GROWTH PERFORMANCE AND CROSSBREEDING SYSTEM EFFICIENCY FOR FOUR BREEDS OF SWINE

By

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

LIST OF FIGURES

Figure Page

CHAPTER II

CHAPTER IV

CHAPTER V

CHAPTER I

INTRODUCTION

Efficient pork production dictates that market hogs be produced by some form of crossbreeding system. Evaluation of experimental swine crossbreeding data is required in order to identify superior breeds and exploitable heterosis for important production traits. This thesis presents analysis of growth performance data from purebred, two, three and four breed cross matings involving the Duroc, Yorkshire, Landrace, and Spotted breeds of pig. Parameter estimates for (numerically) relatively minor breeds, such as the Landrace and Spotted, are required in order to assess their potential contribution to crossbreeding system efficiency in the U.S.

The number of breeds available, and the variety of alternative static, rotational and combined crossbreeding systems, makes comparisons among alternative systems a task well suited to the computer. In addition, the number of economically important traits requiring simulaneous evaluation and the need to not only consider performance in the market hog producing sector, but also to make allowance for purebred and other breeding stock generators required by the system, increases the complexity of obtaining valid comparisons among alternative crossbreeding systems. Experimental evaluation of all possible systems is impractical. Therefore it is necessary to use breed effect and heterosis estimates in order to predict expected performance of systems and breed combinations not evaluated in the field. The quality of such predictions naturally depends upon the accuracy of both parameter estimates and the system model assumed.

This thesis presents individual heterosis estimates for postweaning growth and carcass traits from a crossbreeding experiment involving the Duroc, Yorkshire, Landrace and Spotted breeds of swine carried out at the Oklahoma Agricultural Experiment Station between 1976 and 1979. Effects of purebred and crossbred boars on progeny growth and feed efficiency are also discussed. Parameters estimated from these data, and from reproductive performance data from the same experiment, were used as driving variables in static, deterministic computer models. The models were designed to calculate production efficiency, defined as production cost/kg product, for alternative static, rotational and combination crossbreeding systems involving the above four breeds. The lack of available software in this area prompts the planned modification of the models into more "user-friendly" form in order to provide tools for use in Animal Breeding classes and Extension demonstrations.

CHAPTER II

REVIEW OF LITERATURE

Theoretical Basis for Crossbreeding

Introduction. Crossbreeding can be defined as the mating of individuals from genetically different groups (i.e., breeds, strains or lines) within a species. Systematic crossbreeding programs in farm livestock species are designed to exploit the benefits of heterosis and complementarity (in all but strictly rotational systems) in order to improve production efficency. Grading-up of inferior stock to superior breeds, and the development of new (synthetic) breeds from crossbred foundations, are additional applications of crossbreeding.

The basis of complementarity is primarily the existence of breed differences in maternal effects (Sellier, 1976). Superiority of a cross over the parental mean, ignoring nonadditive (heterotic) gene effects, is due to differences in sex linked and maternal effects. Choosing the appropriate breed(s) to use as the dam line(s) in a static crossbreeding system allows exploitation of these differences.

The term heterosis is often considered synonymous with hybrid vigor, an expression first used in the 18th century to describe the superiority of certain interspecific plant crosses (Zirkle, 1952). It was not until 1907 that a general concept of heterosis emerged, a concept Shull (1952, p. 48) described as "the interpretation of increased vigor, size, fruitfulness, speed of development, resistance to disease and to insect pests, or to climatic rigors of any kind, manifested by crossbred organisms as compared with corresponding inbreds, as the specific results of unlikeness in the constitutions of uniting parental gametes." The term heterosis itself was first proposed by Shull in 1914 to describe the increased vigor of crossbreds relative to their parents (Shull, 1948).

However, much ambiguity as to the precise meaning of the term heterosis has existed for many years. Shull's definition intentionally precluded any unfavorable departure from additivity in crossbred populations - and such a definition of heterosis is still adhered to by many animal breeders today (e.g., Sheridan, 1981; Hill and Webb, 1982). However, a substantial body of evidence suggests that hybrid disvigor also exists (Manwell and Baker, 1970). Stern (1948) suggested the terms positive heterosis and negative heterosis be used in referring to crossbred improvement or decline relative to parental performance. While disputed by Shull (1948), Stern's suggestion seems appropriate in that it allows for generality of the heterosis concept.

Another source of confusion stems from the fact that the original idea of hybrid vigor was of hybrid superiority to both parents. However, Lambert (1940) defined heterosis as the superiority of the crossbred over either parent, and similarly Herskowitz (1967) defined it as heterozygotic superiority to one or both homozygotes. Nevertheless, heterosis is conventionally measured as the deviation of the crossbred from the average of parental lines (Mather, 1949; Lerner, 1958; Falconer, 1960). This is the definition assumed in this manuscript.

Heterosis Models. A number of hypotheses relating to (positive) heterosis have been proposed. Three 'classical' hypotheses discussed by Gowen (1952), Lerner (1954), Mather (1955) and Sang (1956) were reviewed by Bowman (1959). These are:

(a) The dominance model, which assumes dominant alleles are favorable and that parental lines or breeds are homozygous dominant at different loci;

(b) The overdominance model, which assumes the heterozygote to be superior to either homozygote at various loci and

(c) The epistasis model, which assumes heterosis to be the result of some form of inter-locus interaction (see Kinghorn, 1980, 1982 and Sheridan, 1981 for more recent considerations of epistatic models).

Naturally these models are not mutually exclusive. Rather, a number of genetic mechanisms are likely to be involved in heterosis, the relative importance of each depending upon the specific trait and populations involved. Dickerson (1952), for instance, suggested that under long-term, uni-directional selection it is likely that favorable dominant alleles will become fixed, whereas loci exhibiting overdominance will have intermediate gene frequencies. Thus, if overdominance is important, its greatest effect should logically be for traits such as litter size and viability (under continuous 'automatic' selection), while dominance and epistasis may be the primary genetic mechanisms involved in postweaning trait heterotic effects.

The genetic models described above have also been proposed as explanations for inbreeding depression. Indeed, a number of workers have equated heterosis to a reversal of inbreeding depression (Fredeen, 1956; Lerner, 1958; Falconer, 1960). Certainly, traits exhibiting the greatest inbreeding depression also show the greatest heterotic response in crosses. However, such observations do little to help elucidate the genetic mechanisms responsible for heterosis. Sarkissian (1967, cited by Manwell and Baker, 1970, p. 13) maintained that

> "our knowledge of the intimate mechanism(s) of heterosis has not flourished in spite of the fact that we have been aware of heterosis since the time of Koelreuter and Darwin in the 18th and 19th centuries ... That heterosis is a genetic phenomenon cannot be doubted. In fact, one can be somewhat specific in describing the genetic make-up necessary for heterosis by stating that heterosis is associated with heterozygosity. Statements that go beyond this point in attempting to explain further the genetic aspects of heterosis are rather general and vague. Dominance, masking of harmful recessive genes in the heterozygote, epistasis, overdominance, adaptive superiority of the hybrid or 'physiologically active' genes, controlling reactions responsible for heterotic expression - all of these, unfortunately, are circular definitions stating in essence that a given organism exhibits heterosis because it is superior ..."

In an attempt to overcome these shortcomings, Manwell and Baker (1970) proposed the complementation theory. Rather than considering the mechanism of heterosis at the gene or locus level, they proposed a molecular model. The classic example of complementation involves heterokaryon formation in fungi. Two strains, each deficient in a different enzyme required by the same metabolic pathway, combine such that each cell contains nuclei from both strains. Each strain, therefore, complements the deficiency of the other, resulting in restoration of the pathway. Manwell and Baker (1970) proposed that overdominance and epistasis can be viewed as genetic complementation involving proteins or their subunits, providing a noncircular explanation for heterosis bridging genotype and phenotype and amenable to biochemical testing.

More recently, Orozco (1976) proposed a model (similar to one proposed by Langridge in 1962), in which heterosis would occur only in non-optimal environments. Results of the author's work with Tribolium suggested heterosis might involve two types of genes: those acting girectly on the trait, and those acting indirectly via effects on tolerance to environmental stress. Barlow (1981), reviewing the evidence for heterosis x environment interactions in animals, concluded that, taken collectively, the evidence indicated that heterosis for most traits appeared to be greater in sub-optimal environments.

Analysis of Crossbreeding Data

The analysis and genetic interpretation of crossbreeding experimental data has received considerable attention from both geneticists and statisticians over the past 40 years (see Wearden, 1964; Willham, 1980 and Eisen et al., 1983 for brief reviews).

The diallel cross (all possible (p^2) matings among a set of p parental lines) has been used extensively in plants to partition genetic variation into general and specific combining abilities of inbred lines (Sprague and Tatum, 1942; Griffing, 1956). Henderson (1948, 1952) presented a method of analysis appropriate for animal experiments to obtain least-squares estimates of maternal effects in addition to general and specific combining abilities.

Touchberry and co-workers at the University of Illinois (Shreffler and Touchberry, 1959; Dickinson and Touchberry, 1961; Verley and Touchberry, 1961; Touchberry and Bereskin, 1966a,b; Bereskin and Touchberry, 1966, 1967) developed and used various statistical models to analyze dairy cattle crossbreeding data. The basic model assumed was:

$$y_{ijkl} = \mu + a_i + b_{ij} + c_k + (ac)_{ik} + (bc)_{ijk} + e_{ijkl} \qquad (1)$$

where

y_{ijkl} = an observable random variable;

μ = the overall mean (an unknown constant);

a_i = the effect of the i^{th} breed of sire;

b_{ij} = the effect of the j^{th} sire within the i^{th} breed of sire;

c_k = the effect of the k^{th} breed of dam;

$(ac)_{ik}$, $(bc)_{ijk}$ = interaction terms and

e_{ijkl} = the random residual effect associated with the l^{th} animal in the ijk^{th} progeny group, assumed NID $(0, \sigma^2_e)$.

All effects (except the residual) were considered fixed - including sires, more often thought of as random variables in such experimental designs. Later analyses involving a similar model (Batra and Touchberry, 1974 a,b), while not specifically identifying fixed and random effects in the model, used variation among sires as the error term for testing differences among breeds of sire. This is the appropriate test (Sellier, 1980), and implies that sires are considered as random effects in the model.

Variations of the basic model (i.e., including additional fixed effects such as season and sex, and covariables such as age and weight of dam) were used, but do not alter interpretation of the genetic (breed) effects. Significant breed of sire and breed of dam effects indicate differences among additive genetic effects for the breeds. Differences between breed of sire and breed of dam effects are explained by maternal and (or) paternal effects, assuming direct genetic differences between sires and dams of the same breed to be unimportant. Differences due to breed crosses (the breed of sire x breed of dam interaction) indicate nonadditive (heterotic) effects exist. The importance of differences among sires within a breed can also be determined from this type of analysis. Significance of sires nested within breed of sire x breed of dam interaction provides evidence as to the importance of 'nicking' (specific combining ability) between certain sires and different dam breeds. Parekh and Touchberry (1974) later modified the basic model by including percent heterozygosis effects in addition to breed of sire and breed of dam effects.

Gardner and Eberhart (1966) extended Griffing's (1956) diallel model for analysis of plant crossbreeding experiments by subdividing direct heterosis (h_{ij}) into average ($\bar{h}$), variety (h_i) and specific (s_{ij}) direct heterosis.

i.e. $$h_{ij} = \bar{h} + h_i + h_j + s_{ij} \qquad (2)$$

where: $\bar{h}$ = the average direct heterosis contributed by the set of varieties used in crosses;

h_i (h_j)= the average direct heterosis contributed by variety i (j) in its crosses, as a deviation from $\bar{h}$ ($\Sigma h_i = 0$);

and s_{ij} = specific direct heterosis occurring when variety i is mated to variety j ($\sum_i s_{ij} = \sum_j s_{ij} = 0$ and $s_{ij} = s_{ji}$).

Where parental varieties can be selfed, this model allows for the separate estimation of additive and dominance effects. Otherwise, these effects are confounded and must be estimated jointly. The partitioned heterosis parameters ($\bar{h}$, h_{ij} and s_{ij}) are estimable in either case, but only where all p^2 diallel matings are made. An important result of such partitioning is that parameter estimates can be used to predict performance of populations not included in the experiments analysed - thus enhancing the power of experimental data to help in decisions relating to utilization of available varieties and mating systems. As such, Gardner and Eberhart's work represented a significant advance in the analysis of crossbreeding data.

Another milestone in the design and analysis of crossbreeding experiments was Dickerson's (1969) presentation of an analytical approach to the problem of how best to utilize available animal breed resources. He defined various statistical genetic parameters, estimable from crossbreeding data, that could be used to predict performance of alternative crossbreeding schemes. These genetic parameters, defined as mean deviations in offspring performance from average purebred performance of a specified set of breeds, were:

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

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

$g^{M'}_A$ = deviations due to average effects of genotype for breed A maternal granddams, through modification of direct maternal effects;

h^I_{AB} = deviation due to increased average heterozygosity of F_1 crossbreds from A males x B females, or reciprocals, including any nonallelic interaction of A with B gametes;

h^M_{AB} = as h^I_{AB}, but for maternal environmental effects of F_1 crossbred dams;

$h^{M'}_{AB}$ = as h^M_{AB}, but through maternal environmental interaction effects of F_1 crossbred maternal granddams on the maternal influence of the dam;

r^I_{AB} = deviation due to change in nonallelic 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^M_{AB} = as r^I_{AB}, but for indirect maternal environmental effects;

$r^{M'}_{AB}$ = as r^M_{AB} , but through maternal environmental interaction effects of maternal granddams on the maternal influence of the dams.

Dickerson's (1969) model therefore included direct, maternal and grand-maternal average genetic effects, heterosis and epistatic recombination effects. Sex-linked and paternal effects were considered negligible, although paternal effects were included in a subsequent model (Dickerson, 1973). Nongenetic effects (e.g., age, year, season) must, of course, be removed, either in the analysis or by experimental design. Assuming random mating, linkage equilibrium, additivity (no interaction) of gametic and heterotic contributions of different breeds to various crosses and absence of interaction between different parameters, expected performance of various types of mating can be expressed in terms of the above parameters. For example:

$$E(AxA) = A + g^{I}_{A} + g^{M}_{A} + g^{M'}_{A} \quad (3)$$

$$E(AxB) = AB + .5(g^{I}_{A}+g^{I}_{B}) + g^{M}_{B} + g^{M'}_{B} + h^{I}_{AB} \quad (4)$$

$$\begin{aligned} E(CxAB) = {} & ABC + .25(2g^{I}_{C}+g^{I}_{A}+g^{I}_{B}) + .5(g^{M}_{A}+g^{M}_{B}) + g^{M'}_{B} + \\ & .5(h^{I}_{CA}+h^{I}_{CB}) + h^{M}_{AB} + .25r^{I}_{AB} \quad (5) \end{aligned}$$

By further assuming a linear relationship between percent heterozygosity and heterosis (dominance and recombination effects), expectations can be given for mating systems such as rotations and synthetics that maintain between 0 and 100% heterozygosity. Dickerson (1969) pointed out that although the relationship may in fact be curvilinear, expectations obtained assuming linearity should still provide useful approximations for comparison of alternative crossbreeding schemes.

The recombination (r) parameters in the model measure deviations from a linear relationship between percent heterozygosity and heterosis (Dickerson, 1973). Coefficients of these parameters represent the proportion of gametes from both parents expected (assuming linkage equilibrium) to be recombinants, i.e., gametes not present in the original parental populations. That such effects will generally be negative is logical given that favorable combinations of various gene pairs are probably established at different loci, as adaptations to specific environments, during the development of breeds or lines. Thus where such populations are adapted to similar environments, epistatic recombination losses (i.e., the magnitude of r) from crossing these populations may indeed be negligible. Wider crosses, however, may result in recombination losses of practical significance (Falconer, 1960).

Sheridan (1981, p. 140) concluded a review of crossbreeding and heterosis in poultry, pigs, cattle and sheep by stating "the limited experimental evidence available indicates that, in many cases, the level of heterosis in crossbred populations other than F_1 populations is less than would be predicted on the basis of percentage of heterozygosity." Results were, however, far from conclusive - particularly for pigs. McGloughlin (1980), working with mice, demonstrated a clear linear relationship between heterozygosity and heterosis for litter size and weight, and for individual progeny weight at birth and weaning. She cited a number of studies involving corn, mice, dogs, and cattle which also demonstrated linearity--as well as conflicting evidence from experiments with Drosophila, corn and poultry that found nonlinearity suggesting recombination loss. North American breeds of pig, relative to breeds of other livestock species, may be considered to be adapted to somewhat similar environments (Sellier, 1976). Therefore, despite the decided lack of experimental evidence, it may be reasonable to assume that epistatic recombination losses are negligible when comparing alternative swine crossbreeding schemes.

Given the assumptions discussed above (but not that recombination effects are zero), Dickerson (1969, 1973) presented expectations for various crossbreeding schemes in terms of statistically defined genetic parameters (see table 1). In the 1973 paper, grand-maternal effects were dropped from the model, and paternal effects included (to accommodate systems involving crossbred males not considered in 1969). Different coefficients on the recombination parameters were presented for the same mating systems in the two papers. The revised (1973) coefficients are presumed to be appropriate.

Although Dickerson (1969, 1973) did not discuss estimation of genetic parameters, his work had a profound effect on subsequent design and analysis of animal crossbreeding experiments. Least-squares regression procedures that equated genetic group means to their expectations based on Dickerson's model were adopted by a number of workers (e.g., Gregory et al., 1978; Alenda et al., 1980; Dillard et al., 1980; Robison et al., 1980).

Robison et al. (1981) formally proposed a model developed at North Carolina State University as an improvement over conventional techniques for the analysis of crossbreeding data. They set out to extend Gardner and Eberhardt's (1966) work with plants to the development of a model suitable for analyzing animal crossbreeding data. Robison et al. (1981) claimed three advantages for their procedure over alternative analytical techniques. Firstly, that theirs was a statistically less complex procedure; secondly, that it provided a clearer understanding of genetic

TABLE 1. FRACTION OF HETEROSIS AND RECOMBINATION LOSS EXPECTED FOR ALTERNATIVE SYSTEMS OF BREED USE[a].

Mating System[b]	Heterosis			Recombination		
	h^I	h^M	h^P	r^I	r^M	r^P
A x B	1	0	0	0	0	0
A x A-B	1/2	1	0	1/4	0	0
C x A-B	1	1	0	1/4	0	0
A-B x C	1	0	1	1/4	0	0
C-D x A-B	1	1	1	1/2	0	0
Rotations						
2 breed	2/3	2/3	0	2/9	2/9	0
3 breed	6/7	6/7	0	6/21	6/21	0
4 breed	14/15	14/15	0	14/45	14/45	0
C x Rotation						
2 breed	1	2/3	0	2/9	2/9	0
3 breed	1	6/7	0	6/21	6/21	0
4 breed	1	14/15	0	14/45	14/45	0
Synthetic						
2 breed	1/2	1/2	1/2	1/2	1/2	1/2
3 breed	2/3	2/3	2/3	2/3	2/3	2/3
4 breed	3/4	3/4	3/4	3/4	3/4	3/4

---

[a] After Dickerson (1973)

[b] Breed of sire x breed of dam.

components and thirdly, that it allowed prediction of breed crosses not included in the experimental data. The model proposed was as follows:

$$C_{i,j} = \mu + \Sigma_i k_i a_i + \Sigma_j k_j a_j + \Sigma_i k_{i'} p_i + \Sigma_j k_{j'} m_j + \Sigma_{ij} k_{ij} h_{ij}{}^I + \Sigma_j k_{jj'} h_{jj'}{}^M + \Sigma_i k_{ii'} h_{ii'}{}^P \qquad (6)$$

where

$C_{i,j}$ = mean performance of the ij_{th} cross;
μ = a constant;
$k_i(k_j)$ = percentage of genes contributed by breed i(j) through the sire (dam);
$a_i(a_j)$ = average effect of the $i^{th}(j^{th})$ breed;
$k_{i'}(k_{j'})$ = percentage of genes in the sire (dam) from breed i(j);
p_i = paternal effect of the i^{th} breed as a sire;
m_j = maternal effect of the j^{th} breed as a dam;
k_{ij} = percentage of loci in individuals with one gene from the i^{th} breed and the other gene from the j^{th} breed;
$h_{ij}{}^I$ = heterosis due to intra-locus interaction of two alleles from breeds i and j;
$k_{ii'}$ = as k_{ij}, but for the male parent rather than the individual;
$h_{ii'}{}^P$ = paternal heterosis;
$k_{jj'}$ = as $k_{ii'}$, but for the female parent;
and $h_{jj'}{}^M$ = maternal heterosis.

Thus far, the model follows the parameterization suggested by Dickerson (1969, 1973). However, Robison et al. (1981) also suggested that, where data were sufficient (i.e., where all possible purebred and crosssbred matings have been made), the heterosis effects ($h_{ij}{}^I$, $h_{ii'}{}^P$, $h_{jj'}{}^M$) be partitioned into average, breed average and specific heterosis components as proposed by Gardner and Eberhart (1966). Robison et al.

(1981) also pointed out that comparison of the results from their model and from a model fitting breed groups (and thus allowing for any linkage, epistatic and nonlinear genetic effects) would provide evidence as to the importance of these effects.

Eisen et al. (1983) presented a somewhat more theoretical expansion of Gardner and Eberhart's (1966) model, again designed to allow genetic interpretation of diallel crosses involving animals when maternal effects may be important. The authors commented on the frequent lack of clear genetic interpretations placed upon statistical parameters obtained from analysis of animal crossbreeding data, and attempted to clarify interpretation of various parameters. As discussed above, Gardner and Eberhart (1966), partitioned direct heterosis as:

$$h_{ij} = \bar{h}_{..} + h_i + h_j + s_{ij} \qquad (2)$$

Eisen et al. (1983) pointed out that h_i (direct heterosis of line i as a deviation from overall heterosis, $\bar{h}_{..}$) is not identical to the more usual definition of line heterosis ($\bar{h}_{i.}$) found in the animal breeding literature. Rather:

$$h_i = (\bar{h}_{i.} - \bar{h}_{..})(p-1)/(p-2) \qquad (7)$$

where p = number of breeds or lines;

$$\bar{h}_{i.} = \sum_{j(\neq i)} h_{ij}/(p-1)$$

and $\bar{h}_{..} = \sum_{i<j}\sum h_{ij}/(p(p-1)/2)$.

Eisen et al. (1983) cited Casas and Wellhauser (1968) as having shown that:

$$h_{ij} = z_i + z_j - 2w_{ij} \qquad (8)$$

where $z_i = \sum_k (q_{ik} - \bar{q}_{.k})^2 d_k$;

$w_{ij} = \sum_k (q_{ik} - \bar{q}_{.k})(q_{jk} - \bar{q}_{.k}) d_k$;

q_{ik} = frequency of the favorable allele at the k^{th} locus in the i^{th} line;

$\overline{q}_{.k} = (1/p)\sum_i q_{ik}$

and d_k = dominance value of the heterozygote at the k^{th} locus.

In addition, they credit the work of Vencovsky (1970) (reviewed by Hallauer and Miranda, 1981), as having provided considerable insight into the genetic interpretation of $\overline{h}..$, h_i and s_{ij} by deriving z_i in terms of parental and crossbred means. Now, h_i can be expressed as:

$$h_i = (z_i - \overline{z}.)(p/(p-2)) \qquad (9)$$

where $z = (1/p)\sum_i z_i = \sum_k \sigma^2_{qk} d_k$ and σ^2_{qk} is the variance of gene frequency at the k^{th} locus among all lines.

Due, therefore, to the exact linear relationship between h_i, $\overline{h}_i$ and z_i, only one of these statistics needs to be presented. In favor of $\overline{h}_i$ is the fact that it is presently in common use in animal breeding literature. However, Eisen, at al. (1983) claimed that h_i would be more appropriate to evaluate the relative contribution of line heterosis to heterosis and to general combining ability; and that z_i more directly measures gene frequency divergence from mean gene frequency among lines. Eisen et al. (1983) demonstrated interpretation of various crosbreeding statistics using a diallel experiment involving five mouse lines.

Clear definition of the parameters to be investigated, and an awareness of the requirements of statistical models to be used to estimate these parameters, are prerequisites to the design of any crossbreeding experiment. The diallel cross allows for the most detailed genetic analysis possible. However, the limited experimental facilities available to researchers working with farm livestock species places practical restrictions on experimental design in many cases (Sellier, 1980). In order to maintain sufficient matings/cell, it may not be possible to make all desired crosses concurrently. Such was the case for the experiment analyzed in this present study--with the total number of 'lines' consisting of four pure breeds of pig plus all possible two-way crosses.

The analysis of any particular set of animal crossbreeding data is likely to be unique to some extent, demanding the creative application of concepts outlined in this section. Genetic parameter estimates can (and, in practice, usually will) be obtained by making appropriate contrasts among linear model solutions. The number of contrasts to be made often exceed available degrees of freedom. Use of such contrasts, developed a priori to provide insight into the importance of various effects is, however, considered a valid technique (Eisen et al., 1983).

Crossbreeding Experiments with Pigs

Introduction. Comprehensive reviews of swine crossbreeding experiments have been published by a number of American, Canadian and European workers (Dickerson, 1973; Jonsson, 1975; Sellier, 1976; Johnson, 1980, 1981; Glodek, 1982). The objective of this section is to selectively consider reports relevant to the present study. To help establish the context of the present experiment, swine crossbreeding experiments carried out at Oklahoma State University are briefly reviewed. This is followed by a summary of reported heterosis and breed effect estimates for growth and carcass traits for the Duroc, Yorkshire, Landrace and Spotted breeds of swine.

The Oklahoma Swine Crossbreeding Experiments. Foundation herds of Duroc, Hampshire and Yorkshire swine were established at the Oklahoma

State University Experimental Swine Farm at Stillwater in 1969. These herds then supplied breeding stock for a crossbreeding experiment conducted at the USDA Southwest Livestock and Forage Research Station, El Reno, Oklahoma. Phase I of this experiment consisted of diallel matings involving the three breeds, with litters farrowing in the spring and fall of 1971. Johnson et al. (1973) reported results for growth and carcass traits. Reproductive performance data (including numbers of corpora lutea and embryos 30 d postbreeding) were analyzed by Johnson and Omtvedt (1973) and Young et al. (1974). Phase I also served to provide females for Phase II, where purebred boars were mated to purebred and F_1 females to produce all possible two and three breed static cross litters, which farrowed in the spring and fall of 1972. Individual heterosis for ovulation rate and maternal heterosis for litter productivity were estimated from these data (Johnson and Omtvedt, 1975).

Phase I was subsequently replicated in the spring and fall of 1973 (Young et al., 1976a,b), and Phase II in the spring and fall of 1974 and the spring of 1975 (Johnson et al., 1978). These later reports represented complete analyses of the data. In conjunction with this work, Wilson et al. (1977) reported testicular and reproductive characteristics of Duroc, Hampshire and crossbred Duroc x Hampshire and Hampshire x Duroc boars produced at the Stillwater Station between the fall of 1973 and the spring of 1975. Young et al. (1977a,b) also investigated the relationships between a gilt's prebreeding and reproductive performance using data on gilts produced at both the El Reno and Stillwater stations between the fall of 1970 and spring of 1974.

Backcross and three breed static systems involving Duroc, Hampshire and Yorkshire breeds were evaluated at the El Reno Station between the fall of 1975 and the spring of 1977 (Wilson and Johnson, 1981a,b).

In the spring of 1976, Landrace and Spotted purebred herds were established at the Stillwater Swine Farm. This marked the start of a new crossbreeding project with the following objectives:

1. To evaluate purebred performance and combining ability of Duroc, Yorkshire, Landrace and Spotted breeds of swine in two, three and four breed crosses.

2. To investigate the importance of heterosis for male reproductive performance.

3. To identify mating systems that maximize total and lean tissue production efficiency.

There were two phases to the experiment. Diallel matings involving all four breeds produced purebred and all possible two breed cross litters between the fall of 1976 and the fall of 1978 at the Stillwater Experimental Swine Farm. The Stillwater phase was designed to allow evaluation of purebred and two breed cross performance, and to supply breeding stock for use in the El Reno phase. Three and four breed cross litters were farrowed at the El Reno station between the fall of 1977 and the fall of 1979.

Wilson et al. (1978) presented preliminary results for performance of purebred and two breed cross pigs from the first two seasons of the Stillwater phase of the experiment. Hutchens et al. (1981, 1982) reported results of an investigation into the relationship between pubertal and growth characteristics of gilts, and compared age and weight at puberty for breed groups. The gilts were purebred and F_1

crosses farrowed at Stillwater between the fall of 1976 and the spring of 1978. Fent et al. (1983) studied the influence of breed and heterosis on testicular development and serum LH and testosterone (after GnRH challenge) in purebred and crossbred boars produced at the Stillwater Farm between the spring of 1977 and the spring of 1979. Sow productivity comparisons for the four breeds producing purebred and crossbred litters at Stillwater between the fall of 1976 and the fall of 1978 were presented by Gaugler et al. (1984). Buchanan and Johnson (1984) reported reproductive performance of the various crossbred female and purebred and crossbred boar groups that comprised the El Reno phase of the experiment.

Complete analyses of data collected in this experiment have yet to be reported. This present investigation aims to complete analyses of growth and carcass performance data from both phases of the experiment; and to meet the third project objective by using parameters estimated from the entire experiment to simulate performance of alternative swine crossbreeding systems.

Individual and Maternal Heterosis for Postweaning Performance and Carcass Traits. Individual heterosis estimates for postweaning performance traits are presented in tables 2 and 3. Specific estimates for all traits are reasonably consistent between crosses and between experiments (table 2). Most estimates were significant. Note that two figures are reported for Toelle and Robison (1983) in tables 2 and 3. The first (4a) represents estimates from data on purebred and F_1 litters. The second (4b) included data from 'mixed' litters--i.e., purebred and crossbred pigs crossfostered in the same litter. Vigor of

TABLE 2. SPECIFIC INDIVIDUAL HETEROSIS ESTIMATES FOR POSTWEANING PERFORMANCE TRAITS

Trait	Ref[d]	Reciprocal Breed Crosses[c]					
		DL	DS	DY	LS	LY	SY
Postweaning average daily gain (kg/d)	1			.08			
	2			.06			
	3	.07	.09	.09	.05	.05	.05
	4a			.06± .01			
	4b			.09± .01			
154d.wt./154 (kg/d)	4a			.05± .01			
	4b			.07± .01			
154 d. wt. (kg)	4a			8.0 ±1.7			
	4b			11.3 ±1.8			
	5	7.27±1.65		10.07±1.93		4.71±1.62	
Age @ 95.3kg	5	-16.14±3.20		-21.91±3.71		-12.64±3.13	
Age @ 104kg	4a			-17.4 ±3.8			
	4b			-28.05±4.4			
Probed back-fat @ 104kg	4a			-.23± .09			
	4b			-.35± .08			
Gain/feed	2			.009			
Feed/gain 56d-154d	5	-.09± .08		.03± .08		.02± .08	
Feed/gain 56d-95.3kg	5	-.18± .06		-.17± .06		-.09± .06	

[c] D=Duroc, L=Landrace, S=Spot, Y=Yorkshire.

[d] 1-3 estimates cited by Johnson (1981): 1=Schneider (1978), 2=Young et al. (1976b), 3=Hutchens & Johnson (unpublished). 4a,b=Toelle and Robison (1983), 5=Wheat et al. (1981)

TABLE 3. AVERAGE INDIVIDUAL HETEROSIS ESTIMATES FOR POSTWEANING PERFORMANCE TRAITS

Trait	Ref[a]	n[b]	Heterosis	% Heterosis
Postweaning average daily gain	1	5,002	.06 kg/d	8.8
	2	NA	.04 kg/d	6.0
	3	885 (548)		13.7 (11.1)
154d.wt./154	3	885 (548)		13.6 (11.1)
154 d. wt.	3	885 (548)		14.1 (11.4)
	4	823	7.35 kg	12.1
Age @ 95.3 kg	4	823	-16.9 d	-7.9
" " 100.0 kg	1	5,002	-12.7 d	-6.9
" " 100.0 kg	2	NA	-10.0 d	-5.0
" " 104.0 kg	3	885 (548)		-10.2 (-8.0)
Probed backfat @ 104 kg	3	885 (548)		-8.0 (-6.6)
Gain/feed	1	485 pens	.017	5.9
Feed/gain	2	NA	-.08	-3.0
Feed/gain 56d-154d	4	179 litters	-.01	-.0
Feed/Gain	4	179 litters	-.11	-3.3

[a] 1=Johnson (1981); 2=Sellier (1976); 3=Toelle and Robison (1983); 4=Wheat et al. (1981).

[b] n=number of pigs, unless otherwise stated. Sellier (1976) summarized 13 crossbreeding experiments (including Kuhlers et al., (1972), mostly European. Figures in parentheses indicate a subset of the data (see text for details).

crossbred pigs in these litters appeared to have a detrimental effect on the purebred pigs, thus inflating the heterosis estimates.

Averaging over a number of studies (table 3) there appeared to be a 6 to 10% advantage for crossbred individuals over the average of parental contemporaries for postweaning growth. Experimental estimates of individual heterosis for feed to gain ratio and carcass traits have tended to be small and not significant (Johnson, 1981). Estimates of individual heterosis for carcass measurements are given in table 4. Smaller numbers involved in these evaluations explain the greater variation evident among estimates.

Average maternal heterosis values for postweaning performance and carcass merit are presented in table 5. Estimates are small and suggest that the advantages of a crossbred dam are confined to preweaning performance.

Breed Effects. Johnson's (1981) weighted least-squares analysis of crossbreeding data from a number of experiment stations indicated that Duroc sired pigs gained .02 kg/d faster and reached market weight 3.2 d sooner than average (see table 6). Results reported by Wheat et al. (1981) supported the Duroc's superiority for rate of gain, and also indicated that Yorkshire sired pigs grew more slowly than Landrace sired pigs (in contrast to Johnson's, 1981, results), and were less feed efficient (see table 6). Duroc sired pigs had the highest feed efficiency (lowest feed to gain ratio). Johnson's (1981) analysis did not include feed to gain ratio due to insufficient data. Young et al. (1976b) reported significant breed effects for feed efficiency. Hampshire sired pigs were more efficient than Duroc or Yorkshire sired

TABLE 4. INDIVIDUAL HETEROSIS ESTIMATES FOR CARCASS TRAITS

Trait	Ref[d]	Reciprocal Breed Crosses[c]						Average[c]
		DL	DS	DY	LS	LY	SY	
Length (cm)	1			.60±.26				
	2			.56±.23				.00 cm
	3	.5	.3	-.95	-.30	-1.2	-1.3	.0%
	4			-.31±.19				
	5	.08±.43		.36±.46		.00±.43		
Backfat (cm)	1			-.00±.05				
	2			-.01±.06				.04 cm
	3	.08	.22		.14	.13	.25	.20
	4			.23±.04				1.3%
	5	-.18±.08		.08±.10		.13±.08		
Loin eye area (cm^2)	1			.77±.49				
	2			1.03±.58				.23cm^2
	3	-1.4	-.9	2.05	-1.0	-.35	.90	.8%
	4			.06±.34				
	5	.71±.84		.32±.90		-1.16±.84		
% 4 Lean cuts	5	.82±.84		.20±.88		-.70±.80		
% 5 Primal cuts	5	.66±.97		.66±1.02		-.62±.92		
% Ham & loin	5	.33±.67		.59± .71		-.63±.64		
Marbling score	1			6.3%				
	2			-4.6%				.5%
Firmness score	1			3.3%				1.5%
Color score	1			-.4%				
	2			-2.9%				-4.1%

[a] D=Duroc, L=Landrace, S=Spot, Y=Yorkshire.

[b] 1-4 estimates cited by Johnson (1981): 1=Young et al. (1976b), 2=Schneider (1978) et al. (1982), 3=Hutchens and Johnson (unpublished), 4=Bereskin et al. (1971); 5=Wheat et al. (1981).

[c] from Johnson (1981). Average of reported literature results excluding 5, but including results from additional studies involving breed crosses other than those above.

TABLE 5. AVERAGE MATERNAL HETEROSIS VALUES FOR POSTWEANING PERFORMANCE AND CARCASS MERIT

Trait	Reference Johnson et al. (1978)	Schneider (1982)
Postweaning average daily gain	.00±.01 kg/d	-.01± .01 kg/d
Age @ 100 kg	-.4 ±.9 d	1.2 ±1.8 d (.6%)
Gain/feed	-.00±.003	
Carcass length	.00±.2 cm	.17± .19 cm (.2%)
Carcass backfat	.07±.04 cm	.00± .05 cm (.0%)
Carcass yield		.42± .28 kg (.6%)
Loin eye area	.7 ±.3 cm^2	.01± .54 cm^2 (.0%)
% Fat corrected muscle		-.15± .35 (-.3%)
Firmness score	-4.5%	
Marbling score	-2.1%	-.8%
Color score	-2.5%	-.7%

TABLE 6. BREED EFFECTS (LEAST-SQUARES CONSTANTS) FOR POSTWEANING PERFORMANCE TRAITS

	Johnson (1980,1981)[a]			Wheat et al. (1981)[b]					
	n[c]	Postwean. gain kg/d	Age @ 100kg	n	Age @ 95kg	Wt. 154-d	n	Feed/gain 56-154d	Feed/gain 56-95kg
$\hat{\mu}$	5002	.67	179.7	823	202.6	65.89	179	3.02	3.34
		Breed of Sire[d]							
D	1443	.02±.006	-3.2±1.0		-3.5±1.6	1.6±.8		-.08±.02	-.08±.02
Y	1610	.00±.006	-1.0±1.0		5.7±1.7	-2.9±.9		.08±.02	.06±.02
L	193	.00±.012	-1.6±2.3		-2.2±1.5	1.3±.7		.00±.02	.02±.02
S	198	.01±.012	-4.0±2.1						
		Breed of Dam[d]							
D	1348	.02±.006	-3.2±1.1		3.4±1.7	-2.1±.8		-.04±.02	.01±.02
Y	1452	.01±.006	-2.0±1.1		3.5±1.6	-.3±.8		.01±.02	.00±.02
L	213	-.00±.012	.1±2.3		-6.9±1.6	2.4±.8		.03±.02	-.01±.02
S	185	.02±.012	-2.4±2.3						

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[a] From weighted least-squares analysis of experimental results (Young et al., 1976b; Schneider, 1977; Kuhlers et al., 1972, 1977; Bereskin et al., 1971; Hutchens and Johnson, unpublished). Note: breed constants not given above (Chester White, Hampshire, Poland China) account for breed constants not summing to zero and numbers (n) not summing to the total.

[b] Calculated from least-squares means reported.

[c] Number of pigs unless otherwise specified.

[d] D = Duroc, Y = Yorkshire, L = Landrace and S = Spotted.

pigs; and Yorkshire dams had more efficient pigs than dams of either other breed. Johnson et al. (1978) reported similar differences.

