y})$ is the least squares deviation of cross i from the overall mean, and σ_i is the estimated phenotypic standard deviation for each trait.

In evaluating breeds for use in particular mating systems, decisions must be made as to which breeds are to be used as dam lines and which breeds are better suited as sources of sires. Additionally, decisions must be made as to selection criteria and to whether sire and dam lines should be selected for the same or different characteristics. Smith (1964) investigated the development of selection indexes for dam and sire lines using a range of genetic parameters. In that simulation study, selecting each line on a different index was always as efficient as selecting one line on the same index. Separate indexes did become more efficient if there were unfavorable genetic correlations between traits. If selection in the dam line ignores additive genetic value for post-weaning traits, the rate of progress could be reduced.

Moav and Hill (1966) in a theoretical example compared selection for feed conversion and number of pigs per sow per year under three schemes, i.e., selection in one line using one index, selection in one line using male and female indexes, and selection in two lines using two indexes. In their example, selection in two lines with two different indexes was most efficient. The magnitude of the total economic advantage would change depending upon the genetic correlations and heterosis achieved by crossing the two parent lines.

Bichard (1971) considered the rate of dissemination of genetic improvement from selection in a nucleus herd through the multiplier and commercial herds. Several methods of transferring breeding stock were discussed. In swine herds the transferring of females among the three tiers and males direct from nucleus to commercial herds reduced the improvement lag $7\frac{1}{2}$ to $2\frac{5}{8}$ years when compared to the traditional three-tier system with only males being transferred between adjacent tiers. Consideration was given to achieving a balance between minimizing the time lag for dissemination of genetic improvement and the declining overall efficiency of a breeding system, since almost all methods of increasing genetic improvement result in decreased short-term returns.

The literature comparing biological or economic efficiency of swine mating systems is limited. Mating systems have been compared for efficiency using hypothetical breeds with assumed values for reproductive traits and postweaning performance. No reports could be found which used estimates of breed performance from experimental results to compare mating systems for swine production.

Individual Heterosis Estimates

Numerous experiments involving swine crossbreeding have been reported estimating both individual and maternal heterosis for reproductive, growth and carcass traits.

The following are average individual heterosis estimates from several experiments (Sellier, 1976):

Litter size at birth	.30 pig
Litter size at weaning	.45 pig
Individual weight at weaning	.50 kg
Litter weight at weaning	9.00 kg
Postweaning daily weight gain	.04 kg/day
Age at slaughter	-10 days
Feed conversion	-.08 kg feed/kg gain
Body composition and meat quality	0

Young et al. (1976a) reported individual heterosis estimates for reproductive traits with Duroc, Hampshire and Yorkshire breeds of swine. Heterosis estimates for number of pigs at birth, 21-day, and 42-days, were: .38 ± .26, .65 ± .23, and .76 ± .23, respectively. Duroc-Yorkshire crosses showed the most heterosis and Duroc-Hampshire crosses had the least.

Crossbred litters were heavier at birth, 21- and 42-days, by .50 ±

.27 kg, 3.70 ± 1.10 kg, and 9.47 ± 2.43 kg, respectively. Average pig weight heterosis was not significant for these three measurements.

The estimates of heterosis for growth and carcass characteristics of the same Duroc, Hampshire and Yorkshire crosses were reported by Young et al. (1976b). The estimates were as follows: average daily gain (.054 ± .007 kg/day), days to 100 kg (-9.9 ± 1.3 days), probe back-fat thickness (-.06 ± .03 cm), kg of gain per kg of feed consumed (.0073 ± .0030), and average daily feed intake (.077 ± .037 kg/day). Carcass length was the only carcass trait which exhibited significant heterosis.

Schneider (1976) calculated heterosis estimates for the Chester White, Yorkshire, Duroc, and Hampshire breeds for number of pigs born, number of pigs at 21-days, and number of pigs at 56-days to be .0 ± .39, .26 ± 36 and .29 ± .36, respectively. Heterosis for litter weight was .4 ± .5 kg at birth, 3.0 ± 2.1 kg at 21-days, 15.0 ± 6.8 kg at 56-days, and 104.4 ± 32.2 kg at 154-days. As seen in most studies carcass traits showed little heterosis with carcass length, carcass backfat, ham-loin percent, and dressing percent having statistically nonsignificant values.

A six-year study reported by Winters et al. (1935) compared F_1 cross, three-breed cross, and backcross swine for productivity and feed-lot performance. Although limited by numbers, the study does show interesting results. For litter weight at birth and number of live pigs the F_1, three-breed and backcross pigs had an advantage of 2.83 lb, 4.38 lb and 3.53 lb, and .93, 1.66 and -.19 pigs, respectively. At weaning three-breed cross litters had an advantage of 2.05 pigs as compared to .68 pig for backcross litters and .33 pig for F_1 crosses. Total litter weight followed the same pattern with three-breed crosses being heavier than the respective purebreeds by 96 lb, the backcross by 63 lb and the F_1 by 39 lb. Backcross pigs averaged 2 lb heavier than the F_1 and three-breed cross pigs at weaning.

The advantage for the crossbred pigs continued throughout the finishing period for these pigs. The advantages in average daily gain over the purebreds were .12, .11 and .14 lb per day for the F_1, three-breed and backcross, respectively. Three-breed cross pigs required 16.2 lb less feed per 100 lb gain, with the F_1 and the backcross having similar feed efficiency of 12.68 and 12.15 lb of feed per 100 lb gain.

From these results they concluded that there were apparently small differences, if any, between the three-breed cross and backcross for feedlot performance. However, three-breed cross litters showed a marked advantage for number of pigs weaned per litter and total litter weight.

Estimates of Performance for Duroc, Hampshire and Yorkshire Breeds

The performance of Duroc, Hampshire and Yorkshire breeds of swine have been evaluated by several researchers. Nelson and Robison (1976) reported on several specific two- and three-breed crosses utilizing those breeds. In two-breed crosses, Hampshire boars sired the greatest number of live pigs per litter but had the lowest survival rate to weaning. Duroc boars sired the smallest litters at birth but had the greatest survival percentage to weaning. Duroc-sired litters averaged 8.03 ± 0.81 pigs at weaning while Yorkshires averaged 7.86 ± 0.85 and Hampshires averaged 7.67 ± 0.85. Yorkshire dams averaged the largest litters at birth and weaning. They had 8.60 ± 0.85 pigs at weaning while Duroc and Hampshire were very similar with 7.43 ± 0.81 and 7.51 ± 0.85 pigs per litter, respectively. Breed of sire was nonsignificant for number of pigs at birth or 42-days and for average pig weight at these same times. Breed of dam was significant for average pig weight at birth and weaning with Yorkshire dams having the lightest pigs at weaning.

Young et al. (1976a) in an experiment with these three breeds, in which the purebred matings were also included, showed that Yorkshire-sired litters were 0.73 ± 0.35 pigs larger at birth and 1.16 ± 0.30 pigs larger at weaning than those sired by Hampshires. Similarly, Yorkshire-sired litters were 0.25 ± 0.35 pigs larger at birth and 0.63 ± 0.29 pigs larger at weaning than Duroc-sired litters. Yorkshire dams had significantly larger litters at birth and weaning than Duroc and Hampshire dams (0.77 ± 0.32, 1.96 ± 0.31 and 1.18 ± 0.27; 1.43 ± 0.27 pigs, respectively). Litters from Yorkshire sires and dams were significantly heavier at weaning than those from Duroc or Hampshire; however, there were only small differences in average pig weight.

Schneider (1976) estimated the general combining ability of these breeds and found the Hampshire breed to be 0.47 pig and 0.65 pig greater for number born than Yorkshire and Duroc, respectively. At 56-days Yorkshire and Duroc were about the same for number of pigs while Hampshire was about 0.40 pig less.

When Duroc, Hampshire, Yorkshire and Poland sires were mated to two-breed cross gilts of Duroc, Hampshire and Yorkshire breeding, Poland boars sired litters which had significantly fewer pigs at weaning (Nelson and Robison, 1976). Breed of dam was not significant for litter size or average pig weight at birth or weaning.

Breed of sire and breed of dam were significant for weight at 140-days and average backfat probe for the two-breed crosses previously mentioned. Duroc-sired pigs were heaviest at 140-days (72.5 ± 1.5 kg) while Hampshire-sired pigs were the lightest (66.9 ± 1.6 kg). Yorkshire-sired pigs had the greatest amount of backfat probe (2.34 ± 0.05 cm) and Hampshires had the least (2.03 ± 0.05). Those pigs with Hampshire dams were lightest at 140-days (68.3 ± 1.5 kg) and Yorkshire were the heaviest (70.9 ± 1.6 kg). Maternal estimates ranked Yorkshire higher than Duroc and ranked both significantly higher than Hampshire for number of pigs born. At 56-days Yorkshire maternal effect was about .3 pig larger than Duroc and Hampshire, which were very similar for number of pigs.

General combining ability for 56-day litter weight for Duroc, Hampshire and Yorkshire was 15 ± 14, -20 ± 15 and 6 ± 14 lb, respectively. Maternal estimates were quite similar for all three breeds.

Fahmy et al. (1971) reported an experiment in which seven breeds of sows were mated to produce crossbred progeny. Although somewhat confounded by different number of sire breeds per breed of dam, Yorkshire dams produced litters which were significantly larger than Hampshire dams at birth, 21-days and weaning. Duroc dams were intermediate. These three breeds of dams ranked in the same order for litter weight at those same ages. All three were very similar in percent mortality from birth to weaning. As with the sires, Yorkshire dams had the greatest backfat probe (2.23 ± 0.05 cm) while Duroc and Hampshire were very similar (2.16 cm and 2.13 cm). The three-breed cross analysis showed that breed of sire was significant for backfat probe and total litter production but not for weight at 140-days. Breed of dams was significant for backfat probe only.

Young et al. (1976b) reported on growth, probe backfat and feed conversion for Duroc, Hampshire and Yorkshire breeds. Duroc-sired pigs were significantly younger at 100 kg than Hampshire-sired pigs (-4.8 days) and Yorkshire-sired pigs (-3.5 days). Yorkshire and Duroc dams produced pigs which were similar in age at 100 kg, and both were about 3 days younger at 100 kg than pigs with Hampshire dams. Duroc- and Yorkshire-sired gilts were similar for probe backfat thickness but Hampshire-sired gilts had about .2 cm less backfat. Yorkshire dams produced barrows which had significantly less probe backfat than Duroc or Hampshire dams. Hampshire-sired pigs had the best feed conversion ratio which was significantly better than Yorkshire-sired. Hampshire-sired pigs also had the smallest average daily feed consumption. Pigs with Yorkshire dams were significantly more efficient in feed conversion than those with Duroc and Hampshire dams. They also had significantly less average daily feed intake.

Linear Programming

Linear programming techniques have been used previously to compare beef mating systems (Cartwright et al., 1975) and beef production systems (Wilton et al., 1974; Long et al., 1975; and Fitzhugh et al., 1975). These papers compared the efficiencies of various beef production systems on the basis of net returns per fixed amount of input based on estimated costs and returns.

Linear programming is a method of finding the optimal use of resources, given specific linear constraints and several alternative methods to produce a product (Heady and Candler, 1958). The objective function of linear programming can be either to maximize or minimize by choosing the optimal amounts of production within the specifications and restrictions of the particular problem. The answers from linear programming can be interpreted only in context of the estimates of parameters which were used for the problem, and are subject to the constraints of the problem.

Heady and Candler (1958) described the assumptions which underlie linear programming and its application. The first assumption is additivity and linearity, which means that the activities or production alternatives must have a linear response over the range of the problem and not have an interaction at different levels of production. In terms of a mating system context, an example would be that a certain breed cross would produce the same number of pigs per litter whether 10 or 1000 sows of that breed or cross farrowed litters.

Another assumption is divisibility, or that fractional units of a product can be produced. Normally, this is not a limitation because rounding of production to the nearest whole unit does not greatly alter the optimal solution (Heady and Candler, 1958).

The third assumption is that of finiteness, or that there is a limited number of alternatives or limitations which need to be examined. The final assumption is single value expectations. This means that the values and coefficients which are used are known with certainty. This is probably the most serious limitation of comparing mating systems, since most of the coefficients are not known with absolute certainty.

In this study linear programming techniques were used to find the optimum number of pigs produced and not necessarily to study the relationship between the variables and alternative methods of crossbred pig production within a mating system.

Most of the crossbreeding research with swine has dealt with estimating individual heterosis, maternal heterosis and the performance of specific crosses. The Duroc, Hampshire and Yorkshire breeds and their crosses have been the major breeds compared in most recent crossbreeding work done in the United States. The differences between these breeds for reproductive traits, postweaning performance and carcass merit have been studied extensively. However, since the primary effort to date has been to estimate amount of heterosis for important traits and to compare breed performance, there has been no reported research comparing these three breeds in mating systems other than purebreds, two-breed static crosses or three-breed static crosses. Thus, there was a need to experimentally evaluate other mating systems and to compare several different mating systems for efficiency of pig production.

CHAPTER III

COMPARISON OF THREE-BREED AND BACKCROSS SWINE FOR LITTER PRODUCTIVITY AND POSTWEANING PERFORMANCE

Summary

Duroc, Hampshire and Yorkshire boars were mated with crossbred gilts of Duroc-Hampshire, Duroc-Yorkshire and Hampshire-Yorkshire breeding to produce 392 three-breed and backcross litters which were farrowed during four seasons beginning in the fall of 1975. Comparison of three-breed cross litters to backcross litters was of interest because this estimates one-half the individual heterosis. Three-breed cross litters were .31 ± .27, .57 ± .24 and .50 ± .24 pigs larger at birth, 21 and 42 days, respectively. Correspondingly, these litters were .6 ± .34, 2.3 ± 1.2 and 5.4 ± 2.4 kg heavier at these ages. The differences for average pig weight and survival percent were small and not significant. For postweaning traits, three-breed cross litters gained faster (0.24 ± .007 kg/day) and were younger (-4.7 ± 1.5 days) at 100 kg. Three-breed cross pigs were about 3 percent more efficient than backcross pigs. The differences for average backfat probe and average daily feed intake were small and not significant.