Johnson (1981) maintained that breed of sire effects estimated one-half the average direct genetic effect of the breed, while breed of dam effects estimated one-half the direct genetic plus the maternal effect in his analysis. Breed of dam effects for growth rate were in general similar to breed of sire effects (table 6), suggesting maternal effects for rate of gain were small. Differences were more evident in the findings of Wheat et al. (1981), but their estimates are based on far fewer data (table 6).

Breed of dam and breed of sire effects did not appear to be the same for carcass traits, however (table 7), suggesting that maternal effects were important for these traits. An estimate of breed average direct genetic effects was obtained by doubling the breed of sire effects, assuming Johnson's (1981) contention that these effects estimated one-half the direct genetic effects. Maternal effects were estimated as the difference between breed of dam and breed of sire effects. To aid interpretation of tables 6 and 7, these values were calculated and presented in table 8. Relative to direct genetic effects, maternal effects were moderately important for carcass length, backfat and loin eye area. Additional breed effect estimates are presented in table 9. Ahlschwede and Robison (1971a) reported that prenatal and postnatal maternal effects represented approximatly 17% and 11% of the variance in postweaning growth and backfat, respectively. Maternal sources of variation in 140-d weight were also reported to be larger than direct genetic effects for both the Duroc and Yorkshire breeds (Ahlschwede and Robison, 1971b). Toelle and Robison (1983) found breed

TABLE 7. BREED EFFECTS (LEAST-SQUARES CONSTANTS) FOR CARCASS TRAITS

	Johnson (1980,1981)[a]				Wheat et al. (1981)[b]			
	n	Length (cm)	Backfat (cm)	Loin eye area(cm^2)	n	Length (cm)	Backfat (cm)	Loin eye area(cm^2)
$\hat{\mu}$	1382	76.80	3.27	29.08	823	77.66	3.28	30.13
		Breed of Sire						
D	412	-.21±.20	.02±.04	.55±.41		-.33±.22	-.04±.04	.96±.39
Y	456	.64±.19	.14±.04	-.33±.39		-.04±.23	.03±.04	-1.04±.38
L	38	.62±.45	.02±.10	-1.28±.93		.38±.22	.01±.04	.06±.38
S	37	-.65±.46	.15±.10	-.97±.94				
		Breed of Dam						
D	406	.01±.19	.09±.04	-1.44±.40		-.78±.22	-.02±.04	.19±.39
Y	472	.66±.18	-.03±.04	1.02±.38		.58±.23	-.05±.04	.65±.38
L	45	.52±.43	.23±.09	-.90±.90		.20±.22	.07±.04	-.84±.37
S	33	.38±.48	-.05±.10	-.11±.82				

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[a] See footnote to table 6 above.

[b] Calculated from least-squares means reported.

TABLE 8. DIRECT (g^I) AND MATERNAL (g^M) GENETIC EFFECTS FOR POSTWEANING PERFORMANCE AND CARCASS TRAITS[cd]

Trait	Ref	Duroc		Yorkshire		Landrace		Spotted	
		g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M
Postwean gain(kg/d)	a	.04	.00	.00	.01	.00	.00	.02	.01
Age@100 kg (d)	a	-6.4	.00	-2.0	-1.0	-3.2	1.7	-8.0	1.6
Age@95.3kg (d)	b	-7.0	6.9	11.4	-2.2	-4.4	-4.7		
Wt 154d (kg)	b	3.2	-3.7	-5.8	2.6	2.6	1.1		
Feed/gain 56-154d	b	-.16	.04	.16	-.07	.00	.03		
Feed/gain 56d-95.3kg	b	-.16	.09	.12	-.06	.04	-.03		
Carcass length(cm)	a	.42	.22	1.28	.02	1.24	-.10	-1.30	1.03
	b	-.66	-.45	-.08	.62	.76	-.18		
Carcass backfat(cm)	a	.04	.07	.28	-.17	.04	.21	.30	-.20
	b	-.08	.02	.06	-.08	.02	.06		
Loin-eye area(cm^2)	a	1.10	-1.99	-.66	1.35	-2.56	.38	-1.98	-.86
	b	1.92	-.77	-2.08	1.69	.12	-.90		

[a] Johnson (1981)

[b] Wheat et al. (1981)

[c] Calculated form breed effects in table 6 and 7 (see text for details).

[d] See footnotes to table 6 for information regarding source and interpretation of data.

TABLE 9. DIRECT GENETIC (g^I), GENERAL COMBINING ABILITY (GCA) AND MATERNAL EFFECTS (g^M) FOR POSTWEANING PERFORMANCE AND CARCASS TRAITS[a]

Ref[b] Trait	Duroc			Yorkshire		
	GCA	g^I	g^M	GCA	g^I	g^M
1. Age @ 100kg	-2.7		-3.1	-.8		-.5
2. Age @ 100kg		-5.5	.5		.0	.0
1. Carcass length	-.38		.64	.61		-.19
1. Carcass backfat	.06		-.02	.08		-.06
2. Carcass backfat		.20	.22		.00	.00
1. Loin-eye area	1.10		-1.87	-1.10		1.74

[a] After Johnson (1981)

[b] 1 = Schneider (1978); 2 = Wilson and Johnson (unpublished)

prenatal effects to be important for backfat and 154-d weight, but postnatal effects were important for adjusted backfat only.

Assuming sires and dams of each breed to be of equivalent average genetic merit, maternal effects can be estimated from differences in reciprocal crosses. Reported reciprocal cross differences for postweaning gain, feed to gain ratio and carcass backfat are given in table 10. Differences were small for growth rate, but large for feed to gain ratio and backfat. The Duroc-Yorkshire reciprocal cross difference suggested that feed to gain ratio and carcass backfat were improved when Yorkshire was the dam breed.

Crossbred Sires. Interest in using crossbred boars for market hog production has arisen for a number of reasons. Theoretically, crossbred boars are expected to be more vigorous and hardier than purebreds, and to possess greater libido, higher fertility, and improved longevity. Consequently commercial use of crossbred boars might reduce breeding problems. However, any advantages that accrue from the use of crossbred boars must outweigh the disadvantages of having to maintain additional pure lines in the system, as well as the possibly important increase in recombination losses in terminal offspring (table 1).

A number of studies have found young crossbred boars to be more sexually mature (e.g., to have significantly larger testes and more sperm/ejaculate) than purebred boars of the same age (Hauser et al., 1952; Sellier et al., 1971; Wilson et al., 1977; Conlon and Kennedy, 1978; Fent, 1980; Neely et al., 1980). Conception rate following natural service was found to be 8% higher for crossbred than purebred boars (Wilson et al., 1977). Similarly, Anderson et al. (1981) reported a 12% advantage in conception rate for crossbred vs purebred boars. Conlon and

TABLE 10. BREED MATERNAL EFFECTS (LEAST-SQUARES MEANS) FOR POSTWEANING PERFORMANCE AND CARCASS BACKFAT[a]

		Reciprocal Cross Differences[b]					
Trait	Ref[c]	DY-YD	DL-LD	DS-SD	LY-YL	SY-YS	SL-LS
Postweaing average daily gain (kg/d)	1.	-.01					
	2.	.00					
	3.	-.01					
	4.	-.02	-.04	.02	-.01	-.02	.02
Gain to feed ratio	2.	.019					
	3.	.022					
Carcass backfat (cm)	1.	-.04					
	2.	-.22					
	3.	-.25					
	4.	-.89	.11	-.36	-.59	.05	.26
	5.	-.34					

[a] After Johnson (1981)

[b] D = Duroc, Y = Yorkshire, L = Landrace, S = Spotted. e.g., DY-YD = Difference in least-squares means between D x Y pigs and Y x D pigs.

[c] 1 = Schneider (1978); 2 = Young et al. (1976b); 3 = Johnson et al (1978); 4 = Hutchens and Johnson (unpublished); 5 = Bereskin et al (1971).

Kennedy (1978), however, found only a very small advantage for crossbred boars when gilts were artifically inseminated--suggesting that the advantage of the crossbred boar may be due to increased libido rather than increased fertility. Results presented by Buchanan and Johnson (1984) from the Oklahoma four breed swine crossbreeding experiment support this hypothesis. They found crossbred boars averaged an 18% higher first service conception rate than purebred boars. This advantage ranged from 6% for Yorkshire x Spotted boars, to 20% for Landrace x Spotted boars. Heterosis was significantly different from zero for all six crossbred boar groups. When the entire 8 wk breeding season was evaluated, however, average paternal heterosis was only 5%. The authors suggested purebred boars maturing over the 8 wk breeding season as a likely explanation of the results.

No significant differences among boar breeding groups were reported by Buchanan and Johnson (1984) for litter size, weight or survivability. Although King and Thorpe (1974) reported an increase in size and weight of litters sired by crossbred boars, their results have not been supported by other studies. Schlote et al. (1974), Lishman et al. (1975), Fahmy and Holtmann (1977), Conlon and Kennedy (1978) and Anderson et al. (1981) all found the use of crossbred sires to have no effect on litter size and weight traits.

Similarly, little evidence exists for real differences in growing-finishing performance and carcass traits of pigs sired by crossbred vs purebred boars. Rempel et al. (1964), reporting an experiment with Minnesota lines of swine, found no significant differences between progeny of crossbred and purebred sires for feed to gain ratio, percent lean cuts and loin eye area. They did, however, find pigs sired by crossbred boars to be significantly fatter and slower gaining than those sired by purebred boars. The authors pointed out that this result was probably an artifact as purebred boars were selected for decreased backfat thickness and increased average daily gain, whereas crossbred boars were chosen at random.

Lishman et al. (1975) compared postweaning growth and carcass performance of pigs sired by Large White x Landrace and Hampshire x Landrace or Large White boars vs pigs sired by purebred Large White and Landrace boars. No significant differences between purebred and Large White x Landrace sired progeny were detected for average daily gain, feed to gain ratio or 16 of 18 carcass traits. Only loin eye area and fat over the loin were significantly different for the two groups--the purebred sired group having less fat and a larger loin eye area. Differences were not large, however, and only just significant at the 5% level. Given the large number of tests carried out, these 'significant' differences were likely due to chance. Fahmy and Holtmann (1977), comparing Landrace x Yorkshire, Duroc x Yorkshire and Duroc x Lacombe boars to purebred Landrace, Yorkshire, Duroc and Lacombe sires, reported negligible differences for growth rate and carcass quality traits between pigs sired by purebred and crossbred boars. Kennedy and Conlon (1978) also found that progeny of Hampshire x Duroc boars performed similarly to pigs sired by purebred Hampshire and Duroc boars.

Certainly, the overall conclusion suggested by these studies is that paternal heterosis for litter productivity and postweaning performance and carcass traits is negligible. The misconception that use of crossbred sires will increase variability among progeny relative to use of purebred sires has existed in the past (Fahmy and Holtmann, 1977). However, this expectation has not been borne out by experimental results. Rather, a number of workers (Rempel et al., 1964; Lishman et al., 1975; Fahmy and Holtmann, 1977) have reported little difference in the variability of three vs four breed cross pigs. Although use of crossbred boars does not appear disadvantageous in terms of progeny performance, the principal advantage (increasing conception rate when using young boars) must offset the cost to the system of producing such boars in order to be an effective strategy.

Evaluation of Alternative Crossbreeding Systems

Introduction. For clarity, this section has been divided into four parts. The first part outlines alternative breeding systems and the second discusses the development of profit functions and breeding objectives. Computer simulation (the third section) considers how such functions have been used in computer simulation models for various species. The final section specifically discusses results (rather than techniques) of crossbreeding system evaluation in swine.

Crossbreeding Systems. Various alternative crossbreeding systems exist, each with its own expected levels of heterosis and recombination. Some common systems and expected fraction of heterosis and recombination effects are given in table 1 above.

"Essentially maximum utilization of heterosis and breed differences in maternal and paternal performance is obtained in the specific three breed cross of a superior 'male' with the F_1 cross of two superior 'female' breeds" (Dickerson, 1973, p. 61). Use of a crossbred male exploits paternal heterosis, but also doubles the frequency of recombinant gametes, potentially depressing performance. A fourth breed also has to be maintained in the production system.

The two breed rotation or crisscross system was first advocated as a swine breeding strategy 50 years ago (Winters et al., 1935). More recently, Sellier (1976) and Bichard (1977) proposed crisscross females as a viable alternative to F_1 hybrid gilts for European pig breeding programs. Where recombination losses are negligible, and little additional economic advantage is to be gained from using specialized sire and dam lines, rotational crossbreeding may be economically advantageous. Rotational systems require only purebred male replacements as crossbred female progeny from one generation provide dams for the next generation. A rotation system, therefore, reduces the proportion of the population kept as pureline parental stock. The loss in heterosis expected for the rotation vs the specific cross may conceivably be offset by the greater proportion of crossbreds exhibiting some heterosis in the population. In addition, factors such as ease and cost of acquiring female replacements, and the reduced disease risk from use of home-bred females, encourage the use of simple rotations such as the crisscross system.

Using males from a superior sire breed on females produced by rotational crossing among maternal breeds combines advantages of both specific and rotational crossbreeding. Breed differences in maternal and paternal performance are made use of, and only purebred sire replacements are required. Terminal crosses exhibit 100% of the individual heterosis, and have the same expectations for maternal heterosis and recombination, as the rotation (table 1).

Synthetics, while retaining a proportion of individual, maternal and paternal heterosis, are subject to maximum recombination effects and make no use of maternal and paternal breed differences. Lack of success in developing commercially useful synthetic lines in the U.S. has probably been due in large part to the effects of inbreeding in populations with small effective size. The Lacombe breed in Canada provides an example of a successful synthethic that avoided inbreeding (Bichard and Smith, 1972).

From this consideration of alternative crossbreeding systems, it is apparent that the relative magnitudes of breed effects, individual, maternal and paternal heterosis and recombination effects will determine the most efficient production system(s). Just what is meant by 'efficiency' depends in part upon the bioeconomic objective set for the production system. The system necessarily includes not only a terminal phase, but also all breeding stock generators necessary for the system to function. Reliable estimates of the bioeconomic parameters involved in such a program are therefore required in order to meaningfully compare alternative systems and thus to provide useful guidelines for breed utilization.

Evaluation of Crossbreeding Systems. Smith (1964) divided traits associated with meat production into two groups, those concerned with reproductive performance of the dam and those concerned with meat production and quality in the progeny. He discussed how lines and crosses could be ranked based upon actual or predicted performance and relative economic weights for various traits.

Moav (1966a,b,c) developed algebraic and graphical procedures for determining relative profitability of pure lines and their crosses. He considered profitability to be a function of reproductivity (X_1) and productivity (X_2), for example:

$$P = K_1 - K_2X_2 - K_3/X_1 \tag{10}$$

where P = profit/pig;
K_1 = gross income minus fixed costs;
X_1 = number of weaned pigs/sow/year;
X_2 = feed to gain ratio and
K_2, K_3 = economic constants.

"Profit contours" (iso-profit curves) were plotted, with X_1 and X_2 as axes, and their use to identify potentially profitable crosses discussed. Moav's (1966a) aim was to exploit heterosis for profit, and he identified five classes of "profit heterosis":

1. Component trait heterosis;
2. Sex linkage;
3. Maternal effects;
4. Nonlinearity heterosis and
5. Sire-dam heterosis.

Sex linkage and maternal effects result in differences between reciprocal crosses. Nonlinearity heterosis refers to the fact that some traits affect profit in a nonlinear manner. For example, in equation (10) variable costs associated with reproduction are proportional to the reciprocal of the number of pigs reared/litter. Another example would be where returns/carcass depended upon certain threshold values. Thus, even for a genetically additive trait, a nonlinear relationship between the trait and profit will result in mean-offspring profit unequal to mid-parent profit and, thus, "profit heterosis" as defined. Sire-dam heterosis considers the fact that sire and dam lines may contribute unequally to profit. For example, reproductive costs are largely determined by the dam line, whereas both sire and dam lines contribute to progeny production efficiency. Thus if, from a group of available lines, the line with the best reproductive performance is used as the dam line, then the profit of the sire-dam combination will deviate from the mid-parent even in the absence of nonlinearity and component trait heterosis. Although involving only two traits and considering only the terminal crossbred population, Moav established the necessity for evaluation of alternative breeding systems based on an objective, probably nonlinear, profit function.

Based upon this fundamental work by Smith and Moav, Jackubec and Fewson (1970a,b) developed profit functions for crossbreeding in swine, and used these functions to simulate the efficiency of various systems of crossbreeding. They concluded that productivity exerted a far greater influence on profitability than on reproductivity, that efficiency was dependent upon both heterosis and breed differences, and that commercial crossbreeding had the potential to improve the profitability of pig production.

Systems analysis demands precise definition of objectives. Harris (1970) argued that, in the long term, improved efficiency in a livestock sector will result in lower costs to the consumer, increased consumption and increased production, rather than greater profit for producers. Therefore, long-term profitability for a livestock producer will lie in his efficiency relative to other producers. Harris (1970), writing from a breeding company perspective, proposed that animal breeders should adopt the objective of improving the relative efficiency of their "potential customers", i.e., producers. In a capitalist economy, such improvement should result from efficient (and thus profitable) producers increasing their share of the market. Aiming to improve the relative profitability of producers therefore will serve the objectives of society (and the consumer) at large.

Given the objective was to increase efficiency at the producer level, Harris (1970) maintained that the goal of improvement should be either profit, return on investment or cost/unit of production. All three are functions of expenses (costs of production) and income (product adjusted for quality), i.e.:

$$\text{Profit} = \text{Income} - \text{Expenses} \tag{11}$$

$$\text{Return on Investment} = \text{Income/Expenses} \tag{12}$$

$$\begin{aligned}\text{Cost/Unit Product} &= \text{Expenses/(Product} * \text{Quality)} \\ &= \text{Expenses/Income}\end{aligned} \tag{13}$$

Harris presented equations for income and expenses, on a/animal basis, that account for all costs and income incurred, both in the breeding herd and market animals, during the entire life cycle of the animal (Figure 1).

Dickerson (1970, 1976, 1978) similarly expressed net or life-cycle economic efficiency as the ratio of total costs to total animal product. He presented a comprehensive equation for the ratio of expenses/yr to product value/yr (Figure 2), and used it to predict the impact of genetic change upon life-cycle production efficiency.

Although biological measures of efficiency (e.g., feed, energy or protein input/unit edible protein or protein energy output) have often been used to describe animal efficiency, Dickerson (1978) pointed out that their usefulness is limited. Firstly, cost/unit feed input

$$\text{Expenses} = \begin{array}{l}\text{Slaughter}\\ \text{Costs}\end{array} + \left[\begin{array}{l}\text{Cost/}\\ \text{Unit Feed}\end{array}\right] * \left[\begin{array}{l}\text{Feed}\\ \text{Consumed}\end{array}\right] + \left[\begin{array}{l}\text{Labor and}\\ \text{Facilities}\\ \text{Cost/}\\ \text{Unit Time}\end{array}\right] * \left[\begin{array}{c}\text{Time to}\\ \text{Slaughter}\\ \text{Wt}\end{array}\right]$$

$$+ \frac{\begin{array}{l}\text{Cost of Gilt}\\ \text{Production}\end{array} + \left[\begin{array}{l}\text{No. of}\\ \text{Litters}\end{array}\right] * \left[\begin{array}{l}\text{Sow Herd Labor}\\ \text{and Facilities}\\ \text{Cost/Litter}\end{array}\right] + \begin{array}{c}\text{Sow and}\\ \text{Litter Feed}\\ \text{Cost}\end{array} + \begin{array}{c}\text{Boar}\\ \text{Costs/}\\ \text{Litter}\end{array} - \begin{array}{c}\text{Salvage}\\ \text{Value for}\\ \text{Old Sow}\end{array}}{\left[\begin{array}{l}\text{No. of}\\ \text{Litters}\end{array}\right] * \left[\begin{array}{c}\text{Avg. Litter}\\ \text{Size}\end{array}\right] * \left[\begin{array}{c}\text{Pig}\\ \text{Survival}\end{array}\right]} \qquad (14)$$

$$\text{Income} = \left[\begin{array}{c}\text{Carcass}\\ \text{Wt}\end{array}\right] * \left[\begin{array}{c}\text{Carcass}\\ \text{Quality}\end{array}\right] = \left[\begin{array}{c}\text{Slaughter}\\ \text{Wt}\end{array}\right] * \left[\begin{array}{l}\text{Dressing}\\ \text{Percent}\end{array}\right] * \sum_{\text{cuts}} \left[\begin{array}{c}\text{\% each}\\ \text{cut}\end{array}\right] * \left[\begin{array}{l}\text{Value/Unit}\\ \text{Wt ea. cut}\end{array}\right] \qquad (15)$$

Figure 1. Expense and Income Equations (After Harris, 1970)

For breeding female For her progeny

$$\frac{\text{Expense/Yr}}{\text{Product/Yr}} = \frac{(A/Y) + (I_d+B_d*F_{md}+F_{pd}) + N\ D(I_o+B_o*F_{mo}+F_{po}) + S_o}{P_d*V_d + N*P_o*V_o} \tag{16}$$

Where:

A/Y = (Cost, young female - value, old female)/yr in production.

I_d = Annual fixed costs/female, for labor, housing, etc.

B_d = Metabolic body size of female, relative to population mean.

F_{md} = Average maintenance feed costs/female/yr for population.

F_{pd} = Feed cost above maintenance/female/yr.

N = Number progeny reared/female/yr.

D = Days from weaning to market weight for individual,

I_o = Average fixed costs/animal/d.

B_o = Average postweaning metabolic body size for individual, relative to population mean.

Fmo = Average maintenance feed cost/animal/d for population.

F_{po} = Average feed costs above maintenance/d for individual.

S_o = Fixed costs/animal for slaughter, marketing, vaccines, etc.

P_d = Annual volume of product/female.

V_d = Value / unit of female product.

P_o = Live wt of meat animal when marketed.

V_o = Value / unit of live wt.

Figure 2. Economic Efficiency (Cost/Unit Product Value)

(After Dickerson, 1970, 1976, 1978)

generally varies considerably with the maturity and productivity of the animals. Secondly, the price/unit may vary greatly with animal product or composition of product. Lastly, nonfeed costs are not negligible, they vary with phase of production, and they are greatly influenced by biological differences in performance. A series of papers by European workers (Ollivier, 1977; Siler et al., 1977; Lindhe and Holmquist-Albrandt, 1977; Bichard, 1977) explored the question of objectives and strategy for improved economic efficiency of pig breeding schemes in widely different production environments (from the centralized economy of Czechoslovakia to the free-market economy of the United Kingdom).

From equations (14) and (16) (Figures 1 and 2) it can be seen that reproductive rate, rate of gain and feed consumption to market weight and product value are all important in the evaluation of mating systems. Sow costs/pig are inversely proportional to number of progeny, thus at higher rates of reproduction the economic advantage of increasing the number of progeny becomes less (Moav and Hill, 1966).

Moav (1973), again using a two trait model, developed profit equations for different objectives (e.g., producer vs national interest). A "profit map" with feed to gain ratio as the vertical axis and number of weaned pigs/sow/year as the horizontal axis, was plotted. Profit centers (connecting points with the same profit value) were nonlinear, and those for the fixed demand (national) equation differed from those for a fixed number of sows (producer). Thus, it is conceivable that a group of breeds might rank differently due to subtle changes in objectives, demonstrating the need for clearly determined objectives when comparing alternative breed utilization and selection schemes.

Dickerson (1973) calculated the number of sows required/1,000 market pig equivalents for alternative crossbreeding systems. Breed performance and heterosis levels were assumed, and efficiency judged by sow numbers--the fewer required, the more efficient the system. Dickerson's approach served to highlight the organization of the entire system, with purebreeding and crossbreeding sectors, and to emphasize the need for comparisons involving every aspect of the system, not simply terminal crossing sectors.

Sellier (1976) proposed that a crossbreeding system could be analyzed either at equilibrium (a static model), or over time starting from a purebred foundation (a dynamic model). As approach to equilibrium varies for different systems, Sellier suggested a dynamic evaluation would be more appropriate, but also considerably more complex.

The fact that most recent evaluations of alternative crossbreeding stategies have involved the computer is not surprising, given the complexity and systems nature of the desired evaluations. Systems modeling techniques and applications in animal science are discussed in the following sections, with particular emphasis on beef and swine production models.

Computer Simulation. Simulation modeling techniques have been applied to agricultural problems for many years (Dent and Blackie, 1979; France and Thornley, 1984). Various computer models have been constructed in an attempt to gain a better understanding of biological systems, and to target areas in need of experimental research. Other models have aimed to predict animal responses to environmental variables such as nutrition and temperature. More recently, models have been used to predict system responses to changes in animal performance through genetics--i.e., alternative breeds, mating systems and selection practices.

Most of the models reported in the animal science literature have simulated ruminant systems. Rice et al. (1974) modeled a ruminant grazing system and simulated forage production as well as animal performance, which was dependent on simulated available energy and nitrogen. Boyd and Kroger (1974) simulated nutrient intake and cow-calf costs, including postweaning performance, for purebred Hereford and Angus, crisscross Angus - Hereford, Angus - Brahman and Santa Gertrudis - Hereford systems. System efficiency was measured as net returns/brood cow maintained in the herd, and net returns/unit TDN consumed by the entire herd.

Joandet and Cartwright (1975) discussed beef production systems modeling, and concluded that available models had failed to consider either the entire system or the dynamic nature of such systems. Researchers at Texas A & M University subsequently used linear programming (LP) to investigate the effects on beef production efficiency of cow size and herd management (Long et al., 1975), heterosis and complimentarity (Fitzhugh et al., 1975) and different mating plans (Cartwright et al., 1975). Nutritional and fixed costs, cow size and milk production and differences in growth and attrition rates were included in the model. Systems were evaluated based upon cow-calf production and feeder cattle performance.

LP is a computerized procedure allowing maximization (or minimization) of some objective function (e.g., profit, cost) subject to various constraints (e.g., limited land, labor, capital). McCarl and Nuthall (1982) provided a relatively brief, but very useful, introduction to LP. Over the past decade, LP has proved to be a popular tool among animal scientists.

Workers at the University of Guelph (Wilton et al., 1974) constructed an LP beef production model. The model described an integrated on-farm enterprise, i.e., cropping as well as beef production activities were included. Alternative systems were compared using simulated gross margins (revenue over variable costs). Morris et al. (1976) used this model to evaluate the effects of creep feeding, cow size, and milk yield; Wilton and Morris (1976) evaluated effects of reproductive performance and mating systems and Morris and Wilton (1976) used it to study alternative mating and management systems.

Cartwright (1979) and Wilton (1979) provided informative outlines of systems theory and its applications to animal breeding. Although presented at a symposium nine years ago, these papers continue to represent a useful introduction for animal scientists unfamiliar with the field of systems analysis.

Sanders and Cartwright (1979a,b) presented the Texas A & M Cattle Production Systems Model. Not to be confused with the LP model discussed above, in which levels of cattle performance were specified as input data and requirements simulated, the new model simulated levels of performance from specified feed resources and cattle production potentials. Equations used in the model were designed to be biologically interpretable, as opposed to simply statistical 'best fits' to available data. The model simulated the production of cattle varying widely in genotype, with any breeding season length and culling and selling policy, alternative supplementation programs, and any set of environmental conditions that could be expressed as feed resources. Davis et al. (1976) used the model to evaluate alternative management strategies in two different regions of Guyana, and Ordonez (1978) used it to study effects of different genotypes and management alternatives in Venezuela. Using a modification of the model, allowing simulation of dual-purpose systems, Cartwright et al. (1977) simulated milk and beef production for cattle of different genetic potentials under three different sets of forage conditions in Colombia. The model was also used to simulate production of cattle differing in genotype for size and milk production under alternative environments and management systems relevant to Central Texas.

Notter et al. (1979a,b,c) at the University of Nebraska modified the model to allow simulation of crossbreeding systems. They used the modified version to simulate performance of cattle with different genetic potentials in various crossbreeding systems under a Midwestern cow-calf - feedlot management system. Sullivan et al. (1981) interfaced the Texas model with a forage model and adapted the result for tropical production conditions in East Africa. Kahn and Spedding (1983, 1984) and Kahn and Lehrer (1983) also modified the Texas model, using it to test the accuracy of equations predicting weight changes in growing steers under grazing conditions in Botswana and the United Kingdom. Baker (1982) modified the model to account for individual animals, rather than age-sex or month of lactation or gestation classes. This new model, renamed the Texas A & M Beef Cattle Simulation Model, was used recently to simulate the effects of 79 sets of management alternatives on beef cattle growth, reproduction and lactation under conditions typical of the Coastal Prairie region of Texas (Doren et al., 1985).

Workers from Kentucky (Congelton and Goodwill, 1980a,b,c) developed a dynamic model to evaluate the effect of mating plan on herd age structure and productivity. Productivity was measured as kg of calf produced/cow bred; in contrast to the input to output ratio biological and economic efficiency measures used with the Texas model. Nine mating systems were evaluated using the model, under alternative culling and heifer replacement policies.

Simulation of beef cattle systems has also been undertaken by scientists at Oregon State University. Levine et al. (1981) and Levine and Hohenboken (1981) presented a model designed to study beef cattle production on tropical ranges of the Colombian Llanos. Another model, presented by Clarke et al. (1982), was designed to study alternative culling criteria. This model represented a 500-head spring calving cow-calf enterprise, and, with modifications, was subsequently used to study alternative crossbreeding, culling and selection strategies (Clarke et al., 1984a,b).

Chudleigh and Cezar (1982) reviewed eight beef production simulation models proposed since 1970, one of which was the Texas model. The other seven were variously developed in Australia, England, Brazil and Colombia. The authors stressed the need for generalized simulation models, and commented that the Texas model was the only one of the eight reviewed that could be classified as such. Apart from problems of adaptability of models, poor documentation often prevents scientists from using the models. The Texas model is relatively well documented in the literature, but no user's manual or program listing has been published (as far as I am aware).

Evaluation of Swine Systems. The development and early use of profit equations to measure economic efficiency in swine production systems (Moav, 1966, 1973; Moav and Hill, 1966; Dickerson, 1970, 1976, 1978; Harris, 1970; Jackubec and Fewson, 1970) has been discussed above. Bichard and Smith (1972) explored alternative crossbreeding strategies and concluded that the "optimum crossing system" was likely to involve a specialized male line mated to F_1 females. The male line could be purebred, an F_1 or a synthetic line.

Computer simulation models of swine production systems, although less numerous than beef models, cover many aspects of swine production. Agricultural engineers have worked with a number of models to simulate effects of temperature and housing (Teter et al., 1973; De Shazer and Teter, 1974; Phillips and MacHardy, 1979). More recently, Allen and Stewart (1983) presented a model designed to investigate the impact of alternative management strategies for a confinement feeder pig production operation. The model simulates performance, feed, labor, space and feed requirements from entry of replacement gilts through production of feeder pigs.

Whittemore and Fawcett (1974) presented a biological model which predicted gain, composition and feed to gain ratio for growing pigs under different energy and protein intake regimes. Discussion of this model (Whittemore and Fawcett, 1976) identified important aspects and questions related to the physiological utilization of feed for lean and fat tissue growth.

Dickerson (1973) compared the number of sow-years required/1,000 market pig-equivalents for alternative systems, relative to a static three breed cross. Five theoretical breeds with assumed litter size, growth efficiency, cutability and product value were presumed to be available. Heterosis values and replacement rates were assumed, and systems compared based upon predicted requirements for all stages (purebreeding and crossbreeding) of the system. A two breed cross required 15% more sow-years/1,000 pig-equivalents than the static three breed cross. A four breed rotation required 6% more sow-years/1000 pigs. Development and use of synthetic lines was also considered.

Sellier (1976) cited Brun (1974, unpublished) as having used a number of methods to compare purebreds, single crosses, backcrosses and crisscrosses involving the Large White and Landrace breeds in France. Brun calculated Moav's (1966) profit function (for the slaughter generation only); considered the entire system using a procedure similar to that of Dickerson (1973); and considered each system dynamically over a 15 yr period starting from a purebred Large White base population. Moav's profit function suggested a 4 to 5% advantage for crossbreeding over purebreeding, and Dickerson's method a 6 to 8% advantage, plus an additional 1 to 2% for systems with crossbred dams. The dynamic analysis indicated crisscrossing to be most efficient for the breeds considered.

Alsmeyer et al. (1975) presented multiple regression equations for annual net income from 100 sow production units. Regression coefficients were obtained by analysis of simulated data. Eleven cost factors, some related to animal performance, e.g., litter size weaned, conception rate and feed to gain ratio, were used as input variables. The model was designed to allow evaluation of market conditions and production efficiency. Regression coefficients could also be used as economic weightings where merit is defined as net income.

Fahmy et al. (1976) used an index to evaluate different crossbreds for production traits. The index combined postweaning average daily gain, backfat thickness and feed to gain ratio (subscripted 1, 2 and 3, respectively) by the formula:

$$I_i = (Y_{1i} - \overline{Y}_{1.})/S_1 - 1.65(Y_{2i} - \overline{Y}_{2.})/S_2 - 2.49(Y_{3i} - \overline{Y}_{3.})/S_3 \qquad (17)$$

where 1.65 and 2.49 represented relative economic values of backfat and feed to gain ratio to average daily gain, S the estimated standard deviation of the traits and $(Y_{ji} - \overline{Y}_{j.})$ the least-squares deviation of the i^{th} cross from the overall mean for each of the three traits. Five sire breeds and six types of F_1 dam produced 20 different three breed cross progeny groups which were ranked based upon this index.

Siler et al. (1977) developed profit functions to use in the selection of possible crosses for final hybrid production in Czechoslovakia. Bichard (1977) used Dickerson's (1973) method to evaluate alternative crossbreeding systems in the United Kingdom. He reported little variation among two breed systems, although the crisscross system required 2% fewer sow-years/1,000 pig-equivalents than the backcross. Under the conditions assumed, no additional advantage was likely for three breed systems.

Niebel and Fewson (1979a,b) described (in German) a computer model designed to optimize purebreeding in swine. Performance testing procedures were compared, and the efficiency of including reproductive traits in selection indexes for boars and gilts were investigated.

Workers at Texas A & M University have predicted profitability for alternative crossbreeding systems involving the Duroc, Yorkshire and

Hampshire breeds (Merrell et al., 1979; Roberson and Sanders, 1981). Their model was a 320 sow-equivalents confinement system. Literature estimates for breed effects and heterosis were used to predict crossbred litter size weaned, 63-d weight, age at 100 kg and feed to gain ratio. A computerized procedure was used to optimize net income (from predicted costs and returns). Unfortunately, both published reports were abstracts. Just what constituted the "optimum mating combinations" discussed is unclear, limiting interpretation of their results. Merrell et al. (1979), however, concluded a three breed static system raising replacement females was more profitable than the optimized three breed rotation, but similar to the criss-outcross system. Roberson and Sanders (1981) appeared to demonstrate that the optimized three breed rotation was very similar in net income to both the criss-outcross and a modified three breed rotation, somewhat at variance with the earlier report.

A bioeconomic model reported by Singh et al. (1980) aimed to estimate the expected impact of future research and extension activities on profit of a typical 100 sow farrow to finish operation in Hawaii. Designed and used to generate information for use in making funding decisions, the model simulated impact on income and return to capital for various actions. For example, increasing litter size weaned by one pig was predicted to increase average annual income $8,626 and return to capital 3.3%. In contrast, increasing conception rate during first heat from .85 to .90 for sows and .80 to .85 for gilts had only a marginal effect. Decreasing age at market weight by 25 d, at the same feed efficiency, increased average annual income $2,494 and return to capital 1.8%. Improving feed efficiency 10% had a dramatic effect increasing income $11,130 and return to capital 4.9%.

Nimis et al. (1981) reported using a profit function to rank purebred Hampshire, Minnesota No. 1 and their F_1 reciprocal crosses for net returns in total economic performance. Ahlschwede (1981a,b) evaluated potential production of the three breed rotation, production of the same rotation when compromised by a need to continuously replace sows and gilts, and production of four breed static crossbreeding systems. Hampshire, Yorkshire and Duroc breeds were used in the rotations, and Landrace was included for systems involving four breeds. A deterministic model, developed on the Apple II computer for use in producer workshops, calculated breed composition and heterosis levels and assigned economic outcomes. Relative to the three breed rotation, four breed terminal crosses with Yorkshire x Landrace F_1 females were \$50 superior/litter. If maternal purebreds were included in the system, the advantage fell to \$37. Four breed systems with Yorkshire - Landrace crisscross females were \$32 superior. Compromising the rotation by backcrossing cost an average \$30/backcross litter.

Wilson and Johnson (1981b) used linear programming (LP) to compare the efficiency of 21 different crossbreeding systems involving Duroc, Hampshire and Yorkshire breeds of swine. Mating systems were defined to include purebred and crossbred commercial matings needed to maintain 10,000 farrowings. Breed and heterosis effects were estimated from experimental data, and LP used to maximize the number of Yorkshire equivalent pigs for each system. An index with economic weights for age at 100 kg, feed to gain ratio and probed backfat thickness, expressed as deviations from Yorkshire, was calculated for each breed cross. Multiplication by number of pigs weaned yielded Yorkshire equivalent pigs for each cross. Relative efficiency of alternative systems, where purebreds averaged 100, was 127 for three breed statics, 125 for three breed rotations, 124 for static males on crisscross females, 123 for crisscrosses, 122 for backcrosses and 115 for two breed static crosses. Comparing specific systems, the backcrossing of Yorkshire males to F_1 Duroc x Yorkshire females produced the greatest number of Yorkshire equivalent pigs/10,000 farrowings. Duroc males mated to F_1 Hampshire x Yorkshire females was the most efficient terminal cross. However, when all matings needed to support the system were included, it was three percent less efficient than the backcross.

Quintana and Robison (1984), in a similar study, estimated breed and heterosis effects from the results of U.S. and Canadian crossbreeding experiments reported over the past decade. The objective was to evaluate the performance of Duroc, Hampshire, Yorkshire and Landrace swine as purebreds and in two breed rotation and static crosses, three breed rotations and four breed static crosses. A total population of 1,000 sows and a herd life of 20 years was assumed. Based upon predicted reproductive performance, the number of pigs produced by each genetic group within the system and for the total system, annually and over 20 years, were computed. All systems started from a purebred base, rotations approaching equilibrium after five to seven years of the system's dynamic span. Predicted litter size weaned, conception rate, age at 100 kg and backfat thickness were used as a basis for breed comparisons. An economic index, with the above traits expressed as deviations from predicted Yorkshire values, was computed for each genetic group and for the total system. The index represented net dollars/sow exposed, compared to the Yorkshire, and was used to compare systems. Relative to purebreds, the two breed static crosses were $6.00

superior on average and two and three breed rotations $12.15 and $12.93 superior, respectively. Four breed static crosses averaged only 37 cents over the three breed rotations assuming no male heterosis, but $7.04 where paternal heterosis of 7.5% for conception rate and 10% for litter size was assumed. Differences among systems and among breed combinations within purebred and four breed static crosses were largely a function of differences in the reproductive component of the index. Conversely, differences among breed combinations within two and three breed systems were influenced mainly by the production component of the index. The Yorkshire-Landrace crisscross had the highest economic index of all systems, assuming no male heterosis. When male heterosis was assumed, three of the four breed static crosses were superior. Three breed rotation systems always had lower economic value than the best two breed static or crisscrosses due to the addition of a third breed. It was apparent that no one system was superior--average breed effects exerting an important effect on the results. Two and three breed rotation systems were rated to be quite variable in performance from generation to generation, three breed rotations more so than two breed rotations.