Breed of sire contrasts were small and not significant for litter traits. Duroc-sired pigs were six days younger than Hampshire-sired pigs ($P < .01$) at 100 kg and were more efficient than Yorkshire-sired pigs ($P < .05$). Hampshire-sired pigs had .35 ± .04 and .23 ± .04 cm

less average backfat probe than Duroc- and Yorkshire-sired pigs, respectively. Yorkshire-sired pigs also had less backfat probe than pigs by Duroc sires ($P < .01$).

Differences among Duroc-Hampshire, Duroc-Yorkshire and Hampshire-Yorkshire crossbred females were small for number of pigs and for total litter weight at birth, 21-days or 42-days. At 21-days pigs with Duroc-Yorkshire dams had the lightest average pig weight ($P < .05$). Litters with Duroc-Hampshire or Duroc-Yorkshire dams grew faster in the feedlot ($P < .01$) but had greater average backfat probe ($P < .01$) than those with Hampshire-Yorkshire dams. Pigs with Duroc-Yorkshire dams were more efficient than those with Duroc-Hampshire dams ($P < .05$) but were similar to those with Hampshire-Yorkshire dams.

Introduction

Average heterosis values for swine have been calculated in a review of swine crossbreeding by Sellier (1976). Estimates for individual heterosis were: .45 pig per litter at weaning, 9 kg heavier litter weight at weaning, 10 days younger at 100 kg and no heterosis for body composition. Several reports on specific two- and three-breed crosses of swine (Smith and McLaren, 1967; Fahmy, et al., 1971; Fahmy and Bernard, 1971; Young et al., 1976a,b; Nelson and Robison, 1976; Schneider, 1976; and Johnson et al., 1978) have clearly shown the advantage of individual and maternal heterosis.

Moav (1966a,b) and Dickerson (1969, 1973) have developed theoretical bases for evaluating a particular cross or breed combinations in mating systems. There is a lack of experimental results for evaluating different mating schemes. Experimental results are also lacking in verifying whether the amount of heterosis is proportional to degree of heterosygosity.

The purpose of this experiment was to evaluate three-breed cross and backcross pigs from dams with Duroc-Hampshire, Duroc-Yorkshire and Hampshire-Yorkshire breeding for litter and growth traits. Questions of specific interest were to compare the estimate of one-half individual pig heterosis from this study to earlier estimates of heterosis, and to compare the performance of the three types of crossbreed dams and sire breeds for litter traits, growth performance, backfat probe, and feed efficiency.

Materials and Methods

The 392 backcross and three-breed cross litters of Duroc, Hampshire and Yorkshire breeding were farrowed and raised at the Southwest Livestock and Forage Research Station, El Reno, Oklahoma. Farrowings were during four seasons beginning in the fall of 1975 and ending with the spring farrowing in 1977.

Purebred boars and crossbred females used in this study were produced at the Stillwater swine farm from the purebred Duroc, Hampshire and Yorkshire herds which were established in 1969 (Johnson et al., 1975). All females farrowing in this study were gilts.

An eight-week breeding season was used each time, with the fall breeding season beginning December 1 and the spring breeding season beginning June 1. All gilts were farrowed in a central farrowing house with crates and slotted wood floors. At approximately one week of age the litters were moved to a nursery with individual pens and solid concrete floors. All boars were castrated at 21 days of age and creep feed was offered at this time. Litters were weaned at 42 days and were moved approximately two weeks later to the finishing barn. Pigs were group-fed in concrete pens with 10 to 18 per pen. They were allotted to pens by breed group, with barrows and gilts mixed in pens, starting on test at approximately nine weeks of age. They were fed standard 16 and 14 percent protein rations with either wheat (International reference number 4-05-268) or grain sorghum (International reference number 4-05-643) as the grain base. Pigs were weighed weekly as they approached 100 kg, at which time they were probed for backfat and marketed.

All gilts that were saved for breeding were considered sound for breeding. Records were kept on whether a gilt was not detected in estrus, was detected in estrus but did not become pregnant, or became pregnant. The records of five sows which farrowed were deleted from analysis for 21- and 42-days, because one sow died and four sows lost their litters between birth and 21 days.

Table I shows the experimental design and number of boars, sows and pigs of the nine breed combinations. Data were collected on the reproductive failure rate of the gilts, litter size, litter weight, and individual pig weight at birth, 21- and 42-days. Growth rate, days to 100 kg, average backfat probe, and pen feed efficiency were collected on postweaning performance. All fully formed (alive or dead) pigs were included in litter size at birth.

All statistical analyses for litter productivity and postweaning performance were done on litter means. Average daily gain, days to 100 kg, and average backfat probe measurements for gilts were adjusted to a barrow basis by adding the mean difference between barrow and gilt records to gilt records.

TABLE I

EXPERIMENTAL DESIGN AND DISTRIBUTION OF SIRES, LITTERS AND PIGS

Breed of Sire	Number of Sires	Breed of Gilt[a]	Number of Litters at Birth	Number of Litters 21 and 42 Days	Number of Pigs in Feedlot	Number of Pens for Feed Efficiency
Duroc	24	D x H	46	44	324	15
		D x Y	44	44	275	14
		H x Y	43	42	310	17
Hampshire	23	D x H	43	43	260	13
		D x Y	42	42	307	13
		H x Y	43	42	247	11
Yorkshire	25	D x H	48	47	321	17
		D x Y	41	41	278	15
		H x Y	42	42	267	11
Total	72		392	387	2589	126

[a]D = Duroc, H = Hampshire, Y = Yorkshire. Breed of gilt includes reciprocal crosses (D x H includes both D x H and H x D females) in approximately equal numbers.

The statistical model used to analyze the data was:

$$y_{ijklm} = \mu + S_i + B_j + (SB)_{ij} + r_{k(ij)} + D_l + (SD)_{il} + (BD)_{jl} + (SBD)_{ijl} + e_{m(ijkl)},$$

where y_{ijklm} is the litter mean from the i^{th} year-season, j^{th} breed of sire, k^{th} sire within season-year and breed of sire, and l^{th} breed of dam. Variables $r_{k(ij)}$ and $e_{m(ijkl)}$ were assumed to be normally distributed independent random variables with zero mean and variance σ_r^2 and σ_e^2, respectively. All remaining factors were assumed to be fixed. Initial analysis showed that sire within season-year and breed of sire was not significant for average number of pigs at birth, 21- or 42-days, or for litter weight at these times. Therefore, the analyses for these traits were done with a model including season, breed of sire, breed of dam, two-factor interactions and three-factor interactions. Least squares means from the mixed model analyses were computed using Harvey's procedures (1972). Least squares means for each season were averaged over season. Sire within breed of sire and season mean square was used to test season, breed of sire, and the two-way interaction. Linear contrasts of interest compared backcross and three-breed cross litters, breeds of sire and breeds of dam. The comparison of backcross and three-breed cross litters estimates one-half of the individual heterosis (Dickerson, 1969).

Results and Discussion

Reproductive Efficiencies

The distribution of reproductive success and failure is shown in Table II. There were no significant differences between the reciprocal

TABLE II

CONCEPTION RATE FOR BREEDS OF DAM

Breeding of Gilt[a]	Number Saved for Breeding	Number Farrowing	Number not Mating	Number Open	Conception Rate Based on Gilts Mated	Conception Rate Based on Gilts Saved
D x H	161	137	3	21	86.7	85.1
D x Y	144	127	3	14	90.1	88.2
H x Y	148	129	6	13	90.8	87.2
Total	453	393	12	48	89.1	86.8

[a]D = Duroc, H = Hampshire, Y = Yorkshire. Breed of gilt includes reciprocal crosses (D x H includes both D x H and H x D females) in approximately equal numbers.

cross females; thus they were combined. The differences between the breed groups were very small for conception rate whether it was based on the number retained for breeding or the number which mated. The percentage of females which did not mate was 2.7 percent, as compared to 8 percent in crossbreds and 10 percent in purebred females reported by Johnson et al. (1978).

Analyses of Variance

The comparisons of sire mean squares and residual mean squares are shown in Table III. Sire within year-season and breed of sire mean square was significant for average pig weight at birth and at 21-days, and for survival percent from birth to weaning. The failure of sire to be significant for litter size is in agreement with Reddy et al. (1958). Young et al. (1976a) and Johnson et al. (1978) found that sire of the litter was significant or approached significance for litter size at birth, 21- and 42-days, for litter weight at birth, and for average pig weight at 21- and 42-days. Fahmy et al. (1978) reported that sire of litter was a significant source of variation for survival rate at one of four locations.

Tables IV and V contain the analyses of variance for litter productivity traits. Although not of primary interest in this study, year-season was significant for most of the litter traits except litter birth weight and number of pigs at 21-days. Breed of dam was significant for average pig weight at birth, 21- and 42-days, and approached significance for litter birth weight. The breed of sire by breed of dam interaction was significant for number of pigs at 21- and 42-days and for total litter weight at these ages. Breed of sire was not significant for any

TABLE III

COMPARISONS OF SIRE AND RESIDUAL MEAN SQUARES FOR LITTER TRAITS

		Mean Squares									
		Birth			21-Days			42-Days			
Source	df	No. Pigs	Litter Wt., kg	Avg. Pig Wt., kg	No. Pigs	Litter Wt., kg	Avg. Pig Wt., kg	No. Pigs	Litter Wt., kg	Avg. Pig Wt., kg	Survival Percent
Sire (Season Bos)	60	6.15	8.52	.0585[a]	4.14	110.60	.8600[a]	4.39	485.90	2.93	566.90[a]
Residual	296	6.25	10.46	.0398							384.30
	291				5.23	116.3	.6300	5.20	478.50	2.55	

[a]$P < .05$.

TABLE IV

ANALYSES OF VARIANCE FOR LITTER BIRTH TRAITS

Source	df	Mean Square			
		No. Born	Litter Birth Wt., kg	Average Pig Wt., kg	Percent Survival
Season	3	24.97[a]	17.79	.1589[b]	4465.6[c]
Bos	2	9.73	13.28	.0492	284.5
Season* Bos	6	3.60	4.87	.0069	341.8
Sire (Season Bos)	60			.0585[d]	566.9[d]
Bod	2	3.68	28.10[b]	.3331[c]	181.4
Season* Bod	6	4.25	18.94[b]	.0683	66.1
Bos[d] Bod	4	7.70	12.92	.0708	477.6
Season* Bos* Bod	12	5.40	7.80	.0396	398.3
Residual	296			.0398	384.3
	356	6.24	10.13		

[a] $P < .01$.

[b] $P < .10$.

[c] $P < .001$.

*$P < .05$.

TABLE V

ANALYSES OF VARIANCE FOR LITTER 21- AND 42-DAY TRAITS

Source	df	Mean Squares					
		No. Pigs 21-Days	Litter 21-Day Wt., kg	Avg. Pig 21-Day Wt., kg	No. Pigs 42-Days	Litter 42-Day Wt., kg	Avg. Pig 42-Day Wt., kg
Season	3	9.64	1385.8[d]	8.701[d]	24.70[c]	8130.7[d]	31.84[a]
Bos	2	7.81	164.8	.099	3.40	564.8	1.42
Season* Bos	6	4.41	75.9	.321	4.47	476.9	1.10
Sire (Season Bos)	60			.860[b]			2.93
Bod	2	2.55	51.9	3.204[c]	3.90	146.9	7.96[b]
Season* Bod	6	3.38	153.8	.990	3.65	574.1	3.66
Bos* Bod	4	13.51[b]	278.7[b]	.779	16.40[c]	1647.7[c]	1.66
Season* Bos* Bod	12	6.25	204.6[b]	.760	8.08[a]	717.4	1.20
Residual	291			.630			2.55
	351	5.04	115.4		5.06	479.4	

[a]P < .10.

*,[b]P < .05.

[c]P < .01.

[d]P < .001.

of the litter productivity traits. Only 1 of the 30 two-way or three-way interactions other than breed of sire by breed of dam was significant, and therefore it was judged valid to calculate means over seasons.

As with litter productivity traits, season was significant for post-weaning performance traits of average daily gain, age at 100 kg and feed efficiency (Tables VI and VII). Sire within year-season and breed of sire was highly significant for average daily gain, age at 100 kg and backfat probe. Additionally, breed of sire, breed of dam and the interaction between them was significant for the growth measurements, backfat probe and feed efficiency. Breed of dam was significant for average daily feed intake.

Litter Productivity

Breed group means and contrasts for litter productivity are shown in Tables VIII, IX and X. A contrast of particular interest in this study is the comparison of three-breed cross litters to backcross litters, since this is an estimate of one-half individual pig heterosis (Dickerson, 1969). These differences for average number of pigs per litter were .31 ± .27, .57 ± .24 and .50 ± .24 pigs at birth, 21- and 42-days, respectively. Litters of three-breed cross breeding were significantly heavier at 21- and 42-days by 2.3 ± 1.2 and 5.4 ± 2.4 kg. The differences between three-breed and backcross litters for average pig weight were small and nonsignificant at all ages. Survival rate of pigs from birth to weaning was higher for pigs in three-breed cross litter but was not significant. Young et al. (1976a) reported individual heterosis estimates for these traits from purebred and two-breed cross matings with those same breeds. Tables XI and XII compare the heterosis estimates from

TABLE VI

ANALYSES OF VARIANCE FOR GROWTH RATE AND BACKFAT PROBE

Source	df	Mean Squares		
		Avg. Daily Gain, kg/day	Age at 100 kg	Backfat Probe, cm
Season	3	.0390[d]	3381.9[d]	.2117
Bos	2	.0259[b]	1174.0[b]	3.9121[d]
Season* Bos	6	.0161[a]	583.6	.1717
Sire (Season Bos)	60	.0075[d]	324.8[d]	.1107[d]
Bod	2	.0252[c]	447.9[a]	.3481[d]
Season* Bod	6	.0096[b]	374.1[b]	.1342[c]
Bos* Bod	4	.0158[c]	611.1[c]	.1188[b]
Season* Bos* Bod	12	.0033	150.5	.0507
Residual	290	.0039	169.3	.0467

[a]$P < .10$.