Undoubtedly the most elaborate and potentially generalizable bioeconomic computer model of swine production to date is that developed at the University of Nebraska by Tess and Bennett (Tess, 1981; Tess et al., 1983a). This deterministic model was developed to simulate biological and economic inputs and outputs for life cycle pork production in a Midwestern system with environmentally regulated, slatted floor farrowing and nursery units and open-front finishing buildings. Driving variables were mean genetic potentials for number of pigs born alive, birth weight, preweaning viability, lean and fat growth rates, age at puberty, conception rate, milk production and various management decisions (first estrus to mating interval, rebreeding interval, maximum number of parities, age at weaning and marketing strategies). Production inputs included matabolizable energy, crude protein, feed costs and fixed and variable nonfeed costs. Outputs included pigs and culled sows. Efficiency was measured as Mcal or $ input/kg of liveweight, empty body weight or carcass lean output. The model was used to simulate the effect of improved genetic potential on system efficiency (Tess et al., 1983b), allowing prediction of the relative importance of different traits for alternative measures of efficiency (number born alive and viability were found to be of great importance, both for measures of biological and, especially, for economic efficiency). Effects of management systems and feed prices on the relative importance of different traits was also simulated (Tess et al., 1983c). Smith et al. (1983) examined relative response to selection for alternative sets of economic values derived using the model.

Bennett et al. (1983a) simulated the effects of individual and maternal heterosis on efficiency of swine production. Heterosis was simulated by manipulating the values of mean genetic potentials used by the model, based upon results of crossbreeding experiments at Iowa and Oklahoma. Purebred, two and three breed crosses were simulated. Where pigs were sold at 100 kg liveweight, individual heterosis was found to reduce both $/kg lean and $/kg liveweight by four percent. Marketing at average 185-d weight reduced $/kg lean six percent and $/kg liveweight eight percent. Maternal heterosis reduced both measures about four percent. However, where biological measures of efficiency were simulated, individual heterosis reduced feed Mcal/kg lean by only 1% and Mcal/kg liveweight by 3%. Maternal heterosis supplied an additional 1% reduction. Most heterosis effects on the economic efficiency measures were due to traits reducing litter costs/kg output. However, heterosis for growth rate was important for biological efficiency measures. Nonfeed costs/kg output were reduced more than feed costs by heterosis. The percent reductions in total costs due to heterosis were about one-third as large as corresponding increases in output/litter.

In addition to this analyses, Bennett et al. (1983b) reported simulated breed and crossbreeding effects on costs of pork production. Heterosis and breed effect estimates from the Iowa and Oklahoma crossbreeding experiments were used to simulate integrated industry-wide efficiency for alternative systems involving the Duroc, Hampshire, Yorkshire, Landrace, Spotted and Chester White breeds of swine. Breeding systems investigated were purebred, two breed static, backcross and crisscross, and three breed static and rotation crosses. Cost reductions from crossbreeding were found to be greater /100 kg lean marketed at mean 185-d weight than /100 kg live weight or lean. For cost of lean, carcass percent fat was found to be as important as number born alive in all but maternal breed roles. Marketing at mean 185-d weight, age at 100 kg was important for costs/100 kg in all breed roles, but not for costs/100 kg liveweight or lean marketing at 100 kg liveweight. In ranking breeds for use as terminal sires in static systems, only viability was important for costs/100 kg liveweight marketed at 100 kg, viability and carcass fat for costs/100 kg lean at 100 kg and viability, carcass fat and age at 100 kg for costs/100 kg lean marketing at mean

185-d weight. Breeds ranked differently for paternal, maternal and general purpose roles. Greater cost reductions were predicted for the best three breed static (7 to 10%) than for the best three breed rotation (6 to 8%) systems.

Harris et al. (1984) outlined a systematic, nine-step approach to designing animal breeding programs. They reported development of a computer model for analysis of alternative broiler chicken systems, but results were not given. Recently Newman et al. (1985a,b) reported experimental evaluation of the Harris procedure using the mouse as a model for swine.

Interest in models simulating swine production seems likely to continue. Whether duplication of research effort expended in developing such models will occur to the extent it has with cattle production modeling remains to be seen. Recommendations for a methodological development of systems modeling made by Chudleigh and Cezar (1982, p. 288) seem pertinent:

> "Both biological and economic components of models can be transferred more readily among model builders. This may mean that instead of whole models being reported in the literature, we may see whole papers devoted to a single component, but orientated towards an integration with neighboring components. . . This would allow individuals more readily to shop around for particular components to suit the overall objectives of the model they wish to build. Reviews of the various ways in which specific model components can be handled would become more prevalent in the literature."

Without such cooperative development, needless redundancy in model development will occur.

Genotype x Environment Interactions

Efficiency of breed utilization is in part determined by the importance of interactions between genetic components and management or marketing systems (Dickerson, 1973). A review of the evidence for genotype x environment interactions in swine is therefore appropriate.

In the context of crossbreeding, 'genotypes' of interest are both breed differences and heterosis. The environments most commonly studied in breed x environment interaction experiments with pigs have been nutritional regimes. Tables 11-14 summarize these studies. Of a total of 40 different experiments, 24 (60%) studied breed x energy intake (mostly ad lib vs limit feeding), 8 (20%) investigated breed x protein intake and 24 (60%) reported breed x sex, year, season, parity etc. interactions.

The primary objective of genotype x environment experiments is to determine the most suitable environment for selection. Given the economic importance of feeding performance, and the management and testing alternatives in use, the interest in breed x nutritional regime interactions is understandable. It has also probably been assumed that the controlled climatic environment usually imposed on swine would result in negligible genotype x yr or season interactions. A number of studies provide evidence that such an assumption may, however, be false (table 13). The complex of factors involved in such environments may well prove to be more variable than has previously been considered to be the case.

Kempster (1974), in a review of genotype x environment interactions in swine, pointed out that environmental and genotypic differences employed in many experiments were greater than differences likely to be found in practice. The generally low frequency of significant experimental interactions in tables 11 and 12, bearing in mind the above statement, suggests that genotype x environment interactions are unlikely to be of practical importance for conventional feeding practices. This is not meant to imply that such interactions do not occur. Rather, to quote Kuhlers et al. (1977, p. 556):

> ". . . each study has some trait(s) which show significant genotype x environment interaction. The problem is that there does not appear to be a method of predicting which genotypes will respond differentially to the environments to which they are exposed and which traits will be involved."

Table 14 summarizes experiments involving heterosis x environment interactions. Experimental evidence for interaction between heterosis and environment in animals has been reviewed by Barlow (1981). The idea that level of heterosis can be influenced by environmental factors seems reasonable. Lerner's (1954) concept of genetic homeostasis--that heterozygotes are less influenced by environmental effects than homozygotes--suggests a mechanism for interaction. Sang (1964), Griffing and Zsiros (1971), Knight (1971) and Orozco (1976) have presented evidence and models for heterosis x environment interaction in Drosophila, Arabidopsis, Dactylis and Tribolium, respectively. Experimental evaluation of such interactions in pigs have been few, and have yielded contradictory results (table 11). However they do serve to emphasize the fact that assuming such interactions to be nonexistent, while possible practical, is probably a false assumption.

TABLE 11. SUMMARY OF GENOTYPE X ENERGY INTAKE INTERACTION EXPERIMENTS

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
1. Cummings and Winters (1951)	50 in- & outbred Minn., Poland, Duroc & Chester White lines & crosses	Ad lib vs 85%	Dressing % Carcass length BF, LC, fat cuts	
2. Warren and Dickerson (1952)	In- & outbred Landrace, Hampshire & Duroc x Poland China lines	Ad lib vs 80%	ADG**, F/G Wt 154-d BF, % Loin	
3. Gregory and Dickerson (1952)	Inbred Poland China & Hampshire, outbred Durocs, crosses	Ad lib vs 87%	ADG F/G 20 Carcass traits	 Carcass fat traits*
4. Lucas and Calder (1956)	Trial 1: Landrace, Wessex Saddleback x Large White Trial 2: Large White x Essex Saddleback	'High-high' vs 'high-low' vs 'low-low' rations As above	ADG*, F/G* Carcass length, BF, LEA, KO% Carcass length*, streak* % Fore*, Middle*, Ham	Breed rank changes
5. Cole (1957)	5 Minnesota lines, Yorkshire	Ad lib vs 85, 78, 71%, & diluted with ground corncobs	ADG, Age @ 100kg Wt 140-d, Dressing % Carcass length, BF, Est carcass lean, fat	Significant interactions (not specified) were found
6. Bowland and Berg (1959)	Yorkshire & Lacombe x Yorkshire	6 rations: high medium & low energy & protein	ADG**, ADF* F/G* 9 Carcass traits	Growing period only Finishing period only

TABLE 11. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
7. Jonsson (1959)	Danish Landrace, Black Spotted	Standard ration vs sugar beet	ADG BF	
8. Brundstad and Fowler (1959)	4 selection lines from Danish Landrace x Chester White stock	Ad lib vs 70%	Slaughter age Primal cut yield* LEA, BF	
9. Fowler and Ensminger (1960)	2 lines selected for ADG from the same crossbred foundation	Ad lib vs 70%	Selection Response in: ADG* F/G*	Concluded selection under ad lib vs 70% for 2 different genotypes
10. Salmela et al. (1960)	Minnesota No.2,2A & 3 x Minn. No.1	Ad lib vs 85% vs hay ration	ADG**, Age @ 100kg** F/G	Breed rank changes
11. King (1963)	Large White, Wessex Saddleback & Landrace x Large White	Std. vs "high growth" ration " to appetite"	ADG, ADF, F/G Carcass weight, length, BF, streak*	Breed rank changes
12. Hale and Coey(1963)	Litters, mostly Large White	Ad lib vs 80-100%	ADG, F/G, KO%, Carcass length, fat, belly	
13. Plank and Berg (1963)	Yorkshire & Lacombe x Yorkshire	"to appetite" vs 60%	ADG**, ADF*, F/G Carcass length, BF, LEA	Breed rank changes (growing period only)

TABLE 11. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
14. Davey et al. (1969)	Duroc, Yorkshire high & low fat lines	85% vs 65%	ADG*, F/G Carcass lean*, weight, fat, bone	Breed x diet Breed x line x diet
15. Richmond and Berg (1971)	Duroc x Yorkshire Hampshire x Yorkshire Yorkshire x Yorkshire	High vs low energy / protein rations	ADG of carcass wt* ADG of live wt, muscle, F/G, KO%, Carc. wt, BF,	Breed rank changes fat, bone grade, muscle, fat, bone
16. Kuhlers et al. (1972)	Yorkshire, Poland China, reciprocal crosses	55% vs 75% TDN rations, fed ad lib	19 Growth, carcass & efficiency traits @ 4 stages of development	5 of 264 comparisons (2%) were significant
17. Kuhlers et al. (1977)	As above (with sires & dams in stat. model)	As above	15 Grth, carc. & effic. traits @ 3 stgs devel.	4 of 45 comparisons (9%) were significant
18. Clark et al. (1972, 1973)	Yorkshire, Poland China & F_1 females Gilts as above	Ad lib vs 1.82 kg/d As above	OR, CL wt, Follicular fluid wt, # follicles, ant. pit. wt As above	
19. Dailey et al. (1975)	Hampshire, Poland China, Yorkshire & F_1 cross gilts	As above	# follicles, % milky follicles, % gilts with hemorrhagic follicle mean diameter of 4 largest follicles*	

TABLE 11. (Continued)

Experiment	Genotypes	Environments	[a]Traits$^{\text{Sig}}$	Remarks
20. Bereskin et al (1975)	High & low BF Duroc & York lines	High vs low energy / protein	ADG, ADF F/G	
21. Bereskin and Davey (1976)	As above	As above	Carcass BF*, length, belly, LEA, %LC, LCG, Ham: %lean, fat, bone	
22. Bereskin and Davey (1978)	As above	12% vs 16% CP vs 12%+lys+met	Carcass BF, length, belly*, LEA*, %LC*, LCG**, Ham: %lean**, fat**, bone	
23. Stewart and Drewry (1983)	Duroc, Hampshire & Landrace backcross gilts	Normal vs high fiber gilt postweaning rations	Litter size born, weaned Pig weights, litter weights Sow Productivity Index	

Sig: ** P<.01
* P<.05
\+ P<.10
Genotype x environment interaction non-significant for unmarked traits

[a]Traits: ADG = postweaning average daily gain
ADF = average daily feed consumption
BF = backfat thickness
CL = corpora lutea
F/G = feed to gain ratio
KO% = killing out %
LC = lean cuts
LCG = lean cuts gain
LEA = loin-eye area
OR = ovulation rate

TABLE 12. SUMMARY OF GENOTYPE X PROTEIN INTAKE INTERACTION EXPERIMENTS

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
1. Hale and Southwell (1967)	Hampshire, Duroc	15-18% vs 13-16% vs 11-14% CP ad lib	F/G*, ADG, Dressing %, Carcass length, BF, LEA, LC	
2. Bayley and Summers (1968)	Exp.1: Lacombe, Yorkshire, Landrace & crossbreds	13% vs 16% CP	ADG*, F/G	
	Exp.2: Yorkshire, Landrace, Hampshire x Landrace	12% vs 14% CP + 2 levels of syn. lys & met	ADG, F/G	
3. Davey and Morgan (1969)	Duroc, Yorkshire high & low fat lines	12% vs 20% CP 85% of ad lib	ADG Carcass fat*, lean* wt, bone.	line x diet
4. King (1972)		14-16% vs 16-18% CP ad lib	ADG F/G BF	
5. Bereskin et al.(1975)	High & low BF Duroc & Yorkshire lines	High vs low energy / protein	ADG, ADF F/G	

TABLE 12. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
6. Bereskin and Davey (1976)	As above	As above	Carcass BF** LEA, length, %LC, LCG, Ham: %lean, fat, bone	line x protein
7. Bereskin et al. (1976)	As above	12% vs 16% CP vs 12% + lys + met	ADG F/G**	line x diet
8. Christian et al. (1980)	Hampshire, Poland China x Duroc-Yorkshire	12% vs 16% CP	F/G*, ADG 7 Carcass traits	LEA^{+}

Sig: ** P<.01
* P<.05
+ P<.10

Genotype x environment interaction non-significant for unmarked traits

^{a}Traits: ADG = postweaning average daily gain
BF = backfat thickness
F/G = feed to gain ratio
LC = lean cuts
LCG = lean cuts gain
LEA = loin-eye area

TABLE 13. SUMMARY OF GENOTYPE X YEAR, SEASON, SEX, ETC. INTERACTION EXPERIMENTS

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
1. Kristjansson (1957)	Canadian Yorkshire sires	Piggery vs pasture rearing Barrows vs gilts	ADG$^+$, Carcass score$^+$, length, BF$^+$, LEA* As above	Sire rank changes Sire rank changes Sire x sex non-sig.
2. Bowland and Berg (1959)	Yorkshire & Lacombe x Yorkshire	Barrows vs gilts	ADG**, ADF, F/G 9 Carcass traits	
3. Omtvedt et al. (1962)	Hampshire & Duroc lines, crosses	Barrows vs gilts Confinement vs pasture	ADG BF ADG, Carcass length, cutout, LEA, Dressing %*, Probed BF$^+$ Carcass BF*,	 2 of 3 trials 1 of 3 trials
4. Hale and Coey (1963)	Litters, mostly Large White	Barrows vs gilts	ADG**, F/G** Carcass length, fat, belly	1 of 3 groups
5. Plank and Berg (1963)	Yorkshire, Lacombe & Landrace sires	Barrows vs gilts	ADG, ADF, F/G, Carcass length, BF, LEA	
6. Hale and Southwell (1967)	Hampshire, Duroc	Barrows vs gilts	ADG, F/G, LC*, Dressing % Carcass length, fat, LEA	
7. Bayley and Summers (1968)	Exp.1: Lacombe, Yorkshire, Landrace & crossbreds	Boars vs barrows vs gilts	ADG$_*$ F/G*	No significance in Exp. 2

TABLE 13. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
8. Bruner and Swiger (1968)	Yorkshire, Duroc, Poland China, Hampshire, Spotted and Landrace	Barrows vs gilts (=X)	ADG	X^{**} Y^{**} S^{*}
		8 Years (=Y) (1959 - 1966)	F/G	Y^{**} S^{**}
		Spring / fall seasons (=S)	Carcass BF, % ham	X^{**} Y^{**}
			LEA	Y^{**}
			length	Y^{**} S^{**}
			% loin, % LC	X^{**} Y^{**} S^{**}
9. O'Ferrall et al.(1968)	7 Inbred lines	4 Years (1950 - 1953)	Litter size & weight @ birth, 21- & 56-d	
10. Davey and Morgan (1969)	Duroc, Yorkshire high & low fat lines	Barrows vs gilts	ADG Carcass wt*, fat* lean, bone	line x sex
11. Quijandria et al. (1970)	Duroc, Yorkshire, Hampshire, Poland China & Spotted	Barrows vs gilts (=X)	ADG	X^{*} Y^{**} S^{**}
		7 Years (=Y) (1961 - 1967)	F/G	
			Age off test	X^{*} Y^{*} S^{*}
			Carcass BF	Y^{*}
		Spring / fall seasons (=S)	LEA, % shoulder	Y^{**}
			% ham, loin, LC	
12. Richmond and Berg (1971)	Duroc x Yorkshire Hampshire x Yorkshire Yorkshire x Yorkshire	Barrows vs gilts	ADG of live wt*, fat*, carcass wt, lean, bone F/G, KO%, Carcass wt, grade, BF, muscle, fat, bone	Breed rank changes

TABLE 13. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
13. Kuhlers et al. (1972)	Yorkshire, Poland China, F1 crosses	3 Years (1966-1968)	19 Growth, carcass & efficiency traits @ 4 stages of development	3 of 36 comparisons (8%) were significant
14. Kuhlers et al. (1977)	As above (+ sires & dams in stat. model)	2 Years (1968-1969)	15 Gth, carc & effic. traits @ 3 stgs devel	4 of 45 comparisons (9%) were significant
15. Clark et al. (1972)	Yorkshire, Poland China, F1 crosses	Gilts vs sows	Ovulation rate* Several follicular traits (see table 11)	
16. Johnson and Omtvedt(1973)	Yorkshire, Duroc, Hampshire & F1 crosses	Spring / fall seasons	# CL, # live embryos, % live embryos of CL, av. embryo length	
17. Johnson et al. (1973)	As above	As above	ADG** ADG* ADG**, Age 100kg**, ADF** Probed BF* G/F, Carcass length, BF, LEA**, LC**, qual. scores** LEA**	Season x Breed of Sire(BOS) Season x Breed of Dam Season x BOS x BOD Season x BOS x BOD Season x BOD Season x BOS x BOD
18. Fahmy et al. (1975)	Poland China x ea. of 28 different 2-breed cross dam groups	2 Stations Boars vs gilts	Age @ 73kg carcass wt**, BF** Age @ 73kg carcass wt, BF*	
19. Holtmann et al.(1975)	28 different 2-breed cross groups	2 Stations 2 Parities	112-d wt, Age @ puberty, % farrowing Litter size & wt born & @ 21-d	

TABLE 13. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
20. Bereskin et al.(1975)	High & low BF Duroc & Yorkshire lines	Barrows vs gilts	ADG**, ADF* F/G	breed & line x sex
21. Bereskin et al.(1976)	As above	As above	ADG**, F/G** F/G*	line x sex breed x sex
22. Bereskin and Davey (1976)	As above	As above	Several carcass traits (table 12)	line x sex**: all but ham %bone breed x sex: LEA**, LCG**
23. Bereskin and Davey (1978)	As above	As above	As above	line x sex: LEA*, LCG** breed x sex: ham %bone**,LEA**
24. Johnson et al. (1978)	Duroc, Hampshire, Yorkshire F1 females x purebred boars	Year-seasons farrowed (YRS) (spg'72-spg'75)	Age @ 100kg, @ breeding, CR, OR, Litter size & wt @ birth, 21- & 42-d	6 of 84 BOD x YRS F-tests had P<.10
25. Miller et al (1979)	Duroc, Hampshire, Yorkshire & DxY, HxY, Yx(DY) & Yx(HY)	6 Seasons	Birth wt**, Weaning wt** ADG: pre-**, postweaning* weaning to 95kg, d*	
		Barrows vs gilts	Traits as above	No significance

TABLE 13. (Continued)

Experiment	Genotypes	Environments	^{a}Traits^{Sig}	Remarks
26. Christian et al.(1980)	Hampshire, Poland China sires x Duroc-Yorkshire sows	91 vs 114kg slaughter wt	ADG, F/G 7 Carcass traits	 LEA$^+$
		3 Seasons	As above	% ham*, loin*, LEA*, BF*
		Barrows vs gilts	As above	No significance
27. Hutchens et al. (1982)	Duroc, Yorkshire, Landrace & Spotted purebred & F1 gilts	2 Years Spring vs fall Rearing	Age @ puberty Wt @ puberty	No significant interactions with Breed of sire, BOD or BOSxBOD

Sig: ** P<.01
* P<.05
\+ P<.10
Genotype x environment interaction non-significant for unmarked traits
^{a}Traits: ADG = postweaning average daily gain
ADF = average daily feed consumption
BF = backfat thickness
CL = corpora lutea
F/G = feed to gain ratio
LC = lean cuts
LEA = loin-eye area
OR = ovulation rate

TABLE 14. SUMMARY OF HETEROSIS X ENVIRONMENT INTERACTION EXPERIMENTS

Experiment	Heterosis	Environments	^{a}Traits^{Sig}	Remarks	
1. Gregory and Dickerson (1952)	Individual heterosis (inbred Poland China & Hampshire, outbred Durocs, crosses)	Ad lib (F) vs 87% (L)	ADG	Heterosis: F:13%	L: 26%
			F/G	F:-7%	L:-19%
		Ad lib vs 87% (linecross gilts)	ADG	F:30%	L: 13%
			F/G	F:-9%	L: 9%
2. Skarman (1965)	Individual heterosis (Landrace, Yorkshire, crosses)	Ad lib (F) vs limit (L) fed	Slaughter age	F: -.6%	L: -1.9%
			ADG	F: .3%	L: 2.1%
			F/G	F: -.1%	L: -1.2%
			Wt 140-d	F: .1%	L: 3.3%
3. Lean et al (1972)	Individual heterosis (Pietrain, Landrace, crosses)	Ad lib (F) vs limit (L) fed	ADG, Slaughter age	Comparable estimates	
			21 carcass traits	Comparable estimates	
			F/G	F:13.4%	L: -3.1%
4. Comberg et al. (1972,1973. Cited by Barlow, 1981)	Individual heterosis (Pietrain, Landrace, crosses)	Temperature: 8° vs 18°C	ADG	8° 7.9%	18° -5.0%
		18° vs 30°C	ADG	18° 5.5%	30° -6.7%
5. Kuhlers et al. (1977)	Individual heterosis (Yorkshire, Poland China, F1 crosses)	55% (Lo) vs 75% (Hi) TDN rations fed ad lib	Av d TDN consumption	Lo: .9%	Hi: 9.7%
			Protein efficiency	Lo: 9.3%	Hi: 2.2%
			BF	Lo: 7.0%	Hi:-3.8%

TABLE 14. (Continued)

Experiment	Heterosis	Environments	^{a}Traits^{Sig}	Remarks
6. Schneider et al. (1982a)	Individual & maternal heterosis (Chester White, Duroc, Hamp Yorkshire, crosses)	Sex	Age 100kg*	Sex x ind. & mat. heterosis
		Parity	Wt 154-d^{+}	Sex x maternal heterosis
		Year	LEA**	Sex x maternal heterosis
		Season	% fat corr. muscle**	Sex x maternal heterosis
			Litter wt born	Par x maternal heterosis

aSig: ** P<.01
* P<.05
\+ P<.10

Traits: ADG = postweaning average daily gain
BF = backfat thickness
F/G = feed to gain ratio
LEA = loin-eye area

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CHAPTER III

INDIVIDUAL HETEROSIS AND BREED EFFECTS FOR POSTWEANING PERFORMANCE AND CARCASS TRAITS IN FOUR BREEDS OF SWINE

Summary

Individual heterosis and breed effects for postweaning average daily gain (ADG), off-test age (AGE) and probed backfat thickness (BF) were estimated from data on 1,664 pigs produced by diallel matings involving the Duroc, Yorkshire, Landrace and Spotted breeds. Genetic parameter estimates for various carcass traits were obtained by least-squares analysis of data collected on 269 barrow carcasses. Significant breed x environment interactions were found for ADG, AGE and BF. Specific heterosis estimates for ADG and AGE were all highly significant and reasonably consistent between crosses. Overall heterosis for BF was significant, although specific estimates were not. Overall heterosis estimates were .07 kg/d (10.5%) for ADG, -14d (7.5%) for AGE and .83 mm (3.2%) for BF. Of 78 specific heterosis estimates for carcass traits, only six were significantly different from zero. Duroc and Spotted sired pigs grew faster and were younger off-test than Yorkshire and Landrace sired pigs. Landrace sired pigs were fatter, and Duroc sired pigs leaner than pigs with Spotted or Yorkshire sires. Breed of dam effects for ADG were similar to breed of sire effects. Off-test age of pigs with Landrace dams, however, was significantly less than that for Yorkshire dams. Significant breed of sire effects for carcass traits reflected the superiority of Duroc sired pigs for carcass backfat, loin eye area, lean cuts yield and muscle quality (marbling and firmness).

Breed of sire and breed of dam effects were somewhat dissimilar for carcass traits, suggesting the importance of maternal effects for these traits.

(Key Words: Swine, Growth Rate, Carcass Traits, Heterosis, Breed Direct Effects, Maternal Effects.)

Introduction

While the greatest benefits of crossbreeding in swine arise from moderate to high degrees of heterosis exhibited by sow productivity traits, the impact of heterosis and breed effects on postweaning performance and carcass traits should not be overlooked. Reported estimates of individual heterosis for feed to gain ratio and carcass measurements have, in general, been small and not significant, although postweaning rate of gain appears to be moderately (6 to 10%) heterotic (Sellier, 1976; Johnson, 1981; Wheat et al., 1981; Toelle and Robison, 1983). Significant breed direct effects have been demonstrated for postweaning growth and carcass traits. Maternal effects, apparently negligible for postweaning rate of gain, may be important for feed to gain ratio and carcass traits (Johnson, 1981; Wheat et al., 1981).

Duroc, Yorkshire, Landrace and Spotted purebred and crossbred matings were made as part of a crossbreeding experiment carried out at the Oklahoma Agricultural Experiment Station. The relative paucity of experimental results for the Landrace and Spotted breeds prompted their inclusion in the study. Heterosis and breed effects for sow productivity traits from this experiment have been reported previously (Gaugler et al., 1984). The objectives of this present study were to evaluate individual heterosis and breed effects for postweaning performance and various carcass traits for the four breeds.

Materials and Methods

Experimental Procedure. Postweaning performance data were collected on 1,664 purebred and crossbred pigs produced by diallel matings involving the Duroc, Yorkshire, Landrace and Spotted breeds. Pigs were farrowed at the Oklahoma State University Experimental Swine Farm at Stillwater during five consecutive fall and spring seasons starting in the fall of 1976. Establishment and management of the purebred herds have been discussed by Hutchens et al. (1982) and Gaugler et al. (1984). Foundation boars and gilts of each breed were obtained from several different sources, and semi-annual introduction of at least one new boar of each breed was practiced in order to maintain a broad genetic base in the purebred herds.

Boars were randomly mated to at least one female of each purebred herd. Distribution of animal numbers by breed group is given in table 1. Spring litters were farrowed in March and April, fall litters in September and October. Pigs had access to creep feed from between 2 and 3 wk of age, and were weaned at approximately 6 wk of age. The two heaviest boars at weaning from at least four litters of each breed group were left intact. All other males were castrated. At approximately 8 wk of age barrows and some of the gilts were moved to pasture lots, stocking approximately 50 pigs/lot. The other gilts had been randomly allotted within litter to be grouped in pens of 10 and fed in an open-front confinement building adjacent to pens containing the boars. Hutchens et al. (1981, 1982) reported breed comparisons for age and

TABLE 1. NUMBER OF PIGS (CARCASSES) BY BREED GROUP

	Breed of dam			
Breed of sire	D	Y	L	S
Duroc (D)	125 (15)	85 (14)	110 (20)	102 (15)
Yorkshire (Y)	107 (21)	93 (11)	108 (19)	90 (17)
Landrace (L)	101 (19)	87 (13)	142 (20)	87 (18)
Spotted (S)	107 (16)	109 (21)	102 (17)	109 (13)

weight at puberty, and relationships between these and growth performance traits, for these gilts.

Pigs were fed a 14% crude protein corn (IFN 4-02-931) or sorghum grain (IFN 4-04-383) based diet from approximately 8 wk of age until the end of the test period. Gilts were weighed off-test and probed for backfat thickness at approximately 91 kg. Boars and barrows were weighed off-test and probed at approximately 100 kg. Gilt records were adjusted to 91 kg, boar and barrow records were adjusted to 100 kg. All barrows were slaughtered at the Oklahoma State University Meat Laboratory. Carcasses were chilled for at least 24 hr before carcass measurements were made. One loin chop from each carcass was scored subjectively for marbling, firmness and color.

Traits Measured. Postweaning performance traits measured were average daily gain, age off-test and probed backfat thickness. Records were adjusted to constant final weights of approximately 91 kg for gilts and 100 kg for males. Slaughter weight (adjusted for differences in gut weight), carcass weight, length, backfat, loin eye area, quality scores and weight of belly and closely trimmed lean cuts (ham, shoulder and loin) were recorded for 269 barrows (210 crossbred and 59 purebred). Loin chop scores (marbling, firmness and color) were integers between one and seven. One represented muscle devoid of marbling that was very soft and pale, and seven represented very firm very dark muscle with abundant marbling. Backfat was measured at the first rib, last rib and last lumbar vertebra and averaged. Complete gain-test records were collected on 976 gilts, 403 boars and 285 barrows. Due to limited finishing facilities a number of barrows were sold postweaning, resulting in the disproportionate number of males and females. In both the growth and carcass data sets only pigs with complete records (i.e. an observed value for each trait) were included in the analyses.

Statistical Analyses. The following linear model, with the usual distributional assumptions and zero-sum restrictions on fixed parameters, was assumed in analyzing average daily gain, off-test age and probed backfat thickness:

$$y_{ijklmn} = \mu + B_i + F_j + S_k + P_l + (BF)_{ij} + (BS)_{ik} + (BP)_{il} + (FS)_{jk} + l_{mij} + e_{ijklmn}$$

where

y_{ijklmn} = an observable random variable;

μ = an unknown constant;

B_i = fixed effect of the i^{th} breed group, $i = 1, \ldots, 16$;

F_j = fixed effect of the j^{th} farrowing season, $j = 1, \ldots, 5$;

S_k = fixed effect of the k^{th} sex, $k = 1, \ldots, 3$.

P_l = fixed effect of the l^{th} parity, $l = 1, \ldots, 3$.

$(BF)_{ij}$ and similar terms represent interaction effects;

l_{mij} = random effect of the m^{th} litter nested within the ij^{th} breed-farrowing season combination;

and e_{ijklmn} = random residual effect associated with the $ijklmn^{th}$ record.

The SAS Harvey procedure (Joyner, 1983) was used to compute these analyses. The effect of litter nested within breed x year-season was treated as random by including the estimated ratio of residual to litter variances (4.76, assuming heritability of .38 for all three traits). Equations for litters were then absorbed. Where variances are known, solutions for fixed effects are generalized least-squares constants (Harvey, 1982). Preliminary analyses indicated parity x year-season farrowed and parity x sex interactions not to be significant (P>.10). These terms were therefore excluded from the final model.

The linear model assumed in analysing carcass data was:

$$y_{ijklm} = \mu + A_i + B_j + (AB)_{ij} + F_k + s_{li} + \beta w_{ijklm} + e_{ijklm}$$

where

y_{ijklm} = an observable random variable;

μ = an unknown constant;

A_i = fixed effect of the i^{th} breed of sire, $i = 1, \ldots, 4$;

B_j = fixed effect of the j^{th} breed of dam, $j = 1, \ldots, 4$;

$(AB)_{ij}$ = fixed breed of sire x breed of dam interaction effect;

F_k = fixed effect of the k^{th} farrowing season, $k = 1, \ldots, 5$;

s_{li} = random effect of the l^{th} sire nested within the i^{th} breed of sire;

β = linear regression of the dependent variable on adjusted slaughter weight (w_{ijklm});

and e_{ijklm} = random residual effect associated with $ijklm^{th}$ record.

Carcass data were analysed using Harvey's least-squares program, LSML76 (Harvey, 1977, 1982). The covariable slaughter weight was not included in the model for carcass length, backfat and loin eye area as these data had been adjusted to a constant final weight. Preliminary analyses indicated breed x year-season interactions were not significant for any carcass traits, and they were therefore excluded from the final model.

Breed of sire and breed of dam effects were obtained directly from carcass data analyses, and calculated by averaging breed parameter estimates for growth performance traits. To estimate direct and maternal effects the following genetic model was considered:

$$\bar{y}_{i,j} = \mu + .5(g_i^I + g_j^I) + g_j^M + h_{ij}^I$$

where

$\bar{y}_{i,j}$ = mean performance of purebred (i=j) or crossbred (i≠j);

μ = a constant;

g^I, g^M = direct and maternal breed effects, subject to the usual zero-sum restrictions and

h^I_{ij} = individual heterosis.

Let, for example, DS and DD equal averages of least-squares means for the four breed groups having Duroc sires and dams, respectively. Under the above model:

$$E(DD) = 1/2g_D^I + g_D^M + .25(h_{DY}^I + H_{DL}^I + h_{DS}^I)$$

$$E(DS) = 1/2g_D^I + .25(h_{DY}^I + h_{DL}^I + h_{DS}^I)$$

The difference between breed of sire and breed of dam effects therefore provides an unbiased estimate of maternal effects. Twice the breed of sire effect, however, does not provide an unbiased estimate of direct effects. Unbiased estimates were obtained by weighted least-squares analyses of breed group least-squares means assuming the above genetic model, i.e., as:

$$\hat{\underset{\sim}{\beta}} = (X'D^{-1}X)^{-1}X'D^{-1}\underset{\sim}{\bar{y}}$$

where

$\hat{\underset{\sim}{\beta}}$ = represents a vector of parameter estimates;

X = a known design matrix and

D^{-1} = $\underset{\sim}{n}'I$ where $\underset{\sim}{n}$ is a vector of the number of observations on corresponding least-squares means in $\underset{\sim}{\bar{y}}$.

Results and Discussion

Analyses of Variance. Mean squares and significance of F-statistics for effects in the postweaning performance analyses are given in table 2. Differences among breeds, year-seasons farrowed and the sexes were highly significant for postweaning rate of gain, off-test age and probed backfat thickness. The significant year-season x sex interaction reflected differences in the relative performance of gilts, boars and barrows, but not differences in how the sexes ranked across year-seasons. Boars outperformed barrows, averaging .74 kg/d postweaning rate of gain, 173-d of age and 24.1 mm probed backfat at 100 kg. Barrows gained slower (.69 kg/d) and were older (185 d) and fatter (30.4 mm) at 100 kg. Gilt records (adjusted to an off-test weight of 91 kg) averaged .67 kg/d, 174-d and 25.2 mm probed backfat.

Parity differences were significant for off-test age and probed backfat thickness, but not for postweaning rate of gain. Pigs were classified as having first, second or third parity dams. Parity three represented sows of all parities greater than the second. Ranging from third to seventh parity, the 'average' female in this group was a fourth parity sow. Pigs from older dams were younger and fatter off-test. Parities one, two and three averaged 180, 177 and 175 d of age and 25.9, 26.7 and 27.1 mm probed backfat thickness respectively.

The breed x parity interaction approached significance for growth rate, and was significant for probed backfat thickness. Breed x sex was significant for growth rate and breed x year-season farrowed significant for all three postweaning performance traits. While literature reports of genotype x parity interactions for growth rate are virtually

TABLE 2. GENERALIZED LEAST-SQUARES ANALYSES OF VARIANCE FOR POSTWEANING PERFORMANCE TRAITS

Source	df	Mean Squares		
		Average daily gain, kg.	Off-test age, d.	Probed backfat, mm.
Breed of pig (B)	15	.04230**	1955**	47.15**
Year-season farrowed (F)	4	.09268**	4465**	453.00**
Sex (S)	2	.69722**	10969**	2930.20**
Parity (P)	2	.00654	839*	53.50**
F x S	8	.03501**	1406**	22.19*
B x F	60	.00792**	324**	12.56*
B x S	30	.00732*	331**	11.93
B x P	30	.00641+	255+	15.18*
Residual	1512	.00556	216	10.76

+P<.10

*P<.05

**P<.01

non-existant, significant genotype x sex (generally barrows and gilts) interactions have been reported for growth rate by a number of workers (Bowland and Berg, 1959; Hale and Coey, 1963; Bruner and Swiger, 1968; Quijandria et al., 1970; Richmond and Berg, 1971 and Bereskin et al., 1975, 1976). However, even more studies have reported genotype x sex interactions not to be significant for growth rate (Kristjansson, 1957: Omtvedt et al., 1962; Plank and Berg, 1963; Hale and Southwell, 1967; Bayley and Summers, 1968; Davey and Morgan, 1969; Fahmy et al., 1975; Miller et al., 1979 and Christian et al., 1980). Significant breed x year and (or) season interactions have been reported for growth rate (Bruner and Swiger, 1968; Quijandria et al., 1970 and Miller et al., 1979) and for both growth rate and probed backfat thickness by Johnson et al. (1973). Genotype x year and (or) season interactions, however, were unimportant for growth performance traits in a number of other studies (Kuhlers et al., 1972, 1977; Johnson et al., 1978; Christian et al., 1980 and Hutchens et al., 1982).

Examination of subclass means suggested that the significant breed x sex and breed x parity interactions did not preclude examination of breed as a main effect. Rank changes between breeds were, in general, relatively minor. Averaging breed across sex (which included boars) resulted in parameter estimates that are biased with reference to a normal production population of only barrows and gilts. Although influencing absolute values of breed parameters, the effect upon breed comparisons is hopefully small. The 16 breed groups, in general, ranked similarly for both boar and barrow average daily gain and age off-test (although some rank changes did occur). The effect on constant estimates from including boars should therefore, in most cases, be similar for all breeds, resulting in negligable bias in breed comparisons.

Breed ranks appeared somewhat more variable across year-seasons farrowed. Many environmental factors undoubtedly contributed to the year-season effect, but seasonal temperature differences and fluctuating health status were probably both important for the Stillwater herd. Barlow (1981) reviewed the evidence for heterosis x environment interactions in animals and concluded that heterosis for most traits appeared to be greater in sub-optimal environments. Differences in purebred and crossbred performance levels might therefore be expected under various levels of disease and climatic stress. Conceptually, it seems appropriate to consider year-seasons as complex random effects. Estimating breed parameters for individual year-seasons would have little utility since we wish to make inferences to the breeds in general. In making breed comparisons, therefore, we not only assume adequate sampling of the breeds, but also that year-seasons are representative of those in the target population to which inference is made.

Mean squares and significance of F-statistics for effects in carcass trait analyses are given in table 3. Preliminary analyses established that breed x year-season interactions were not significant. Breed of sire and breed of dam were significant for weight of ham, shoulder, total lean cuts and for marbling and firmness scores. Breed of sire was also significant for carcass weight, backfat thickness and loin eye area. The breed of sire x breed of dam interaction was significant for weight of ham, loin and loin eye area. Sires within breed of sire were important sources of variation for all traits except carcass weight,

TABLE 3. LEAST-SQUARES ANALYSES OF VARIANCE FOR CARCASS TRAITS

		Mean Squares												
										Lean Cuts as a % of		Quality scores		
Source	df	Carcass wt, kg	Length, cm	Backfat, mm	Loin eye area, cm^2	Ham, kg	Loin, kg	Shoulder, kg	Belly, kg	adj live wt.	carcass wt.	Marbling	Firmness	Color
Breed of a sire^a (BOS)	3	18.48*	10.35	228.26**	245.38**	22.45**	18.70	2.75*	34.41	107.58**	211.00**	11.76**	7.81**	.83
Sires w/in BOS	33	4.31	19.68**	36.51	18.04**	1.56**	164.68**	.73^{+}	170.46	8.13**	12.49*	1.92	1.55	.79
Breed of dam (BOD)	3	2.41	18.66	53.00	16.22	5.31**	.89	2.24**	.93	19.59**	24.36*	6.46**	7.93**	1.04
Year-season farrowed	4	44.27**	92.07**	153.12**	70.58**	1.90*	1.76**	.09	2.58**	94.97**	244.44**	12.85**	12.08**	10.53**
BOS x BOD	9	7.94	6.00	22.00	19.00*	1.28*	1.15*	.53	.55	7.71^{+}	13.44	1.57	1.28	.68
Adj. Live weight	1	2285.45**	-	-	-	76.90**	50.41**	23.91**	53.19**	284.24**	145.50**	.63	.14	.02
Residual^b	215	4.82	10.87	25.35	9.23	.58	.50	.53	.56	4.52	8.30	1.56	1.51	.76

$^{+}$P<.10

*P<.05

**P<.01

[a] Error term for BOS F-statistic is sires w/in BOS. Error term for all other effects is the residual mean square.

[b] 216 df for length, backfat and loin eye area (adjusted data, no covariable in the model).

backfat, shoulder weight and quality scores. Breed group least-squares means for growth and carcass traits are given in tables 4 and 5.

Heterosis Estimates. Individual heterosis estimates for postweaning performance traits are given in table 6. Specific estimates for average daily gain and off-test age were all highly significant and reasonably consistent between crosses. Although specific estimates for probed backfat thickness were not significantly different from zero, overall heterosis was significant. These data suggest that average heterosis values for growth rate and probed backfat should be adequate when comparing alternative crossbreeding systems. The overall performance of crossbreds relative to the contemporary purebred mean was .07 kg/d (10.5%) for postweaning average daily gain; -14d (7.5%) for off-test age and .83 mm (3.2%) for probed backfat.

Literature estimates of specific individual heterosis for postweaning gain and off-test age are also reasonably consistent, both among crosses and experiments, in agreement with the findings of this study. Johnson (1981), in a weighted least-squares analysis of results from crossbreeding experiments in the U.S. and Canada, reported an average heterosis of .06 kg/d (8.8%) for postweaning average daily gain. Sellier (1976), in a summary of mostly European experiments, reported a .04 kg/d (6.0%) crossbred advantage. A higher estimate (13.7%) reported by Toelle and Robison (1983) included data from 'mixed' litters--i.e., purebred and crossbred pigs crossfostered in the same litter. Vigor of crossbred pigs in these litters appeared to have a detrimental effect on the purebred pigs, thus inflating heterosis estimates. Ignoring 'mixed' litter data, heterosis of 11.1% was calculated from means presented by Toelle and Robison (1983)--similar to the 10.5% estimate of the present

TABLE 4. PUREBRED & F_1 CROSSBRED GENERALIZED LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE TRAITS

Breed of pig	No. pigs	Postweaning Av. d. gain (kg/d)	Age off-test, d.	Probed backfat, mm.
Overall	1164	.7015	177.1	26.56
Duroc (D)	125	.6625	183.8	24.98
Yorkshire (Y)	93	.6384	193.5	25.13
Landrace (L)	142	.6352	189.5	27.60
Spotted (S)	109	.6655	184.2	26.06
D x Y	85	.7187	174.9	23.94
D x L	110	.7318	171.7	25.85
D x S	102	.7400	170.1	25.71
Y x D	107	.7388	170.1	27.74
Y x L	108	.7003	175.4	27.15
Y x S	90	.6953	180.1	25.32
L x D	101	.7127	172.8	28.41
L x Y	87	.6809	183.8	27.61
L x S	87	.7293	170.1	27.56
S x D	107	.7305	171.7	27.76
S x Y	109	.7298	171.9	26.64
S x L	102	.7142	170.8	27.55

TABLE 5. PUREBRED AND F_1 CROSSBRED LEAST-SQUARES MEANS FOR CARCASS TRAITS

Breed	No.	Carcass wt., kg	Length, cm	Backfat, mm	Loin-eye area, cm^2	Ham, kg	Loin, kg	Shoulder, kg	Belly, kg	Lean cuts as a % of		Quality scores		
										adj live wt	carcass wt.	Marbling	Firmness	Color
Overall	269	67.98	78.29	32.75	29.78	14.29	12.79	12.31	8.76	43.31	59.67	3.51	4.22	4.97
Duroc (D)	15	66.40	77.25	29.08	32.05	14.79	12.37	12.48	7.78	44.05	62.02	4.84	5.17	5.14
York (Y)	11	67.68	79.11	33.03	28.56	14.45	12.44	12.31	9.61	44.05	60.90	3.09	3.92	5.10
Land (L)	20	67.29	78.77	33.47	29.90	13.84	13.61	12.35	8.64	42.65	59.37	2.90	3.59	4.79
Spot (S)	13	68.69	77.04	34.16	28.07	14.59	12.32	11.96	8.56	43.42	59.13	3.98	4.61	5.39
D x Y	14	68.92	78.68	29.49	34.74	15.79	13.53	13.07	7.88	46.73	63.66	3.51	4.50	4.80
D x L	20	67.83	78.38	30.99	32.11	14.54	12.67	12.57	7.87	44.44	61.42	3.54	4.00	4.50
D x S	15	68.55	79.46	30.70	31.96	15.25	12.88	12.35	7.94	45.51	62.20	4.47	5.23	5.06
Y x D	21	68.58	76.80	36.21	27.93	13.79	12.50	12.37	9.96	42.92	58.56	3.54	4.28	5.18
Y x L	19	68.12	78.81	35.49	27.35	13.73	12.27	12.06	9.74	41.98	57.82	2.93	3.87	4.83
Y x S	17	67.36	78.25	31.49	30.88	14.59	12.67	12.26	9.34	43.53	60.51	3.06	3.72	4.86
L x D	19	67.24	78.60	33.36	29.15	13.51	13.66	12.10	8.94	42.02	58.39	3.02	4.44	4.64
L x Y	13	67.64	78.89	33.07	29.29	13.70	13.60	12.60	9.05	42.73	59.06	3.44	4.17	5.19
L x S	18	67.33	78.60	30.93	28.58	13.61	13.20	11.76	8.84	41.37	57.51	3.45	3.86	4.96
S x D	16	69.33	77.43	34.18	28.50	13.90	12.34	12.26	8.99	42.52	57.50	3.76	4.42	5.11
S x Y	21	68.82	78.90	33.02	29.45	14.42	12.36	12.38	8.62	42.87	58.56	3.56	4.10	4.98
S x L	17	67.88	77.70	35.32	28.03	14.11	12.25	12.07	8.36	42.23	58.16	3.06	3.57	5.03

TABLE 6. INDIVIDUAL HETEROSIS ESTIMATES FOR POSTWEANING PERFORMANCE TRAITS

Reciprocal crosses[a]	Average daily gain, kg/d	%	Off-test age, d	%	Probed backfat, mm	%
D-Y	.080 ± .015**	(12.0)	-16.3 ± 2.9**	(-8.6)	.85 ± .65	(3.2)
D-L	.074 ± .014**	(11.3)	-14.4 ± 2.7**	(-7.7)	.85 ± .60	(3.2)
D-S	.071 ± .014**	(10.7)	-13.1 ± 2.8**	(-7.1)	1.21 ± .62^{+}	(4.8)
Y-L	.055 ± .013**	(8.5)	-12.2 ± 2.5**	(-6.2)	1.01 ± .56^{+}	(3.9)
Y-S	.062 ± .014**	(9.3)	-13.2 ± 2.7**	(-6.8)	.44 ± .60	(1.5)
L-S	.070 ± .013**	(11.0)	-16.2 ± 2.6**	(-8.8)	.73 ± .57	(2.7)
Overall	.069 ± .008**	(10.5)	-14.2 ± 1.6**	(-7.5)	.86 ± .35*	(3.2)

$^{+}$P<.10

*P<.05

**P<.01

[a] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.

study, but somewhat higher than earlier reported estimates. It should be noted that while the estimate from Toelle and Robison's results was based on 548 pigs, Johnson's (1981) estimate was based on data from approximately 5,000 pigs.

Heterosis estimates of -13 d (6.9%) and -10 d (5.0%) for age at 100 kg, and of -17 d (7.9%) for age at 95 kg have been reported by Johnson (1981), Sellier (1976) and Wheat et al. (1981), respectively. Ignoring 'mixed' litters, heterosis of -8.0% was evident from results reported by Toelle and Robison (1983). Overall heterosis of -14 d (7.5%) obtained in the present study was in good agreement with previous estimates. Least-squares means presented by Toelle and Robison (1983), again excluding 'mixed' litters, indicated a -6.6% heterosis for probed backfat thickness, in contrast to the 3.2% estimate of this study.

Experimental estimates of individual heterosis for carcass traits have in general been small and mostly not significant (Johnson, 1981; Wheat et al., 1981). Estimates obtained from this study (table 7) provide additional evidence that individual heterosis for carcass traits is close to zero. Of 78 specific estimates, only six were significantly different from zero.

Breed Effects. Breed of sire and breed of dam effects for postweaning performance traits are given in table 8. Duroc and Spotted sired pigs gained approximately .02 kg/d faster, and reached off-test weight approximately 4.5 d earlier, than Yorkshire and Landrace sired pigs. Spotted and Yorkshire sired pigs had average probed backfat, while Landrace sired pigs were 2.7 mm fatter than pigs with Duroc sires. Breed of dam effects for average daily gain, apart from a not significant change in rank between Yorkshire and Landrace, were similar

TABLE 7. INDIVIDUAL HETEROSIS ESTIMATES FOR CARCASS TRAITS

Reciprocal crosses^a	Carcass wt, kg	Length, cm	Backfat, mm	Loin eye area, cm^2	Ham, kg	Loin, kg	Shoulder, kg	Belly, kg	Lean cuts as a % of		Quality scores		
									adj live wt.	carcass wt.	Marbling	Firmness	Color
D-Y	1.71±.62**	-.47±.92	1.96±1.40	.85±.85	.12±.21	.57±.20**	.32±.20	-.24±.21	.72±.60	-.45±.81	-.38±.35	-.14±.35	-.11±.25
D-L	.69±.55	.47±.82	.90±1.26	-.35±.76	-.30±.19	.18±.18	-.08±.18	.20±.19	-.13±.52	-.81±.72	-.58±.31^{+}	-.16±.31	-.40±.22^{+}
D-S	1.40±.62*	1.29±.92	.79±1.41	.19±.85	-.12±.22	.27±.20	.09±.21	.30±.21	.28±.60	-.73±.82	-.30±.35	-.07±.35	-.19±.25
Y-L	.44±.60	.00±.89	.98±1.37	-.94±.82*	-.43±.21*	-.09±.19	-.03±.20	.27±.20	-1.04±.58^{+}	-1.77±.78*	.17±.34	.29±.33	.04±.24
Y-S	-.07±.60	.53±.92	-1.28±1.40	1.76±.86*	-.03±.21	.12±.20	.17±.21	-.10±.21	-.59±.60	-.56±.81	-.20±.35	-.34±.35	-.33±.25
L-S	-.37±.57	.25±.85	-.70±1.29	-.69±.78	-.36±.20^{+}	-.24±.18	-.25±.19	.00±.19	-1.25±.55*	-1.45±.75^{+}	-.18±.32	-.38±.32	-.10±.23
Overall	.58±.36^{+}	.35±.53	.43± .81	.00±.49	-.22±.12^{+}	.11±.12	.00±.12	.15±.12	-.39±.35	-.99±.47*	-.27±.20	-.14±.20	-.19±.14

^{a}D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.

$^+$P<.10

*P<.05

**P<.01

TABLE 8. BREED EFFECTS[a] (GENERALIZED LEAST-SQUARES CONSTANTS) FOR POSTWEANING PERFORMANCE TRAITS

	Average daily gain, kg	Off-test age, d	Probed backfat, mm
$\hat{\mu}$	.701 ± .004	177.15 ±.69	26.56 ± .15
Breed of sire			
Duroc	.012	-2.03	-1.44
Yorkshire	-.008	2.64	-.22
Landrace	-.012	1.90	1.23
Spotted	.008	-2.51	.43
Breed of dam	±.003	±.65	±.58
Duroc	.010	-2.56	.66
Yorkshire	-.010	3.89	-.73
Landrace	-.006	-.29	.47
Spotted	.006	-1.04	-.40
Std. Error[a]	±.003	±.65	±.58

[a] approximate (average) breed effect standard errors.

to breed of sire effects. Pigs with Duroc dams took 6.5 fewer d to reach final weight than those with Yorkshire dams. Pigs with Spotted and Landrace dams were approximately 2 d older off-test than those with Duroc dams. Breed of dam differences were not significant for probed backfat thickness.

These results are very similar to those presented by Johnson (1981) for postweaning average daily gain and age at 100 kg. Breed effects for age at 95 kg, from least-squares means reported by Wheat et al. (1981), showed Yorkshire sired pigs to be significantly older (-8 d) than Duroc or Landrace sired pigs, which were not significantly different. Pigs with Landrace dams, however, were approximately 10 d younger than pigs with either Duroc or Yorkshire dams.

Breed of sire and breed of dam effects for carcass traits are given in table 9. The largest differences among sire breed effects for traits for which breed of sire was significant were due to superiority of the Duroc as a sire breed. Duroc sired pigs were significantly leaner, with larger loin eye areas and heavier hams, and shoulders. Lean cuts as a percent of both live and carcass weight, and marbling and firmness scores, were also greater for Duroc than for Yorkshire, Landrace or Spotted sired pigs. Landrace sired pigs were superior for yield of closely trimmed loin, however. With the exception of carcass weight, backfat and loin eye area, breed of dam was significant for the same traits as breed of sire. Dam breed effects, however, were generally dissimilar to breed of sire effects, suggesting that maternal effects were important for carcass traits. Pigs with Yorkshire and Spotted dams had heavier hams than those with Duroc and Landrace dams. Yorkshire dams produced pigs with the highest shoulder weight, but pigs with

TABLE 9. BREED EFFECTS (LEAST-SQUARES CONSTANTS) FOR CARCASS TRAITS

	Carcass wt, kg	Length, cm	Backfat, mm	Loin eye area, cm^2	Ham, kg	Loin kg	Shoulder, kg	Belly, kg	Lean cuts as a % of		Quality scores		
									adj live wt.	carcass wt.	Marbling	Firmness	Color
$\hat{\mu}$	67.98 ±.18	78.29 ±.41	32.75 ±.54	29.78 ±.40	14.29 ±.12	12.79 ±1.39	12.31 ±.08	8.76 ±1.41	43.31 ±.27	59.67 ±.32	3.51 ±.58	4.22 ±.10	4.97 ±.07
Breed of sire													
Duroc	-.05	.15	-2.68	2.93	.80	.07	.31	-.89	1.87	2.65	.58	.51	-.10
Yorkshire	-.04	-.05	1.30	-1.10	-.15	-.32	-.06	.91	-.19	-.22	-.35	-.27	.02
Landrace	-.60	.42	-.04	-.56	-.62	.73	-.11	.11	-1.12	-1.09	-.31	-.20	-.08
Spotted	.70	-.52	1.42	-1.27	-.03	-.47	-.14	-.13	-.55	-1.34	.08	-.04	.15
Std. Error[a]	±.24	±.55	±.72	±.53	±.16	±1.82	±.10	±1.85	±.36	±.43	±.16	±.14	±.10
Breed of dam													
Duroc	-.09	-.77	.46	-.38	-.29	-.07	-.01	.16	-.44	-.56	.28	.36	.05
Yorkshire	.29	.60	-.60	.73	.30	.19	.28	.03	.78	.87	-.11	-.04	.04
Landrace	-.20	.12	1.07	-.44	-.23	-.09	-.05	-.11	-.49	-.48	-.40	-.46	-.18
Spotted	.00	.05	-.93	.09	.22	-.03	-.22	-.09	.14	.16	.23	.14	.09
Std. Error[a]	±.25	±.37	±.57	±.34	±.09	±.08	±.08	±.08	±.24	±.33	±.14	±.14	±.10

[a] approximate (average) breed effect standard errors are shown.

Spotted dams had the lightest shoulders. Yorkshire was the most favorable dam breed for lean cuts as a percent of live and carcass weights. Pigs with Duroc and Landrace dams had the lowest lean cut yield and those with Spotted dams were intermediate. Duroc and Spotted dam breed effects for marbling and firmness were superior to Yorkshire, and Yorkshire superior to Landrace .

Average Direct and Maternal Effects. Sires' influence on progeny was limited to genes transmitted in the sperm. Breed of dam effects represented an equivalent direct genetic contribution, plus average maternal effects. Such effects may involve cytoplasmic inheritance, the pre-natal environment and post-natal milk production and mothering ability (Robison, 1972).

Estimates of direct genetic and maternal effects are presented in tables 10 and 11. Table 10 illustrates that, compared to direct effects, maternal effects were relatively unimportant for average daily gain. Maternal effects were somewhat larger for off-test age, as might be expected given the dam's influence on preweaning growth rate. More surprisingly, perhaps, maternal effects were found to be substantial relative to direct effects for probed backfat and carcass traits in many cases (table 11). Johnson (1981) and Wheat et al. (1981) have also reported maternal effects as being important for carcass length, backfat and loin eye area; and Toelle and Robison (1983) found breed prenatal effects to be important for backfat and 154-d weight. Considering the Duroc in this present study, average direct effects were for leaner pigs with lighter bellies, increased loin eye area and increased ham and shoulder weights relative to the other three breeds. However Duroc maternal effects were for fatter pigs with heavier bellies, decreased

TABLE 10. AVERAGE DIRECT (g^I) AND MATERNAL (g^M) GENETIC EFFECTS FOR POSTWEANING PERFORMANCE TRAITS[a]

Trait	Duroc		Yorkshire		Landrace		Spotted	
	g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M
Average d gain, kg	.015	-.003	-.011	-.001	-.021	.006	.018	-.003
Off-test age	-3.50	-.46	4.59	1.20	3.94	-2.20	-5.03	1.46
Probed backfat, mm	-3.04	2.08	-.32	-.49	2.41	-.75	.94	-.83

TABLE 11. AVERAGE DIRECT (g^I) AND MATERNAL (g^M) GENETIC EFFECTS FOR CARCASS TRAITS[a]

Trait	Duroc		Yorkshire		Landrace		Spotted	
	g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M
Carcass wt, kg	-1.07	-.04	-.18	.35	-.62	.40	1.87	-.70
Carcass length, cm	.09	-.88	.37	.69	1.08	-.35	-1.54	.54
Carcass backfat, mm	-6.55	3.19	2.48	-1.88	-.08	1.12	4.16	-2.43
Loin eye area, cm^2	5.73	-3.32	-2.86	1.77	.14	.11	-3.01	1.43
Ham, kg	1.45	-1.07	-.41	.44	-.95	.38	-.08	.25
Loin, kg	-.18	-.13	-.75	.50	1.75	-.83	-.82	.46
Shoulder, kg	.53	-.32	-.29	.33	.01	.07	-.24	-.07
Belly, kg	-1.91	1.04	1.83	-.87	.21	-.21	-.13	.04
Lean cuts as % adj live wt	2.79	-2.28	-.43	.94	-1.52	.63	-.84	.72
Lean cuts as % carcass wt	4.84	-3.18	-.49	1.04	-1.60	.61	-2.75	1.53
Marbling	1.44	-.31	-.86	.25	-.72	-.08	.14	.14
Firmness	.97	-.13	-.64	.24	-.46	-.27	.13	.16
Color	-.10	.14	-.03	.02	-.21	-.10	-.35	-.07

loin eye area and decreased ham and shoulder weights. At the other extreme, average direct effects for the Spotted were for increased backfat, decreasd loin eye area and decreased lean cuts yield--whereas maternal effects were just the opposite (table 11).

Fat as a percent of carcass weight in the pig increases dramatically from approximately 1% to 25% in the first month of life, and hyperplasia (increasing fat cell numbers by cell division) appears to be important during the first two months of life (Leat and Cox, 1980). Maternal effects on carcass traits, mediated via establishment of adipose cell number, might not seem unreasonable therefore. Pre-natal determination of muscle fiber number, and evidence that dietary restriction of pigs during the first month of life does not reduce subcutaneous fat cell number (Leat and Cox, 1980), suggests the possible importance of the prenatal environment in determining carcass characteristics of progeny. However the mechanism(s) by which dams transmitting relatively desirable genes for carcass traits (such as the Duroc) have undesirable maternal effects, and vice versa, is by no means clear and warrants further investigation.

Assuming sires and dams of each breed to be of equivalent average genetic merit, maternal effects can also be estimated from differences in reciprocal crosses (tables 12 and 13). Differences for average daily gain were not significant. Two of six contrasts were significant for off-test age, three of six for probed backfat. Reciprocal cross differences for carcass traits are given in table 13. Of 78 contrasts, only eight were significant, little more than might be expected due solely to chance.

TABLE 12. DIFFERENCES AMONG RECIPROCAL CROSS MEANS FOR POSTWEANING PERFORMANCE TRAITS

Difference[a]	Average daily gain, kg	Off-test age, d	Probed backfat, mm
DxY - YxD	-.020 ± .020	4.7 ± 4.0	-3.81 ± .90**
DxL - LxD	.019 ± .018	-1.0 ± 3.6	-2.56 ± .81**
DxS - SxD	.010 ± .018	-1.6 ± 3.6	-2.05 ± .80*
YxL - LxY	.019 ± .019	-8.4 ± 3.7*	-.46 ± .83
YxS - SxY	-.035 ± .020+	8.1 ± 3.9*	-1.32 ± .87
LxS - SxL	.015 ± .019	-.7 ± 3.8	.01 ± .85

[a] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.
First letter indicates breed of sire, second letter indicates breed of dam.

+ $P<.10$

* $P<.05$

**$P<.01$

TABLE 13. DIFFERENCES AMONG RECIPROCAL CROSS MEANS FOR CARCASS TRAITS.

Difference^{a}	Carcass wt, kg	Length, cm	Backfat, mm	Loin eye cm^{2}	Ham, kg	Loin, kg	Shoulder, kg	Belly, kg	Lean Cuts as a % of adj live wt.	Lean Cuts as a % of carcass wt.	Quality scores Marbling	Quality scores Firmness	Quality scores Color
DxY - YxD	-.03±.56	.30±.84	-1.67±1.29	1.68±.78*	.45±.19*	.38±.18*	.04±.19	-.16±.19	.53±.55	.80±.74	-.58±.32^{+}	-.15±.32^{+}	-.26±.22
DxL - LxD	.14±.55	-.84±.82	-.34±1.25	-.47±.75	-.45±.19*	-.32±.18^{+}	.09±.18	.20±.19	.52±.53	-.78±.72	.32±.31	-.33±.31	.11±.22
DxS - SxD	-.12±.57	.54±.85	2.01±1.30	-1.21±.78	-.00±.20	-.06±.19	-.14±.19	-.04±.19	-.01±.55	-.01±.74	.26±.32	.48±.32	.15±.22
YxL - LxY	.41±.57	.87±.85	-.60±1.30	-.22±.78	.08±.20	.00±.18	-.26±.19	-.03±.19	-.40±.55	-.76±.75	-.17±.32	.15±.32	-.22±.23
YxS - SxY	-.43±.56	-.57±.83	-1.08±1.27	1.90±.77*	.37±.19^{+}	.37±.18*	-.31±.18^{+}	-.19±.19	.93±.54^{+}	1.55±.73*	-.40±.32	-.33±.31	-.03±.22
LxS - SxL	.55±.56	.03±.83	-.93±1.28	-.69±.77	-.37±.19^{+}	-.32±.18^{+}	-.17±.18	.23±.19	-.92±.54^{+}	-1.54±.73*	.14±.32	-.15±.31	-.12±.22

^{a}D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted. First letter indicates breed of sire, second letter indicates breed of dam.

$^{+}$P<.10

*P<.05

**P<.01

Results of this study indicate a crossbred advantage for average daily gain and age off-test, but little or no heterosis for probed backfat thickness or carcass traits. The superiority of Duroc sired pigs for average daily gain, probed backfat, loin eye area and yield of lean cuts suggests utility of the Duroc as a sire breed. Gaugler et al. (1984) reported Landrace and Yorkshire to be superior for litter productivity traits, relative to Duroc and Spotted dams. The potential role of the Spotted breed is unclear. If more than one sire breed is required by a system it is important that each breed has desirable characteristics. Thus a breed excelling in carcass merit might seem to be a logical adjunct to the Duroc. The Spotted breed did not fit this role.

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CHAPTER IV

GROWTH PERFORMANCE FOR FOUR BREEDS OF SWINE: CROSSBRED FEMALES AND PUREBRED AND CROSSBRED BOARS

Summary

Purebred and crossbred boars mated to two breed cross females produced all possible three and four breed cross pigs involving the Duroc, Yorkshire, Landrace and Spotted breeds. A total of 213 pens were evaluated for postweaning feed to gain ratio (F/G) and average daily feed consumption (ADF). Individual average daily gain (ADG), age at 100 kg (AGE) and probed backfat thickness (BF) data were collected on 3,456 pigs. Genotype x environment interactions, specifically breed x year-season farrowed and (for ADG) breed x parity, were found to be highly significant. Certain results, however, were reasonably consistent across environments. Duroc sired pigs grew more efficiently than other breed groups. They were also leaner than other three breed cross pigs involving the same dam breeds, whereas Landrace sired pigs were fatter. No real differences between purebred and crossbred sired pigs were apparent for F/G, ADF, ADG, AGE or BF. This suggested that mating crossbred rather than purebred boars to females of different breeding should have little or no impact on feedlot performance of the offspring produced.

(Key Words: Swine, Crossbred Boars, Growth, Feed Efficiency, Genotype x Environment Interactions.)

Introduction

Interest in the use of crossbred boars for market hog production has arisen for a number of reasons. Theoretically, they are expected to be hardier and more vigorous than purebreds, and to possess greater libido and higher fertility. Consequently their use might improve breeding herd efficiency in commercial operations.

Any advantages that accrue from use of crossbred boars must, however, outweigh disadvantages inherent in the need to maintain additional pure lines in the production system. Literature reports of 6 to 20% improvements in conception rates appear to be the result of accelerated maturity in crossbred boars (Wilson et al., 1977; Conlon and Kennedy, 1978; Anderson et al., 1981; Buchanan and Johnson, 1984). No difference between purebred and crossbred boars for sow productivity, growth or carcass traits characteristics of progeny is suggested by literature reports (Rempel et al., 1964; Lishman et al., 1975; Fahmy and Holtmann, 1977; Conlon and Kennedy, 1978; Kennedy and Conlon, 1978; Anderson et al., 1981; Buchanan and Johnson, 1984).

The objective of this study was to evaluate growth performance and feed efficiency for three and four breed cross pigs involving the Duroc, Yorkshire, Landrace and Spotted breeds. In addition to estimating paternal heterosis for these traits, evalution of (numerically) relatively minor breeds in the U.S., such as the Landrace and Spotted, is needed in order to establish their potential role in an efficient pork production industry.

Materials and Methods

A project aimed at evaluating purebred and crossbred performance of Duroc, Yorkshire, Landrace and Spotted breeds of swine was carried out at the Oklahoma Agricultural Experiment Station between 1976 and 1979. As part of this project, three and four breed cross litters were produced over five consecutive farrowing seasons starting in fall of 1977 at the USDA Southwest Livestock and Forage Research Station, El Reno, Oklahoma. Postweaning performance records on 1,339 four breed cross and 2,117 three breed cross pigs were available for analysis.

Experimental Procedure. Seedstock for the three and four breed cross phase of the experiment was produced at the Oklahoma State University Experimental Swine Farm at Stillwater by mating purebred Duroc, Yorkshire, Landrace and Spotted males and females in all possible combinations to produce purebred and two breed cross offspring. Establishment and management of the purebred herds have been discussed by Hutchens et al. (1982) and Gaugler et al. (1984). Foundation boars and gilts of each breed were obtained from several different sources, and semi-annual introduction of at least one new boar of each breed was practiced in order to maintain a broad genetic base in the purebred herds.

Boars from each breed group were selected for use in the second phase of the experiment based on an index of age and probed backfat at 100 kg, and transported to El Reno to be used as herd sires each season. Crossbred gilts were sent to El Reno upon detection of estrus. Breeding stock from each breed group were used, but reciprocal crosses were combined for all analyses.

Generally three boars from each breed group were used at El Reno each season, although for some breeds in some seasons as few as two and as many as five different boars were used. Purebred boars were mated to crossbred females to produce all possible three breed cross litters, and crossbred boars were mated to crossbred females to produce four breed cross litters. The breeding season extended over an 8 wk period starting in mid May and mid November each year. The total number of litters farrowed per breed group is given in table 1. Only gilts were farrowed in the first season (fall 1977). In subsequent seasons about half the litters were from second parity sows and half from gilts. A total of 309 gilt and 178 sow litters were analyzed in this study.

Litters were farrowed in a barn equipped with crates and slatted floors. Sows and litters were moved to a nursery 3 to 7 d postfarrowing, where they remained in individual pens until weaning at approximately 6 wk of age. Creep feed was made available, and male pigs castrated, at 3 wk of age. Buchanan and Johnson (1984) have reported reproductive performance for this phase of the experiment.

Pigs were moved to one of two confinement finishing barns for gain test approximately 2 wk postweaning, and penned in groups of 12 to 20 pigs/pen by breed of sire (Duroc, Yorkshire, Landrace, Spotted or Crossbred). A 7 d adjustment period was allowed before pigs were weighed on test at approximately 9 wk of age. A 16% crude protein corn (IFN 4-02-931) or sorghum grain (IFN 4-04-383) based diet was fed ad libitum until average pig wt/pen was approximately 54 kg. A 14% crude protein diet was fed ad libitum for the duration of the test period. Pigs were weighed off test weekly at approximately 100 kg, at which time probed backfat thickness was measured. Measurements were taken at the

TABLE 1. NUMBER OF LITTERS FARROWED AND PIGS COMPLETING GAIN TEST BY BREED GROUP[a]

Breed of sire[c]	No. of sires[d]	Breed of dam[b,c]					
		D-Y	D-L	D-S	Y-L	Y-S	L-S
D	17				22(168)	26(163)	28(212)
Y	17		27(192)	23(151)			24(189)
L	15	20(146)		25(189)		23(150)	
S	14	27(189)	26(187)		23(181)		
X	15	29(213)	35(268)	34(242)	34(250)	30(174)	31(192)

[a] Number of pigs in parentheses.

[b] Reciprocal crosses combined (i.e., D-Y represents DxY and YxD).

[c] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted, X=Crossbred. For each dam breed group, crossbred boars represented F_1's involving the two breeds not included in the F_1 dam.

[d] n=15 for each crossbred sire group except for Y-L sires, where n=14.

level of the first rib, last rib and last lumbar vertebra and averaged. Average daily gain, age and backfat records were adjusted to a 100 kg basis. Total gain, total feed consumed and total days on test were obtained for each pen. During the five seasons of this phase of the experiment, 80 four breed cross pens and 133 three breed cross pens were tested.

Statistical Analyses. The following linear model, with the usual zero-sum restrictions on fixed parameters, was assumed in analyzing pen data (feed to gain ratio and average daily feed consumption):

$$y_{ijkl} = \mu + B_i + F_j + (BF)_{ij} + R_k + (FR)_{ik} + e_{ijkl}$$

where

y_{ijkl} = an observable random variable;

B_i = fixed effect of the i^{th} sire breed group, i=1, ..., 5;

F_j = fixed effect of the j^{th} farrowing season, j=1, ..., 5;

R_k = fixed effect of the k^{th} finishing barn, k=1, 2;

$(BF)_{ij}$, $(FR)_{jk}$ = interaction terms;

and e_{ijkl} = random residual effect, e's assumed NID($0,\sigma^2$).

Preliminary analyses revealed the remaining two way and all three way interactions to be non-significant (P>.20). Number of pigs/pen, included as a covariable in preliminary models, failed to approach significance (P>.50). These terms were therefore not included in the final model.

The model assumed in analysing postweaning average daily gain, age at 100 kg and probed backfat thickness at 100 kg was:

$$y_{ijkmno} = \mu + B_i + F_j + (BF)_{ij} + l_{kij} + S_m + P_n + (BP)_{in} + e_{ijkmno}$$

where

y_{ijkmno} = an observable random variable

μ = an unknown constant;

B_i = fixed effect of the i^{th} breed of pig, i=1, ..., 18;

F_j = fixed effect of the j^{th} farrowing season, j=1, ..., 5;

S_m = fixed effect of the k^{th} sex, k=1, 2;

P_n = fixed effect of the n^{th} parity, n=1, 2;

$(BF)_{ij}$, $(BP)_{in}$ = interaction effects;

l_{kij} = random effect of the k^{th} litter nested within the ij^{th} breed-farrowing season subclass;

and e_{ijkmno} = random residual effect, e's assumed $NID(0,\sigma^2)$.

The estimated ratio of the residual to litter components of variance (4.76, assuming heritability of .38 for all three traits) was included in litter equations, which were then absorbed. Where variances are known, solutions are generalized least squares estimates of fixed effects (Harvey, 1982). Additional fixed interactions, found not to be significant in preliminary analyses (P>.10), were not included in the final model. All analyses were computed using the SAS Harvey procedure (Joyner, 1983).

Paternal heterosis was estimated as the deviation of the four breed cross least-squares mean from the average of corresponding three breed cross means. Significance was tested using the t statistic.

Results and Discussion.

Pen Feed Data. Mean squares and significance of F-statistics for pen data analyses are given in table 2. Breed of sire and year-season x breed of sire were significant for feed to gain ratio, but not for average daily feed consumption.

TABLE 2. LEAST-SQUARES ANALYSES OF VARIANCE FOR PEN DATA

		Mean Squares	
Source	df	F/G[a]	ADF[b]
Breed of sire (BOS)	4	.08087**	.04447
Year-season farrowed (YRS)	4	.04814*	.69471**
Barn	1	.12246*	.01156
YRS x Barn	4	.03675+	.00979
YRS x BOS	16	.03365*	.02902
Residual	183	.01867	.03341

[a] feed to gain ratio

[b] average daily feed intake, kg/pig/d

+P<.10

*P<.05

**P<.01

Feed to gain ratio, averaged across year-seasons, was 3.11 for Duroc sired pens, 3.20 for Crossbred and Yorkshire sired pens, 3.22 for Landrace and 3.23 for Spotted sired pens. Given the significant interaction, breed of sire x year-season least-squares means are illustrated graphically in Figure 1. Duroc sired pigs were consistently more efficient than other breed groups throughout the experiment. The significant breed x year-season interaction was due to the similarity of the breeds for the fall 1977 and spring 1979 farrowings, and changes in rank of breed groups other than the Duroc sires in other year-seasons (Figure 1). Pigs farrowed in the fall of 1977 suffered badly from Atrophic Rhinitis, and those farrowed in the spring of 1979 from Mycoplasmal Pneumonia. It is conceivable that disease stress prevented expression of potential differences in feed efficiency between breed groups in these two year-seasons. Analyzing the data by year-season revealed significant differences between breeds of sire in the spring 1978 and the fall 1979 farrowed pigs, and differences approached significance in the fall 1978 pigs.

Duroc sired pens were significantly more efficient than both Landrace and Spotted sired pens in the spring 1978 farrowed group, and more efficient than Landrace sired pens in the fall 1979 farrowed group. A different set of boars was used each breeding season. Thus the significant year-season x breed of sire interaction may reflect the fact that sires selected were more important than the breed the sires were from--with the exception of the consistent advantage for Duroc sired pigs.

Comparing average feed efficiency for purebred sired pens to that for crossbred sired pens revealed no significant difference in any

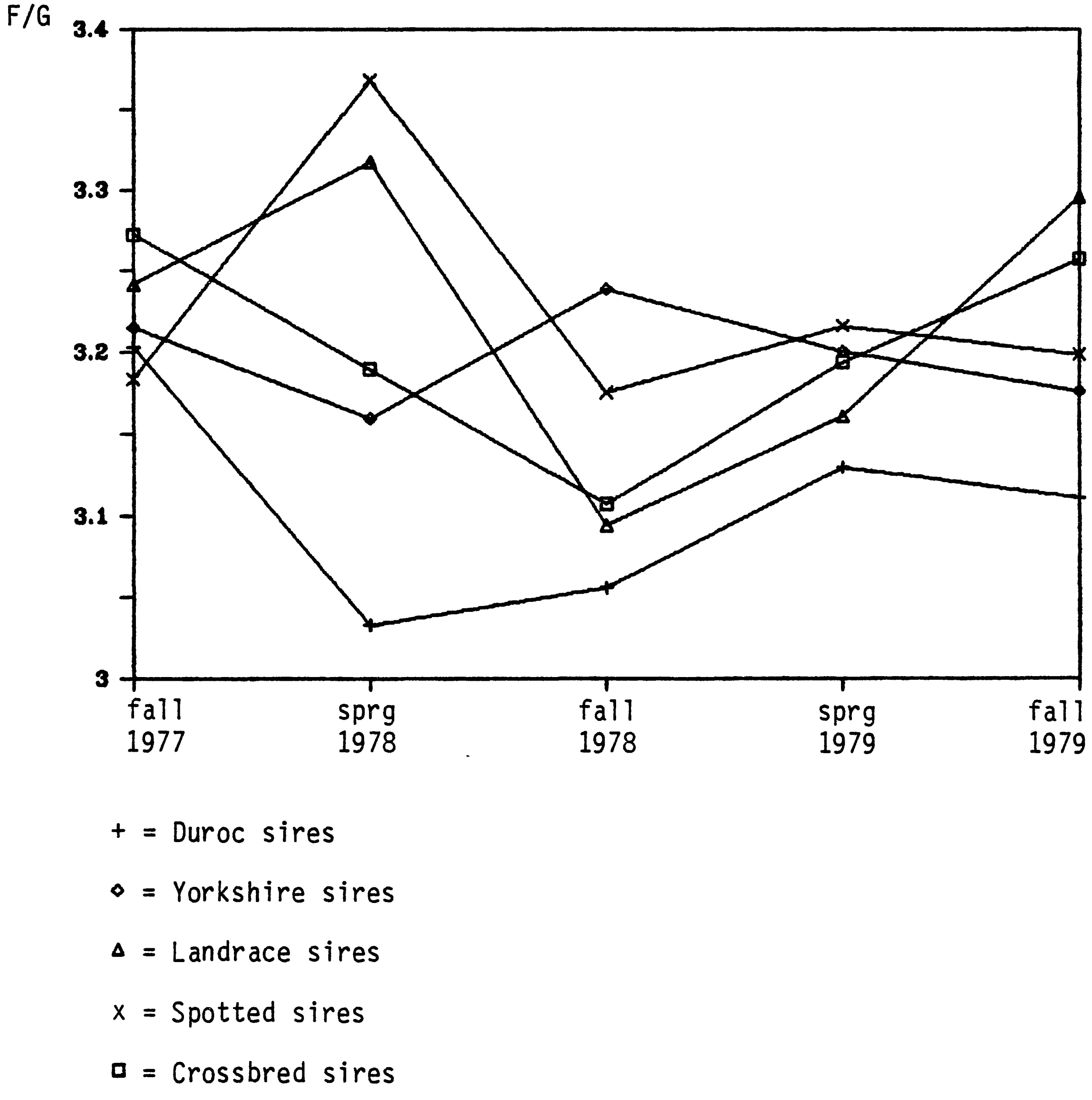

Figure 1. Feed to Gain Ratio (F/G) for Purebred and Crossbred Sired Pens by Year-Season Farrowed.

individual year-season or overall. Average paternal heterosis was .015 ± .020 for feed to gain ratio and -.005 ± .027 for average daily feed intake. Mating two breed cross rather than purebred males to females of different breeding would therefore be expected to have little or no impact on subsequent feed efficiency of offspring produced.