*,[b]$P < .05$.

[c]$P < .01$.

[d]$P < .001$.

TABLE VII

ANALYSES OF VARIANCE FOR FEED EFFICIENCY AND FEED INTAKE

Source	df	Mean Squares: Feed Efficiency	Mean Squares: Avg. Daily Feed Intake, kg/day
Season	3	.000583[b]	.0499
Bos	2	.000653[b]	.0358
Bod	2	.000412[a]	.1336[b]
Season* Bos	6	.000177	.1209[c]
Season* Bod	6	.000204	.0982[b]
Bos* Bod	4	.000728[c]	.0221
Season* Bos* Bod	12	.000151	.0647[b]
Residual	90	.000160	.0345

[a]P < .10.

*,[b]P < .05.

[c]P < .01.

TABLE VIII

BREED GROUP LEAST SQUARES MEANS FOR LITTER BIRTH TRAITS

Breeding[a]	No. of Pigs[b]	Litter Wt., kg[b]	Avg. Pig Wt., kg[b]	Survival Percent[b]
D x DH	10.43	13.4	1.27	73.1
D x DY	10.01	12.5	1.24	75.7
D x HY	10.32	12.4	1.24	76.0
H x DH	9.46	12.8	1.38	74.3
H x DY	10.68	13.4	1.27	77.3
H x HY	10.15	12.4	1.24	68.0
Y x DH	10.60	14.3	1.36	69.2
Y x DY	10.82	12.8	1.21	72.1
Y x HY	10.50	13.0	1.26	72.5
Contrasts Between Breed of Sire				
D - H	.15 ± .31	-.1 ± .4	-.04 ± .03	1.0 ± 3.0
D - Y	-.39 ± .31	-.6 ± .4	-.02 ± .03	2.9 ± 3.0
H - Y	-.54 ± .32	-.5 ± .4	.02 ± .03	1.9 ± 3.0
Contrasts Between Breed of Dam				
DH - DY	-.34 ± .31	.6 ± .4	.09 ± .03[d]	-2.1 ± 2.5
DH - HY	-.16 ± .31	.9 ± .4[c]	.09 ± .03[d]	0.0 ± 2.5
DY - HY	.18 ± .32	.3 ± .4	.01 ± .03	2.2 ± 2.5
Three-Breed Vs. Backcross				
Three-Breed - Backcross	.31 ± .27	.6 ± .34	.02 ± .02	1.9 ± 2.2

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Standard errors for means ranged from .36 to .39 pigs for number of pigs, .47 to .50 kg for litter weight, .03 to .04 kg for average pig weight, and 3.3 to 3.6 percent for survival percent.

[c]$P < .05$.

[d]$P < .01$.

TABLE IX

BREED GROUP LEAST SQUARES MEANS FOR LITTER 21-DAY TRAITS

Breeding[a]	No. of Pigs[b]	Litter Wt., kg[b]	Avg. Pig Wt., kg[b]
D x DH	8.23	38.5	4.65
D x DY	7.65	33.2	4.45
D x HY	8.24	38.8	4.89
H x DH	7.00	33.6	4.82
H x DY	8.43	36.8	4.37
H x HY	7.29	33.9	4.69
Y x DH	7.90	36.3	4.55
Y x DY	7.90	35.6	4.54
Y x HY	7.82	36.2	4.67
<u>Contrasts Between Breed of Sire</u>			
D - H	.48 ± .28	2.3 ± 1.4	.02 ± .12
D - Y	.19 ± .28	1.0 ± 1.4	.05 ± .12
H - Y	-.30 ± .29	-1.3 ± 1.4	.04 ± .12
<u>Contrasts Between Breed of Dam</u>			
DH - DY	-.28 ± .28	0.9 ± 1.4	.24 ± .10[c]
DH - HY	-.10 ± .28	-0.4 ± 1.4	-.07 ± .10
DY - HY	.18 ± .29	-1.3 ± 1.4	-.32 ± .10[d]
<u>Three-Breed Vs. Backcross</u>			
Three-Breed - Backcross	.57 ± .24[c]	2.3 ± 1.2[c]	-.02 ± .09

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Standard errors for means ranged from .34 to .39 pigs for for number of pigs, 1.6 to 1.7 kg for litter weight and .140 to .143 kg for average pig weight.

[c]$P < .05$.

[d]$P < .01$.

TABLE X

BREED GROUP LEAST SQUARES MEANS
FOR LITTER 42-DAY TRAITS

Breeding[a]	No. of Pigs[b]	Litter Wt., kg[b]	Avg. Pig Wt., kg[b]
D x DH	7.89	76.8	9.72
D x DY	7.12	66.2	9.57
D x HY	7.94	79.5	10.31
H x DH	6.80	66.1	9.85
H x DY	8.23	76.5	9.35
H x HY	6.94	67.4	9.87
Y x DH	7.32	70.9	9.68
Y x DY	7.70	71.9	9.50
Y x HY	7.54	72.9	9.67
Contrasts Between Breed of Sire			
D - H	.33 ± .28	4.2 ± 2.8	.13 ± .22
D - Y	.13 ± .28	2.3 ± 2.8	.21 ± .22
H - Y	-.20 ± .28	-2.0 ± 2.8	.08 ± .22
Contrasts Between Breed of Dam			
DH - DY	-.35 ± .28	-0.2 ± 2.8	.32 ± .21
DH - HY	-.14 ± .28	-2.0 ± 2.8	-.20 ± .21
DY - HY	.21 ± .29	-1.8 ± 2.8	-.52 ± .21[c]
Three-Breed Vs. Backcross			
Three-Breed - Backcross	.50 ± .24[c]	5.4 ± 2.4[c]	.10 ± .18

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Standard errors for means ranged from .33 to .36 pigs for number of pigs, 3.2 to 3.5 kg for litter weight and .26 to .27 kg for average pig weight.

[c]$P < .05$.

TABLE XI

COMPARISON OF HETEROSIS ESTIMATES FOR LITTER PRODUCTIVITY AT BIRTH

Item	Estimate of Individual Heterosis	Birth: No. Pigs	Birth: Litter Wt., kg	Birth: Avg. Pig Wt., kg	Survival Percent
F_1--Purebred;[a]	1	.38 ± .26	.50 ± .27	.014 ± .021	7.78 ± 2.4[b]
Three-Breed - Backcross	$\frac{1}{2}$	.31 ± .27	.60 ± .34	.02 ± .02	1.90 ± 2.2

[a]Young et al. (1976a).

[b]$P < .05$.

TABLE XII

COMPARISON OF HETEROSIS ESTIMATES FOR LITTER PRODUCTIVITY AT 21- AND 42-DAYS

Item	Estimate of Individual Heterosis	21 Days			42 Days		
		No. Pigs	Litter Wt., kg	Avg. Pig Wt., kg	No. Pigs	Litter Wt., kg	Avg. Pig Wt., kg
F_1--Purebred;[a]	1	.65 ± .23[c]	3.70 ± 1.14[c]	.155 ± .094	.76 ± .23[c]	9.47 ± 2.40[c]	.316 ± .196
Three-Breed - Backcross	$\frac{1}{2}$	.57 ± .24[b]	2.30 ± 1.20[b]	-.020 ± .090	.50 ± .24[b]	5.40 ± 2.40[b]	.100 ± .180

[a]Young et al. (1976a).

[b]$P < .05$.

[c]$P < .01$.

this study with those of Young et al. (1976a). The comparison indicates generally a good agreement with expectations for average number of pigs per litter at birth, at 21- and 42-days, and for litter weight at 21- and 42-days. The heterosis estimates from this study for litter size are 82, 80 and 66 percent of those from Young et al. (1976a) and for litter weight at 21- and 42-days are 62 and 57 percent as compared to expected value of 50 percent. The estimate of one-half heterosis for litter weight at birth was .1 kg greater than the previous estimate. The heterosis estimates in this study are greater than those of Schneider (1976) in which the difference between purebreds and crossbreds was .0 for number of pigs born and .29 pigs for number of pigs at 56 days. These results would indicate that a backcross mating system probably would not have a greater than expected loss in individual heterosis for these litter productivity traits. The survival rate estimate in this study appears to be below that which would be expected based on the estimate of Young et al. (1976a).

Differences between Duroc-, Hampshire- and Yorkshire-sired litters for preweaning traits were small and nonsignificant. Yorkshire-sired litters tended to be larger at birth, but by 42-days Duroc- and Yorkshire-sired litters were similar for number of pigs and slightly larger than Hampshire-sired litters (Tables VIII and X). Similar results were reported by Nelson and Robison (1976) and Fahmy et al. (1971). Young et al. (1976a) found that Yorkshire-sired litters were significantly larger at 21- and 42-days than those out of Duroc and Hampshire sires. Litter weight and average pig weight differences among breed of sire were small. Several authors have found nonsignificant differences for average pig weight when these breeds are used as sires (Nelson and Robison, 1976; Fahmy et al., 1971; Young et al., 1976a).

Another objective of this study was to compare the three crossbred female groups for litter productivity. Previous research at this station had not allowed for the comparison of these dam groups by the fact that they were confounded with breed of sire (Johnson et al., 1978). Reciprocal crossbred female groups were combined to form three female groups, since these female types were not significantly different from each other for litter productivity traits.

Although the contrasts between dam breeds were not significant at birth, at 21- or 42-days, the differences were very consistent for all three ages as a result of little difference in survival rate among the dam breeds. The rankings and differences between these crosses in number of pigs raised per litter is inconclusive at this time. The study by Holtman et al. (1975) ranked Duroc-Yorkshire and Hampshire-Yorkshire slightly higher than Hampshire-Duroc while Nelson and Robison (1976) suggested a reversal in the rankings. As found with average number of pigs, differences in total litter weight were on the most part small and not significant. Duroc-Hampshire dams produced litters which were .9 ± .4 kg heavier at birth but by 21 days this difference was not present. At birth Duroc-Hampshire females had the heaviest pigs ($P < .01$) but by 21 days the average pig weight of pigs with Hampshire-Yorkshire dams were similar (Table X). Hampshire cross dams had heavier pigs than Duroc-Yorkshire females ($P < .05$). At 42-days, pigs with Hampshire-Yorkshire dams averaged .52 ± .21 kg heavier than those with Duroc-Yorkshire dams (Table X).

Since there were only small differences among these breeds as sires and dams, it appears that decisions concerning the selection of a mating plan for litter production must be made from specific crosses.

Feedlot Performance

Table XIII presents the breed group means and contrasts for postweaning traits. Three-breed cross pigs grew significantly faster, were younger at 100 kg and more efficient in feed utilization than backcross pigs. Young et al. (1976b) found significant individual heterosis for all postweaning traits which were measured in this study. The differences between three-breed cross pigs and backcross pigs for average daily gain and days to 100 kg were very close to one-half the individual heterosis estimates given by Young et al. (1976b), which are shown in Table XIV.

Three-breed cross pigs had a slightly greater backfat probe than backcross pigs; however, this difference was not significant. Young et al. (1976b) reported a decrease in backfat probe (-.06 ± .03 cm) for crossbred gilts, but a difference of .02 ± .04 cm in carcass backfat measurement between crossbred and purebred barrows. Kuhlers et al. (1972) did not find significant heterosis for average carcass backfat at 90 kg in Yorkshire and Poland China crosses. Schneider (1976) also did not find significant heterosis for average carcass backfat, while Bereskin et al. (1971) reported crossbreds had .23 cm more carcass backfat than purebreds. In general, it appears that heterosis for backfat must be close to zero.

The efficiency of feed utilization was significantly greater in three-breed crosses, amounting to about a 3 percent increase in kg

TABLE XIII

BREED GROUP LEAST SQUARES MEANS
FOR POSTWEANING TRAITS

Breeding[a]	Avg. Daily Gain, kg/day[b]	Days to 100 kg[b]	Backfat Probe, cm[b]	Gain/ Feed[b]	Avg. Daily Feed Intake kg/day[b]
D x DH	.704	186.1	3.39	.320	2.06
D x DY	.700	187.2	3.36	.326	2.02
D x HY	.710	183.5	3.23	.331	2.00
H x DH	.675	192.2	2.92	.311	2.04
H x DY	.699	187.5	3.04	.331	1.98
H x HY	.651	196.3	2.95	.320	1.92
Y x DH	.704	185.6	3.26	.322	2.03
Y x DY	.703	185.5	3.23	.314	2.04
Y x HY	.654	192.8	3.11	.317	1.86
<u>Contrasts Between Breed of Sire</u>					
D - H	$.029 \pm .011^{c}$	-6.0 ± 2.3^{d}	$.35 \pm .04^{d}$	$.005 \pm .003$	$.05 \pm .05$
D - Y	$.016 \pm .011$	-2.0 ± 2.3	$.11 \pm .04^{d}$	$.008 \pm .003^{c}$	$.05 \pm .04$
H - Y	$-.012 \pm .011$	4.0 ± 2.3	$-.23 \pm .04^{d}$	$.003 \pm .003$	$.00 \pm .05$
<u>Contrasts Between Breed of Dam</u>					
DH - DY	$-.004 \pm .008$	0.9 ± 1.7	$-.01 \pm .03$	$-.006 \pm .003^{c}$	$.03 \pm .05$
DH - HY	$.023 \pm .008^{d}$	-2.9 ± 1.7	$.09 \pm .03^{d}$	$.005 \pm .003$	$.12 \pm .05^{c}$
DY - HY	$.028 \pm .008^{d}$	-3.8 ± 1.7^{d}	$.10 \pm .03^{d}$	$.001 \pm .003$	$.09 \pm .05$
<u>Three-Breed Vs. Backcross</u>					
Three-Breed - Backcross	$.024 \pm .007^{d}$	-4.7 ± 1.5^{d}	$.02 \pm .02$	$.010 \pm .002^{d}$	$.02 \pm .04$

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Standard errors for the means ranged from .012 to .013 kg/day for average daily gain, 2.4 to 2.7 days for days to 100 kg, .04 to .05 cm for backfat probe, .003 to .004 for gain/feed, and .05 to .06 kg/day for average daily feed intake.