Theoretically, differences in progeny performance from using crossbred vs purebred boars is only expected assuming an epistatic heterosis model and significant recombination effects. Under such a model the coefficient for recombination effects for three breed crosses is one-quarter, vs a coefficient of one-half for four breed crosses (Dickerson, 1973).

Breed of sire was not significant for average daily feed consumption (table 2). Differences in feed efficiency were therefore not associated with differences in average daily feed consumption.

Genotype x Environment Interactions. Mean squares and significance of F-statistics for postweaning average daily gain, age and probed backfat thickness at 100 kg are given in table 3. Breed of pig, year-season farrowed and sex were highly significant for all three traits. Parity was highly significant for growth rate and age at 100 kg, but not for probed backfat. The breed x parity interaction was highly significant for average daily gain, approached significance for age at 100 kg, but was not significant for probed backfat. The breed x year-season farrowed interaction, however, was highly significant for all three traits. Significant breed x year and (or) season interactions have been reported for growth rate (Bruner and Swiger, 1968; Quijandria et al., 1970 and Miller et al., 1979) and for both growth rate and probed backfat thickness by Johnson et al. (1973). Genotype x year and

TABLE 3. GENERALIZED LEAST SQUARES ANALYSIS OF VARIANCE FOR GAIN TEST DATA

		Mean Squares		
Source	df	ADG[a]	AGE[b]	BF[c]
Breed (BR)	17	.01567**	451.1**	58.49**
Year-season farrowed (YRS)	4	.19218**	9572.3**	598.95**
Sex	1	4.36946**	74314.3**	8672.72**
Parity (PAR)	1	.19755**	8153.3**	11.40
BR x PAR	17	.01233**	255.9+	5.66
BR x YRS	68	.01564**	349.9**	13.25**
Residual	3347	.00717	188.2	8.75

[a] Postweaning average daily gain, kg/d.

[b] Age at 100 kg, d.

[c] Probed backfat thickness at 100 kg, mm.

+P<.10

*P<.05

**P<.01

(or) season interactions, however were unimportant for growth performance traits in a number of other studies (Kuhlers et al., 1972, 1977; Johnson et al., 1978; Christian et al., 1980 and Hutchens et al., 1982).

To illustrate some consequences of the breed x year-season interaction in these data, consider the following examples for probed backfat thickness:

1. The leanest Yorkshire sired pigs overall (Yorkshire x Duroc-Spotted) were the fattest Yorkshire sired pigs farrowed in the spring of 1978.
2. While Duroc x Yorkshire-Spotted pigs were, overall, slightly leaner than the Duroc-Landrace x Yorkshire-Spotted pigs, they were fatter in three year-seasons.
3. Landrace x Duroc-Spotted pigs were significantly leaner than Yorkshire-Landrace x Duroc-Spotted pigs in the fall of 1979, although the reverse was true in other year-seasons.
4. There was very little difference in Duroc-Landrace dam means for the sire groups overall (table 4). Significant differences did exist in different year-seasons, but due to rank changes those differences were not seen when means were averaged across year-seasons.

Many factors undoubtedly contributed to year-season effects, but fluctuating disease status and seasonal temperature differences were probably both important. Conceptually, it seems reasonable to regard year-season effects as random. Comparing breed group performance in individual year-seasons decreases precision, and would restrict inference to populations under the same environmental conditions,

TABLE 4. BREED GROUP PROBED BACKFAT THICKNESS GENERALIZED LEAST-SQUARES MEANS[a]

Breed of	Breed of dam[b,c]					
sire[c]	D-Y	D-L	D-S	Y-L	Y-S	L-S
D				25.13	24.95	25.65
Y		27.40	25.97			26.73
L	28.11		28.10		27.39	
S	27.20	27.63		26.92		
X	27.77	27.13	27.34	27.61	25.39	27.22

[a] Standard error, range ±.33 to .50 mm.

[b] Reciprocal crosses combined (i.e., D-Y represents DxY and YxD).

[c] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted, X=Crossbred. For each dam breed group, crossbred boars represented F_1's involving the two breeds not included in the F_1 dam.

conditions which cannot be adequately characterized. The objective of the study was to compare breed performance, necessitating averaging over such effects. In making breed comparisons we assume not only adequate sampling of the breeds, but also that year-seasons were representative of environments to which the population of inference is exposed. These data do serve as a caution, however, that the importance of genotype x 'physical' environment interactions in swine should not be overlooked.

Despite many changes in ranking of breeds in different year-seasons, certain consistant results were observed. Rank for the three sire breed groups mated to Yorkshire-Landrace dams was consistent from one year-season to the next and, for all practical purposes, consistent for sire breeds mated to Landrace-Spotted dams. Duroc-Landrace x Yorkshire-Spotted pigs were the leanest four breed cross pigs in all but the first year-season. Comparisons between purebred breeds of sire mated to the same breed of dam revealed that Landrace sired pigs were fatter than the alternative purebred sired pigs for each breed of dam each year-season (i.e., Landrace x Duroc-Yorkshire pigs were fatter than Spotted x Duroc-Yorkshire pigs each year-season; Landrace x Duroc-Spotted pigs were fatter than Yorkshire x Duroc-Spotted pigs each year-season; etc.). Similarly, Duroc sired pigs were leaner than the alternative sired pigs for each breed of dam each year-season.

Probed Backfat. Breed group means for probed backfat thickness are presented in table 4. Averaged over year-seasons, comparison of three breed cross probed backfat means indicated no breed of sire x breed of dam interaction. In pairwise comparisons between sire pure breeds by breed of dam, sire breeds ranked Duroc, Yorkshire, Spotted and Landrace from leanest to fattest.

A comparison of average probed backfat of all purebred sired pigs vs crossbred sired pigs yielded no significant differences either overall, or in any individual year-season's data. Paternal heterosis estimates are given in table 5. Contradictory signs on significant differences resulted in a small overall estimate, probably not different from zero.

Paternal heterosis was significantly different from zero in 6 of 30 breed of dam x year-season subclasses, apparently at random (once in each year-season, involving all but one dam breed group and with four positive and two negative differences). It seems likely, therefore, that observed differences were due to chance.

Age at 100 kg. In addition to breed, sex, year-season and the breed x year-season interaction, parity was also highly significant for age at 100 kg, and the breed x parity interaction approached significance (table 3). Barrows averaged 10 d younger at 100 kg than gilts. Pigs from second parity sows averaged 6 d younger at 100 kg then those farrowed in gilt litters.

Breed group least-squares means, averaged across year-seasons, are presented in table 6. As with probed backfat thickness, three breed cross means suggest no breed of sire x breed of dam interaction. Pairwise comparisons of purebred sires within breed of dam ranked sire breeds Yorkshire, Landrace, Duroc, Spotted from youngest to oldest at 100 kg.

Paternal heterosis estimates are given in table 5. Two estimates approached significance--one suggested positive heterosis, the other negative heterosis. The Duroc-Landrace breed of dam estimate reflected a large difference among gilts in only one year-season. The Yorkshire - Spotted estimate reflected significant differences for gilt and sow

TABLE 5. PATERNAL HETEROSIS ESTIMATES[a]

Breed of Sire[a]	Paternal Heterosis (h^p)		
	ADG[b]	AGE[c]	BF[d]
Landrace-Spotted	.015 ± .014	-1.81 ± 2.30	.11 ± .50
Yorkshire-Spotted	.020 ± .012	-3.72 ± 1.95[+]	.39 ± .42
Yorkshire-Landrace	.016 ± .013	-2.11 ± 2.06	-.89 ± .44[*]
Duroc-Spotted	-.001 ± .013	.35 ± 2.06	1.58 ± .44[**]
Duroc-Landrace	-.021 ± .014	3.94 ± 2.22[+]	-.78 ± .48[+]
Duroc-Yorkshire	-.004 + .013	-.12 ± 2.06	1.03 ± .44[*]
Overall	.000 ± .005	-.10 ± .86	.31 ± .19[+]

[a] Reciprocal crosses combined.

[b] Postweaning average daily gain, kg/d.

[c] Age at 100 kg, d.

[d] Probed backfat thickness at 100 kg, mm.

[+] P<.10

[*] P<.05

[**] P<.01

TABLE 6. BREED GROUP AGE AT 100 KG GENERALIZED LEAST-SQUARES MEANS[a]

Breed of sire[b,c]	Breed of dam[b,c]					
	D-Y	D-L	D-S	Y-L	Y-S	L-S
D				180.3	184.4	184.7
Y		183.3	179.6			181.3
L	178.6		181.4		183.1	
S	190.0	186.7		184.5		
X	182.5	181.3	181.3	182.7	187.7	182.9

[a] Standard error, range ± 1.5 to 2.3 d.

[b] Reciprocal crosses combined (i.e. D-Y represents DxY and YxD).

[c] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted, X=Crossbred. For each dam breed group, crossbred boars represented F_1's involving the two breeds not included in the F_1 dam.

litters in different year-seasons. However, this estimate was negative, in contrast to other specific estimates, and overall paternal heterosis was not significant.

Average Daily Gain. Breed, year-season, sex and parity were all highly significant for postweaning average daily gain, as were the breed x year-season and breed x parity interactions (table 3). Barrows grew significantly (.075 kg/d) faster than gilts. Pigs born to second parity sows gained significantly (.031 kg/d) faster than these farrowed in gilt litters. Breeds, however, ranked differently for average daily gain not only in different year-seasons, but also across parities.

Additional analyses were therefore conducted by parity. Breed, year-season, sex and the breed x year-season interaction were highly significant for both parities. Yorkshire x Landrace-Spotted and Yorkshire-Spotted x Duroc-Landrace were the only breed groups for which pigs farrowed in gilt litters had faster postweaning rate of gain than those farrowed by second parity sows. The reverse was true for all other breed groups. Change in rank of the Landrace x Duroc-Yorkshire was particularly noticeable between parities (from 15th in parity one to 1st in parity two). If sire breed ranks within breed of dam were considered, rank changes across parities were evident for all but the Yorkshire-Spotted dams. Considering only purebred sire breeds, however, the only rank change occurred between Duroc and Yorkshire sired pigs with Landrace-Spotted dams. As well as rank changes, differences between breed groups were in many cases of very different magnitudes for the two parities. For example, Landrace and Spotted sired pigs by Duroc-Yorkshire gilts had very similar growth rates--but by second parity sows these breed groups represented the extremes of the range in breed average daily gain least-squares means. The breed x parity interaction was also apparent if dam breed rankings within purebred sire breed groups were compared. Dam breeds mated to Duroc and Spotted sires ranked the same in both parities, but this was not the case for Yorkshire or Landrace sires.

Despite significant interactions, breed group means averaged across year-seasons and parities are presented in table 7. Pairwise comparisons among three breed cross means by breed of dam ranked sire breeds Yorkshire, Duroc, Landrace and Spotted from fastest to slowest postweaning gain. The same result was obtained for pigs farrowed in gilt litters. However, a breed of sire x breed of dam interaction was evident in parity two means, Duroc sires ranking inconsistently. These results for Spotted sires are at variance with those obtained from the purebred and F_1 phase of this experiment, in which Spotted sired pigs gained almost as well as the fastest gaining sire breed group, the Duroc (McLaren et al., 1985). Postweaning average daily gain of crossbred sired pigs from second parity litters was not found to be significantly different from that of purebred sired second parity litter pigs in any year-season's data, or overall. For pigs farrowed in gilt litters, significant differences in growth rate were found in two year-seasons. Crossbred sired pigs farrowed in the spring of 1978 grew significantly faster than purebred sired pigs. However the reverse was true in the fall of 1979 pigs, the three breed cross pigs gaining significantly faster than the four breed cross pigs. Overall, no significant difference was detected between growth rate of purebred and crossbred sired pigs. Estimates of paternal heterosis are given in table 5.

TABLE 7. BREED GROUP POSTWEANING AVERAGE DAILY GAIN GENERALIZED LEAST-SQUARES MEANS[a]

Breed of sire[b,c]	Breed of dam[b,c]					
	D-Y	D-L	D-S	Y-L	Y-S	L-S
D				.723	.698	.689
Y		.703	.719			.708
L	.716		.703		.681	
S	.665	.677		.690		
X	.707	.710	.704	.706	.668	.694

[a] Standard error, range ± .009 to .014 kg/d.

[b] Reciprocal crosses combined (i.e. D-Y represents DxY and YxD).

[c] D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted, X=Crossbred. For each dam breed group, crossbred boars represented F_1's involving the two breeds not included in the F_1 dam.

These results indicated zero paternal heterosis for feed efficiency, growth rate and probed backfat, in agreement with the concensus of published studies. Rempel et al. (1964) reported pigs sired by crossbred boars to be significantly fatter and slower gaining than those sired by purebred boars. However the purebred boars used were selected for decreased backfat and increased average daily gain, whereas crossbred boars were chosen at random. Lishman et al. (1975) reported no significant difference between average daily gain and feed to gain ratio for pigs sired by Large White vs Large White x Landrace boars. Fahmy and Holtmann (1977), compared Landrace x Yorkshire, Duroc x Yorkshire and Duroc x Lacombe boars to boars of the four pure breeds and found negligible differences for growth rate of progeny. Kennedy and Conlon (1978) found progeny of Hampshire x Duroc boars performed similarly to those sired by purebred Hampshire and Duroc boars.

The misconception that use of crossbred boars is expected to increase variability among progeny relative to use of purebred sires has existed in the past (Fahmy and Holtmann, 1977). While the residual mean square from analysis of four breed cross data in this study was greater than that for the entire (three and four breed cross) dataset for average daily gain (.0074 vs .0056 kg^2/d^2), the reverse was true for age and probed backfat @ 100 kg. For these traits the four breed cross residual mean squares were $189 d^2$ and $9.8\ mm^2$, respectively, vs $216\ d^2$ and $10.8\ mm^2$ for the entire data set. A number of workers have also reported little difference in variability of three vs four breed cross pigs (Rempel et al., 1964; Lishman et al., 1975; Fahmy and Holtmann, 1977).

Buchanan and Johnson (1984) found no significant differences among boar breed groups for litter size, weight or survivability, but did report an 18% increase in first service conception rate for crossbred vs purebred boars. Over the 8 wk breeding season, however, this advantage was only 5%, due probably to purebreds maturing as the season progressed. Crossbred boars have not been shown to adversely affect progeny performance. 'Hybrid' boars might therefore be advantageous to a system using young boars. This advantage must, however, at least offset the costs of maintaining an additional pure breed in the production system if it is to improve overall efficiency. A subsequent paper will pool results from the Oklahoma four breed swine crossing experiment and compare economic efficiency of alternative crossbreeding systems involving the Duroc, Yorkshire, Landrace and Spotted breeds using a computer simulation model.

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CHAPTER V

ECONOMIC EVALUATION OF ALTERNATIVE CROSSBREEDING SYSTEMS INVOLVING FOUR BREEDS OF SWINE

Summary

Static, deterministic computer models, developed on the IBM PC, were used to calculate production efficiency (costs/kg product) for four purebred and 69 alternative crossbreeding systems involving the Duroc, Yorkshire, Landrace and Spotted breeds of swine. Crossbreeding systems were defined as including all purebred, crossbred and commercial matings necessary to maintain a total of 10,000 farrowings. Driving variables for the models were predicted mean conception rate, litter size born, percent survival to 42-d, postweaning average daily gain, feed to gain ratio and carcass backfat. Predictions were computed using genetic parameter estimates obtained from crossbreeding experimental data involving the four breeds collected at the Oklahoma Agricultural Experiment Station. Breeding systems involving the Spotted breed were predicted to be at a decided disadvantage relative to the Duroc, Landrace and Yorkshire breeds. The most efficient breed combinations for each of the nine types of crossbreeding system evaluated were predicted to reduce costs/kg of product by 14.7 to 17.5%, relative to the most efficient purebred (Duroc). The Landrace x (Duroc x Yorkshire) three breed static was predicted to be the most efficient system, followed by the Duroc x (Yorkshire x Landrace). The Duroc, Landrace two breed rotation, and the Duroc, Landrace, Yorkshire three breed rotation ranked third and fourth overall, respectively. Backcross, three breed combination and four breed static systems also ranked in the 10 most efficient systems. Results of this study suggested that a two or three breed rotation system utilizing efficient breeds should prove almost as effective as a three breed static system.

(Key Words: Swine Crossbreeding, Mating Systems, Economic Efficiency,
Computer Simulation.)

Introduction

Efficient pork production dictates that market hogs be produced by some form of crossbreeding system. Due to the impracticality of experimentally evaluating all possible systems, breed effects and heterosis estimates must be used to predict expected performance for crossbreeding systems not evaluated in the field. The number of available breeds, and the variety of alternative, crossbreeding systems, makes comparisons among systems a task well suited to the computer. In addition, the number of economically important traits requiring simultaneous evaluation, and the need to not only consider performance in the market hog producing sector, but to also make allowance for purebred and other breeding stock generators required by the system, increases the complexity of obtaining meaningful comparisons among alternative systems.

The objectives of this study were to develop simulation models to calculate economic efficiency for alternative pure- and crossbreeding systems based upon user-input genetic, economic and management parameters. Models were used to compare predicted efficiencies of 73 alternative mating systems involving the Duroc, Yorkshire, Landrace and Spotted breeds. Genetic parameters for conception rate, litter size born, percent survival to 42-d, postweaning average daily gain, feed to gain ratio and carcass backfat were estimated from experimental data and used to predict performance for the different systems. Each system was defined as including all purebred and crossbred sub-systems required to maintain 10,000 total females farrowing in the system.

Materials and Methods

The Data. Heterosis and breed effects were required input data for the simulation models. Reproductive, growth and carcass data for Duroc, Yorkshire, Landrace and Spotted purebreds and crosses were collected between 1976 and 1979 at the Oklahoma Agricultural Experiment Station. Genetic parameter estimates used in the models (table 1) were obtained by weighted (by number of observations) least-squares analyses of breed group means reported for this experiment (Buchanan and Johnson, 1984; Gaugler et al., 1984; McLaren et al., 1985 a,b). Models were parameterized based upon Dickerson's (1969, 1973) crossbreeding effects models. The full model assumed was:

$$\bar{\underset{\sim}{y}} = X\underset{\sim}{\beta} + \underset{\sim}{e} \qquad (1)$$

where

$\bar{\underset{\sim}{y}}$ = a vector of breed group means, ~ $N(X\underset{\sim}{\beta},\sigma^2 D)$;

D = a diagonal matrix, elements are reciprocals of the no. observations on corresponding elements of $\bar{\underset{\sim}{y}}$;

X = a known design matrix;

$\underset{\sim}{\beta}$ = vector of direct genetic (g^I_i), maternal (g^M_i) and individual, maternal and paternal heterosis (h^I_{ij}, h^M_{ij}, h^P_{ij}) parameters, i.e.,

$$\underset{\sim}{\beta}' = (g^I_D \; g^I_Y \; g^I_L \; g^M_D \; g^M_Y \; g^M_L \; h^I_{DY} \cdots h^I_{LS} \; h^M_{DY} \cdots h^M_{LS} \; h^P_{DY} \cdots h^P_{LS}),$$

TABLE 1. GENETIC PARAMETER ESTIMATES

	Trait[a]					
Parameter[b]	CR	LSB	SURV	ADG	F/G	BF
MU	69.76	10.58	70.81	.6504	3.212	32.43
GID	-10.01	.35	-.88	.0148	-.210	-6.55
GIY	1.34	.78	-4.48	-.0111	-.027	2.48
GIL	8.62	.07	5.05	-.0215	.020	-.08
GIS	.05	-1.20	-.31	.0178	.217	4.16
GMD	above estimates		-2.13	-.0026	0	3.19
GMY	represent		-2.12	-.0010	0	-1.88
GML	GI + GM		1.12	.0062	0	1.12
GMS			3.13	-.0026	0	-2.43
HIDY		.23	4.31	.0796	.009	1.96
HIDL		.23	5.73	.0736	.009	.90
HIDS		.23	7.86	.0712	.009	.79
HIYL		.23	9.88	.0545	.009	.98
HIYS		.23	6.41	.0622	.009	-1.28
HILS		.23	-.18	.0705	.009	-.70
HMDY	2.8	.93	0	0	0	0
HMDL	2.8	.93	0	0	0	0
HMDS	2.8	.93	0	0	0	0
HMYL	2.8	.93	0	0	0	0
HMYS	2.8	.93	0	0	0	0
HMLS	2.8	.93	0	0	0	0
HPDY	7.31[c]	.09	1.92	.015	-.008	.11
HPDL	9.39[c]	-.09	-.41	.020	-.008	.39
HPDS	4.25[c]	.71	-3.58	.016	-.008	-.89
HPYL	4.23[c]	-.05	-1.71	-.001	-.008	1.58
HPYS	3.70[c]	.61	-8.72	-.021	-.008	-.78
HPLS	9.33[c]	.23	-1.60	-.004	-.008	1.03

[a] CR=conception rate (%); LSB=litter size born; SURV=% survival to 42-d; ADG=postweaning average daily gain (kg/d); F/G=feed to gain ratio; BF=average carcass backfat thickness (probed backfat for HP).

[b] MU=a constant; GI=direct genetic effects; GM=breed maternal effects. H=heterosis: I=individual, M=maternal, P=paternal. D, Y, L, S suffixes represent the Duroc, Yorkshire, Landrace and Spotted breeds.

[c] Figures are one-half paternal heterosis for first service conception rate.

subject to the restrictions $\Sigma g^I_i = \Sigma g^M_i = 0$

and $\underset{\sim}{e}$ = vector of residual effects, $\sim N(\underset{\sim}{0}, \sigma^2 D)$

Appropriate reduced models were used to analyse the purebred, F_1, three and four breed cross means reported. Solutions were obtained as:

$$\underset{\sim}{\hat{\beta}} = (X'D^{-1}X)^{-1}X'D^{-1}\underset{\sim}{y} \qquad (2)$$

Direct and maternal effects were confounded for conception rate and litter size born, and were therefore estimated jointly. Paternal heterosis for conception rate (table 1) represents one-half the estimate obtained for first service conception rate. This assumed boars were used for two distinct breeding seasons, and that the crossbred advantage was present only during the first breeding season. Note also that backfat parameters were for carcass measurements, except for paternal heterosis where estimates for probed backfat thickness were used.

Maternal heterosis estimates (table 1) were taken from Johnson (1981), except for the zero assumed for percent survival to 42-d, for which no literature estimates were available. Maternal breed effects for feed to gain ratio were also assumed to be zero due to the lack of experimental estimates for the breeds involved in this study.

The Crossbreeding Model. The swine production system modeled included purebred, crossbred and commercial matings necessary to maintain a total of 10,000 farrowings. For example, a three breed static cross (C x (A x B)) system consisted of C, A and B purebreds, plus hybrid A x B gilt and terminal C x (A x B) market hog producing sub-systems, with a total of 10,000 A, B, C and A x B females farrowing.

Static, deterministic computer models, written in Basic, were developed on the IBM PC. The models predicted performance, structure and economic efficiency for 10 alternative types of mating system involving the Duroc, Yorkshire, Landrace and Spotted breeds. One program modeled purebreds, two, three and four breed rotations and combination systems (a terminal sire breed mated to two or three breed rotation females). All rotational systems were assumed to be at equilibrium. A second program modeled purebreds, backcrosses and two, three and four breed static cross sytems. Program listings are given in Appendixes A and B. Copies of the programs (on diskette) may be obtained from the author. A diagramatic overview of calculations performed by the programs is given in Figure 1.

Driving variables for the models were predicted mean conception rate, litter size born, percent survival to 42-d, postweaning average daily gain, feed to gain ratio and carcass backfat. Predictions for alternative sub-systems were computed from parameter estimates which served as input to the programs. Base parameters were as given in table 1, except for paternal heterosis which was assumed to be 6.22 for conception rate for all crosses and zero for all other traits. Where systems involved F_1 females, reciprocal crosses were compared based upon litter size born/female exposed (conception rate * litter size born). Only the most prolific cross in each of six reciprocal pairs was used as the hybrid female, restricting the total number of systems considered.

It might be argued that, as approach to equilibrium varies for different systems, a dynamic model (i.e., simulating performance over time starting from a purebred foundation) would be more appropriate than the static, equilibrium models developed in this study. While true for the producer concerned with short-term relative efficiency of systems, where the objective is long-term efficiency of pork production comparisons at system equilibrium would seem to be more appropriate.

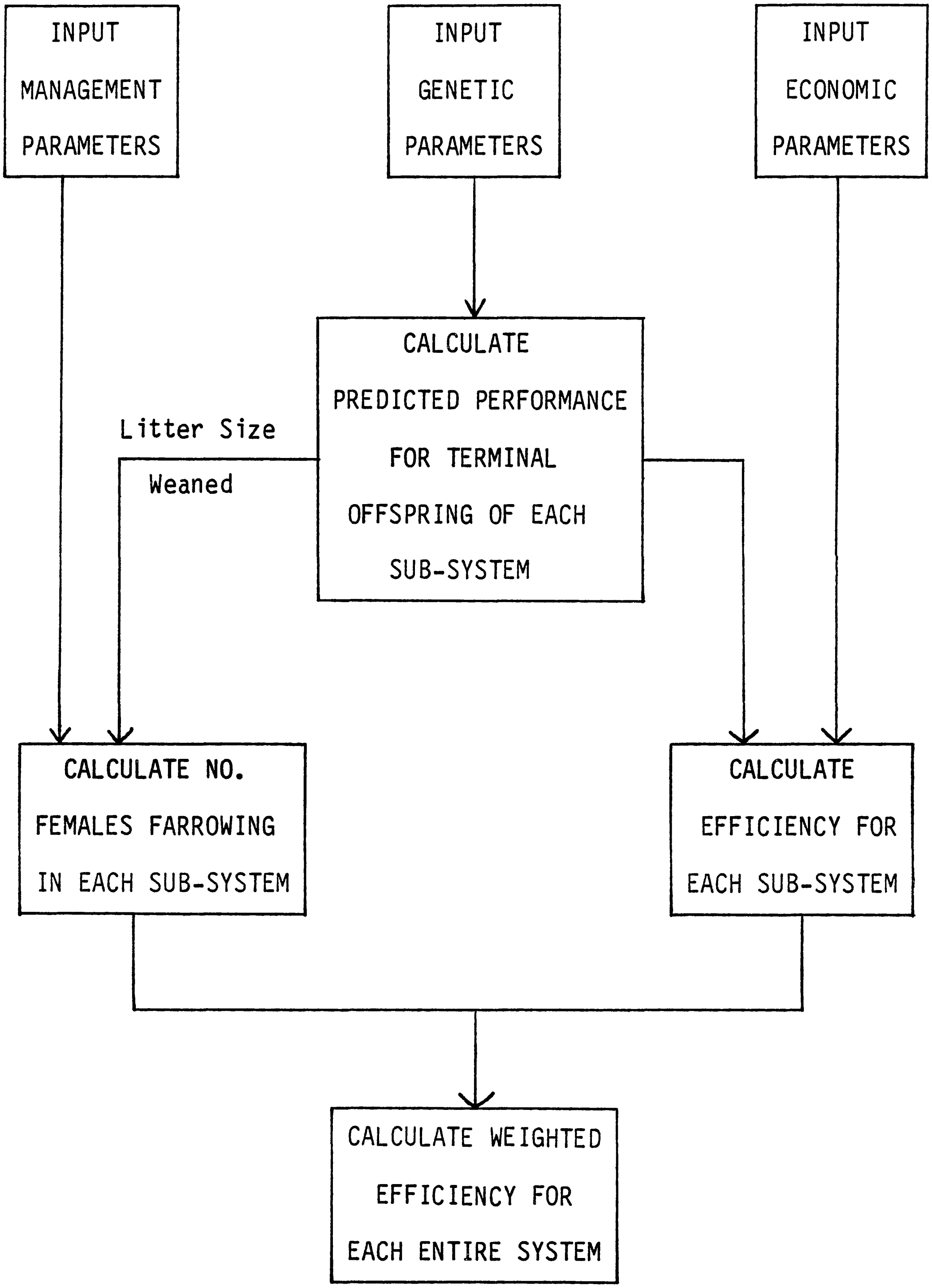

Figure 1. Diagramatic Overview of Calculations Performed by the Crossbreeding Simulation Models.

Breed Cross Performance Simulation. The model used to predict conception rate, litter size born, percent survival to 42-d, postweaning average daily gain, feed to gain ratio and carcass backfat thickness was:

$$\bar{y}_{ij} = \mu + .5\left(\sum_{i=1}^{s} k_i g^I{}_i + \sum_{j=1}^{d} k_j g^I{}_j\right) + \sum_{j=1}^{d} k_j g^M{}_j + r_x \sum_{i \neq j}^{sd} k_{ij} h^I{}_{ij} + r_z \sum_{j \neq j'}^{d} k_{jj'} h^M{}_{jj'} + \sum_{i \neq i'}^{s} k_{ii'} h^P{}_{ii'} \tag{3}$$

where

$\bar{y}_{ij}$ = predicted mean of the cross for a given trait;

μ = an overall constant;

i = sire breed index, i=1, ..., s.

j = dam breed index, j=1, ..., d;

$k_{i,j}$ = proportion of genes from the i^{th} and (or) j^{th} breed;

g^I = direct breed effects;

g^M = maternal breed effects;

$h^{I,M,P}$ = individual, maternal and paternal heterosis;

r_x = 1 for all but strict rotation systems, where r_x = 2/3, 6/7 and 14/15 for 2, 3 and 4 breed rotations, respectively

and r_z = r_x for all but combination systems, where r_z = 2/3 and 6/7 for the 3 and 4 breed combinations, respectively.

For rotational systems, breeds were entered as both sire and dam breeds in the above equation. For conception rate and litter size born, $g^I{}_i$ and $g^I{}_j$ were considered effects of the sire and dam of the female. Thus only the four breed static cross acknowledges breed of sire effects (crossbred vs purebred boars) on conception rate.

System Structure. Calculating the number of females farrowing in each sub-system required the following user-input information:

T = total number of females farrowing in the system;

MR = proportion of males replaced each breeding cycle;

FR = proportion of females replaced each breeding cycle;

MS = proportion of male offspring in herds generating replacement males that are used as breeding stock;

FS = proportion of female offspring in herds generating replacement females that are used as breeding stock;

SB = number of females/boar in the breeding herd;

PS = prob. surviving from weaning to marketing at 100 kg, and

LSW_i = predicted litter size weaned for the i^{th} breed group.

Simulations assumed the following values: T = 10,000; MR = FR = .5; MS = .6; FS = .8; SB = 10 and PS = .97 (purebreds), .98 (crossbreds). Different purebred and crossbred values for MR and FR can also be input to the model. These values were used to calculate the number of females required to produce boars of the i^{th} breed, as a proportion of the total number of females farrowing in the sub-system(s) that these boars were used in (FM_i); and the equivalent statistic for females needed to produce gilts, again as a proportion of all farrowings involving such females (FF_i). Formulas were:

$$FM_i = 2 * MR/(SB * MS * PS * LSW_i) \tag{4}$$

$$FF_i = 2 * FR/(FS * PS * LSW_i) \tag{5}$$

Values of FM averaged .023 for purebreds and .021 for crossbred males, i.e., a little over 2% of females were required to produce replacement boars. Replacement gilts were either purebred, two breed crosses or the product of two or three breed rotation systems. Average values of FF were .174, .159, .156 and .151, respectively.

Derivation of system structure equations can be illustrated using the two breed rotation as an example. Let the two breeds be called A and B. Critical needs for the system, then, are purebred A and B males, the rotation generating its own females replacements. Let A equal the number of purebred A females farrowing, B equal the number of purebred B females farrowing and AB equal the number of rotation females, half mated to breed A and half to breed B boars. Then:

$$A + B + AB = T \tag{6}$$

By definition: $A = FM_A * (A + AB/2)$, giving

$$2A*(1-FM_A) = FM_A*AB, \text{ thus}$$

$$A = (FM_A*AB)/(2-2FM_A). \tag{7}$$

Similarly: $B = FM_B\ (B + AB/2)$, giving

$$B = (FM_B*AB)/(2-2FM_B) \tag{8}$$

Substituting (7) and (8) into (6) above, collecting terms in AB and simplifying gives:

$$AB = T/[(FM_A/(2-2FM_A)) + (FM_B/(2-2FM_B)) + 1] \tag{9}$$

All elements in the right hand side of equation (9) are known, therefore AB is calculated and substituted into equations (7) and (8) to yield A and B. The same logic was followed in developing equations for all crossbreeding system. Complete formulae for all systems are given in Appendix C.

Calculating Efficiency. Efficiency of terminal production for each sub-system was measured as cost/unit product (Dickerson, 1970, 1976, 1978; Harris, 1970; Newman, 1985). Efficiency (E) was computed from predicted performance values for sub-systems, and from assumed economic parameter values, as:

$$\begin{aligned} E_i &= (\text{Lifetime Costs/Dam})/(\text{Lifetime Product/Dam}) \\ &= (CB_i + (\text{no. litters}) * CG_i)/(PB_i + (\text{no. litters}) * PG_i) \\ &= (CB_i + (1/FR) * CG_i)/(PB_i + (1/FR) * PG_i) \end{aligned} \tag{10}$$

where i = breeding system index, i=1, ..., 10;

CB = reproduction costs, \$/dam-lifetime;

CG = costs of postweaning growth, \$/litter;

PB = salvage breeding stock product, kg/dam-lifetime and

PG = postweaning growth product, kg/litter.

Additional parameters involved in efficiency equations were:

BCI_i = average breeding to rebreeding interval for the i^{th} female breed group,

$$= 160 + 21*(1-CR_i), \text{ d} \tag{11}$$

and the following constants:

FIB = breeding herd (including boars, replacements and baby pigs to 18 kg) feed intake, kg/sow/day;

GP = gilt costs from 100 kg until first breeding, \$;

FCB = cost of breeding herd ration, \$/kg;

FCG = cost of growing-finishing ration, \$/kg;

LOCR = labor and overhead costs of reproduction, \$/sow farrowed/d and

LOCG = growing-finishing labor and overhead costs from 18-100 kg, \$/market pig/d.

Breeding to rebreeding interval assumed 113 d from conception to farrowing, 42 d lactation and 5 d from weaning to first estrus (160 d total), plus $(1-CR_i)$ of females who conceived 21 d later at second estrus. The following constant values were assumed in the base model: FIB = 3.728 kg; GP = \$30; FCB = \$ .129; FCG = \$ .126; LOCR = \$ .867 and LOCG = \$ .136. These values were based upon data from "Estimated Returns from Farrowing and Finishing Hogs in Iowa", averaged over the 10 yr 1974 - 1983 (Futrell, 1974, 1980, 1983). Breeding herd feed intake (FIB) accounted for replacements needed by a system farrowing sows only twice. Hence FR was set at .5 in the base program. Varying FR would require consideration of changes in FIB. Gilt costs (GP) were computed as 110% of costs/finishing pig/d over the 60 d interval from finishing (100 kg) to entering the breeding herd at 118 kg. Feed costs and labor and overhead costs were based on averages of monthly figures presented by Futrell (1974, 1980, 1983).

Components of efficiency (costs/unit product) have been identified as costs and products of reproduction and growth (equation (10)). These components are now defined in turn:

Growth phase product

$$PG_i = \text{Relative Value} * \text{P(Survive)} * \text{Litter Size Weaned} * \text{Slaughter wt}$$

$$= RV * PS * LSW_i * 100, \quad \text{kg/dam/litter} \qquad (12)$$

The above equation was used except for purebred herds and herds producing crossbred boars, where it was assumed that 10% of males were castrated, and that boar meat was worth 70% of equivalent (100 kg) market hog meat. Therefore, in those herds:

$$PG_i = RV * .865 * PS * LSW_i * 100, \quad \text{kg/dam/litter} \qquad (13)$$

Relative value was determined according to NPPC "pork value" guidelines (NPPC, 1984) for 211-230 lb market hogs, based upon carcass backfat at the last rib. The simulations, however, predicted average backfat thickness. Average backfat was assumed to equal last rib backfat plus 7.6 mm. The regression of relative values recommended by NPPC (1984) on average carcass backfat was:

$$RV = 114 - .3937 * (\text{av. backfat, mm}) \qquad (14)$$

Thus predicted backfat of 35.56 mm had a relative value of 100. Plus or minus 5 mm corresponded to approximately minus or plus two points on the value index.

Salvage Breeding Stock Product.

$$\begin{aligned}
PB_i &= \text{Relative Value} * \text{Cull Female Wt} \\
&\quad + \text{Relative Value} * \text{Cull Boar Share} \qquad \text{, kg/dam-lifetime.} \\
&= RV_S *(\text{cull sow wt}) + [\text{no. open females/sow}] * \\
&\quad [\text{prop. gilts} * RV_G * \text{cull wt} + \text{prop. sows} * RV_S * \text{cull wt}] + \\
&\quad (\text{no. boars/sow}) * RV_B * \text{cull wt.} \\
&= .85 * (129.3 + 27.2/FR) + [(1/FR) * ((100/CR_i)-1)] * \\
&\quad [FR * .9 * 129.3 + (1-FR) * .85 * (129.3 + (27.2/FR))] \\
&\quad + (MR/(SD * FR)) * .65 * 181.4 \qquad (15)
\end{aligned}$$

The program then allows for a 1.5% breeding herd death loss/cycle by setting $PB_i = .985\ PB_i$.