[c]$P < .05$.

[d]$P < .01$.

TABLE XIV

COMPARISON OF HETEROSIS ESTIMATES FOR POSTWEANING TRAITS

Item	Estimate of Individual Heterosis	Avg. Daily Gain, kg/day	Age at 100 kg	Backfat Probe cm	Gain/Feed	Avg. Daily Feed Intake kg/day
F_1--Purebred;[a]	1	$.054 \pm .007^c$	-9.9 ± 1.3^c	$-.06 \pm .03^b$	$.0073 \pm .0030^b$	$.077 \pm .037^b$
Three-Breed - Backcross	$\frac{1}{2}$	$.024 \pm .007^c$	-4.7 ± 1.5^c	$.02 \pm .02$	$.0100 \pm .0020^c$	$.020 \pm .040$

[a]Young et al. (1976b).

[b]$P < .05$.

[c]$P < .01$.

gain/kg feed for three-breed crosses as compared to backcrosses. There was a nonsignificant difference in feed intake. Young et al. (1976b) reported an increase of .0073 ± .0030 kg gain/kg feed as compared to an increase of .010 ± .002 kg gain/kg feed in this study. This amount of heterosis for feed efficiency appears to be greater than most reports in the literature. Kuhlers et al. (1972) did not find significant heterosis for feed conversion or feed intake for the period from 56 day to 90 kg. Young et al. (1976b) found that crossbred pigs consumed .077 ± .037 kg more feed per day than purebred pigs. With the exception of feed efficiency, the results in this experiment do not deviate greatly from theoretical expectation on the amount of heterosis exhibited for post-weaning traits.

Duroc-sired pigs had significantly greater average daily gain and were 6.0 ± 2.3 days younger at 100 kg than Hampshire-sired pigs. Yorkshire-sired pigs were 4.0 ± 2.3 days younger at 100 kg than Hampshire-sired pigs. This is in general agreement with the literature. Nelson and Robison (1976) reported that Duroc-sired pigs were heavier than Yorkshire-sired pigs which were again heavier than Hampshire-sired pigs at 140 days of age when two-way cross pigs were produced. When three-breed cross pigs were produced, the differences between breeds of sire were very small. Fahmy et al. (1976) found that Yorkshire- and Duroc-sired pigs were similar and both significantly younger than Hampshire-sired pigs at 90 kg, while Young et al. (1976b) observed that Duroc-sired pigs were significantly younger at 100 kg than either Yorkshire- or Hampshire-sired pigs.

All contrasts between breeds of sire were significant for average backfat probe at 100 kg. Hampshire-sired pigs had .35 ± .04 and .23 ± .04

cm less backfat than Duroc- and Yorkshire-sired pigs, respectively. This is in agreement with Young et al. (1976b) and Fahmy et al. (1976). Nelson and Robison (1976) found that Yorkshire-sired pigs had significantly greater average probe at 72.7 kg than either Duroc-or Hampshire-sired pigs.

Duroc-sired pigs were the most efficient for feed utilization, being significantly more efficient than Yorkshire-sired pigs. Differences for average daily feed consumption were small and nonsignificant.

Both Duroc-Hampshire and Duroc-Yorkshire females produced pigs which had greater average daily gains and were 2.9 ± 1.7 and 3.8 ± 1.7 days younger at 100 kg than those pigs with Hampshire-Yorkshire dams. Hampshire-Yorkshire dams produced pigs which were .09 ± .03 and .10 ± .03 cm leaner than those of Duroc-Hampshire and Duroc-Yorkshire dams. This result might be expected because of the combining ability for leanness from the Hampshire breed and the apparent maternal component for leanness in the Yorkshire (Young et al., 1976b). Duroc-Yorkshire females produced pigs which were significantly more efficient than Duroc-Hampshire offspring but very similar to pigs with Hampshire-Yorkshire dams. Offspring of Duroc-Hampshire females had significantly greater average daily feed consumption than pigs with Hampshire-Yorkshire dams.

CHAPTER IV

COMPARISONS OF MATING SYSTEMS WITH DUROC, HAMPSHIRE AND YORKSHIRE BREEDS OF SWINE FOR EFFICIENCY OF SWINE PRODUCTION

Summary

The data from 1,242 litters farrowed in eight years of crossbreeding experiments involving Duroc, Hampshire and Yorkshire breeds of swine were analyzed to estimate direct genetic and maternal effects of the breeds, as well as individual and maternal heterosis. These estimates were used to predict number of pigs at 42-days, age at 100 kg, backfat probe and feed efficiency for various breed crosses. Crossbred mating systems were defined to include purebred, crossbred and commercial matings needed to maintain a particular cross. Differences in number of pigs produced per 10,000 farrowing sows were compared for 21 mating systems involving Duorc, Hampshire and Yorkshire breeding and used as an estimate of differences in production efficiency for these systems. Comparisons for number of index value pigs produced was also done for selected systems when the proportion of gilts retained for breeding and average number of sows retained were changed.

For number of pigs at 42-days, Yorkshire was 1.03 ± 0.53 and 1.63 ± 0.54 pigs greater than Duroc and Hampshire for direct genetic effect and .74 ± .33 and .45 ± .33 pigs greater for maternal genetic effect. Estimates of individual heterosis for number of pigs at 42-days were

1.07 ± 0.34, .88 ± .34 and .46 ± .34 pigs for Duroc-Hampshire, Duroc-Yorkshire and Hampshire-Yorkshire crosses, respectively. Maternal heterosis estimates were 1.39 ± 0.34, 1.11 ± 0.34 and 1.16 ± 0.34 for Duroc-Hampshire, Duroc-Yorkshire and Hampshire-Yorkshire crosses, respectively.

The direct genetic effect for age at 100 kg showed Duroc 5.5 ± 2.6 days younger than Yorkshire and Yorkshire 3.5 ± 2.6 days younger than Hampshire. The maternal genetic effects of Duroc and Hampshire breeds were not significantly different from Yorkshire for age at 100 kg. Individual heterosis estimates ranged from -8.6 days for Hampshire-Yorkshire crosses to -11.0 days for Duroc-Hampshire crosses. Maternal heterosis estimates for age at 100 kg were small and nonsignificant.

For feed efficiency measured as gain/feed, Yorkshire direct genetic effect was significantly less than Duroc and Hampshire; however, Yorkshire maternal effect was significantly greater than the other two breeds. Individual heterosis was significant for feed efficiency but maternal heterosis was essentially zero. Hampshire direct genetic effect for backfat probe was .45 ± .06 cm less than Yorkshire while Yorkshire was .20 ± .06 cm less than Duroc. Yorkshire maternal effect was .22 ± .04 and .33 ± .04 cm less than Duroc and Hampshire, respectively. Individual and maternal heterosis estimates were not significant for backfat probe.

A Yorkshire X Duroc-Yorkshire (Y x DY) mating system produced the greatest number of pigs per 10,000 sows and produced 2.4 percent more index value pigs than the best three-breed static cross, Duroc X Hampshire-Yorkshire (D x HY). The three-breed rotation, Duroc X (Hampshire-Yorkshire rotation female), Duroc-Yorkshire rotation, Hampshire X Duroc-Yorkshire, Yorkshire X Duroc-Hampshire, Yorkshire X Hampshire-Yorkshire, and Duroc X Duroc-Yorkshire produced 3.33, 2.69, 2.85, 3.81, 2.86, 0.96, and 4.50 percent fewer index value pigs than D-HY, respectively.

A D x HY static system maintained 7.4, 16.3 and 76.3 percent of its farrowing sows in sire line, dam line and commercial production, respectively, as compared to the backcross system Y x DY, which maintained 18.5 percent of its sows in placement production and 81.5 percent in commercial production. The three-breed rotation contains 91.7 percent of its farrowing sows in commercial production and the remaining 8.3 percent in purebred herds to provide replacement sires.

Introduction

The advantage of crossbreeding swine for commercial production has been well documented. Recommendations for specific mating systems for producers have been based on comparisons of specific crosses, with little consideration for the cost of maintaining the purebred and/or multiplier herds needed to support the system.

Moav (1966) developed methods for comparing specific crossbred progeny for economical profitability by economic weighting of reproductive and performance traits of various breeds and breed combinations; however, this does not consider the cost of the parental purebred herds. Dickerson (1973) compared hypothetical swine populations in several mating systems considering the cost in efficiency for maintaining the purebred and multiplier levels. Under those conditions, costs per pig were 15 percent higher for static two-breed crosses than static three-breed crosses.

Mating systems for other livestock species have been examined by several authors. Cartwright et al. (1975) examined beef cattle mating systems comparing the amount of return for a fixed amount of input. In that study three sizes of cattle were compared in two environments for several mating systems. Dickerson (1973) compared relative production for industry-wide sheep breeding systems considering the cost of producing all the parent breeding stock. Nitter (1978) did a similar type of study comparing the number of ewes in different mating systems required to produce an arbitrary amount of lamb; however, the cost of producing terminal sires was not included.

An objective of this study was to estimate direct genetic effects, maternal effects, and individual and maternal heterosis for the Duroc, Hampshire and Yorkshire breeds. These estimates are used to predict performance for various breed combinations and to evaluate the efficiency of several mating systems using these breeds and their crosses. In addition, the effect on pig production for varying sow replacement rates and two selection intensities for gilts was investigated for several selected mating systems.

Materials and Methods

The data used in this study were taken from two earlier experiments in which purebred, two-breed and three-breed crosses with Duroc, Hampshire and Yorkshire breeds of swine were produced (Young et al., 1976a; Young et al., 1976b; Johnson et al., 1978). In addition, the data reported in Chapter III were included in the analyses.

The three previous experiments were composed of three phases. The first phase included purebred and two-breed cross matings. The second phase compared two-breed and three-breed crosses, while the third phase compared backcross and three-breed cross swine. A total of 1,243 litters were included in the analyses.

These data were used to estimate the parameters of breed and breed cross means defined by Dickerson (1969). The parameters estimated were g_A^I, g_A^m, h_{AB}^I, and h_{AB}^m for Duroc, Hampshire and Yorkshire breeds, where g_A^I is the deviation due to average effects of the individual's own genes of breed A, g_A^m is the deviation due to average effect through maternal environment for genes of breed A dams, h_{AB}^I is the deviation due to increased average heterozygosity of F_1 crossbreds from crossing breeds A and B, and h_{HB}^m is similar to h_{AB}^I except that it is the effect of using a crossbred dam from a cross between breeds A and B. Dickerson (1969) included additional parameters such as deviations due to grandmaternal effects, grandmaternal heterosis, and recombination effects, but since these cannot be estimated from the data they were ignored. This model assumes a linear relationship between degree of heterozygosity and amount of heterosis (Dickerson, 1969).

The data were analyzed with the following linear model:

$$\underset{\sim}{y} = X\underset{\sim}{\beta} + \underset{\sim}{e}$$

where

$\underset{\sim}{y}$ = 30 x 1 vector of breed cross means;

X = 30 x 13 design matrix based on genetic expectation of means;

$\underset{\sim}{\beta}$ = 13 x 1 vector of parameters which include:

μ - a common constant;

p_i - effect of phase, i = 1, 2, 3;

g_j^I - direct genetic effect, j = 1, 2, 3;

g_k^m - maternal genetic effect, k = 1, 2, 3;

h_ℓ^I - individual heterosis, ℓ = 1, 2, 3;

h_n^m - maternal heterosis, n = 1, 2, 3;

$\underset{\sim}{e}$ = 30 x 1 vector having multivariate distribution with mean zero and variance-covariance matrix $V\sigma^2$ where V is a 30 x 30 diagonal matrix with the reciprocal of the number of observations comprising each breed cross mean on the diagonal.

Generalized least squares were used to obtain solutions to the equations with the following restrictions:

$$\sum_{i=1}^{3} p_i = \sum_{j=1}^{3} g_j^I = \sum_{k=1}^{3} g_k^m = 0.$$

Traits of interest for these analyses were number of pigs at 42-days, age at 100 kg, average backfat probe and feed efficiency. Predicted values for various breed combinations and crosses including purebred, two-breed, three-breed, backcross, and various rotation crosses were calculated.

Mating Systems

Mating systems were defined to include the entire population of purebred and crossbred herds which were needed to maintain and provide breeding stock as replacements for a particular mating structure. The efficiencies of different mating systems could be compared on a total economic basis (Cartwright et al., 1975) or on the amount of product produced per female in the herd (Dickerson, 1973; Nitter, 1978). Harris (1970) defined the following equations to evaluate the expense and income per individual pig:

$$P = \text{Production cost of a pig} = \begin{matrix}\text{slaughter}\\ \text{cost}\end{matrix} + \begin{pmatrix}\text{cost per}\\ \text{unit feed}\end{pmatrix}$$

$$\begin{pmatrix}\text{feed}\\ \text{consumption}\end{pmatrix} + \begin{pmatrix}\text{labor and}\\ \text{facilities cost}\\ \text{per unit time}\end{pmatrix} \begin{pmatrix}\text{time to}\\ \text{reach}\\ \text{slaughter}\end{pmatrix};$$

$$R = \text{Reproduction cost} = \begin{matrix}\text{No. of}\\ \text{litters}\end{matrix} \left[\begin{matrix}\text{sow and}\\ \text{litter fixed}\\ \text{costs}\end{matrix}\right.$$

$$\left. + \begin{matrix}\text{sow and}\\ \text{litter feed}\\ \text{costs}\end{matrix} + \begin{matrix}\text{boar costs}\\ \text{per litter}\end{matrix}\right];$$

$$(\text{Rep}) = \text{Replacement cost} = \begin{matrix}\text{cost of gilt}\\ \text{production}\end{matrix} - \begin{matrix}\text{salvage}\\ \text{value from}\\ \text{old sows}\end{matrix};$$

and

$$N = \text{Number of pigs} = \begin{matrix}\text{No. of}\\ \text{litters}\end{matrix} \begin{pmatrix}\text{average}\\ \text{litter}\\ \text{size}\end{pmatrix} \begin{pmatrix}\text{pig}\\ \text{survival}\end{pmatrix}.$$

Then,

$$\text{Expense (E)} = P + \frac{R + (\text{Rep})}{N};$$

$$\text{Income (I)} = (\text{carcass weight})(\text{carcass quality});$$

and

$$\text{Total Profit} = N(I - E) = N(I) - N(P) - R - (\text{Rep}).$$

This can be extended to compare two mating systems, S_1 and S_2, where the total number of litters farrowed was fixed. Then R_1 equals R_2 if litter costs are independent of litter size. This assumption probably is not true but differences should be quite small. Thus to compare two mating systems,

$$D = (\text{total profit})_1 - (\text{total profit})_2 = [N_1(I_1) - N_1(P_1) - R_1$$

$$- (\text{Rep})_1] - [N_2(I_2) - N_2(P_2) - R_2 - (\text{Rep})_2]$$

and reduces to

$$N_1(I_1 - P_1) - N_2(I_2 - P_2) + (Rep_2) - (Rep_1).$$

If the salvage value of a sow is equivalent to the cost of raising a gilt from birth until the time she enters the breeding herd and is bred, then (Rep_i) will be zero and the difference between (Rep_1) and (Rep_2) will be zero. Then

$$D = N_1(I_1 - P_1) - N_2(I_2 - P_2).$$

If this assumption is not true, there will be a larger discrepancy in mating systems with lower conception rates since more gilts will be retained.

For each mating system, there are several breed combinations which make up the total pig production for a mating system. Each breed combination has its own value for the quantity (I - P) which is equal to

$$\text{carcass value} - \begin{pmatrix}\text{cost per}\\ \text{unit feed}\end{pmatrix} \begin{pmatrix}\text{feed}\\ \text{consumption}\end{pmatrix} - \begin{pmatrix}\text{labor and}\\ \text{facilities cost}\\ \text{per unit time}\end{pmatrix} \begin{pmatrix}\text{time to}\\ \text{reach}\\ \text{slaughter}\end{pmatrix};$$

therefore, N(I - P) is actually $\sum_{i=1}^{k} n_i(I_i - P_i)$ with n_i the number of pigs of the i^{th} breed group, I_i the carcass value of the i^{th} breed group, and p_i the production cost of the i^{th} breed group. Costs of labor, feed per unit and fixed costs per day would be constant for each system. The major production costs between weaning and 100 kg were feed and fixed costs per day. Differences in carcass value at a fixed weight were primarily due to differences in carcass composition. Thus the quantity that is of interest is an economic weighting of these three traits for the various breed groups. The quantity $(I_i - P_i)$ was estimated by the following index:

$$\text{Index}_i = \frac{100 - .10(D_i - D_y) + 90(FE_i - FE_y) - 2.16(Bf_i - BF_y)}{100}$$

where

D_i = days to 100 kg for the i^{th} breed group;

D_y = mean days to 100 kg for Yorkshire;

FE_i = gain/feed for the i^{th} breed group;

FE_y = gain/feed ratio for Yorkshire;

BF_i = backfat probe for i^{th} breed group; and

BF_y = mean backfat probe for Yorkshire.

The economic values of -$.10 for each day decrease in days to 100 kg, $90 for increased feed efficiency, and -$2.16 per cm increase in backfat probe were used by Cunningham (personal communication, 1978). The value 100 was arbitrary and would represent a 100 kg market hog having a value of $100. Changes in market price would change this value but would not greatly change the index value of systems over normal price ranges. Yorkshire market hogs would have a relative value of 1.00, with all other breeds and breed crosses compared to Yorkshire.

Linear programming techniques were used to find the optimum production from 21 different mating systems with Duroc, Hampshire, and Yorkshire breeds of swine. Linear programming was readily adaptable to this problem, since the objective was to optimize the number of pigs produced in a mating system with the constraint that total number of farrowing sows in a system would be 10,000. Restrictions on minimum purebred herd size, replacement rates, conception rates, and proportion of offspring which were saved for breeding could thus be imposed for each mating system. The IBM MPSX Linear Programming Package was used as the computer program for this study.

Model Assumptions and Restrictions

Mating systems were considered to be at equilibrium, producing only as many replacements as were needed to maintain the system under the restrictions which were imposed. The restrictions which follow were placed on all mating systems. The total number of sows farrowing within a mating system was 10,000 females. Purebred herds had a minimum of 100 gilts farrowing, and 90 percent of the gilts farrowing in dam lines were available to be transferred to F_1 gilt production herds. Conception rate, based on number of females saved, for the various female breed groups were as follows: Duroc, 81.6 percent; Hampshire, 86.0 percent; Yorkshire, 70.9 percent; Duroc-Hampshire, 78.1 percent; Duroc-Yorkshire, 83.4 percent; and Hampshire-Yorkshire, 82.4 percent (Johnson et al., 1978). Conception rate was assumed to be the same for all gilts and sows (Young et al., 1976a).

The number of litters that a sow farrows affects the number of gilts which must be retained as replacements and the length of generation interval, thus influencing rate of progress from selection. For the primary analysis, average retention rate for purebred sows farrowing crossbred litters was set at 50 percent and the retention rate for commercial sows was set at 60 percent.

At any level of production, a maximum of 90 percent of the gilts which farrowed could be retained for the breeding herd. Therefore, average retention rate pertains only to sows which have farrowed two or more litters and is calculated by dividing the total number of sows which were retained by the total number of sows which were available for selection, all of which farrowed two or more litters. Sows were retained at random without regard to parity. Consequently, several parity distributions could result in the same retention rate.

Additional assumptions included the following: (1) sows weaned 1.2 more pigs per litter than gilts of the same breeding (Young et al., 1976a; Johnson et al., 1978); (2) maximum number of young females saved from purebred or F_1 offspring was 80 percent; (3) maximum number of young boars retained for breeding was one-half; (4) boars were utilized at the rate of one boar per ten females in the breeding herd; and (5) boars were replaced for each pig crop.

All mating systems were compared at average sow retention rates of 50 percent for purebred and 60 percent for commercial sows. Also, several selected mating systems were compared at various purebred and commercial sow retention rates, and two limits (.5 and .8) of the proportion of purebred gilts retained for breeding were investigated. These comparisons should give an estimate of the effect that diverse selection intensities have on efficiency of production.

Results and Discussion

Breed Effects

Table XV presents the differences between breeds for direct and maternal effects, and additionally, for individual and maternal heterosis values for number of pigs per litter at 42-days, days to 100 kg, feed efficiency, and backfat probe. The direct genetic effect for Yorkshire was 1.03 ± 0.53 and 1.63 ± 0.54 pigs greater than Duroc and Hampshire, respectively, for number of pigs per litter at 42-days.

TABLE XV

ESTIMATED BREED EFFECTS, INDIVIDUAL HETEROSIS AND MATERNAL HETEROSIS FOR NUMBER OF PIGS AT 42-DAYS, AGE AT 100 KG, FEED EFFICIENCY, AND BACKFAT PROBE

Effect	No. Pigs at 42-Days	Days to 100 kg	Gain/Feed	Backfat Probe, cm
Direct				
D-Y[a]	-1.03 ± .53[b]	-5.5 ± 2.6[c]	.012 ± .005[c]	.20 ± .06[d]
H-Y	-1.63 ± .54[d]	3.5 ± 2.6	.014 ± .005[c]	-.45 ± .06[d]
Maternal				
D-Y	-0.74 ± .33[c]	0.5 ± 1.6	-.022 ± .003[d]	.22 ± .04[d]
H-Y	-0.45 ± .33	-0.9 ± 1.6	-.028 ± .003[d]	.33 ± .04[d]
Ind. Heterosis				
DH	1.07 ± .34[d]	-11.0 ± 1.7[d]	.013 ± .004[d]	-.05 ± .04
DY	0.88 ± .34[c]	-9.6 ± 1.7[d]	.008 ± .003[c]	-.07 ± .04
HY	0.46 ± .34	-8.6 ± 1.7[d]	.008 ± .003[c]	.04 ± .04
Mat. Heterosis				
DH	1.39 ± .34[d]	-1.5 ± 1.6	-.000 ± .003	-.01 ± .04
DY	1.11 ± .34[d]	-1.4 ± 1.6	-.001 ± .003	.06 ± .04
HY	1.16 ± .34[d]	1.6 ± 1.6	-.000 ± .003	.05 ± .04

[a]D = Duroc, H = Hampshire, Y = Yorkshire.

[b]$P < .10$.

[c]$P < .05$.

[d]$P < .01$.

Similarly, maternal effects for Yorkshire were significantly greater than Duroc, .74 ± .33 pigs, and tended to be larger than Hampshire, .45 ± .33 pigs. Schneider (1976) found small and nonsignificant differences between these breeds for general combining ability and maternal effects for number of pigs at 56-days. These conflicting results may be due to sampling, since Schneider (1976) used approximately 70 females and 9 males per breed. Bereskin et al. (1974) found that maternal effects were not significant for number of pigs at 56-days in Yorkshire and Duroc crosses from lines which had been selected for low- and high-fat. Estimates of individual heterosis effects for number of pigs at 42-days were 1.07 ± 0.34 pigs for Duroc-Hampshire crosses, .88 ± .34 pigs for Duroc-Yorkshire crosses and .46 ± .34 pigs for Hampshire-Yorkshire crosses. Schneider (1976) gave specific heterosis values of .47 pigs for Duroc-Hampshire, -.58 pigs for Duroc-Yorkshire and -.92 pigs for Hampshire-Yorkshire, all at 56-days. From this study, maternal heterosis for number of pigs at 42-days was significant and similar for all crosses ranging from 1.11 to 1.39 pigs per litter.

For days to 100 kg, the direct effect for Duroc was 5.5 ± 2.6 days less than Yorkshire and 9.0 days less than Hampshire. Yorkshire direct effect was 3.5 ± 2.6 days less than Hampshire. Maternal effects for age at 100 kg were small and not significant. Estimates of individual heterosis for all crosses were highly significant for age at 100 kg, ranging from -11 days for Duroc-Hampshire corsses to -8.6 days for Hampshire-Yorkshire crosses. Maternal heterosis estimates for age at 100 kg were small and not significant.

For feed efficiency both Duroc and Hampshire direct effects were significantly greater than Yorkshire; however, the Yorkshire maternal effect was about twice as great as the direct effect. Thus Yorkshire dams would have a much greater effect on increasing the feed efficiency of their offspring than dams of the other two breeds. Individual heterosis was significant for feed efficiency but maternal heterosis was not significant, having esentially an estimate of zero. The Hampshire direct genetic effect was .45 ± .06 cm less than Yorkshire for average backfat probe, and Yorkshire was .20 ± .06 cm less than Duroc. Nelson and Robison (1976) reported that Hampshire-sired pigs had less average backfat probe than Yorkshire and Duroc. The Yorkshire maternal effect significantly reduced backfat probe by .22 ± .04 cm and .33 ± .04 cm over Duroc and Hampshire, respectively. This is in agreement with Bereskin et al. (1971). Individual and maternal heterosis estimates were not significantly different from zero for any of the crosses.

The predicted breed or breed cross performance calculated from these direct affects, maternal effects, and individual and maternal heterosis values is shown in Table XVI. The rotation crosses were calculated based on the equilibrium heterosis levels and the average direct and maternal effects for the breeds which compose the rotation crosses.

Mating Systems

Table XVII and Figure 2 present the number of index value pigs produced per 10,000 farrowing sows for various mating systems. These comparisons were made with the restriction that 50 percent of the purebred sows farrowing two or more litters and producing crossbred litters would be available for the breeding herd. Sixty percent of the commercial sows farrowing two or more litters were available as replacements in the sow herd. The number of gilts available for replacement was limited to 80

TABLE XVI

PREDICTED MEAN PERFORMANCE OF BREED CROSSES FOR NUMBER OF PIGS AT 42-DAYS, AGE AT 100 KG, FEED EFFICIENCY, BACKFAT PROBE, AND INDEX VALUE

Breeding Type	No. of Pigs at 42 Days	Age at 100 kg	Gain/ Feed	Backfat Probe, cm	Index Value
D x D	5.48	187.3	.310	3.33	.983
H x H	5.18	195.0	.307	2.79	.983
Y x Y	7.26	188.2	.321	2.91	1.000
D x H	6.55	179.5	.319	3.06	1.004
D x Y	7.62	178.0	.334	2.94	1.022
H x D	6.25	180.8	.325	2.95	1.010
H x Y	6.90	183.4	.335	2.72	1.022
Y x D	6.88	178.5	.313	3.16	.997
Y x H	6.45	182.5	.307	3.05	.991
D x DH	7.41	181.9	.314	3.19	.995
D x DY	7.67	181.3	.321	3.19	1.002
D x HY	8.24	180.3	.326	3.04	1.010
H x DH	7.11	186.4	.316	2.87	.998
H x DY	7.69	180.8	.329	2.90	1.015
H x HY	7.20	190.8	.321	2.80	1.000
Y x DH	8.06	179.0	.310	3.10	.995
Y x DY	8.18	182.0	.316	3.09	.998
Y x HY	8.01	187.0	.314	3.02	.992
DH rot.	6.97	182.8	.317	3.02	1.000
DY rot.	7.70	180.5	.320	3.11	1.003
HY rot.	7.30	186.9	.319	2.90	1.000
D x (HY rot.)	7.86	179.8	.326	3.02	1.011
H x (DY rot.)	7.32	181.2	.329	2.88	1.016
Y x (DH rot.)	7.60	179.5	.310	3.10	.996
DHY rot.	7.71	181.5	.320	3.01	1.005

[a]D = Duroc, H = Hampshire and Y = Yorkshire. Breed of sire listed first.