Cost of Postweaning Growth.

$$\begin{aligned}
CG_i &= [\text{No. Pigs/Litter}] * \text{No. Days} * \text{Costs/Day} \\
&= [(LSB_i * SURV_i/100)((1 + PS)/2] * (81.65/ADG_i) \\
&\quad * (LOCG + FCG * ADG_i * F/G_i) \qquad \text{, \$/dam/litter} \qquad (16)
\end{aligned}$$

Reproduction Costs.

$$\begin{aligned}
CB_i &= [\text{Cost of Breeding Stock}] + \text{No. Days in Breeding Herd} * \text{Costs/d} \\
&= [\text{Cost of Stock}] + \text{No. Litters} * BCI_i * (LOCR + FIB * FCB) \\
&= [(1 + MR/(SB * FR)(100 * FR * CB_j)/(PS * LSW_j * CR_j) \\
&\quad + 100 * (G_j/(PS * LSW_j * CR_j) + 100 * GP/CR_j)] + (1/FR) * BCI_i \\
&\quad * (LOCR + FIB * FCB) \qquad \text{, \$/dam-lifetime} \qquad (17)
\end{aligned}$$

where j indexed the sub-system replacements were produced in.

System Efficiency. Having calculated efficiency for terminal offspring of systems, and the number of sows farrowing in different sub-systems, the programs proceed to compute system efficiency as the weighted (by number of females) average of sub-system efficiencies.

Model Evaluation and Sensitivity Analysis.

Comparison of predicted mean performance (table 2 and Appendix D) for different crosses to data used to estimate parameters helped evaluate that aspect of the programs. Comparison with results of other studies that predicted expected relative efficiency for different swine crossbreeding systems also helped evaluate the models.

Results obtained were not found to be sensitive to substituting average for specific heterosis estimates. Assuming individual heterosis for litter size born, percent survival to 42-d, average daily gain and backfat to be 0 pigs, 5.66%, .0688 kg/d and .43 mm, respectively, the same combinations ranked highest for each system as when specific estimates were used.

Excluding the NPPC "pork value" aspect of the economic evaluation was also found not to affect system ranking. However systems were generally 1 to 2% more efficient under the pork value program, indicating that the average pig was earning a premium for decreased backfat.

Results and Discussion

Evaluation Techniques. Profit equations and simulation techniques aimed at predicting economic efficiency for swine production systems have been developed by a number of workers over the past two decades. Smith (1964) discussed ranking lines and crosses based upon actual or predicted performance and relative economic weights for various traits. Moav (1966, 1973) developed algebraic and graphical procedures to determine the relative profitability of purebreds and crosses, assuming

TABLE 2. PREDICTED DRIVING VARIABLES FOR PUREBREDS

Breed	Conception rate %	Litter size born	% Survival -42d	Litter size weaned	Average d gain kg/d	Carcass backfat mm	Feed to gain ratio
Duroc	59.8	10.9	67.8	7.4	.663	29.1	3.00
Yorkshire	71.1	11.4	64.2	7.3	.638	33.0	3.19
Landrace	78.4	10.7	77.0	8.2	.635	33.5	3.23
Spotted	69.8	9.4	73.6	6.9	.666	34.2	3.43
"Exotic"	69.8	14.0	82.6	11.6	.350	39.4	4.00

profitability to be a function of reproductivity (number of weaned pigs/sow/yr) and productivity (feed to gain ratio). Moav established the necessity for evaluation of alternative breeding systems based on an objective, probably nonlinear, profit function.

Systems analysis demands precise definition of objectives. Harris (1970) argued that, in the long term, improvement of efficiency in a livestock sector will result in lower costs to the consumer, increased consumption and increased production, rather than in greater profit for producers. Long term profitability for a livestock producer therefore lies in his efficiency relative to other producers. In a capitalist economy, improvement of production efficiency should result from efficient (and thus profitable) producers increasing their share of the market. Aiming to improve the relative profitability of producers therefore serves the wider objectives of society (and the consumer) at the same time. Harris (1970) maintained that the goal of improvement should be either profit, return on investment or cost/unit of production. All three are functions of expenses (costs of production) and income (product adjusted for quality), and Harris (1970) presented equations that accounted for all costs and income, both in the breeding herd and market animals, during the entire life cycle of an animal.

Dickerson (1970, 1976, 1978) also expressed net or life-cycle economic efficiency as the ratio of total costs to total animal product. He presented a comprehensive equation for the ratio of expenses/yr to product value/yr. Although biological measures of efficiency (e.g., feed, energy or protein input/unit edible protein or protein energy output) have often been used to describe animal efficiency, Dickerson (1978) pointed out limitations on their usefulness. Firstly, cost/unit feed input generally varies considerably with the maturity and productivity of the animals. Secondly, income/unit may vary greatly with animal product or composition of product. Lastly, nonfeed costs are not negligible, they vary with phase of production, and they are greatly influenced by biological differences in performance.

Predicted Efficiency. Alternative crossbreeding systems, and predicted efficiencies for the most efficient (lowest cost/kg product) breed combination in each system, are given in table 3, and illustrated in Figures 2-4. The 10 most efficient of the 73 systems evaluated are listed in table 4. Economic efficiencies for each of the 73 mating systems are presented in Appendix E.

Breeding systems involving the Spotted breed were found to be at a decided disadvantage relative to the Duroc, Yorkshire and Landrace breeds. This was despite the assumed superiority of the Spotted breed for average daily gain (table 1). In contrast to the Spotted, the Duroc was involved in the most efficient combination for each of the 10 mating systems (table 3), and in the top 10 most efficient systems overall (table 4).

The most efficient of the 73 systems considered was the three breed static Landrace x (Duroc x Yorkshire), at .7029 $/kg. As Dickerson (1973) pointed out, the three breed static system essentially maximizes use of heterosis and breed differences. Bichard and Smith (1972) maintained an optimum crossing system was likely to involving a specialized male line mated to F_1 females, but did not rule out the possibility of using crossbred or synthetic line boars. This present study found the best four breed static ((Yorkshire x Landrace) x (Spotted x Duroc)), assuming 6.22% paternal heterosis for conception

TABLE 3. ALTERNATIVE CROSSBREEDING SYSTEMS AND THE MOST EFFICIENT BREED COMBINATIONS

System	No. Breed Combinations	Most Efficient Combination[a]	Efficiency[b]	
			$/kg	%
3 Breed Static	12	L x (DxY)	.7029	117.5
2 Breed Rotation	6	D, L	.7088	116.8
3 Breed Rotation	4	D, Y, L	.7098	116.7
Backcross	12	L x (DxL)	.7124	116.4
3 Breed Combination	12	L x (D, Y)	.7148	116.1
4 Breed Static	6	(SxL) x (DxY)	.7148	116.1
4 Breed Rotation	1	D, Y, L, S	.7195	115.6
4 Breed Combination	4	D x (Y, L, S)	.7241	115.0
2 Breed Static	12	L x D	.7271	114.7
Purebred	4	D	.8521	100.0

[a] Breed of sire x breed of dam
D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.

[b] $/kg=costs of producing 1 kg-equivalent of product
%=reduction in cost/kg as a percent of purebred Duroc efficiency.

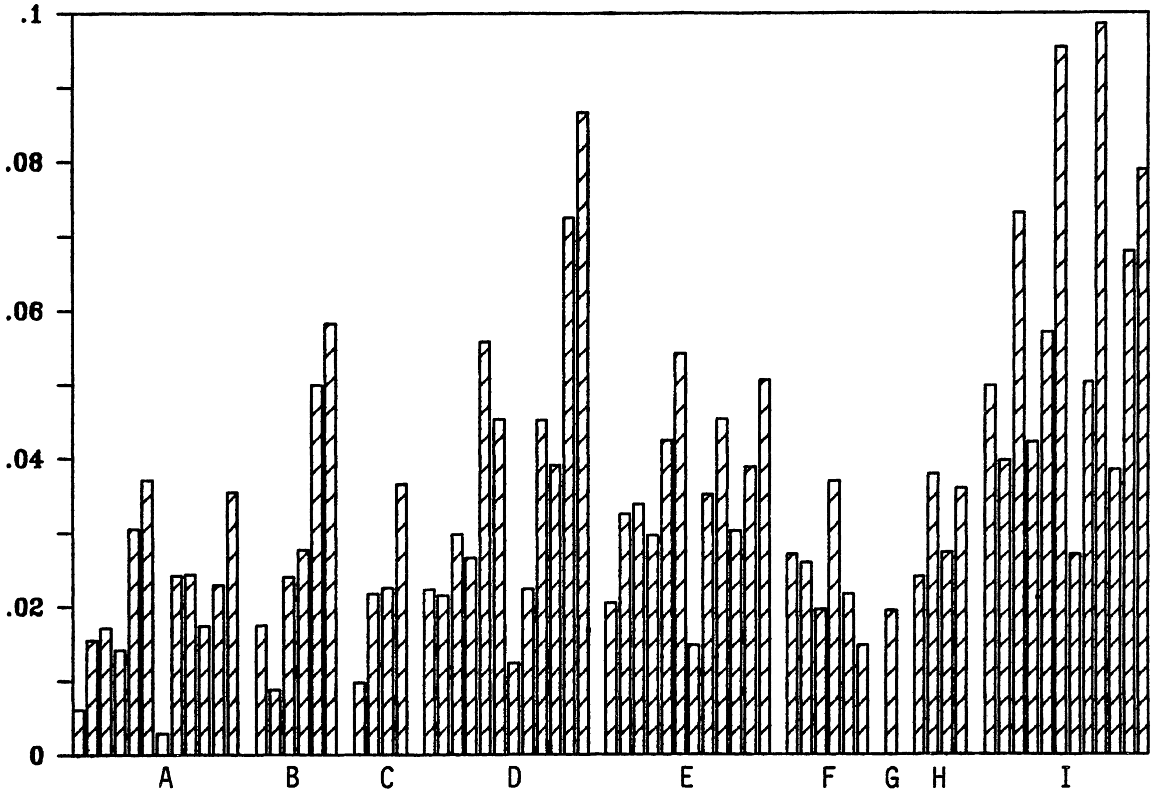

Figure 2. Relative Efficiencies (cost/kg product) for the 69 Alternative Crossbreeding Systems Evaluated[a].

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[a] The y axis represents efficiency, \$/kg, as a deviation from .70. More efficient systems therefore have shorter bars. Different types of system are separated by a blank. Systems are identified by the legend on the following page.

A=Three Breed Static

A1 = D x (YxL)
A2 = D x (SxY)
A3 = D x (SxL)
A4 = Y x (DxL)
A5 = Y x (SxD)
A6 = Y x (SxL)
A7 = L x (DxY)
A8 = L x (SxD)
A9 = L x (SxY)
A10= S x (DxY)
A11= S x (DxL)
A12= S x (YxL)

B=Two Breed Rotation

B1 = D, Y
B2 = D, L
B3 = D, S
B4 = Y, L
B5 = Y, S
B6 = L, S

C=Three Breed Rotation

C1 = D, Y, L
C2 = D, Y, S
C3 = D, L, S
C4 = Y, L, S

D=Backcross

D1 = D x (DxY)
D2 = D x (DxL)
D3 = D x (SxD)
D4 = Y x (DxY)
D5 = Y x (YxL)
D6 = Y x (SxY)
D7 = L x (DxL)
D8 = L x (YxL)
D9 = L x (SxL)
D10= S x (SxD)
D11= S x (SxY)
D12= S x (SxL)

E=Three Breed Combination

E1 = D x (Y, L)
E2 = D x (Y, S)
E3 = D x (L, S)
E4 = Y x (D, L)
E5 = Y x (D, S)
E6 = Y x (L, S)
E7 = L x (D, Y)
E8 = L x (D, S)
E9 = L x (Y, S)
E10= S x (D, Y)
E11= S x (D, L)
E12= S x (Y, L)

F=Four Breed Static

F1 = (DxY) x (SxL)
F2 = (DxL) x (SxY)
F3 = (YxL) x (SxD)
F4 = (SxD) x (YxL)
F5 = (SxY) x (DxL)
F6 = (SxL) x (DxY)

G=Four Breed Rotation

D, Y, L, S

H=Four Breed Combination

H1 = D x (Y, L, S)
H2 = Y x (D, L, S)
H3 = L x (D, Y, S)
H4 = S x (D, Y, L)

I=Two Breed Static

I1 = D x Y
I2 = D x L
I3 = D x S
I4 = Y x D
I5 = Y x L
I6 = Y x S
I7 = L x D
I8 = L x Y
I9 = L x S
I10= S x D
I11= S x Y
I12= S x L

Figure 2 (Continued). Legend[a]

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[a] Numbers indicate relative position, from left to right, of systems on the above figure. Systems are coded as breed of sire x breed of dam. D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.

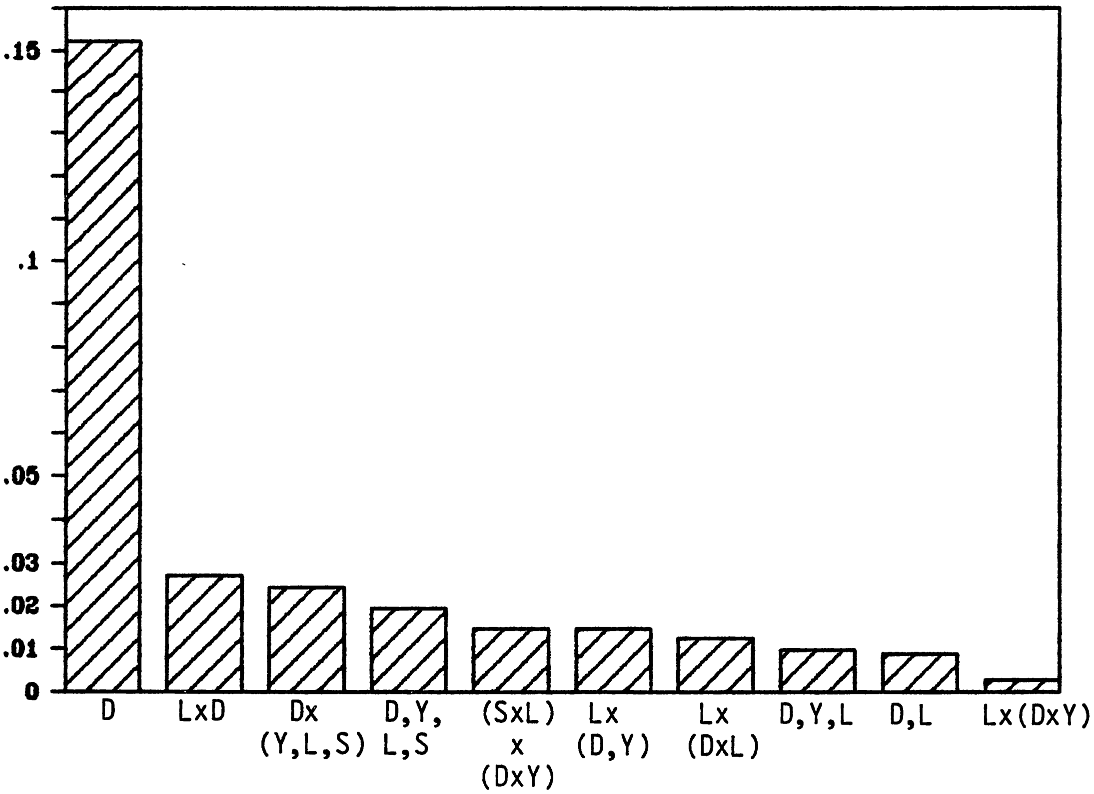

Figure 3. Most Efficient Breed Combinations for Each Mating System[a].

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[a] The y axis represents system efficiency, $/kg, as a deviation from .70. More efficient systems therefore have shorter bars. Systems are identified on the x axis. Breeds are D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted. Systems are coded as breed of sire x breed of dam. Commas between breed codes denote rotations.

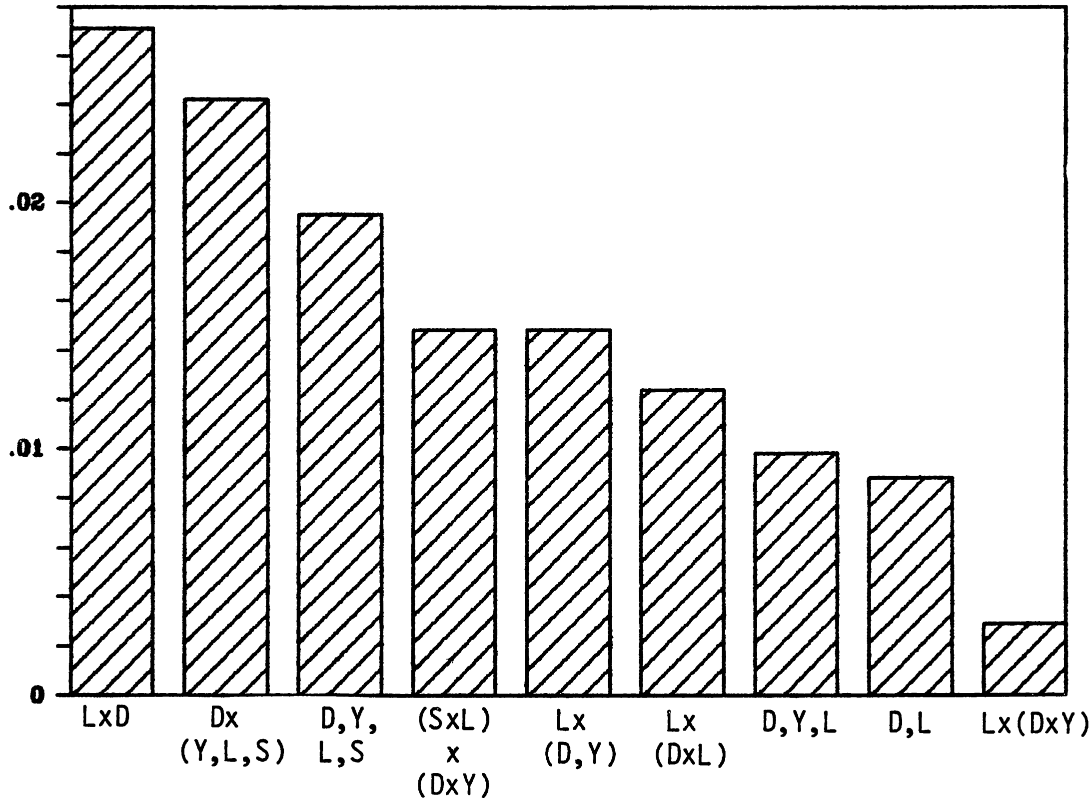

Figure 4. Most Efficient Breed Combinations for Each Crossbreeding System[a].

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[a] The y axis represents system efficiency, \$/kg, as a deviation from .70. More efficient systems therefore have shorter bars. Systems are identified on the x axis. Breeds are D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted. Systems are coded as breed of sire x breed of dam. Commas between breed codes denote rotations.

TABLE 4. HIGHEST RANKING BREEDING SYSTEM EFFICIENCIES

Rank	System	Breed Combination[a]	Efficiency[b]	
			$/kg	%
1	3 Breed Static	L x (DxY)	.7029	117.5
2	3 Breed Static	D x (YxL)	.7061	117.1
3	2 Breed Rotation	D, L	.7088	116.8
4	3 Breed Rotation	D, Y, L	.7098	116.7
5	Backcross	L x (DxL)	.7124	116.4
6	3 Breed Combination	L x (D, Y)	.7148	116.1
6	4 Breed Static	(SxL) x (DxY)	.7148	116.1
8	4 Breed Static	(YxL) x (SxD)	.7196	115.5
9	3 Breed Combination	D x (Y, L)	.7205	115.4
10	Backcross	D x (DxL)	.7215	115.3

[a] Breed of sire x breed of dam
D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.

[b] $/kg=costs of producting 1 kg-equivalent of product
%=reduction in cost/kg as a percent of purebred Duroc, efficiency (.8521)

rate, to be 1.4% less efficient than the best 3 breed static system as a result of including a fourth (relatively inferior) breed in the system.

The simple two breed rotation or crisscross system was first advocated as a swine breeding strategy 50 yr ago (Winters et al., 1935). The most efficient two breed rotation (Duroc, Landrace) ranked third overall, with efficiency of .7088 $/kg, only .7% less efficient than the best three breed static. The Duroc, Landrace rotation outperformed the best three breed (Duroc, Yorkshire, Landrace) rotation by .2%. The most efficient three breed combination system, Landrace boars mated to Duroc, Yorkshire rotation females (.7148 $/kg), ranked sixth overall, as did the best four breed static. The Landrace x (Duroc x Landrace) backcross was the fifth ranked system at .7124 $/kg.

The importance of considering purebred and other breeding stock generators when calculating system efficiency was demonstrated by examining efficiency considering only terminal matings for each system. The most efficient crossbreeding systems appeared to decrease cost/kg product by 15.6 to 19.0% under this simplification, vs the 14.7 to 17.5% increases in efficiency where breeding stock genertors were included in the system (table 3). Failing to allow for these sub-systems, while not altering the most efficient breed combinations predicted for each system, did change system ranking based upon these combinations. Ignoring required breeding stock generators, the Landrace x (Duroc x Landrace) backcross was the most efficient system, followed by the three breed static cross. Other noticeable changes in rank were the Landrace x Duroc two breed static cross, which ranked ninth based upon the entire system, but third if only the terminal cross was considered. Two and three breed rotations ranked fifth and sixth by this model, as opposed to second and third where the entire system was considered (table 3).

Use of an Exotic Breed. An exotic swine breed was evaluated in place of the Spotted by assuming the following parameters: direct genetic plus maternal effects of 3.41 pigs for litter size born, direct and maternal genetic effects each of 5.91% for percent survival to 42-d, and direct effects for average daily gain, carcass backfat and feed to gain ratio of -.30 kg/d, 7.0 mm and .788, respectively. Maternal effects were assumed to be zero for these traits, and conception rate effects set equal to those for the Spotted breed. The exotic breed averaged 14 pigs born and 11.6 pigs weaned/litter, with postweaning average daily gain of .35 kg/d and feed to gain ratio of 4.0 (table 2). These values were based on averages for Chinese breeds of swine reported by Gianola et al. (1982).

Good reproductive performance, however, failed to compensate for the poor growth performance of the breed, and the exotic failed to be utilized in the most efficient breed combination for any system (except, of course, for four breed systems). Compared to using the Spotted breed, use of the Exotic increased costs/kg of product by an average 3.3, 1.8 and 1.2% for two, three and four breed rotations involving the breed, respectively. However, as a rotation breed in three and four breed combination systems costs were decreased 1.3 and 1.0%, and as the maternal breed in two and three breed static systems the exotic decreased costs by 1.6 and 1.1%, respectively. No advantage was seen for backcrosses to the breed of the sire of the dam, however, and where used as a sire breed in backcross and three and four breed combination systems costs were increased approximately 6.5%.

Genetic parameters for average daily gain and feed to gain ratio for the Exotic breed were varied in order to determine at what level of performance the breed would be included in least cost systems. Increasing predicted average daily gain from .35 kg/d to .45 kg/d, while litter size weaned and feed to gain ratio remained at 11.6 pigs and 4.0, respectively, resulted in the Duroc x (Yorkshire x Exotic) becoming the most efficient system. The Duroc x (Yorkshire, Exotic) rotation was the most efficient three breed combination system. Increasing average daily gain to .55 kg/d resulted in the Duroc x Exotic and Duroc x (Duroc x Exotic) also becoming the most efficient two breed static and backcross systems.

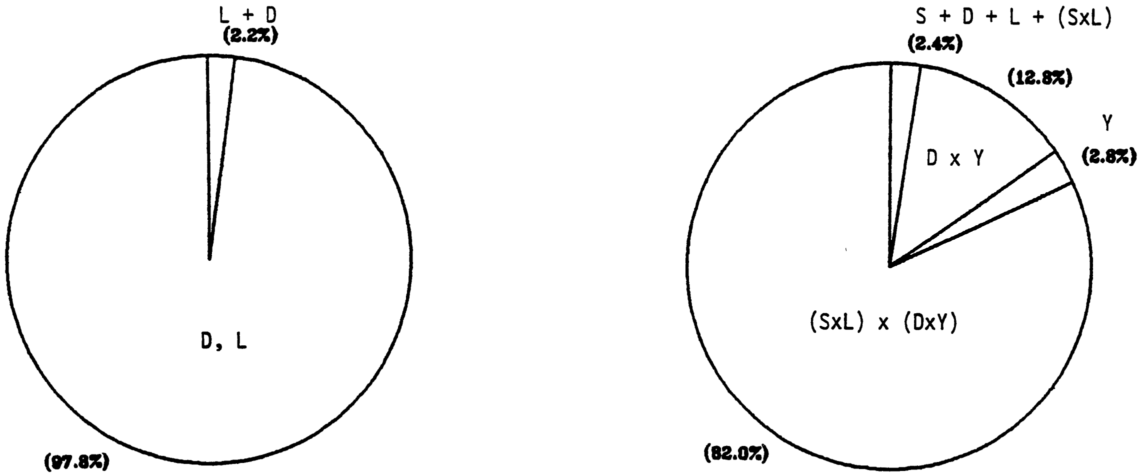
Improving feed to gain ratio for the exotic from 4.0 to 3.8, again with litter size weaned and average daily gain fixed at 11.6 pigs and .35 kg/d, the Duroc x (Yorkshire x Exotic) became the most efficient system. Further improvement to 3.6 resulted in the Duroc x (Yorkshire, Exotic) rotation becoming the most efficient three breed combination. With a feed to gain ratio of 3.4 the exotic was involved in the most efficient backcross, two and three breed static and three breed combination systems (as for the high rate of gain above).

System Structure. Structure (i.e., the number of females farrowing in different sub-systems) for the most efficient breed combinations for each system is presented in table 5 and illustrated in Figure 5. Structure for each of the 69 alternative crossbreeding systems is given in Appendix F. Systems not shown in Figure 5 have similar structures to the examples given. The most efficient three and four breed rotations required 2.3% purebred farrowings. Structure for the best four breed combination was .3% Landrace, Yorkshire and Spotted purebred farrowings,

TABLE 5. STRUCTURE FOR ALTERNATIVE CROSSBREEDING SYSTEMS

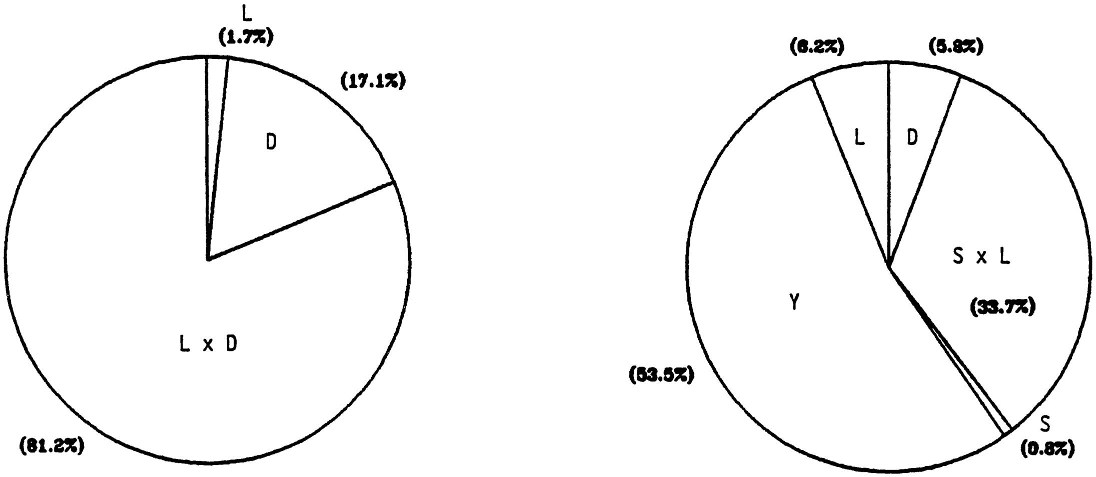
System[a]	No. Females farrowing/sub-system
L x (DxY)	31 D, 176 L, 276 Y, 1,288 DxY, 8,229 L x (DxY)
D, L	105 L, 116 D, 9,779 D, L
D, Y, L	70 L, 77 D, 79 Y, 9,779 D, L
L x (DxL)	30 D, 183 L, 1,254 DxL, 8,533 D x (DxL)
L x D, Y	18 D, 19 Y, 177 L, 1,540 D, Y, 8,246 LxD, Y
(SxL) x (DxY)	4 S, 30 D, 32 L, 2,75 Y, 173 SxL, 1,283 DxY, 8,201 (SxL)x(DxY)
D, Y, L, S	52 L, 58 D, 59 Y, 62 S, 9,769 D, Y, L, S
DxY, L, S	10 L, 12 Y, 12 S, 197 D, 1,452 Y, L, S, 8,316 DxY, L, S
L x D	174 L, 1709 D, 8,117 LxD
D	10,000 D

[a] Breed of sire x breed of dam.
See table 2 for system descriptions
D=Duroc, Y=Yorkshire, L=Landrace, S=Spotted.



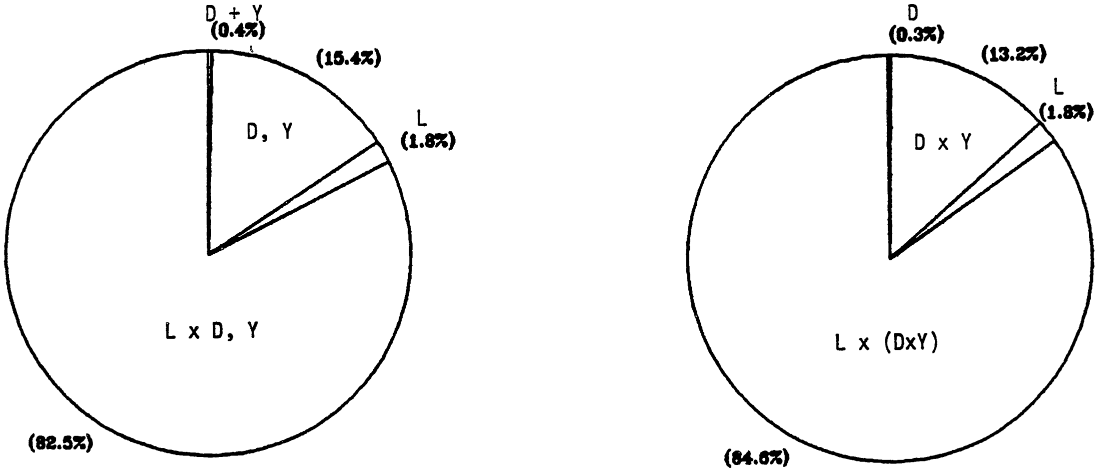
4a. Two Breed Rotation

4d. Four Breed Static



4b. Two Breed Static

4e. Four Breed Static: Sub-systems



4c. Three Breed Combination

4f. Three Breed Static

Figure 5. Structure for Alternative Crossbreeding Systems

14.5% three breed rotation, 2.0% purebred Duroc and 83.2% terminal Duroc x (Yorkshire, Landrace, Spotted) rotation females farrowing. The backcross required .3% Duroc, 12.5% Duroc x Landrace and 1.8% Landrace farrowings to support 86.3% Landrace x (Duroc x Landrace) farrowings.

Literature Reports. A number of workers have reported economic evaluations of alternative swine crossbreeding systems. Dickerson (1973) compared the number of sow-years required/1,000 market pig-equivalents for alternative systems, relative to a static three breed cross. Five theoretical breeds with assumed litter size, growth efficiency, cutability and product value were presumed to be available. Heterosis values and replacement rates were also assumed, and systems compared based upon all purebreeding and crossbreeding sectors of the system. A static two breed cross required 15% more sow-years per 1,000 pig-equivalents than the three breed cross, and a four breed rotation required 6% more sow-years/1,000 pigs. The expected advantage of the most efficient three breed static vs two breed static and four breed rotation systems was noticeably smaller (2.8% and 1.9%, respectively) in this study.

Bichard (1977) used Dickerson's (1973) method to evaluate alternative crossbreeding systems in the United Kingdom. He reported little variation among two breed systems, although the two breed rotation required 2% fewer sow-years per 1,000 pig-equivalents than the backcross. In the present study, the best two breed rotation was .4% more efficient than the best backcross, and 2.1% superior to the best two breed static system.

Sellier (1976) cited Brun (1974, unpublished) as having used a number of methods to compare crossbreeding systems involving the Large

White and Landrace breeds in France. Moav's (1966) profit function suggested a 4 to 5% advantage of crossbreeding over purebreeding, and Dickerson's (1973) method suggested a 6 to 8% advantage, plus an additional 1 to 2% for systems with crossbred dams. A dynamic analysis over a 15 yr period starting from a purebred Large White base population indicated crisscrossing to be the most efficient two breed system, in agreement with results of the present static analysis involving American breeds. However, this present study suggested a 15 to 18% avantage for crossbreeding over purebreeding--noticeably greater than Brun's estimates.

Wilson and Johnson (1981) used linear programming to compare the efficiency of 21 different crossbreeding systems involving Duroc, Hampshire and Yorkshire breeds of swine. Mating sytems were defined, as in the present study, as including purebred and crossbred matings necessary to maintain 10,000 total farrowings. Breed and heterosis effects were estimated from experimental data collected at the Oklahoma Agricultural Experiment Station. Relative efficiency of alternative systems, where purebreds averaged 100, was 127 for three breed statics, 125 for three breed rotations, 124 for three breed combinations, 123 for two breed rotations, 122 for backcrosses and 115 for two breed static crosses. These results suggested a greater advantage for crossbreeding than the earlier reports discussed above, but are in closer agreement to the results of this study. Comparing the most efficient combination of each system, where the Duroc averaged 100, the three breed static was 118, the two breed rotation 117, the three breed combination and backcross 116 and the two breed static 115 in the present study (table 3). Wilson and Johnson (1981) found backcrossing of Yorkshire boars to

Duroc x Yorkshire females to be the most efficient system. The six most efficient systems were two backcrosses, two three breed statics, one two breed rotation and a three breed combination system.

Quintana and Robison (1984) evaluated the performance of Duroc, Hampshire, Yorkshire and Landrace swine as purebreds and in various crosses, based upon breed and heterosis effects from the results of U.S. and Canadian crossbreeding experiments reported over the past decade. A population of 1,000 sows and a herd life of 20 yr was assumed. Number of pigs produced by each genetic group within the system and for the total system, annually and over 20 years, were computed, based upon predicted reproductive performance. All systems started from a purebred base. An economic index of litter size weaned, conception rate, age at 100 kg and backfat was computed for each genetic group and for the total system. Relative to purebreds, two breed static crosses were $6.00 superior/sow exposed on average, and two and three breed rotations $12.15 and $12.93 superior, respectively. Somewhat at variance to results of the present study, which suggested a 2% advantage for two and three breed rotations over the two breed static, relative to a 15% advantage for the two breed static over the purebred Duroc. Quintana and Robison (1984) also reported four breed static crosses as averaging only 37 cents over three breed rotations assuming no male heterosis, but $7.04 where paternal heterosis of 7.5% for conception rate and 10% for litter size was assumed. There is, however, no evidence for such an effect on litter size (Buchanan and Johnson, 1984).

Tess et al. (1983) reported a bioeconomic computer model designed to simulate biological and economic inputs and outputs for life cycle pork production. Simulated breed and crossbreeding effects on costs of pork production using this model were reported by Bennett et al. (1983). Heterosis and breed effect estimates from crossbreeding experiments at Iowa and Oklahoma were used to simulate efficiency for alternative systems involving the Duroc, Hampshire, Yorkshire, Landrace, Spotted and Chester White breeds. Breeding systems investigated were purebred, two breed static, rotation and backcross, and three breed static and rotation crosses. Breeds ranked differently for paternal, maternal and general purpose roles. Greater cost reductions were predicted for the best three breed static (7 to 10%) than for the best three breed rotation (6 to 8%) systems, noticeably lower than the 17% cost reductions estimated for these systems by the present study.

Discussion. Rotational systems require only purebred male replacements as crossbred female progeny from one generation provide dams for the next generation. A rotation system, therefore, substantially reduces the proportion of the population required as breeding stock generators (2.2% for the two breed rotation vs 18.8% for the two breed static, Figure 5). The loss in heterosis expected for the rotation vs the specific cross is offset to some extent by the greater proportion of crossbreds exhibiting some heterosis in the population. In addition, factors such as ease and cost of acquiring female replacements, and the reduced disease risk from use of home-bred females, encourage the use of simple systems such as the two breed rotation. Results of this present study suggested only a three breed static system to be superior to the best two breed rotation for the breeds considered (table 3).

Simulations did, however, assume recombination losses to be negligible. If such effects are important, static crossbreeding systems have an additional advantage over rotations (Dickerson, 1969, 1973). Evidence for important deviations from a linear relationship between percent heterozygosity and heterosis (suggesting recombination loss) is far from conclusive, particularly for swine (Sheridan, 1981). Theoretically such losses are expected due to the breaking up favorable parental combinations of various gene pairs, established at different loci as adaptations to specific environments during breed development. North American breeds of pig, relative to breeds of other livestock species, may be considered to be adapted to somewhat similar environments. Therefore, despite the lack of experimental evidence, it may be reasonable to assume that epistatic recombination losses are negligible when comparing alternative swine crossbreeding schemes.

Using males from a superior sire breed on females produced by rotation crossing among maternal breeds combines advantages of both specific and rotational crossbreeding. Breed differences in maternal and paternal performance are made use of, and only purebred female replacements of the sire breed are required. Terminal crosses exhibit 100% of the individual heterosis and have the same expectations for maternal heterosis as the rotation. Sellier (1976) and Bichard (1977) proposed two breed rotation females as a viable alternative to F_1 hybrid gilts for European pig breeding programs. While practical considerations lend support to this idea, results presented in table 3 suggested introduction of a third breed into the system, except for the three breed static, would have a deleterous effect on overall efficiency given the parameters assumed. Considering predicted driving variables for the purebreds (table 2), it is clear that while the Duroc was superior for growth and the Landrace for litter size weaned, the

Yorkshire was inferior to the Duroc for all traits. Thus despite the improved heterosis expected in combination systems, the Duroc, Landrace rotation was still more efficient.

It should, however, be stressed that differences in predicted efficiency for the alternative crossbreeding systems were generally small. In advising producers, emphasis should be placed upon the practicality of available systems as regards the individual producer's situation. More important, possibly, than which system is adopted is that the chosen plan be adhered to. Level of management and the relative complexity of different systems are therefore important considerations. The disease risk associated with importing breeding stock onto the farm should also not be overlooked. To quote Bichard and Smith (1972, p. 51): "It is vital that the disease risks involved should not outweigh the planned genetic advantages".

Unless recombination losses are in fact important, the results of this study suggest that a two or three breed rotation system utilizing efficient breeds should prove almost as effective as the three breed static. It is proposed to further develop the programs used in this study into more "user-friendly" form in order to provide models for use in Animal Breeding classes and Extension demonstrations.