TABLE XVII

NUMBER OF PIGS, NUMBER OF INDEX VALUE PIGS AND COMPARISONS FOR MATING SYSTEMS

Mating System	No. of Pigs	No. of Index Value Market Pigs[b]	No. of Rep. Gilts	No. of Index Value Gilts	Total No. of Index Value Pigs	Percent Change From D-HY
DHY[a] rot.	75059	75392	5709	5720	81112	-3.33
Y-(DH rot.)	73254	72993	6138	6134	79127	-5.69
D-(HY rot.)	75355	76035	5631	5613	81648	-2.69
DH rot.	66912	66866	6126	6107	72973	-13.03
DY rot.	75893	76091	5425	5429	81520	-2.85
HY rot.	71792	71770	5538	5521	77291	-7.89
D-HY	77435	78155	5721	5753	83908	
H-DY	73990	75025	5638	5690	80714	-3.81
Y-DH	75881	75563	5936	5945	81505	-2.86
Y-DY	80782	80673	5177	5249	85922	2.40
Y-HY	78206	77746	5190	5353	83099	-.96
D-DY	75040	75161	4943	4968	80129	-4.50
D-DH	70771	70472	5488	5502	75974	-9.46
H-HY	70350	70281	4980	4943	75224	-10.35
H-HD	68641	68507	5404	5404	73911	-11.91
DH	63630	63844	4607	4529	68373	-18.51
DY	71893	73012	6393	6378	79390	-5.38
HY	67863	68584	6372	6361	74945	-10.68
D	55630	54684	5025	4940	59624	-28.94
H	53548	52637	4474	4398	57035	-32.02
Y	70821	70821	6683	6683	77504	-7.63

[a] D = Duroc, H = Hampshire, and Y = Yorkshire.

[b] $\sum_{j=1}^{k} n_i$ (Index Value$_i$), where n_i is the number of pigs of i^{th} breed or breed cross.

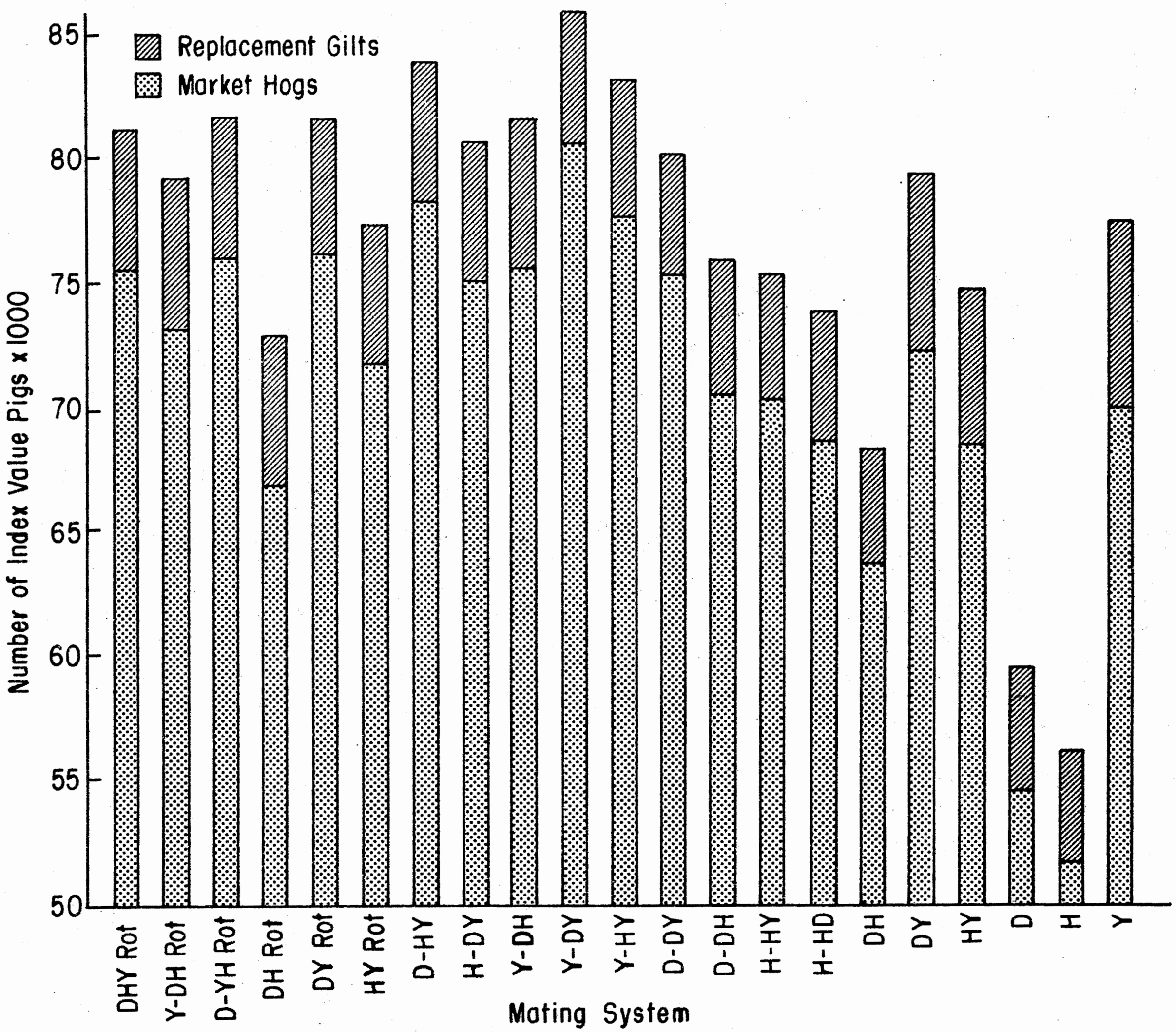

Figure 2. Number of Index Value Pigs Produced by Various Mating Systems

percent of the female offspring. The best three-breed system was a Duroc sire mated to a Hampshire-Yorkshire cross female. Yorkshire sires mated to a Duroc-Hampshire female produced 2,398 fewer index value pigs, or a decrease of 2.86 percent, as compared to the D - HY system. The static three-breed cross with Hampshire sires decreased the number of index value pigs produced by 3.81 percent from D - HY. Backcrossing a Yorkshire sire with a Duroc-Yorkshire female produced 2.4 percent more index value pigs than the best three-breed static cross, which is due primarily to the need for only two purebred herds and the high litter productivity of the breeds and crosses involved.

Each rotation cross was less efficient in number of pigs produced than the D - HY mating system. Two-breed rotation crosses with Duroc-Yorkshire, with Duroc terminal sire on a Hampshire-Yorkshire rotation female, and with the three-breed rotation cross were all similar in their production. Although the three-breed rotation maintains a higher proportion of sows farrowing in the commercial level (Figure 3), the litter productivity is not at the level of D - HY crosses. Three-breed rotation crosses cannot take advantage of those breeds which are superior as maternal or paternal parents, because they are the mean of the three breeds included in the cross plus six-sevenths of individual and maternal heterosis (Dickerson, 1969).

Mating systems which maintained a high proportion of Duroc and Hampshire breeding produced 4.5 to 32.0 percent fewer index value pigs per 10,000 farrowing sows. Mating systems involving these three breeds should contain Yorkshire breeding in the same line. Although the mating system Y - DH produced only 2.86 percent fewer index value pigs than D - HY, this sytem does not take advantage of the Yorkshire maternal

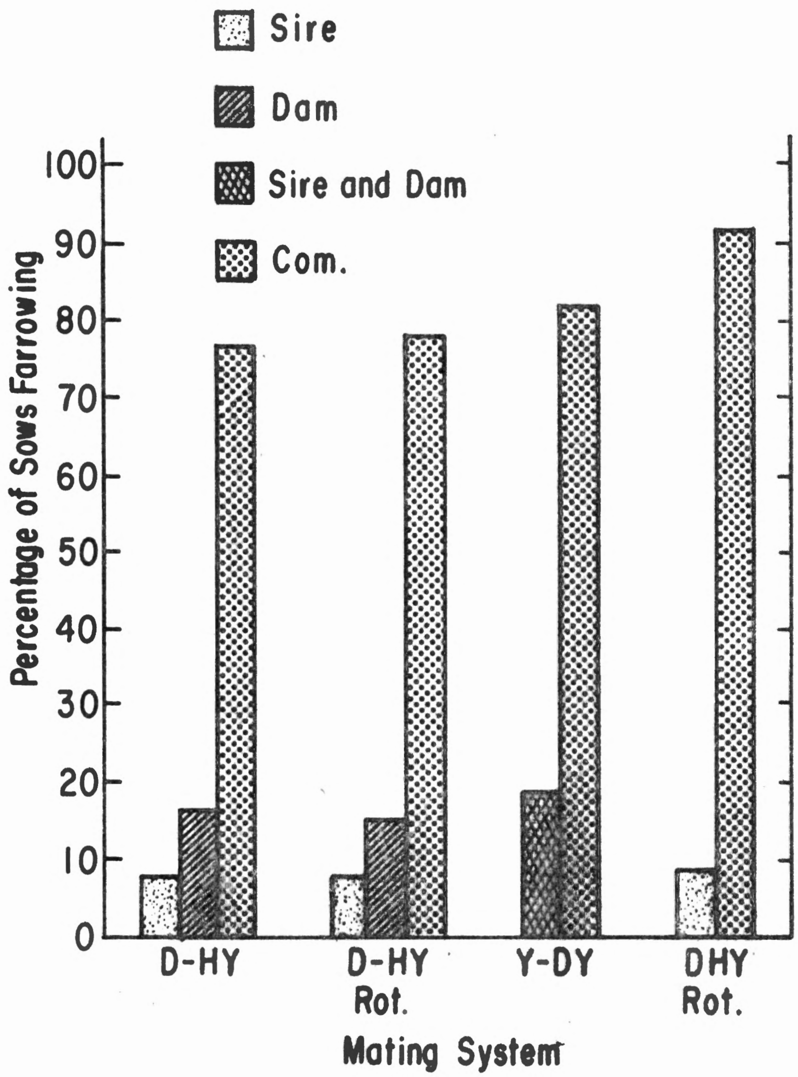

Figure 3. Distribution of Farrowing Sows for Four Mating Systems

effect for number of pigs weaned, feed efficiency, and backfat probe. The Y - DH system would be much less productive than the D - HY, except that the Y - DH system has 163 fewer gilts required in the sire line than the D - HY system (Table XVIII). The higher reproductive rate of Yorkshire allows fewer gilts to produce the required boars and thus increases the number of females in the dam line and commercial herds.

Figure 3 shows the percentage of sows farrowing from different breeding stock levels for four mating systems. With either three-breed system, D - HY or D - (HY rotation), the number of sows farrowing in each production level is similar. In the D - HY system, 7.4, 16.3 and 76.3 percent of the sows are in sire line, crossbred F_1 gilt and commercial production, while in the D - (HY rotation) system there are 7.5, 15.1 and 77.4 percent, respectively, in each level of production. The backcross system of Y - DY maintains 18.5 percent of its farrowing sows in purebred herds and 81.5 percent in commercial production. A three-breed rotation maintains the largest proportion of females in commercial production, with 91.7 percent of farrowing females producing three-breed offspring. The three purebred herds, which supply sires, comprise 8.3 percent of the farrowing females for that system.

The effect of selection intensity and/or change in generation interval upon productivity of mating systems is an area of interest. Of further interest would be the expected response due to decisions regarding selection programs; however, that is beyond the scope of this study. The procedures used to simulate selection policies were to vary gilt selection intensities, purebred and crossbred sow retention rates, and various combinations.

To estimate the effect of changing selection intensities on present production, six systems were compared setting the proportion of gilts saved at the practical limits of .5 and .8 of purebred gilts produced in the sow lines. Table XIX and Figure 4 give these comparisons. In the backcross systems, D - DY, Y - DY and Y - HY, the differences in number of index value pigs produced were 50 index value pigs or less for each mating when the limit for gilt selection was changed. This was due to the restriction that one-half of the young boars could be retained for the breeding herd, which contributed to an excess of purebred gilts and increased selection intensity (Tables XXII and XXIII). For the three-breed static system H - DY and D - HY, production was decreased 97 and 152 index value pigs, respectively; however, the Y - HD system had a loss of 880 index value pigs (Table XX). The differences in production due to changing proportion of gilts retained were similar when average retention rate of purebred sows was held constant and average retention rate for commercial sows was changed from 60 to 70 percent (Table XX).

The length of time a female stays in a breeding herd also affects the amount of genetic progress per year that a herd makes through selection, as either the generation interval is lengthened or selection intensity decreases or both (Dickerson and Hazel, 1944). Table XXI and Figure 5 show the results of varying the average sow retention rate for purebred sows producing F_1 offspring in the Y - DY, Y - DH, and D - HY systems. The average increase in number of index value pigs for each 10 percent increase in average retention rate of sows farrowing their second litter or more was 68, 48, and 147 for the D - HY, Y - DY and Y - DH systems, respectively. Decreasing the limit on the proportion of purebred gilts saved for breeding and then varying the retention rate for purebred sows

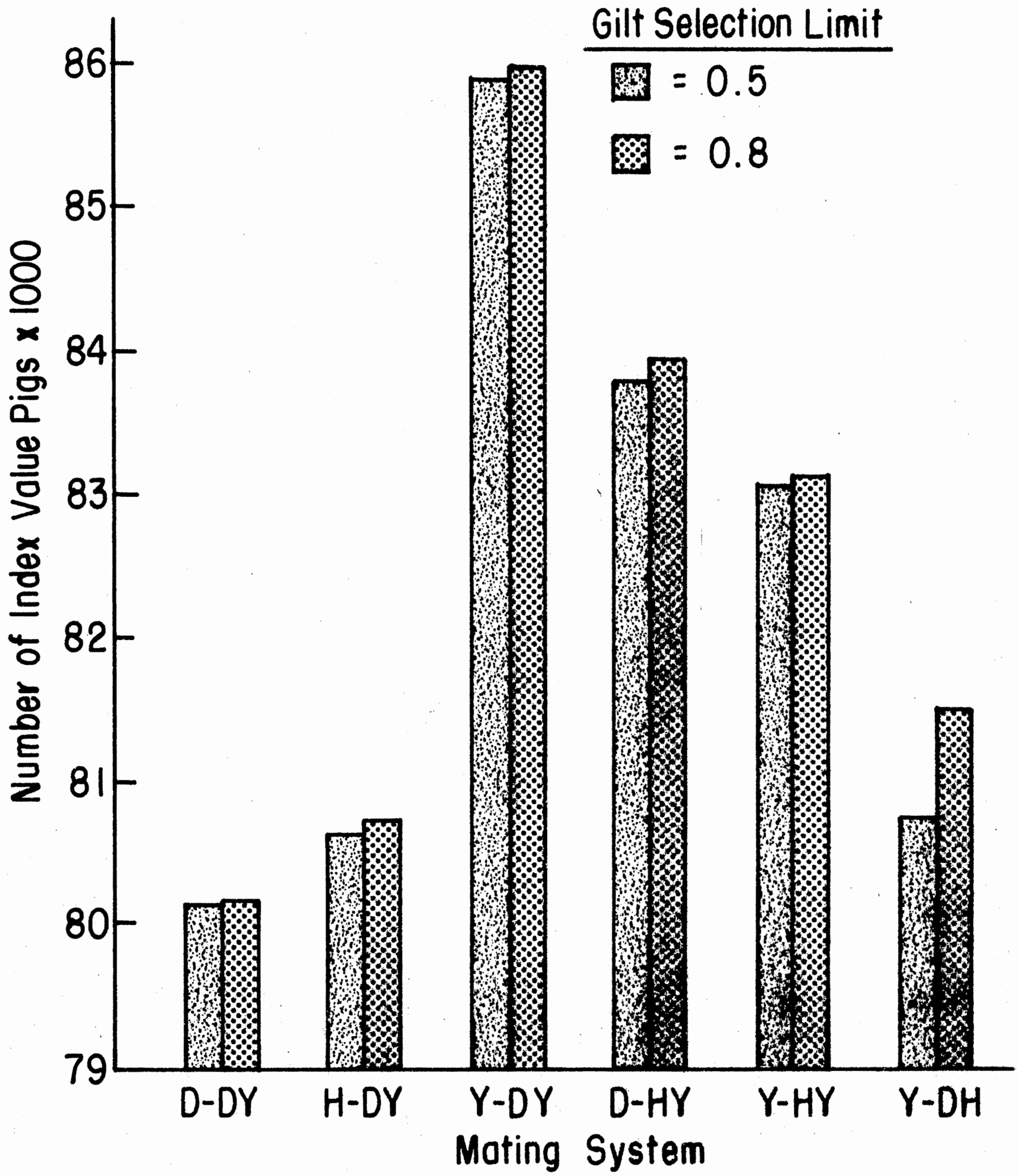

Figure 4. Comparison of Number of Index Value Pigs for Six Mating Systems at Two Limits of Purebred Gilt Selection

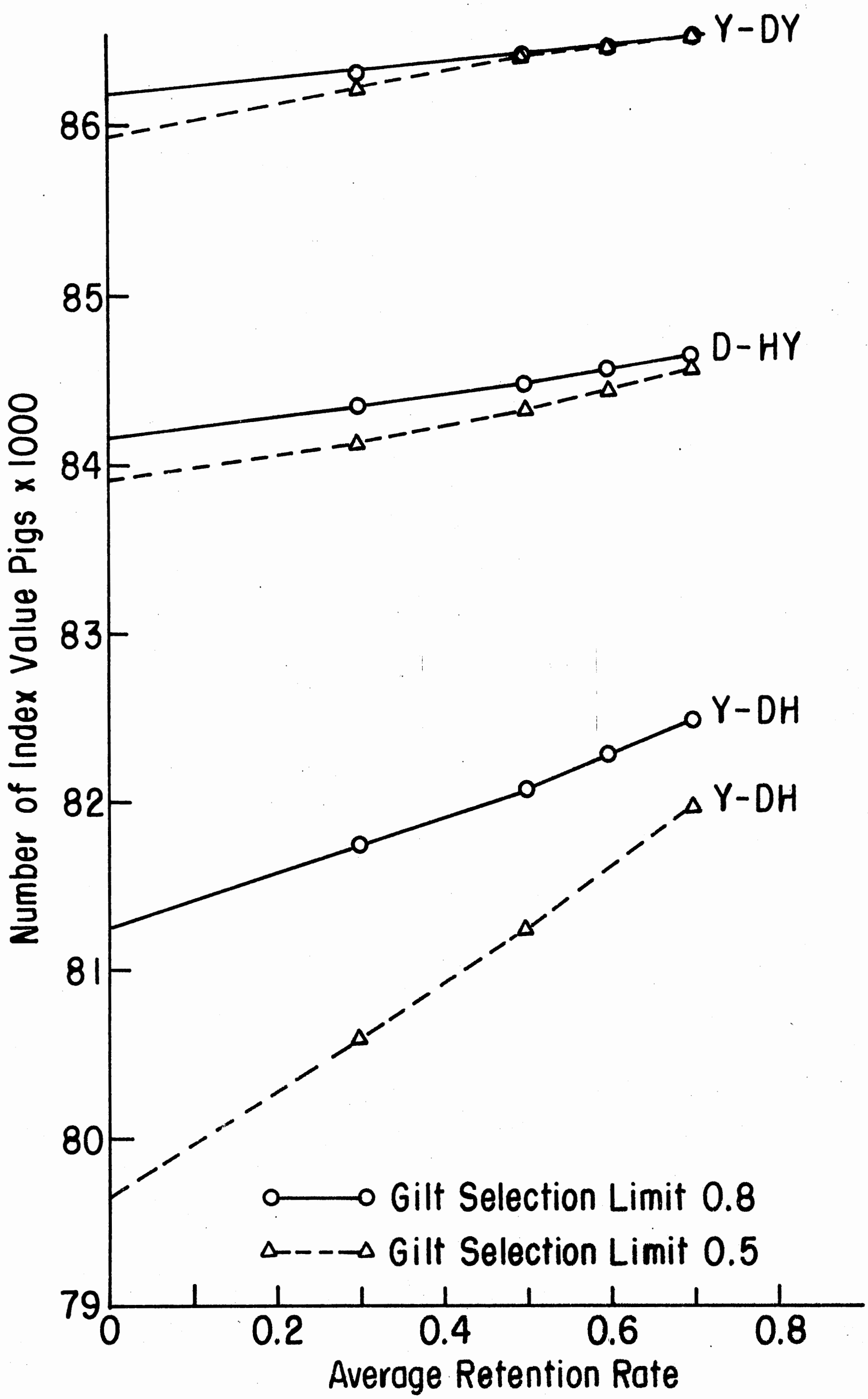

Figure 5. Comparison of Number of Index Value Pigs for Three Mating Systems at Various Retention Rates for Purebred Sows Producing F_1 Offspring and Farrowing Two or More Litters

show the most dramatic effect on production in the Y - DH system (Figure 5). Production is decreased by 528 index value pigs at the retention rate of 70 percent and by 1,582 index value pigs when no sows are retained past their second litter for commercial production, with the selection limit for purebred gilts being 50 percent. Those values compare to 109 and 314 index value pigs in the D - HY system and to zero and 252 index value pigs for the Y - DY system. At the higher levels of commercial sow retention in the Y - DY system, less than .5 of the gilts are retained for breeding; therefore, the limit of .5 does not decrease production until the average sow retention rate becomes less than 50 percent (Tables XXII and XXIII).

An additional factor that affects productivity of mating systems is the length of time that a commercial sow is retained in production. Table XXIV and Figure 6 show the result of varying the average retention rate of commercial sows when holding the gilt selection limit constant at .8 and when retaining 50 percent of the purebred sows producing F_1 gilts and farrowing two or more litters. The total decrease in production as a result of changing from retaining an average of 70 percent of those sows to not retaining any commercial sow for more than two litters was 2,724, 2,441, 2,281, 2,779, and 2,377 index value pigs for D - HY, Y - DY, DHY rotation, Y - HD and H - DY mating systems, respectively. These range from a decrease of 2.8 percent in Y - DY and DHY rotation to a decrease of 3.4 percent in the Y - HD system.

Table XXV and Figure 7 compare the number of index value pigs produced by the D - HY and Y - HD systems over various commercial sow retention rates when the purebred retention rate and proportion of purebred gilts selected are varied. This figure shows that in the Y - DY and

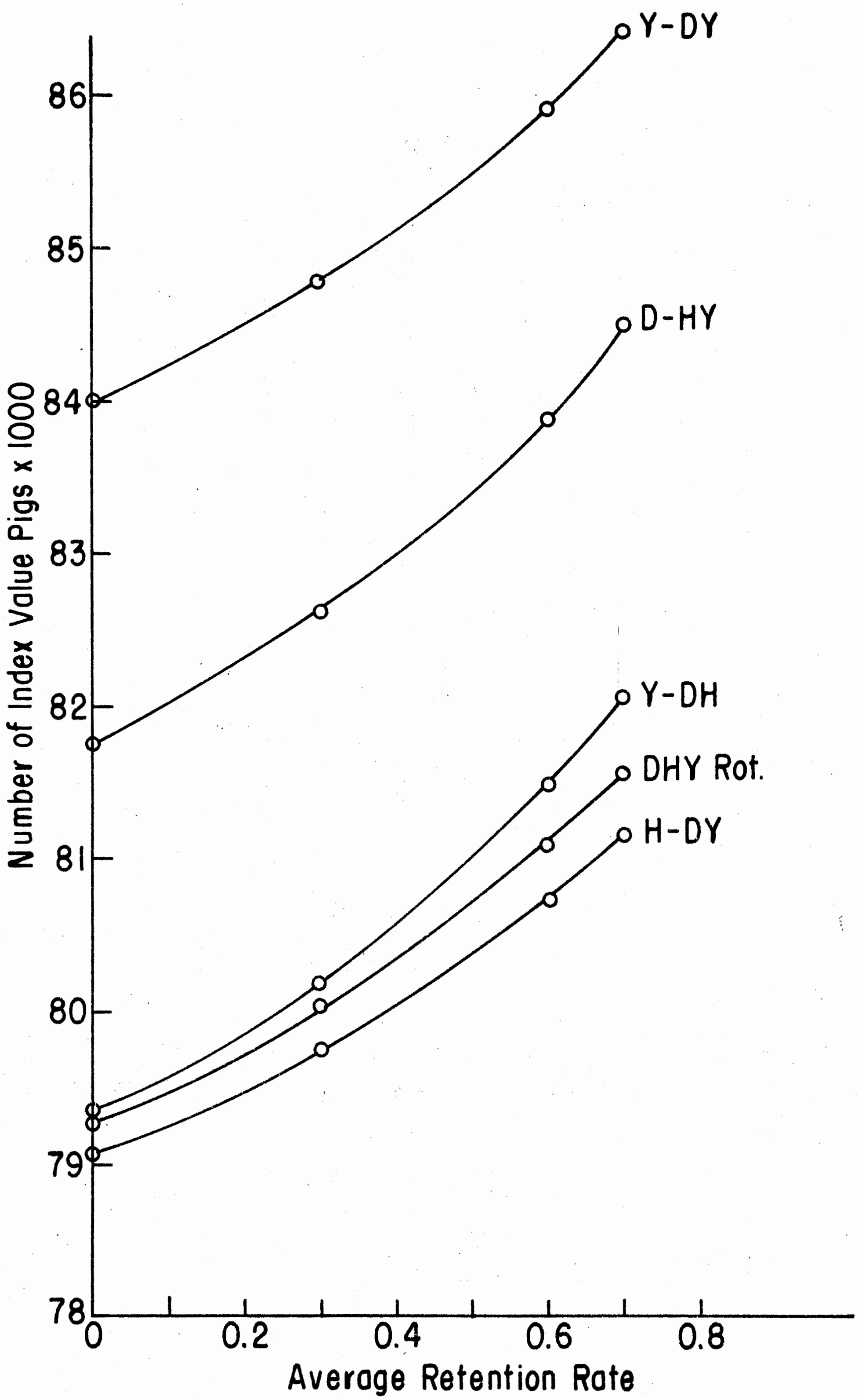

Figure 6. Number of Index Value Pigs Produced From Five Mating Systems at Various Commercial Sow Retention Rates