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APPENDIXES

APPENDIX A

ROTATIONAL CROSSBREEDING SIMULATION PROGRAM

```
10 'SAVE "ROTATE",A
20 '
30 ' PERFORMANCE VARIABLES ARE INDICATED BY THE FOLLOWING PREFIXES
THROUGHOUT THE PROGRAM:
40 '
50 'CR - FIRST SERVICE CONCEPTION RATE (%)
60 'SUR - SURVIVAL TO 42 d (%)
70 'LSB - LITTER SIZE BORN
80 'LSW - LITTER SIZE WEANED ( = LSB*SUR/100 )
90 'LSFE - LITTER SIZE WEANED / FEMALE EXPOSED ( =LSW*CR/100 )
100 'ADG - POSTWEANING AVERAGE DAILY GAIN (kg/d)
110 'FG - FEED TO GAIN RATIO
120 'BF - CARCASS BACKFAT (mm)
130 '
140 ' THE FOLLOWING SUFFIXES INDICATE THE DIFFERENT BREEDING SYSTEMS:
150 '
160 'P - PUREBRED
170 'AB - 2 BREED ROTATION (crisscross)
180 'ABC - 3 BREED ROTATION
190 'ABCD - 4 BREED ROTATION
200 '3BC - 3 BREED COMBINATION (i.e. terminal sire breed x crisscross
females)
210 '4BC - 4 BREED COMBINATION (i.e. term. sire x 3 breed rotation
females)
220 '
230 ' THE FOLLOWING SUFFIXES REFER TO GENETIC PARAMETERS:
240 '
250 'MU - CONSTANT
260 'GIM - DIRECT AVERAGE BREED + MATERNAL EFFECTS
270 'GI - DIRECT AVERAGE BREED EFFECT
280 'GM - DIRECT AVERAGE MATERNAL EFFECT
290 'HI - INDIVIDUAL HETEROSIS
300 'HM - MATERNAL HETEROSIS
310 'HP - PATERNAL HETEROSIS
320 '
330 'DIMENSIONING ARRAYS
340 '
350 CLS:PRINT:PRINT:PRINT "ROTATE.BAS":PRINT
360 '
370 DIM
CRGIM(4),CRHM(6),CRHP(6),CRP(4),CRAB(6),CRABC(4),CRABCD(1),CR3BC(12),CR4
BC(4)
380 DIM
LSBGIM(4),LSBHI(6),LSBHM(6),LSBHP(6),LSBP(4),LSBAB(6),LSBABC(4),LSBABCD(
1),LSB3BC(12),LSB4BC(4)
390 DIM
SURGI(4),SURGM(4),SURHI(6),SURHM(6),SURHP(6),SURP(4),SURAB(6),SURABC(4),
SURABCD(1),SUR3BC(12),SUR4BC(4)
400 DIM
ADGGI(4),ADGGM(4),ADGHI(6),ADGHM(6),ADGHP(6),ADGP(4),ADGAB(6),ADGABC(4),
ADGABCD(1),ADG3BC(12),ADG4BC(4)
410 DIM
BFGI(4),BFGM(4),BFHI(6),BFHM(6),BFHP(6),BFP(4),BFAB(6),BFABC(4),BFABCD(1
),BF3BC(12),BF4BC(4)
```

```
420 DIM
FGGI(4),FGGM(4),FGHI(6),FGHM(6),FGHP(6),FGP(4),FGAB(6),FGABC(4),FGABCD(1
),FG3BC(12),FG4BC(4)
430 DIM
LSWP(4),LSWAB(6),LSWABC(4),LSWABCD(1),LSW3BC(12),LSW4BC(4),LSFEP(4)
440 'THE FOLLOWING VARIABLES ARE DEFINED AS THEY OCCUR IN THE PROGRAM
450 DIM
FMP(4),FFP(4),FMAB(6),FFAB(6),FMABC(4),FFABC(4),STRAB(6,3),STRABC(4,4),S
TRABCD(5),STR3BC(12,5),STR4BC(4,6)
460 DIM BCIP(4),BCIAB(6),BCIABC(4),BCIABCD(1),BCI3BC(12),BCI4BC(4)
470 DIM CGP(4),CGAB(6),CGABC(4),CGABCD(1),CG3BC(12),CG4BC(4)
480 DIM CBP(4),CBAB(6),CBABC(4),CBABCD(1),CB3BC(12),CB4BC(4)
490 DIM CP(4),CAB(6),CABC(4),CABCD(1),C3BC(12),C4BC(4)
500 DIM PGP(4),PGAB(6),PGABC(4),PGABCD(1),PG3BC(12),PG4BC(4)
510 DIM PBP(4),PBAB(6),PBABC(4),PBABCD(1),PB3BC(12),PB4BC(4)
520 DIM PP(4),PAB(6),PABC(4),PABCD(1),P3BC(12),P4BC(4)
530 DIM EP(4),EAB(6),EABC(4),EABCD(1),E3BC(12),E4BC(4),XP(4),B$(12)
540 DIM SEP(4),SEAB(6),SEABC(4),SEABCD(1),SE3BC(12),SE4BC(4)
550 DIM RVP(4),RVAB(6),RVABC(4),RVABCD(1),RV3BC(12),RV4BC(4)
560 '
570 ' READING GENETIC PARAMETER VALUES
580 '
590 'GI, GM, GIM DATA ARE READ IN ORDER :
600 ' I=1 : DUROC
610 ' I=2 : YORK
620 ' I=3 : LAND
630 ' I=4 : SPOT
640 'HI, HM, HP DATA ARE READ IN ORDER :
650 ' I=1 : DUROC-YORK
660 ' I=2 : DUROC-LAND
670 ' I=3 : DUROC-SPOT
680 ' I=4 : YORK-LAND
690 ' I=5 : YORK-SPOT
700 ' I=6 : LAND-SPOT
710 '
720 CRMU=69.76
730 FOR I=1 TO 4: READ CRGIM(I): NEXT I
740 FOR I=1 TO 6: READ CRHM(I): NEXT I
750 '
760 DATA -10.01,1.34,8.62,.05,2.8,2.8,2.8,2.8,2.8,2.8
770 '
780 LSBMU=10.58
790 FOR I=1 TO 4: READ LSBGIM(I): NEXT I
800 FOR I=1 TO 6: READ LSBHI(I): NEXT I
810 FOR I=1 TO 6: READ LSBHM(I): NEXT I
820 DATA .35,.78,.07,-
1.2,.23,.23,.23,.23,.23,.23,.93,.93,.93,.93,.93,.93
830 '
840 SURMU=70.81
850 FOR I=1 TO 4: READ SURGI(I): NEXT I
860 FOR I=1 TO 4: READ SURGM(I): NEXT I
870 FOR I=1 TO 6: READ SURHI(I): NEXT I
880 FOR I=1 TO 6: READ SURHM(I): NEXT I
```

```
890 DATA -.88,-4.48,5.05,-.31,-2.13,-
2.12,1.12,3.13,4.31,5.73,7.86,9.88,6.41,-.18,0,0,0,0,0,0
900 '
910 ADGMU=.6504
920 FOR I=1 TO 4: READ ADGGI(I): NEXT I
930 FOR I=1 TO 4: READ ADGGM(I): NEXT I
940 FOR I=1 TO 6: READ ADGHI(I): NEXT I
950 FOR I=1 TO 6: READ ADGHM(I): NEXT I
960 DATA .0148,-.0111,-.0215,.0178,-.0026,-.0010,.0062,-
.0026,.0796,.0736,.0712,.0545,.0622,.0705,0,0,0,0,0,0
970 '
980 BFMU=32.43
990 FOR I=1 TO 4: READ BFGI(I): NEXT I
1000 FOR I=1 TO 4: READ BFGM(I): NEXT I
1010 FOR I=1 TO 6: READ BFHI(I): NEXT I
1020 FOR I=1 TO 6: READ BFHM(I): NEXT I
1030 DATA -6.55,2.48,-.08,4.16,3.19,-1.88,1.12,-2.43,1.96,.90,.79,.98,-
1.28,-.70,0,0,0,0,0,0
1040 '
1050 FGMU=3.212
1060 FOR I=1 TO 4: READ FGGI(I): NEXT I
1070 FOR I=1 TO 4: READ FGGM(I): NEXT I
1080 FOR I=1 TO 6: READ FGHI(I): NEXT I
1090 FOR I=1 TO 6: READ FGHM(I): NEXT I
1100 DATA -.210,-
.027,.020,.217,0,0,0,0,.009,.009,.009,.009,.009,.009,0,0,0,0,0,0
1110 PRINT:INPUT "PRESS ENTER ";Z$:CLS
1120 '
1130 'CALCULATING PREDICTED PERFORMANCE FOR TERMINAL OFFSPRING OF
ALTERNATIVE                              CROSSBREEDING SYSTEMS
1140 '
1150 'NOTE THAT CR IS ASSUMED TO BE A FUNCTION OF DAM BREED EFFECTS,
PLUS THE
1160 'EFFECT OF USING A CROSSBRED SIRE IN THE CDXAB SYSTEM. EXPANSION OF
THE
1170 'PROGRAM TO INCLUDE HAMPSHIRE SIRES WILL REQUIRE PROGRAM
MODIFICATIONS
1180 '
1190 'PUREBREDS
1200 FOR I=1 TO 4
1210 CRP(I)=CRMU+CRGIM(I)
1220 LSBP(I)=LSBMU+LSBGIM(I)
1230 SURP(I)=SURMU+SURGI(I)+SURGM(I)
1240 LSWP(I)=LSBP(I)*SURP(I)/100
1250 LSFEP(I)=LSWP(I)*CRP(I)/100
1260 ADGP(I)=ADGMU+ADGGI(I)+ADGGM(I)
1270 BFP(I)=BFMU+BFGI(I)+BFGM(I)
1280 FGP(I)=FGMU+FGGI(I)+FGGM(I)
1290 NEXT I:I=0
1300 PRINT:PRINT:PRINT "PUREBREDS":PRINT
1310 PRINT "PREDICTED DRIVING VARIABLES ":PRINT
1320 PRINT STRING$(70,"-"):B$(1)="D":B$(2)="Y":B$(3)="L":B$(4)="S"
1330 PRINT "BREED   CR      LSB      SUR      LSW     LSFE     ADG      BF
FG":PRINT STRING$(70,"-")
```

```
1340 FOR I=1 TO 4
1350 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#    ##.#    .###
##.#    #.##
";B$(I),CRP(I),LSBP(I),SURP(I),LSWP(I),LSFEP(I),ADGP(I),BFP(I),FGP(I):NE
XT I: PRINT STRING$(70,"-")
1360 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
1370 '
1380 '2 BREED ROTATIONS
1390 FOR J=1 TO 3: FOR K=2 TO 4
1400 IF K§=J GOTO 1550
1410 IF J=1 AND K=2 OR J=2 AND K=1 THEN L=1
1420 IF J=1 AND K=3 OR J=3 AND K=1 THEN L=2
1430 IF J=1 AND K=4 OR J=4 AND K=1 THEN L=3
1440 IF J=2 AND K=3 OR J=3 AND K=2 THEN L=4
1450 IF J=2 AND K=4 OR J=4 AND K=2 THEN L=5
1460 IF J=3 AND K=4 OR J=4 AND K=3 THEN L=6
1470 I=I+1
1480 CRAB(I)=CRMU+.5*(CRGIM(J)+CRGIM(K))+2*CRHM(L)/3
1490 LSBAB(I)=LSBMU+.5*(LSBGIM(J)+LSBGIM(K))+2*LSBHM(L)/3
1500
SURAB(I)=SURMU+.5*(SURGI(J)+SURGI(K))+.5*(SURGM(J)+SURGM(K))+2*SURHI(L)/
3+2*SURHM(L)/3
1510 LSWAB(I)=LSBAB(I)*SURAB(I)/100
1520
ADGAB(I)=ADGMU+.5*(ADGGI(J)+ADGGI(K))+.5*(ADGGM(J)+ADGGM(K))+2*ADGHI(L)/
3+2*ADGHM(L)/3
1530
BFAB(I)=BFMU+.5*(BFGI(J)+BFGI(K))+.5*(BFGM(J)+BFGM(K))+2*BFHI(L)/3+2*BFH
M(L)/3
1540
FGAB(I)=FGMU+.5*(FGGI(J)+FGGI(K))+.5*(FGGM(J)+FGGM(K))+2*FGHI(L)/3+2*FGH
M(L)/3
1550 NEXT K,J:I=0
1560 PRINT:PRINT:PRINT "2 BREED ROTATION":PRINT
1570 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
1580 PRINT STRING$(62,"-"):FOR I=1 TO 6:READ B$(I):NEXT I
1590 DATA DY,DL,DS,YL,YS,LS
1600 PRINT "BREED   CR     LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
1610 FOR I=1 TO 6
1620 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRAB(I),LSBAB(I),SURAB(I),LSWAB(I),ADGAB(I),BFAB(I),FGAB(I):NEXT
I: PRINT STRING$(62,"-")
1630 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
1640 '
1650 '3 BREED ROTATIONS
1660 FOR J=1 TO 3: FOR K=2 TO 4
1670 FOR L=3 TO 4
1680 IF L§=K OR K§=J THEN 1950
1690 IF K=1 AND L=2 OR K=2 AND L=1 THEN M=1
1700 IF K=1 AND L=3 OR K=3 AND L=1 THEN M=2
1710 IF K=1 AND L=4 OR K=4 AND L=1 THEN M=3
1720 IF K=2 AND L=3 OR K=3 AND L=2 THEN M=4
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1730 IF K=2 AND L=4 OR K=4 AND L=2 THEN M=5
1740 IF K=3 AND L=4 OR K=4 AND L=3 THEN M=6
1750 IF J=1 AND K=2 OR J=2 AND K=1 THEN N=1
1760 IF J=1 AND K=3 OR J=3 AND K=1 THEN N=2
1770 IF J=1 AND K=4 OR J=4 AND K=1 THEN N=3
1780 IF J=2 AND K=3 OR J=3 AND K=2 THEN N=4
1790 IF J=2 AND K=4 OR J=4 AND K=2 THEN N=5
1800 IF J=3 AND K=4 OR J=4 AND K=3 THEN N=6
1810 IF J=1 AND L=2 OR J=2 AND L=1 THEN O=1
1820 IF J=1 AND L=3 OR J=3 AND L=1 THEN O=2
1830 IF J=1 AND L=4 OR J=4 AND L=1 THEN O=3
1840 IF J=2 AND L=3 OR J=3 AND L=2 THEN O=4
1850 IF J=2 AND L=4 OR J=4 AND L=2 THEN O=5
1860 IF J=3 AND L=4 OR J=4 AND L=3 THEN O=6
1870 I=I+1
1880
CRABC(I)=CRMU+(CRGIM(J)+CRGIM(K)+CRGIM(L))/3+6*(CRHM(N)+CRHM(O)+CRHM(M))
/21
1890
LSBABC(I)=LSBMU+(LSBGIM(J)+LSBGIM(K)+LSBGIM(L))/3+6*(LSBHM(N)+LSBHM(O)+L
SBHM(M))/21
1900
SURABC(I)=SURMU+(SURGI(J)+SURGI(K)+SURGI(L))/3+(SURGM(J)+SURGM(K)+SURGM(
L))/3+6*(SURHI(N)+SURHI(O)+SURHI(M))/21+6*(SURHM(N)+SURHM(O)+SURHM(M))/2
1
1910 LSWABC(I)=LSBABC(I)*SURABC(I)/100
1920
ADGABC(I)=ADGMU+(ADGGI(J)+ADGGI(K)+ADGGI(L))/3+(ADGGM(J)+ADGGM(K)+ADGGM(
L))/3+6*(ADGHI(N)+ADGHI(O)+ADGHI(M))/21+6*(ADGHM(N)+ADGHM(O)+ADGHM(M))/2
1
1930
BFABC(I)=BFMU+(BFGI(J)+BFGI(K)+BFGI(L))/3+(BFGM(J)+BFGM(K)+BFGM(L))/3+6*
(BFHI(N)+BFHI(O)+BFHI(M))/21+6*(BFHM(N)+BFHM(O)+BFHM(M))/21
1940
FGABC(I)=FGMU+(FGGI(J)+FGGI(K)+FGGI(L))/3+(FGGM(J)+FGGM(K)+FGGM(L))/3+6*
(FGHI(N)+FGHI(O)+FGHI(M))/21+6*(FGHM(N)+FGHM(O)+FGHM(M))/21
1950 NEXT L,K,J:I=0
1960 PRINT:PRINT:PRINT "3 BREED ROTATION":PRINT
1970 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
1980 PRINT STRING$(62,"-"):FOR I=1 TO 4:READ B$(I):NEXT I
1990 DATA DYL,DYS,DLS,YLS
2000 PRINT "BREED   CR      LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
2010 FOR I=1 TO 4
2020 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRABC(I),LSBABC(I),SURABC(I),LSWABC(I),ADGABC(I),BFABC(I),FGABC(
I):NEXT I: PRINT STRING$(62,"-")
2030 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
2040 '
2050 '4 BREED ROTATION
2060 J=1:K=2:L=3:M=4
2070 N=4:O=1:P=2:Q=3:R=5:S=6:I=1
```

```
2080
CRABCD(I)=CRMU+.25*(CRGIM(J)+CRGIM(K)+CRGIM(L)+CRGIM(M))+14*(CRHM(O)+CRH
M(P)+CRHM(Q)+CRHM(N)+CRHM(R)+CRHM(S))/90
2090
LSBABCD(I)=LSBMU+.25*(LSBGIM(J)+LSBGIM(K)+LSBGIM(L)+LSBGIM(M))+14*(LSBHM
(O)+LSBHM(P)+LSBHM(Q)+LSBHM(N)+LSBHM(R)+LSBHM(S))/90
2100
SURMGIM=SURMU+.25*(SURGI(J)+SURGI(K)+SURGI(L)+SURGI(M))+.25*(SURGM(J)+SU
RGM(K)+SURGM(L)+SURGM(M))
2110
SURABCD(I)=SURMGIM+14*(SURHI(O)+SURHI(P)+SURHI(Q)+SURHI(N)+SURHI(R)+SURH
I(S))/90+14*(SURHM(O)+SURHM(P)+SURHM(Q)+SURHM(N)+SURHM(R)+SURHM(S))/90
2120 LSWABCD(I)=LSBABCD(I)*SURABCD(I)/100
2130
ADGMGIM=ADGMU+.25*(ADGGI(J)+ADGGI(K)+ADGGI(L)+ADGGI(M))+.25*(ADGGM(J)+AD
GGM(K)+ADGGM(L)+ADGGM(M))
2140
ADGABCD(I)=ADGMGIM+14*(ADGHI(O)+ADGHI(P)+ADGHI(Q)+ADGHI(N)+ADGHI(R)+ADGH
I(S))/90+14*(ADGHM(O)+ADGHM(P)+ADGHM(Q)+ADGHM(N)+ADGHM(R)+ADGHM(S))/90
2150
BFABCD(I)=BFMU+.25*(BFGI(J)+BFGI(K)+BFGI(L)+BFGI(M))+.25*(BFGM(J)+BFGM(K
)+BFGM(L)+BFGM(M))+14*(BFHI(O)+BFHI(P)+BFHI(Q)+BFHI(N)+BFHI(R)+BFHI(S))/
90+14*(BFHM(O)+BFHM(P)+BFHM(Q)+BFHM(N)+BFHM(R)+BFHM(S))/90
2160
FGABCD(I)=FGMU+.25*(FGGI(J)+FGGI(K)+FGGI(L)+FGGI(M))+.25*(FGGM(J)+FGGM(K
)+FGGM(L)+FGGM(M))+14*(FGHI(O)+FGHI(P)+FGHI(Q)+FGHI(N)+FGHI(R)+FGHI(S))/
90+14*(FGHM(O)+FGHM(P)+FGHM(Q)+FGHM(N)+FGHM(R)+FGHM(S))/90
2170 PRINT:PRINT:PRINT "4 BREED ROTATION":PRINT
2180 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
2190 PRINT STRING$(62,"-"):READ B$(I)
2200 DATA DYLS
2210 PRINT "BREED   CR      LSB      SUR       LSW       ADG      BF
FG":PRINT STRING$(62,"-")
2220 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRABCD(I),LSBABCD(I),SURABCD(I),LSWABCD(I),ADGABCD(I),BFABCD(I),
FGABCD(I): PRINT STRING$(62,"-")
2230 PRINT: INPUT "PRESS ENTER ";Z$:CLS:I=0
2240 '
2250 '3 BREED COMBINATIONS
2260 FOR J=1 TO 4: FOR K=1 TO 3: FOR L=2 TO 4
2270 IF J=K OR J=L THEN 2550
2280 IF L§=K THEN 2550
2290 IF K=1 AND L=2 OR K=2 AND L=1 THEN M=1
2300 IF K=1 AND L=3 OR K=3 AND L=1 THEN M=2
2310 IF K=1 AND L=4 OR K=4 AND L=1 THEN M=3
2320 IF K=2 AND L=3 OR K=3 AND L=2 THEN M=4
2330 IF K=2 AND L=4 OR K=4 AND L=2 THEN M=5
2340 IF K=3 AND L=4 OR K=4 AND L=3 THEN M=6
2350 IF J=1 AND K=2 OR J=2 AND K=1 THEN N=1
2360 IF J=1 AND K=3 OR J=3 AND K=1 THEN N=2
2370 IF J=1 AND K=4 OR J=4 AND K=1 THEN N=3
2380 IF J=2 AND K=3 OR J=3 AND K=2 THEN N=4
2390 IF J=2 AND K=4 OR J=4 AND K=2 THEN N=5
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2400 IF J=3 AND K=4 OR J=4 AND K=3 THEN N=6
2410 IF J=1 AND L=2 OR J=2 AND L=1 THEN O=1
2420 IF J=1 AND L=3 OR J=3 AND L=1 THEN O=2
2430 IF J=1 AND L=4 OR J=4 AND L=1 THEN O=3
2440 IF J=2 AND L=3 OR J=3 AND L=2 THEN O=4
2450 IF J=2 AND L=4 OR J=4 AND L=2 THEN O=5
2460 IF J=3 AND L=4 OR J=4 AND L=3 THEN O=6
2470 I=I+1
2480 CR3BC(I)=CRMU+.5*(CRGIM(K)+CRGIM(L))+2*CRHM(M)/3
2490 LSB3BC(I)=LSBMU+.5*(LSBGIM(K)+LSBGIM(L))+2*LSBHM(M)/3
2500
SUR3BC(I)=SURMU+.25*(2*SURGI(J)+SURGI(K)+SURGI(L))+.5*(SURGM(K)+SURGM(L)
)+.5*(SURHI(N)+SURHI(O))+2*SURHM(M)/3
2510 LSW3BC(I)=LSB3BC(I)*SUR3BC(I)/100
2520
ADG3BC(I)=ADGMU+.25*(2*ADGGI(J)+ADGGI(K)+ADGGI(L))+.5*(ADGGM(K)+ADGGM(L)
)+.5*(ADGHI(N)+ADGHI(O))+2*ADGHM(M)/3
2530
BF3BC(I)=BFMU+.25*(2*BFGI(J)+BFGI(K)+BFGI(L))+.5*(BFGM(K)+BFGM(L))+.5*(B
FHI(N)+BFHI(O))+2*BFHM(M)/3
2540
FG3BC(I)=FGMU+.25*(2*FGGI(J)+FGGI(K)+FGGI(L))+.5*(FGGM(K)+FGGM(L))+.5*(F
GHI(N)+FGHI(O))+2*FGHM(M)/3
2550 NEXT L,K,J:I=0
2560 PRINT:PRINT:PRINT "TERMINAL SIRE BREED X 2 BREED ROTATION
FEMALES":PRINT
2570 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
2580 PRINT STRING$(62,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
2590 DATA DxYL,DxYS,DxLS,YxDL,YxDS,YxLS,LxDY,LxDS,LxYS,SxDY,SxDL,SxYL
2600 PRINT "BREED   CR     LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
2610 FOR I=1 TO 12
2620 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CR3BC(I),LSB3BC(I),SUR3BC(I),LSW3BC(I),ADG3BC(I),BF3BC(I),FG3BC(
I):NEXT I: PRINT STRING$(62,"-")
2630 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
2640 '
2650 '4 BREED COMBINATIONS
2660 FOR J=1 TO 4: FOR K=1 TO 2: FOR L=2 TO 3: FOR M=3 TO 4
2670 IF L§=K OR M§=L THEN GOTO 3130
2680 IF J=K OR J=L OR J=M THEN 3130
2690 IF K=1 AND L=2 OR K=2 AND L=1 THEN N=1
2700 IF K=1 AND L=3 OR K=3 AND L=1 THEN N=2
2710 IF K=1 AND L=4 OR K=4 AND L=1 THEN N=3
2720 IF K=2 AND L=3 OR K=3 AND L=2 THEN N=4
2730 IF K=2 AND L=4 OR K=4 AND L=2 THEN N=5
2740 IF K=3 AND L=4 OR K=4 AND L=3 THEN N=6
2750 IF J=1 AND K=2 OR J=2 AND K=1 THEN O=1
2760 IF J=1 AND K=3 OR J=3 AND K=1 THEN O=2
2770 IF J=1 AND K=4 OR J=4 AND K=1 THEN O=3
2780 IF J=2 AND K=3 OR J=3 AND K=2 THEN O=4
2790 IF J=2 AND K=4 OR J=4 AND K=2 THEN O=5
2800 IF J=3 AND K=4 OR J=4 AND K=3 THEN O=6
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```
2810 IF J=1 AND L=2 OR J=2 AND L=1 THEN P=1
2820 IF J=1 AND L=3 OR J=3 AND L=1 THEN P=2
2830 IF J=1 AND L=4 OR J=4 AND L=1 THEN P=3
2840 IF J=2 AND L=3 OR J=3 AND L=2 THEN P=4
2850 IF J=2 AND L=4 OR J=4 AND L=2 THEN P=5
2860 IF J=3 AND L=4 OR J=4 AND L=3 THEN P=6
2870 IF J=1 AND M=2 OR J=2 AND M=1 THEN Q=1
2880 IF J=1 AND M=3 OR J=3 AND M=1 THEN Q=2
2890 IF J=1 AND M=4 OR J=4 AND M=1 THEN Q=3
2900 IF J=2 AND M=3 OR J=3 AND M=2 THEN Q=4
2910 IF J=2 AND M=4 OR J=4 AND M=2 THEN Q=5
2920 IF J=3 AND M=4 OR J=4 AND M=3 THEN Q=6
2930 IF K=1 AND M=2 OR K=2 AND M=1 THEN R=1
2940 IF K=1 AND M=3 OR K=3 AND M=1 THEN R=2
2950 IF K=1 AND M=4 OR K=4 AND M=1 THEN R=3
2960 IF K=2 AND M=3 OR K=3 AND M=2 THEN R=4
2970 IF K=2 AND M=4 OR K=4 AND M=2 THEN R=5
2980 IF K=3 AND M=4 OR K=4 AND M=3 THEN R=6
2990 IF L=1 AND M=2 OR L=2 AND M=1 THEN S=1
3000 IF L=1 AND M=3 OR L=3 AND M=1 THEN S=2
3010 IF L=1 AND M=4 OR L=4 AND M=1 THEN S=3
3020 IF L=2 AND M=3 OR L=3 AND M=2 THEN S=4
3030 IF L=2 AND M=4 OR L=4 AND M=2 THEN S=5
3040 IF L=3 AND M=4 OR L=4 AND M=3 THEN S=6
3050 I=I+1
3060
CR4BC(I)=CRMU+(CRGIM(K)+CRGIM(L)+CRGIM(M))/3+6*(CRHM(N)+CRHM(R)+CRHM(S))
/21
3070
LSB4BC(I)=LSBMU+(LSBGIM(K)+LSBGIM(L)+LSBGIM(M))/3+6*(LSBHM(N)+LSBHM(R)+L
SBHM(S))/21
3080
SUR4BC(I)=SURMU+(3*SURGI(J)+SURGI(K)+SURGI(L)+SURGI(M))/6+(SURGM(K)+SURG
M(L)+SURGM(M))/3+(SURHI(O)+SURHI(P)+SURHI(Q))/3+6*(SURHM(N)+SURHM(R)+SUR
HM(S))/21
3090 LSW4BC(I)=LSB4BC(I)*SUR4BC(I)/100
3100
ADG4BC(I)=ADGMU+(3*ADGGI(J)+ADGGI(K)+ADGGI(L)+ADGGI(M))/6+(ADGGM(K)+ADGG
M(L)+ADGGM(M))/3+(ADGHI(O)+ADGHI(P)+ADGHI(Q))/3+6*(ADGHM(N)+ADGHM(R)+ADG
HM(S))/21
3110
BF4BC(I)=BFMU+(3*BFGI(J)+BFGI(K)+BFGI(L)+BFGI(M))/6+(BFGM(K)+BFGM(L)+BFG
M(M))/3+(BFHI(O)+BFHI(P)+BFHI(Q))/3+6*(BFHM(N)+BFHM(R)+BFHM(S))/21
3120
FG4BC(I)=FGMU+(3*FGGI(J)+FGGI(K)+FGGI(L)+FGGI(M))/6+(FGGM(K)+FGGM(L)+FGG
M(M))/3+(FGHI(O)+FGHI(P)+FGHI(Q))/3+6*(FGHM(N)+FGHM(R)+FGHM(S))/21
3130 NEXT M,L,K,J:I=0
3140 PRINT:PRINT:PRINT "TERMINAL SIRE BREED X 3 BREED ROTATION
FEMALES":PRINT
3150 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
3160 PRINT STRING$(62,"-"):FOR I=1 TO 4:READ B$(I):NEXT I
3170 DATA DxYLS,YxDLS,LxDYS,SxDYL
3180 PRINT "BREED   CR      LSB      SUR      LSW      ADG      BF
FG":PRINT STRING$(62,"-")
```

```
3190 FOR I=1 TO 4
3200 PRINT USING "³   ³  ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CR4BC(I),LSB4BC(I),SUR4BC(I),LSW4BC(I),ADG4BC(I),BF4BC(I),FG4BC(
I):NEXT I: PRINT STRING$(62,"-")
3210 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
3220 '
3230 '------------------------------------------------------------------
------
3240 '
3250 ' CALCULATING THE NUMBER OF FEMALES FARROWING IN EACH SUB-SYSTEM
3260 '
3270 '   T - TOTAL NUMBER FEMALES FARROWING IN THE SYSTEM
3280 ' FMR - NUMBER OF FEMALES / MALE IN BREEDING HERD
3290 ' PSP - PROBABILITY OF SURVIVING FROM WEANING (42d) TO 100KG
(PUREBREDS)
3300 ' PSC - PROBABILITY OF SURVIVING FROM WEANING (42d) TO 100KG
(CROSSBREDS)
3310 '  NOTE: POSTWEANING SURVIVAL SHOULD REALLY BE CALCULATED FOR EACH
SYSTEM,
3320 '       AS FOR THE OTHER TRAITS. LACK OF LITERATURE PARAMETER
ESTIMATES
3330 '       AND THE RELATIVELY SMALL EXPECTED DIFFERENCES BETWEEN
DIFFERENT
3340 '       CROSSBREEDING SYSTEMS MAKE THIS SIMPLIFYING ASSUMPTION
REASONABLE.4440 '        REASONABLE
3350 ' FRP - PROPORTION OF FEMALES REPLACED EACH BREEDING CYCLE
(PUREBREDS)          ' FRC - PROPORTION OF FEMALES REPLACED EACH
BREEDING CYCLE (CROSSBREDS)
3360 ' MRP - PROPORTION OF MALES REPLACED EACH BREEDING CYCLE (PUREBRED
HERDS)
3370 ' MRC - PROPORTION OF MALES REPLACED EACH BREEDING CYCLE (CROSSBRED
HERDS)
3380 '  FS - PROPORTION OF FEMALE OFFSPRING SELECTED AS REPLACEMENTS IN
HERDS                GENERATING FEMALE REPLACEMENTS
3390 '  MS - PROPORTION OF MALE OFFSPRING SELECTED AS REPLACEMENTS IN
HERDS                  GENERATING MALE REPLACEMENTS
3400 '
3410 T=10000
3420 FMR=10
3430 PSP=.97
3440 PSC=.98
3450 FRP=.5          ' .15 ? PROBABLY MORE REASONABLE IN PRACTISE,
HOWEVER SEE
3460 FRC=.5          '       NOTE WITH FIB IN ECONOMIC CALCULATIONS BELOW
3470 MRP=.5
3480 MRC=.5
3490 FS=.8
3500 MS=.6
3510 '
3520 '
3530 'The next section calculates FM and FF for purebreds and 2 and 3
breed     rotations. These are the only ones necessary for these
calculations.'
```

```
3540 'FM =( # FEMALES REQUIRED TO PRODUCE NEEDED BOARS) / (TOTAL #
FEMALES                IN SUB-SYSTEMS THE BOARS ARE USED IN)
3550 'FF =( # FEMALES REQUIRED TO PRODUCE NEEDED GILTS) / (TOTAL #
FEMALES                IN SUB-SYSTEMS THE GILTS ARE USED IN)
3560 CLS
3570 PRINT "FM and FF for purebreds"
3580 FOR I = 1 TO 4
3590 FMP(I) = 2*MRP/FMR/MS/PSP/LSWP(I)
3600 FFP(I) = 2*FRP/FS/PSP/LSWP(I)
3610 PRINT USING "#########.#####";FMP(I),FFP(I)
3620 NEXT I
3630 PRINT
3640 PRINT "FM and FF for 2 breed rotations"
3650 FOR J = 1 TO 6
3660 FMAB(J) = 2*MRC/FMR/MS/PSC/LSWAB(J)
3670 FFAB(J) = 2*FRC/FS/PSC/LSWAB(J)
3680 PRINT USING "#########.#####";FMAB(J),FFAB(J)
3690 NEXT J
3700 'INPUT "PRESS ENTER ";Z$
3710 PRINT
3720 PRINT "FM and FF for 3 breed rotations"
3730 FOR K = 1 TO 4
3740 FMABC(K) = 2*MRC/FMR/MS/PSC/LSWABC(K)
3750 FFABC(K) = 2*FRC/FS/PSC/LSWABC(K)
3760 PRINT USING "#########.#####";FMABC(K),FFABC(K)
3770 NEXT K
3780 INPUT "PRESS ENTER ";Z$:CLS
3790 PRINT
3800 'This section calculates the structure for the 2 BREED ROTATIONS.
The      screen output shows the two breeds and the numbers for Purebred
A, Purebred B   and the AB rotation.'
3810 PRINT "     STRUCTURE FOR 2 BREED ROTATIONS":PRINT
3820 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(42,"-
")
3830 PRINT "     A     B    #A    #B    #AB":PRINT STRING$(42,"-")
3840 K=0
3850 FOR I=1 TO 3: FOR J=2 TO 4
3860 IF J §=I GOTO 3920
3870 K=K+1
3880 STRAB(K,3)=T/((FMP(I)/(2*(1-FMP(I))))+(FMP(J)/(2*(1-FMP(J))))+1) '
ABrot
3890 STRAB(K,1)=FMP(I)*STRAB(K,3)/(2*(1-FMP(I))) '
Purebred
3900 STRAB(K,2)=FMP(J)*STRAB(K,3)/(2*(1-FMP(J))) '
Purebred
3910 PRINT USING "######.";I,J,STRAB(K,1),STRAB(K,2),STRAB(K,3)
3920 NEXT J,I
3930 PRINT:INPUT "PRESS ENTER ";Z$
3940 CLS
3950 PRINT
3960 'This section calculates the structure for the 3 BREED ROTATIONS.
The      screen output shows the three breeds and the numbers for
Purebred A, Purebred B,Purebred C and the ABC rotation. '
3970 PRINT "     STRUCTURE FOR 3 BREED ROTATIONS":PRINT
```

```
3980 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(50,"-
")
3990 PRINT "     A     B     C     #A     #B     #C  #ABC":PRINT
STRING$(50,"-")
4000 L=0
4010 FOR I=1 TO 2: FOR J=2 TO 3
4020 IF J §= I GOTO 4120
4030 FOR K=3 TO 4
4040 IF K§= J GOTO 4110
4050 L = L+1
4060 STRABC(L,4) = T/((FMP(I)/(3*(1-FMP(I))))+(FMP(J)/(3*(1-
FMP(J))))+(FMP(K)/(3*(1-FMP(K))))+1)
'   ABC rotation
4070 STRABC(L,1) = FMP(I)*STRABC(L,4)/(3*(1-FMP(I)))          '
purebred A
4080 STRABC(L,2) = FMP(J)*STRABC(L,4)/(3*(1-FMP(J)))          '
purebred B
4090 STRABC(L,3) = FMP(K)*STRABC(L,4)/(3*(1-FMP(K)))          '
purebred C
4100 PRINT USING
"######.";I,J,K,STRABC(L,1),STRABC(L,2),STRABC(L,3),STRABC(L,4)
4110 NEXT K
4120 NEXT J,I
4130 PRINT:INPUT "PRESS ENTER ";Z$
4140 CLS
4150 PRINT
4160 'This section calculates the structure for the 4 BREED ROTATION.
With 4   breeds there is only one. The screen output shows the 4 breeds
and the numbers  for each purebred type and the ABCD rotation.'
4170 PRINT "     STRUCTURE FOR 4 BREED ROTATIONS":PRINT
4180 PRINT STRING$(46,"-")
4190 PRINT "    #D    #Y    #L    #S  #DYLS":PRINT STRING$(46,"-")
4200 STRABCD(5) = T/((FMP(1)/(4*(1-FMP(1))))+(FMP(2)/(4*(1-
FMP(2))))+(FMP(3)/(4*(1-FMP(3))))+(FMP(4)/(4*(1-FMP(4))))+1)
' ABCD rotation
4210 STRABCD(1) = FMP(1)*STRABCD(5)/(4*(1-FMP(1)))            '
Purebred D
4220 STRABCD(2) = FMP(2)*STRABCD(5)/(4*(1-FMP(2)))            '
Purebred Y
4230 STRABCD(3) = FMP(3)*STRABCD(5)/(4*(1-FMP(3)))            '
Purebred L
4240 STRABCD(4) = FMP(4)*STRABCD(5)/(4*(1-FMP(4)))            '
Purebred S
4250 PRINT USING
"######.";STRABCD(1),STRABCD(2),STRABCD(3),STRABCD(4),STRABCD(5)
4260 PRINT:INPUT "PRESS ENTER ";Z$
4270 CLS
4280 PRINT
4290 'This section calculates the structure for the 3 BREED SPECIALIZED
CROSSES where C males are mated to ABrot females. The M variables are
used to recall theFM and FF values for the rotation females.'
4300 ' The screen output shows the breeds involved (C, A, B) and the
numbers for the 3 purebreds (C, A, B), the ABrot, and the CxAB terminal
cross'
```

```
4310 PRINT "STRUCTURE FOR TERMINAL SIRE BREED X 2 BREED ROTATION FEMALES
4320 PRINT:PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT
STRING$(54,"-")