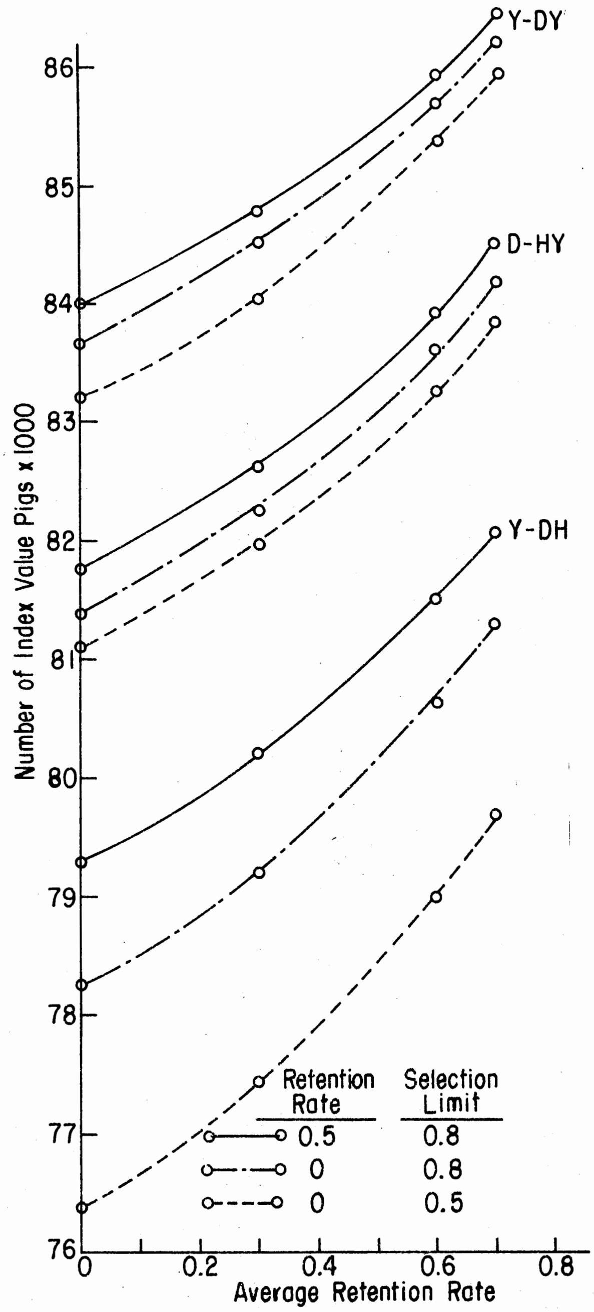

Figure 7. Comparison of Y-DY, D-HY and Y-DH Mating Systems for Number of Index Value Pigs at Purebred Sow Retention Rates of .0 and .5, Purebred Gilt Selection Rates of .5 and .8, and Varying Commercial Sow Retention Rates

D - HY systems, decreasing the average retention rate for commerical sows from 70 to 60 percent decreases total production by almost the same amount as decreasing the average retention rate from 50 percent to zero for purebred sows producing crossbred offspring and farrowing two or more litters. This indicates that commercial sows should be retained at maximum retention rates while purebred females producing crossbred offspring should be culled after the second litter. This selection procedure may increase the response to selection per year in these systems by decreasing the generation interval, since purebred sows would farrow fewer litters. In the Y - DH system, culling all purebred sows farrowing F_1 offspring after the second litter reduces production from 819 to 1,043 index value pigs which is greater than the reduction from reducing average retention rate for commercial sows from 70 to 60 percent. In the Y - DH system, changing retention rate for purebred sows and/or increasing selection intensity for purebred gilts have a marked effect on production from that system (Figure 7).

In choosing a mating system several points must be taken into consideration. These considerations include production of replacement females, making use of maternal and paternal differences, how much selection will be practiced, selection based on a general index or both maternal and paternal indexes, and balancing future returns to present returns. A backcross system such as Y - DY produced the greatest number of index value pigs per 10,000 sows. Even though a system like this needs only two purebred herds and maintains maximum maternal heterosis, it does not allow for selection based on maternal and paternal lines. Smith (1964) has shown that selection in maternal and paternal lines will always be as effective--and may be much more efficient--than selection in two lines based on a general index. A three-breed rotation system has the advantages of high percentage of sows in commercial production and ease of gilt replacements, but production is decreased by 3.3 percent when compared to the best three-breed static. The three-breed static cross D - HY has the second highest production rate and allows for taking full advantage of maternal and paternal traits of the three breeds. Since selection can be based on maternal and paternal indexes in this system, this selection scheme would need to be more effective for the long term than a general selection index in the Y - DY mating system in order for the D - HY system to become as efficient as Y - DY. This mating system is more complicated than a backcross or rotation system but may offer a good combination of present returns and selection for future improvement.

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APPENDIX

TABULAR DATA

TABLE XVIII

NUMBER AND BREED GROUP DISTRIBUTION OF FARROWING SOWS FOR EIGHT MATING SYSTEMS

Mating System	Commercial Sow Retention Rate[a]	Breed Group[b]						
		DD	HH	YY	Dx	Hx	Yx	Commercial
Terminal								
D-HY	.6	742	107	289		342	893	7628
	.7	754	100	270		287	836	7753
Y-DH	.6	103	345	579	310	1104		7559
	.7	100	315	587	301	1010		7686
H-DY	.6	109	783	312	135		966	7695
	.7	100	796	283	124		875	7822
Backcross								
Y-DY	.6	114		594	141		1006	8136
	.7	102		601	127		907	8263
Y-HY	.6		130	593		176	1087	8013
	.7		118	601		160	985	8136
D-HY	.6	786		100	975		193	7947
	.7	784		100	973		99	8045
Rotation								
DHY	.6	299	316	218				9167
	.7	299	316	218				9167

[a]The selection rate limit for gilts was .8 of the gilts produced and 50 percent of the purebred sows farrowing two or more litters were available as replacement females.

[b]DD, HH and YY represent the number of purebred gilts; Dx, Hx and Yx represent the number of purebred females producing F_1 offspring, and Commercial represents the number of sows producing commercial offspring.

TABLE XIX

NUMBER OF INDEX VALUE PIGS PRODUCED FROM EIGHT MATING SYSTEMS AT TWO GILT SELECTION LIMITS

Mating System[a]	Gilt Selection Limit	No. of Index Value Pigs Produced With Commercial Sow Retention Rate .6	.7
Terminal			
D-HY	.5	83756	84333
	.8	83908	84490
H-DY	.5	80617	81038
	.8	80714	81149
Y-HD	.5	80625	81256
	.8	81505	82084
Backcross			
D-DY	.5	70178	80551
	.8	80129	80551
Y-DY	.5	85878	86438
	.8	85922	86438
Y-HY	.5	83049	83647
	.8	83099	83664
Rotation			
DHY		81112	81568
DY		81520	81997

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

TABLE XX

CHANGE IN NUMBER OF INDEX VALUE PIGS DUE TO CHANGE IN PROPORTION OF GILTS IN DAM LINES KEPT FOR BREEDING

Mating System[a]	Change in Production Due to Selecting .5 or Less Gilts Rather Than .8	
	Sow Retention Rate = .6	Sow Retention Rate = .7
D-DY	-7	0
D-HY	-152	-157
H-DY	-97	-111
Y-DY	-44	0
Y-HD	-880	-828
Y-HY	-50	-17

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

TABLE XXI

NUMBER OF INDEX VALUE PIGS PRODUCED FROM THREE MATING SYSTEMS AT VARIOUS RETENTION RATES FOR PUREBRED SOWS PRODUCING F_1 OFFSPRING AND FARROWING TWO OR MORE LITTERS

Mating System[a]	Gilt Selection Limit	Retention Rate[b]	No. of Index Value Rep. Gilts	No. of Index Value Market Pigs	Total
D-HY	.8	0	5634	78544	84178
	.8	.3	5471	78880	84351
	.8	.5	5347	79143	84490
	.8	.6	5282	79289	84571
	.8	.7	5211	79448	84659
	.5	0	5800	78064	83864
	.5	.3	5591	78543	84134
	.5	.5	5430	78903	84333
	.5	.6	5340	79099	84439
	.5	.7	5244	79306	84550
Y-DY	.8	0	5079	81132	86211
	.8	.3	4925	81412	86337
	.8	.5	4794	81644	86438
	.8	.6	4718	81778	86496
	.8	.7	4630	81916	86546
	.5	0	5158	80801	85959
	.5	.3	4945	81298	86243
	.5	.5	4794	81644	86438
	.5	.6	4718	81778	86496
	.5	.7	4630	81916	86546
Y-DH	.8	0	5861	75404	81265
	.8	.3	5703	76024	81727
	.8	.5	5577	76507	82084
	.8	.6	5509	76772	82281
	.8	.7	5435	77054	82489
	.5	0	5887	73796	79683
	.5	.3	5690	74904	80594
	.5	.5	5546	75710	81256
	.5	.6	5468	76135	81603
	.5	.7	5389	76572	81961

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Retention rate changes were for purebred sows farrowing two or more litters. Retention rate for commercial sows farrowing two or more litters is 70 percent.

TABLE XXII

PROPORTION OF PUREBRED GILTS AND BOARS RETAINED FOR BREEDING AT TWO SELECTION LIMITS FOR SIX MATING SYSTEMS[a]

Mating System[b]	Breed[b]	Sex	Selection Limit for Purebred Gilts	
			P ≤ .8	P ≤ .5
Y-DY	Y	M	.500	.500
	Y	F	.490	.490
	D	M	.500	.500
	D	F	.447	.447
D-HY	Y	M	.073	.049
	Y	F	.800	.500
	H	M	.500	.500
	H	F	.737	.500
	D	M	.500	.500
	D	F	.447	.447
Y-HY	Y	M	.500	.491
	Y	F	.516	.500
	H	M	.500	.500
	H	F	.449	.500
D-DY	D	M	.500	.500
	D	F	.447	.447
	Y	M	.367	.367
	Y	F	.388	.388
Y-HD	D	M	.473	.500
	D	F	.800	.500
	H	M	.090	.056
	H	F	.800	.500
	Y	M	.500	.500
	Y	F	.389	.389
H-DY	D	M	.495	.473
	D	F	.447	.447
	Y	M	.054	.047
	Y	F	.800	.500
	H	M	.500	.500
	H	F	.449	.449

[a]Retention rate for purebred sows producing F_1 offspring was 50 percent and for commercial sows was 70 percent.

[b]D = Duroc, H = Hampshire and Y = Yorkshire.

TABLE XXIII

PROPORTION OF PUREBRED GILTS AND BOARS RETAINED FOR BREEDING AT TWO SELECTION LIMITS FOR SIX MATING SYSTEMS AT VARYING SOW RETENTION RATES[a]

Mating System[b]	Breed[b]	Sex	Selection Limit for Purebred Gilts	
			P ≤ .8	P ≤ .5
Y-DY	Y	M	.500	.476
	Y	F	.526	.500
	D	M	.500	.500
	D	F	.447	.500
D-HY	Y	M	.077	.049
	Y	F	.800	.500
	H	M	.500	.500
	H	F	.800	.500
	D	M	.500	.500
	D	F	.447	.447
Y-HY	Y	M	.500	.445
	Y	F	.554	.500
	H	M	.500	.500
	H	F	.449	.500
D-DY	D	M	.500	.500
	D	F	.447	.447
	Y	M	.368	.307
	Y	F	.572	.500
Y-DH	D	M	.500	.500
	D	F	.800	.500
	H	M	.087	.056
	H	F	.800	.500
	Y	M	.500	.500
	Y	F	.389	.389
H-DY	D	M	.500	.500
	D	F	.447	.447
	Y	M	.053	.046
	Y	F	.800	.500
	H	M	.500	.500
	H	F	.449	.449

[a]Retention rate for purebred sows producing F offspring was .5 and for commercial sows was .6.

[b]D = Duroc, H = Hampshire and Y = Yorkshire.

TABLE XXIV

NUMBER OF INDEX VALUE PIGS PRODUCED IN FIVE MATING SYSTEMS AT FOUR RETENTION RATES FOR COMMERCIAL SOWS

Mating System[a]	Retention Rate	No. Index Value Rep. Gilts	No. Index Value Market Pigs	Total
Y-DY	0	6946	77051	83997
	.3	6262	78512	84774
	.6	5249	80673	85922
	.7	4794	81644	86438
D-HY	0	7283	74483	81766
	.3	6670	75957	82627
	.6	5753	78155	83908
	.7	5347	79143	84490
Y-DH	0	7307	71998	79305
	.3	6755	73440	80195
	.6	5942	75563	81505
	.7	5577	76507	82084
DHY Rot.	0	7596	71691	79287
	.3	6811	73239	80050
	.6	5720	75392	81112
	.7	5257	76311	81568
H-DY	0	6866	72206	79072
	.3	6638	73112	79750
	.6	5690	75024	80714
	.7	5262	75887	81149

[a]D = Duroc, H = Hampshire and Y = Yorkshire.

[b]Retention rate for purebred sows producing F_1 offspring is .5 and the limit of gilts selected is .80 of female offspring.

TABLE XXV

NUMBER OF INDEX VALUE PIGS PRODUCED FROM THREE MATING SYSTEMS AT TWO GILT SELECTION LIMITS AND VARYING COMMERCIAL SOW RETENTION RATES

Mating System[a,b]	Gilt Selection Limit	Commercial Sow Retention Rate	Number of Index Value Pigs
D-HY	.8	0	81373
		.3	82225
		.6	83577
		.7	84178
	.5	0	81108
		.3	81962
		.6	83226
		.7	83864
Y-DH	.8	0	78262
		.3	79214
		.6	80628
		.7	81265
	.5	0	76381
		.3	77416
		.6	78971
		.7	79683
Y-DY	.8	0	83670
		.3	84509
		.6	85685
		.7	86211
	.5	0	83204
		.3	84036
		.6	85356
		.7	85959

[a]Retention rate of purebred sows producing crossbred offspring and farrowing their second litter is zero.

[b]D = Duroc, H = Hampshire and Y = Yorkshire.

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