4330 PRINT "     C      A      B     #C     #A     #B   #AB    #CxAB":PRINT
STRING$(54,"-")
4340 L=0
4350 FOR I = 1 TO 4
4360 LL=0
4370 FOR J=1 TO 3: FOR K=2 TO 4
4380 IF I = J OR I = K GOTO 4530
4390 IF K §=J GOTO 4530
4400 IF J = 1 AND K = 2 THEN M = 1
4410 IF J = 1 AND K = 3 THEN M = 2
4420 IF J = 1 AND K = 4 THEN M = 3
4430 IF J = 2 AND K = 3 THEN M = 4
4440 IF J = 2 AND K = 4 THEN M = 5
4450 IF J = 3 AND K = 4 THEN M = 6
4460 L=L+1
4470 STR3BC(L,5)=T/((FFAB(M)/(2*(1-FFAB(M)))*(FMP(J)/(1-
FMP(J))+FMP(K)/(1-FMP(K))))+FMP(I)/(1-FMP(I))+FFAB(M)/(1-FFAB(M))+1)
' Crossbred CxABrot
4480 STR3BC(L,4)=FFAB(M)*STR3BC(L,5)/(1-FFAB(M))      ' Crossbred ABrot
4490 STR3BC(L,3)=FMP(I)*STR3BC(L,5)/(1-FMP(I))        ' Purebred C
4500 STR3BC(L,2)=FMP(K)*STR3BC(L,4)/(2*(1-FMP(K)))    ' Purebred B
4510 STR3BC(L,1)=FMP(J)*STR3BC(L,4)/(2*(1-FMP(J)))    ' Purebred A
4520 PRINT USING
"######.";I,J,K,STR3BC(L,3),STR3BC(L,1),STR3BC(L,2),STR3BC(L,4),STR3BC(L
,5)
4530 NEXT K,J,I
4540 PRINT:INPUT "PRESS ENTER ";Z$
4550 CLS
4560 PRINT
4570 'This section calculates the structure for the 4 BREED SPECIALIZED
CROSSES (DxABCrot). The M variable is used to recall the values for FM
and FF for the   rotation females.'
4580 'The screen output shows the breeds used (D,A,B,C) and the numbers
for the purebreds (D, A, B, C), the ABC rotation and the DxABCrot
terminal crosses.'
4590 PRINT "STRUCTURE FOR TERMINAL SIRE BREED X 3 BREED ROTATION FEMALES
4600 PRINT:PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT
STRING$(64,"-")
4610 PRINT "     D      A      B      C     #D     #A     #B    #C    #ABC
#DxABC":PRINT STRING$(64,"-")
4620 L=0
4630 FOR I=1 TO 4: FOR J=1 TO 2: FOR K=2 TO 3
4640 IF K §=J GOTO 4810
4650 FOR N = 3 TO 4
4660 IF N §= K GOTO 4800
4670 IF I = J OR I = K OR I = N GOTO 4800
4680 IF J = 1 AND K = 2 AND N = 3 THEN M = 1
4690 IF J = 1 AND K = 2 AND N = 4 THEN M = 2
4700 IF J = 1 AND K = 3 AND N = 4 THEN M = 3
4710 IF J = 2 AND K = 3 AND N = 4 THEN M=4
4720 L=L+1
```

```
4730 STR4BC(L,6)=T/((FFABC(M)/(3*(1-FFABC(M))))*(FMP(J)/(1-
FMP(J))+FMP(K)/(1-FMP(K))+FMP(N)/(1-FMP(N)))+FMP(I)/(1-
FMP(I))+FFABC(M)/(1-FFABC(M))+1) 'Cross DxABC
4740 STR4BC(L,5)=FFABC(M)*STR4BC(L,6)/(1-FFABC(M))                ' Rot
ABC
4750 STR4BC(L,4) = FMP(I)*STR4BC(L,6)/(1-FMP(I))                 '
Purebred D
4760 STR4BC(L,3) = FMP(N)*STR4BC(L,5)/(3*(1-FMP(N)))             '
Purebred C
4770 STR4BC(L,2) = FMP(K)*STR4BC(L,5)/(3*(1-FMP(K)))             '
Purebred B
4780 STR4BC(L,1) = FMP(J)*STR4BC(L,5)/(3*(1-FMP(J)))             '
Purebred A
4790 PRINT USING
"######.";I,J,K,N,STR4BC(L,4),STR4BC(L,1),STR4BC(L,2),STR4BC(L,3),STR4BC
(L,5),STR4BC(L,6)
4800 NEXT N
4810 NEXT K,J,I
4820 PRINT:INPUT "PRESS ENTER ";Z$
4830 '
4840 '
4850 ' CALCULATING BREEDING TO REBREEDING INTERVAL
4860 '
4870 'NOTE: 160 = 113d GESTATION + 42d LACTATION + 5d TO FIRST ESTRUS
4880 'FEMALES THAT FAIL TO CONCEIVE BY SECOND ESTRUS ARE CULLED.
THEREFORE:
4890 '
4900 BCIABCD(1)=160+(1-CRABCD(1)/100)*21
4910 FOR I=1 TO 4
4920 BCIP(I)=160+(1-CRP(I)/100)*21
4930 BCIABC(I)=160+(1-CRABC(I)/100)*21
4940 BCI4BC(I)=160+(1-CR4BC(I)/100)*21
4950 NEXT I:I=0
4960 FOR I=1 TO 6
4970 BCIAB(I)=160+(1-CRAB(I)/100)*21
4980 NEXT I:I=0
4990 FOR I=1 TO 12
5000 BCI3BC(I)=160+(1-CR3BC(I)/100)*21
5010 NEXT I
5020 '
5030 '------------------------------------------------------------------
------
5040 '
5050 ' CALCULATE EFFICIENCY FOR EACH SUB-SYSTEM
5060 '
5070 ' NOTE : EFFICIENCY = (LIFETIME COSTS/DAM) / (LIFETIME PRODUCT/DAM)
E () = C () / P ()
5080 '
5090 ' BCI() - BREEDING TO REBREEDING INTERVAL (DAYS)
5100 ' CONSTANTS :
5110 ' LOCG - GROWING-FINISHING LABOR & OVERHEAD COSTS FROM 40-220lb/
5120 '                                                          MARKET
PIG/DAY ($)
```

```
5130 ' LOCR - LABOR & OVERHEAD COSTS OF REPRODUCTION/SOW FARROWED/DAY
($)
5140 '   GP - GILT COSTS FROM 220lb TO FIRST BREEDING ($)
5150 '  FIB - BREEDING HERD (MALES, FEMALES, LITTERS) FEED
INTAKE/SOW/DAY (KG)
5160 '        (SHOULD PROBABLY BE A VARIABLE, SEE NOTE BELOW)
5170 '  FCB - COST OF BREEDING HERD RATION ($/KG)
5180 '  FCG - COST OF GROWING / FINISHING RATION. ($/KG)
5190 '
5200 ' ECONOMIC PARAMETER ESTIMATES ARE CALCULATED FROM "ESTIMATED
RETURNS FROM
5210 ' FARROWING AND FINISHING HOGS IN IOWA" FOR THE 10 YEARS 1974-1983,
5220 ' PUBLISHED BY THE IOWA STATE UNIVERSITY COOPERATIVE EXTENSION
SERVICE
5230 ' ( REPORTS  M-1171, FEB 1974;  M-1198(REV), JUNE 1980;  M-1231,
JAN 1983 )5408 '
5240 LOCG=.136
5250 LOCR=.867
5260 GP=30!        ' CALC. AS 110% OF TOTAL FINISHING COSTS FOR 60 DAY
PERIOD
5270 FIB=3.728     ' NOTE: FIB SHOULD REALLY BE TREATED AS VARIABLE. THE
IOWA
5280               '       FIGURES ARE BASED ON REPLACING SOWS AFTER 2
LITTERS,
5290               '       i.e. FIB DEPENDS UPON FR, AS WELL AS LSW,
ETC.
5300 FCB=.129
5310 FCG=.126
5320 '
5330 CLS:PRINT:PRINT:PRINT "     ECONOMIC CONSTANTS ASSUMED":PRINT
5340 PRINT "     LOCG      LOCR      GP        FIB       FCB
FCG":PRINT
5350 PRINT USING "     .###      .###      ##.#     #.###     .###
.###";LOCG,LOCR,GP,FIB,FCB,FCG:PRINT
5360 PRINT"LOCG - GROWING-FINISHING LABOR & OVERHEAD COSTS FROM 40-
220lb/"
5370 PRINT"                                                      MARKET
PIG/DAY ($)"
5380 PRINT"LOCR - LABOR & OVERHEAD COSTS OF REPRODUCTION/SOW
FARROWED/DAY ($)"
5390 PRINT"  GP - GILT COSTS FROM 220lb TO FIRST BREEDING ($)"
5400 PRINT" FIB - BREEDING HERD (MALES, FEMALES, LITTERS) FEED
INTAKE/SOW/DAY (KG)"
5410 PRINT" FCB - COST OF BREEDING HERD RATION ($/KG)"
5420 PRINT" FCG - COST OF GROWING / FINISHING RATION. ($/KG)"
5430 PRINT:INPUT "PRESS ENTER ";Z$
5440 '
5450 ' CALCULATING CG (COST OF POSTWEANING GROWTH / DAM / LITTER)
5460 '
5470 ' CG = [ (1+PS)/2 * LSW ] * [ (final - wean wt)/ADG * (LOCG +
FCG*ADG*FG) ]9745 ' CG = [ pigs/dam/litter ]*[ costs/pig ]
5480 '
```

```
5490
CGABCD(1)=(1+PSC)/2*LSWABCD(1)*81.64701/ADGABCD(1)*(LOCG+FCG*ADGABCD(1)*
FGABCD(1))
5500 CLS:PRINT " CGABCD(1)":PRINT:PRINT CGABCD(1):PRINT
5510 PRINT " CGP(I)        CGABC(I)      CG4BC(I)":PRINT
5520 FOR I=1 TO 4
5530 CGP(I)=(1+PSP)/2*LSWP(I)*81.64701/ADGP(I)*(LOCG+FCG*ADGP(I)*FGP(I))
5540
CGABC(I)=(1+PSC)/2*LSWABC(I)*81.64701/ADGABC(I)*(LOCG+FCG*ADGABC(I)*FGAB
C(I))
5550
CG4BC(I)=(1+PSC)/2*LSW4BC(I)*81.64701/ADG4BC(I)*(LOCG+FCG*ADG4BC(I)*FG4B
C(I))
5560 PRINT CGP(I),CGABC(I),CG4BC(I)
5570 NEXT I
5580 PRINT:PRINT " CGAB(I)":PRINT
5590 FOR I=1 TO 6
5600
CGAB(I)=(1+PSC)/2*LSWAB(I)*81.64701/ADGAB(I)*(LOCG+FCG*ADGAB(I)*FGAB(I))
5610 PRINT CGAB(I)
5620 NEXT I
5630 PRINT:INPUT "PRESS ENTER ";Z$:CLS
5640 PRINT:PRINT " CG3BC(I)":PRINT
5650 FOR I=1 TO 12
5660
CG3BC(I)=(1+PSC)/2*LSW3BC(I)*81.64701/ADG3BC(I)*(LOCG+FCG*ADG3BC(I)*FG3B
C(I))
5670 PRINT CG3BC(I)
5680 NEXT I
5690 PRINT:INPUT "PRESS ENTER ";Z$:CLS
5700 '
5710 ' CALCULATING CB (REPRODUCTION COSTS / DAM / LIFETIME)
5720 '
5730 ' CB = (COST OF BREEDING STOCK (GILT + BOAR SHARE ) AT FIRST MATING
5740 '      + (# LITTERS) * BCI() * (LOCR + FCB*FIB)
5750 '
5760 '    = [1 + MR/(FMR*FR)] * [ CB()/(PS*LSW/FR) + CG()/(PS*LSW) + GP
]
5770 '      note : cb & cg values for the system replacements produced
in
5780 '      + [ (1/FR) ] * BCI * [ LOCR + FCB*FIB ]
5790 '
5800 ' FOR PUREBRED SYSTEMS, CB & CB() ARE FOR THE SAME SYSTEM.
MULTIPLYING THRU      AND SIMPLIFYING RESULTS IN :
5810 ' CB = [ (1+MR/(FM*FR))*(CG/(PS*LSW)+GP) +
(1/FR)*BCI*(LOCR+(FCB*FIB))            / [ 1 - FR/(PS*LSW) -
MR/(FMR*PS*LSW) ] i.e.,
5820 '
5830 PRINT:PRINT " CBP(I)":PRINT
5840 FOR I=1 TO 4
5850
CBP(I)=((1+(MRP/(FMR*FRP)))*((100*CGP(I))/(PSP*LSWP(I)*CRP(I))+(100*GP/C
RP(I)))+((1/FRP)*BCIP(I)*(LOCR+(FCB*FIB))))/(1-
(100*FRP)/(PSP*LSWP(I)*CRP(I))-(100*MRP)/(FMR*PSP*LSWP(I)*CRP(I)))
```

```
5860 PRINT CBP(I)
5870 NEXT I
5880 '
5890 ' FOR ALL SYSTEMS REQUIRING ONLY PUREBRED MALES FROM OUTSIDE THE
SYSTEM
5900 ' (I.E. ROTATIONAL SYSTEMS), THE BOAR SHARE OF COSTS
5910 ' (CALCULATED BY THE MR/(FMR*FR) COEFFICIENT) DEPENDS UPON THE
WEIGHTED
5920 ' AVERAGE CB(I) AND CG(I) FOR THE PUREBREDS INVOLVED. THE FOLLOWING
5930 ' VARIABLE (XP) IS FIRST CALCULATED FOR EACH PUREBRED :
5940 '
5950 PRINT:PRINT " XP(I)":PRINT
5960 FOR I=1 TO 4
5970 XP(I)=(FRP*CBP(I)+CGP(I))/(PSP*LSWP(I))
5980 PRINT XP(I)
5990 NEXT I
6000 PRINT:INPUT "PRESS ENTER ";Z$:CLS
6010 '
6020 'AND USED IN THE FOLLOWING EQUATIONS, WHERE BOAR IS THE WEIGHTED
AVERAGE:
6030 '
6040 '4 BREED ROTATION
6050
BOAR=(STRABCD(1)*XP(1)+STRABCD(2)*XP(2)+STRABCD(3)*XP(3)+STRABCD(4)*XP(4
))/(STRABCD(1)+STRABCD(2)+STRABCD(3)+STRABCD(4))
6060
CBABCD(1)=(CGABCD(1)/(PSC*LSWABCD(1))+(1+MRC/(FMR*FRC))*(100*GP/CRABCD(1
))+(MRC/(FMR*FRC))*BOAR+(1/FRC)*BCIABCD(1)*(LOCR+FCB*FIB))/(1-
FRC/(PSC*LSWABCD(1)))
6070 PRINT:PRINT " CBABCD(1)":PRINT:PRINT CBABCD(1):PRINT
6080 '
6090 '3 BREED ROTATIONS
6100 PRINT " CBABC(I)":PRINT
6110 FOR I=1 TO 4
6120 IF I=1 THEN J=1:K=2:L=3
6130 IF I=2 THEN J=1:K=2:L=4
6140 IF I=3 THEN J=1:K=3:L=4
6150 IF I=4 THEN J=2:K=3:L=4
6160
BOAR=(STRABC(I,1)*XP(J)+STRABC(I,2)*XP(K)+STRABC(I,3)*XP(L))/(STRABC(I,1
)+STRABC(I,2)+STRABC(I,3))
6170
CBABC(I)=(CGABC(I)/(PSC*LSWABC(I))+(1+MRC/(FMR*FRC))*(100*GP/CRABC(I))+(
MRC/(FMR*FRC))*BOAR+(1/FRC)*BCIABC(I)*(LOCR+FCB*FIB))/(1-
FRC/(PSC*LSWABC(I)))
6180 PRINT CBABC(I)
6190 NEXT I
6200 '
6210 '2 BREED ROTATIONS
6220 PRINT:PRINT " CBAB(I)":PRINT
6230 FOR I=1 TO 6
6240 IF I=1 THEN J=1:K=2
6250 IF I=2 THEN J=1:K=3
6260 IF I=3 THEN J=1:K=4
```

```
6270 IF I=4 THEN J=2:K=3
6280 IF I=5 THEN J=2:K=4
6290 IF I=6 THEN J=3:K=4
6300 BOAR=(STRAB(I,1)*XP(J)+STRAB(I,2)*XP(K))/(STRAB(I,1)+STRAB(I,2))
6310
CBAB(I)=(CGAB(I)/(PSC*LSWAB(I))+(1+MRC/(FMR*FRC))*(100*GP/CRAB(I))+(MRC/
(FMR*FRC))*BOAR+(1/FRC)*BCIAB(I)*(LOCR+FCB*FIB))/(1-FRC/(PSC*LSWAB(I)))
6320 PRINT CBAB(I)
6330 NEXT I
6340 PRINT:INPUT "PRESS ENTER ";Z$:CLS
6350 '
6360 ' COMBINATION SYSTEMS REQUIRE PUREBRED MALES AND ROTATIONAL
FEMALES,
6370 ' RESULTING IN THE FOLLOWING EQUATIONS :
6380 '
6390 '3 BREED COMBINATIONS
6400 PRINT:PRINT " CB3BC(I)":PRINT
6410 FOR I=1 TO 12
6420 IF I=1 THEN J=2:K=3:L=1:M=4        ' J,K,L INDEX PUREBREDS
6430 IF I=2 THEN J=2:K=4:L=1:M=5        ' M INDEXES 2 BREED ROTATIONS
6440 IF I=3 THEN J=3:K=4:L=1:M=6
6450 IF I=4 THEN J=1:K=3:L=2:M=2
6460 IF I=5 THEN J=1:K=4:L=2:M=3
6470 IF I=6 THEN J=3:K=4:L=2:M=6
6480 IF I=7 THEN J=1:K=2:L=3:M=1
6490 IF I=8 THEN J=1:K=4:L=3:M=3
6500 IF I=9 THEN J=2:K=4:L=3:M=5
6510 IF I=10 THEN J=1:K=2:L=4:M=1
6520 IF I=11 THEN J=1:K=3:L=4:M=2
6530 IF I=12 THEN J=2:K=3:L=4:M=4
6540
BOAR=(STR3BC(I,1)*XP(J)+STR3BC(I,2)*XP(K)+STR3BC(I,3)*XP(L))/(STR3BC(I,1
)+STR3BC(I,2)+STR3BC(I,3))
6550
CB3BC(I)=(CBAB(M)*FRC+CGAB(M))/(PSC*LSWAB(M))+(1+MRC/(FMR*FRC))*(100*GP/
CRAB(M))+(MRC/(FMR*FRC))*BOAR+(1/FRC)*BCI3BC(I)*(LOCR+FCB*FIB)/(1-
FRC/(PSC*LSW3BC(I)))
6560 PRINT CB3BC(I)
6570 NEXT I
6580 '
6590 '4 BREED COMBINATIONS
6600 PRINT:PRINT " CB4BC(I)":PRINT
6610 FOR I=1 TO 4
6620 IF I=1 THEN J=2:K=3:L=4:M=1:N=4                ' J,K,L & M
INDEX
6630 IF I=2 THEN J=1:K=3:L=4:M=2:N=3                '  PUREBREDS,
6640 IF I=3 THEN J=1:K=2:L=4:M=3:N=2                ' N INDEXES 3
BREED
6650 IF I=4 THEN J=1:K=2:L=3:M=4:N=1                '  ROTATIONS
6660
BOAR=(STR4BC(I,1)*XP(J)+STR4BC(I,2)*XP(K)+STR4BC(I,3)*XP(L)+STR4BC(I,4)*
XP(M))/(STR4BC(I,1)+STR4BC(I,2)+STR4BC(I,3)+STR4BC(I,4))
6670
CB4BC(I)=(CBABC(N)*FRC+CGABC(N))/(PSC*LSWABC(N))+(1+MRC/(FMR*FRC))*(100*
```

```
GP/CRABC(N))+(MRC/(FMR*FRC))*BOAR+(1/FRC)*BCI4BC(I)*(LOCR+FCB*FIB)/(1-
FRC/(PSC*LSW4BC(I)))
6680 PRINT CB4BC(I)
6690 NEXT I
6700 PRINT:INPUT "PRESS ENTER ";Z$:CLS
6710 '
6720 ' CALCULATING C (LIFETIME COSTS / DAM) FROM CB, CG & # OF
LITTERS(1/FR_)
6730 '
6740 CABCD(1)=CBABCD(1)+(1/FRC)*CGABCD(1)
6750 FOR I=1 TO 4
6760 CP(I)=CBP(I)+(1/FRP)*CGP(I)
6770 CABC(I)=CBABC(I)+(1/FRC)*CGABC(I)
6780 C4BC(I)=CB4BC(I)+(1/FRC)*CG4BC(I)
6790 NEXT I:I=0
6800 FOR I=1 TO 6
6810 CAB(I)=CBAB(I)+(1/FRC)*CGAB(I)
6820 NEXT I:I=0
6830 FOR I=1 TO 12
6840 C3BC(I)=CB3BC(I)+(1/FRC)*CG3BC(I)
6850 NEXT I
6860 '
6870 ' CALCULATING PG (GROWTH PHASE PRODUCT / DAM / PARITY)
6880 '
6890 ' PG = RELATIVE VALUE*P(SURVIVE WEAN-100kg)*LITTER SIZE
WEANED*SLAUGHTER WT
6900 '    = RV * PS * LSW * 100  (kg)
6910 ' EXCEPT FOR PUREBRED HERDS, AND HERDS PRODUCING CROSSBRED BOARS
(CXD), WHERE IT IS ASSUMED THAT 10% OF MALES ARE
6920 ' CASTRATED, AND THAT BOAR (100kg) MEAT IS WORTH 70% OF EQUIVALENT
6930 ' BARROW / GILT MARKET HOG MEAT. THEREFORE, IN THESE HERDS :
6940 ' PG = RV * (Prop. gilts & barrows + 70% prop. boars) * PS * LSW *
100(kg)
6950 '    = RV * .865 * PS * LSW * 100
6960 '
6970 ' THE FOLLOWING SET OF EQUATIONS MAY BE USED TO FIX RV = 1.00
6980 '
6990 'PGABCD(1)=100*PSC*LSWABCD(1)
7000 'FOR I=1 TO 4
7010 'PGP(I)=86.5*PSP*LSWP(I)
7020 'PGABC(I)=100*PSC*LSWABC(I)
7030 'PG4BC(I)=100*PSC*LSW4BC(I)
7040 'NEXT I:I=0
7050 'FOR I=1 TO 6
7060 'PGAB(I)=100*PSC*LSWAB(I)
7070 'NEXT I:I=0
7080 'FOR I=1 TO 12
7090 'PG3BC(I)=100*PSC*LSW3BC(I)
7100 'NEXT I
7110 '
7120 ' THE FOLLOWING EQUATIONS PAY A PREMIUM FOR LEANER HOGS, ACCORDING
TO
7130 ' NPPC "PORK VALUE" GUIDELINES FOR 211-230 lb MARKET HOGS, I.E.,
7140 ' fat,last rib,in.:    .7     .8     .9     1.0   1.1    1.2    1.3
```

```
7150 ' av. backfat, in.:   1.0    1.1    1.2    1.3   1.4    1.5    1.6
7160 ' relative value  :   104    103    102    101   100     99     98
7170 ' NOTE: THE RELATIONSHIP "av. fat = last rib fat + .3 in." IS
ASSUMED
7180 '      NPPC USES LAST RIB FAT TO ASIGN VALUE
7190 ' THE REGRESSION OF VALUE ON AV. FAT IS:
7200 '  RELATIVE VALUE = 114 - 10. * (av. fat, in)
7210 '                 = 114 - .3937 * (av. fat, mm)
7220 ' RV IS CALCULATED FOR TERMINAL OFFSPRING OF EACH SYSTEM:
7230 '
7240 RVABCD(1)=(114-.3937*BFABCD(1))/100
7250 FOR I=1 TO 4
7260 RVP(I)=(114-.3937*BFP(I))/100
7270 RVABC(I)=(114-.3937*BFABC(I))/100
7280 RV4BC(I)=(114-.3937*BF4BC(I))/100
7290 NEXT I
7300 FOR I=1 TO 6
7310 RVAB(I)=(114-.3937*BFAB(I))/100
7320 NEXT I
7330 FOR I=1 TO 12
7340 RV3BC(I)=(114-.3937*BF3BC(I))/100
7350 NEXT I
7360 '
7370 ' PG IS THEN CALCULATED:
7380 '
7390 PGABCD(1)=RVABCD(1)*100*PSC*LSWABCD(1)
7400 PRINT:PRINT " PGABCD(1)":PRINT:PRINT PGABCD(1):PRINT:PRINT
7410 PRINT " PGP(I)        PGABC(I)      PG4BC(I)":PRINT
7420 FOR I=1 TO 4
7430 PGP(I)=RVP(I)*86.5*PSP*LSWP(I)
7440 PGABC(I)=RVABC(I)*100*PSC*LSWABC(I)
7450 PG4BC(I)=RV4BC(I)*100*PSC*LSW4BC(I)
7460 PRINT PGP(I),PGABC(I),PG4BC(I)
7470 NEXT I:I=0
7480 PRINT:INPUT "PRESS ENTER ";Z$:CLS
7490 PRINT:PRINT " PGAB(I)"
7500 FOR I=1 TO 6
7510 PGAB(I)=RVAB(I)*100*PSC*LSWAB(I)
7520 PRINT PGAB(I)
7530 NEXT I:I=0
7540 PRINT:PRINT " PG3BC(I)"
7550 FOR I=1 TO 12
7560 PG3BC(I)=RV3BC(I)*100*PSC*LSW3BC(I)
7570 PRINT PG3BC(I)
7580 NEXT I
7590 PRINT:INPUT "PRESS ENTER ";Z$:CLS
7600 '
7610 '
7620 ' CALCULATING PB (SALVAGE PRODUCT / DAM LIFETIME)
7630 '
7640 ' PB =PRODUCT (AS % SLAUGHTER WT) * [ CULL FEMALE WT + (CULL BOAR
WT / (FMR*(MALE HERD LIFE/FEMALE HERD LIFE)) ]
7650 '
7660 ' EQUATIONS WERE DEVELOPED AS FOLLOWS :
```

```
7670 '
7680 '  SALVAGE PRODUCT CONSISTS OF SOWS CULLED AT THE END OF THEIR
7690 '  REPRODUCTIVE LIFE ( i.e. AFTER 1/FR LITTERS, FR=PROP FEMALES
REPLACED
7700 '  EACH CYCLE ), OPEN SOWS AND GILTS AND CULL BOARS.
7710 '  EACH CYCLE ), OPEN SOWS AND GILTS AND CULL BOARS.
7720 '  FOR EVERY FEMALE CONCEIVING EACH CYCLE, (100/CR)-1 FEMALES ARE
SOLD AS
7730 '  OPEN. OVER A FEMALES LIFETIME, (1/FR)*((100/CR)-1) CULL FEMALES
HAVE
7740 '  BEEN SOLD.
7750 '
7760 '  ASSUMING THE FOLLOWING RELATIVE PRODUCT VALUES :
7770 '   2201b MARKET BARROW/GILT                       = 1.00
7780 '   OPEN GILT (2551b)                              =  .90
7790 '   OPEN/CULL SOW (2551b + 301b / PARITY ¶ 1 ) =  .85
7800 '   CULL BOAR (4001b)                              =  .65
7810 '
7820 ' PB = .85*(255+(30/FR)) + (1/FR)*((100/CR)-1) *
7830 '          cull sow       # open females/dam lifetime
7840 '
7850 '         [ .9*255*FR + .85*(255+(15/FR))*(1-FR) ] +
(.65*400)/(FM*FR/MR)
7860 '         open gilts          open sows                   cull boars
7870 '
7880 ' CONVERTING TO KG AND SIMPLIFYING GIVES THE EQUATIONS USED BELOW,
EXCEPT
7890 ' FOR THE CONSTANT MULTIPLIER OF .985, USED TO REFLECT THE ASSUMED
1.5%
7900 ' BREEDING HERD DEATH LOSS / CYCLE
7910 '
7920 PBABCD(1)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRABCD(1)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
7930 PRINT:PRINT " PBABCD(1)":PRINT:PRINT PBABCD(1):PRINT:PRINT
7940 PRINT " PBP(I)        PBABC(I)      PB4BC(I)"
7950 FOR I=1 TO 4
7960 PBP(I)=.985*(109.883+(23.133/FRP)+(1/FRP)*(100/CRP(I)-
1)*(116.346*FRP+(1-FRP)*(109.883+23.133/FRP))+117.934/(FMR*FRP/MRP))
7970 PBABC(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRABC(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
7980 PB4BC(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CR4BC(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
7990 PRINT PBP(I),PBABC(I),PB4BC(I)
8000 NEXT I:I=0
8010 PRINT:INPUT "PRESS ENTER ";Z$:CLS
8020 PRINT:PRINT " PBAB(I)"
8030 FOR I=1 TO 6
8040 PBAB(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRAB(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8050 PRINT PBAB(I)
8060 NEXT I:I=0
8070 PRINT:PRINT " PB3BC(I)"
8080 FOR I=1 TO 12
```

```
8090 PB3BC(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CR3BC(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8100 PRINT PB3BC(I)
8110 NEXT I
8120 PRINT:INPUT "PRESS ENTER ";Z$:CLS
8130 '
8140 ' CALCULATING P (LIFETIME PRODUCT / DAM) FROM PB, PG & # LITTERS
PRODUCED
8150 '
8160 PABCD(1)=PBABCD(1)+(1/FRC)*PGABCD(1)
8170 FOR I=1 TO 4
8180 PP(I)=PBP(I)+(1/FRP)*PGP(I)
8190 PABC(I)=PBABC(I)+(1/FRC)*PGABC(I)
8200 P4BC(I)=PB4BC(I)+(1/FRC)*PG4BC(I)
8210 NEXT I
8220 FOR I=1 TO 6
8230 PAB(I)=PBAB(I)+(1/FRC)*PGAB(I)
8240 NEXT I
8250 FOR I=1 TO 12
8260 P3BC(I)=PB3BC(I)+(1/FRC)*PG3BC(I)
8270 NEXT I
8280 '
8290 ' CALCULATING E (EFFICIENCY) FROM C & P
8300 '
8310 EABCD(1)=CABCD(1)/PABCD(1)
8320 FOR I=1 TO 4
8330 EP(I)=CP(I)/PP(I)
8340 EABC(I)=CABC(I)/PABC(I)
8350 E4BC(I)=C4BC(I)/P4BC(I)
8360 NEXT I:I=0
8370 FOR I=1 TO 6
8380 EAB(I)=CAB(I)/PAB(I)
8390 NEXT I:I=0
8400 FOR I=1 TO 12
8410 E3BC(I)=C3BC(I)/P3BC(I)
8420 NEXT I
8430 '
8440 ' E REPRESENTS EFFICIENCY FOR TERMINAL SUB-SYSTEMS OF EACH SYSTEM.
8450 ' TOTAL SYSTEM EFFICIENCY (SE), HOWEVER, IS THE WEIGHTED AVERAGE OF
EFFICIENCIES OF BOTH THE BREEDING STOCK GENERATORS AND TERMINAL
8460 ' CROSSES THAT COMPRISE THE 10,000 FEMALES FARROWING IN EACH
SYSTEM.
8470 ' THUS :
8480 '
8490 'PUREBREDS
8500 FOR I=1 TO 4
8510 SEP(I)=EP(I)
8520 NEXT I
8530 '
8540 '4 BREED ROTATION
8550
SEABCD(1)=(STRABCD(1)*EP(1)+STRABCD(2)*EP(2)+STRABCD(3)*EP(3)+STRABCD(4)
*EP(4)+STRABCD(5)*EABCD(1))/10000
8560 '
```

```
8570 '3 BREED ROTATIONS
8580 FOR I=1 TO 4
8590 IF I=1 THEN J=1:K=2:L=3
8600 IF I=2 THEN J=1:K=2:L=4
8610 IF I=3 THEN J=1:K=3:L=4
8620 IF I=4 THEN J=2:K=3:L=4
8630
SEABC(I)=(STRABC(I,1)*EP(J)+STRABC(I,2)*EP(K)+STRABC(I,3)*EP(L)+STRABC(I
,4)*EABC(I))/10000
8640 NEXT I
8650 '
8660 '2 BREED ROTATIONS
8670 FOR I=1 TO 6
8680 IF I=1 THEN J=1:K=2
8690 IF I=2 THEN J=1:K=3
8700 IF I=3 THEN J=1:K=4
8710 IF I=4 THEN J=2:K=3
8720 IF I=5 THEN J=2:K=4
8730 IF I=6 THEN J=3:K=4
8740 SEAB(I)=(STRAB(I,1)*EP(J)+STRAB(I,2)*EP(K)+STRAB(I,3)*EAB(I))/10000
8750 NEXT I
8760 '
8770 '3 BREED COMBINATIONS
8780 FOR I=1 TO 12
8790 IF I=1 THEN J=2:K=3:L=1:M=4  'L INDEXES THE BREED OF TERMINAL SIRE
8800 IF I=2 THEN J=2:K=4:L=1:M=5  'M INDEXES THE FEMALE 2 BREED ROTATION
GROUP
8810 IF I=3 THEN J=3:K=4:L=1:M=6  'J,K INDEX PUREBREDS IN THE ROTATION
8820 IF I=4 THEN J=1:K=3:L=2:M=2
8830 IF I=5 THEN J=1:K=4:L=2:M=3
8840 IF I=6 THEN J=3:K=4:L=2:M=6
8850 IF I=7 THEN J=1:K=2:L=3:M=1
8860 IF I=8 THEN J=1:K=4:L=3:M=3
8870 IF I=9 THEN J=2:K=4:L=3:M=5
8880 IF I=10 THEN J=1:K=2:L=4:M=1
8890 IF I=11 THEN J=1:K=3:L=4:M=2
8900 IF I=12 THEN J=2:K=3:L=4:M=4
8910
SE3BC(I)=(STR3BC(I,1)*EP(J)+STR3BC(I,2)*EP(K)+STR3BC(I,3)*EP(L)+STR3BC(I
,4)*EAB(M)+STR3BC(I,5)*E3BC(I))/10000
8920 NEXT I
8930 '
8940 '4 BREED COMBINATIONS
8950 FOR I=1 TO 4
8960 IF I=1 THEN J=2:K=3:L=4:M=1:N=4   'M = BREED OF TERMINAL SIRE
8970 IF I=2 THEN J=1:K=3:L=4:M=2:N=3   'N = FEMALE 3 BREED ROTATION
GROUP
8980 IF I=3 THEN J=1:K=2:L=4:M=3:N=2   'J,K,L = PUREBREDS IN THE
ROTATION
8990 IF I=4 THEN J=1:K=2:L=3:M=4:N=1
9000
SE4BC(I)=(STR4BC(I,1)*EP(J)+STR4BC(I,2)*EP(K)+STR4BC(I,3)*EP(L)+STR4BC(I
,4)*EP(M)+STR4BC(I,5)*EABC(N)+STR4BC(I,6)*E4BC(I))/10000
9010 NEXT I
```

```
9020 SUMP=0: SUMAB=0: SUMABC=0: SUM3BC=0: SUM4BC=0
9030 AVGABCD=SEABCD
9040 FOR L=1 TO 4
9050 SUMP=SEP(L)+SUMP
9060 SUMABC=SEABC(L)+SUMABC
9070 SUM4BC=SE4BC(L)+SUM4BC
9080 NEXT L
9090 FOR L=1 TO 6
9100 SUMAB=SEAB(L)+SUMAB
9110 NEXT L
9120 FOR L=1 TO 12
9130 SUM3BC=SE3BC(L)+SUM3BC
9140 NEXT L
9150 AVGP=SUMP/4: AVGABC=SUMABC/4: AVG4BC=SUM4BC/4: AVGAB=SUMAB/6:
AVG3BC=SUM3BC/12
9160 '
9170 CLS:PRINT TAB(12)" NO. BREED           EFFICIENCY ( COST / KG
PRODUCT )"
9180 PRINT "SYSTEM     COMBINATIONS        MEAN           MIN
MAX"
9190 PRINT STRING$(70,"-")
9200 PRINT USING "  P           4                ###.####        ###.##
###.##";AVGP,MINP,MAXP
9210 PRINT USING "  AB          6                ###.####        ###.##
###.##";AVGAB,MINAB,MAXAB
9220 PRINT USING " ABC          4                ###.####        ###.##
###.##";AVGABC,MINABC,MAXABC
9230 PRINT USING "ABCD          1                ###.####        ###.##
###.##";SEABCD(1),SEABCD(1),SEABCD(1)
9240 PRINT USING " 3BC         12                ###.####        ###.##
###.##";AVG3BC,MIN3BC,MAX3BC
9250 PRINT USING " 4BC          4                ###.####        ###.##
###.##";AVG4BC,MIN4BC,MAX4BC
9260 PRINT:INPUT "PRESS ENTER";Z$:CLS
9270 '
9280 PRINT:PRINT:PRINT "     PUREBREDS":PRINT
9290 PRINT "BREEDS             EFFICIENCY ( COST / KG PRODUCT )":PRINT
9300 PRINT STRING$(48,"-"):B$(1)="D":B$(2)="Y":B$(3)="L":B$(4)="S"
9310 FOR I=1 TO 4
9320 PRINT USING "³  ³                        ###.####";B$(I),EP(I):NEXT
I
9330 PRINT:INPUT "PRESS ENTER ";Z$:CLS
9340 '
9350 PRINT:PRINT:PRINT "     2 BREED ROTATIONS":PRINT
9360 PRINT "BREEDS             EFFICIENCY ( COST / KG PRODUCT )":PRINT
9370 PRINT STRING$(48,"-"):FOR I=1 TO 6:READ B$(I):NEXT I
9380 DATA DY,DL,DS,YL,YS,LS
9390 FOR I=1 TO 6
9400 PRINT USING "³    ³
###.####";B$(I),SEAB(I):NEXT I
9410 PRINT:INPUT "PRESS ENTER ";Z$:CLS
9420 '
9430 PRINT:PRINT:PRINT "     3 BREED ROTATIONS":PRINT
9440 PRINT "BREEDS             EFFICIENCY ( COST / KG PRODUCT )":PRINT
```

```
9450 PRINT STRING$(48,"-"):FOR I=1 TO 4:READ B$(I):NEXT I
9460 DATA DYL,DYS,DLS,YLS
9470 FOR I=1 TO 4
9480 PRINT USING "³    ³
###.####";B$(I),SEABC(I):NEXT I
9490 PRINT:INPUT "PRESS ENTER ";Z$:CLS
9500 '
9510 PRINT:PRINT:PRINT "     4 BREED ROTATION":PRINT
9520 PRINT "BREEDS           EFFICIENCY ( COST / KG PRODUCT )":PRINT
9530 PRINT STRING$(48,"-")
9540 PRINT USING "DYLS                          ###.####";SEABCD(1)
9550 PRINT:INPUT "PRESS ENTER ";Z$:CLS
9560 '
9570 PRINT:PRINT:PRINT "     TERMINAL SIRE BREED X 2 BREED ROTATION
FEMALES":PRINT
9580 PRINT "BREEDS           EFFICIENCY ( COST / KG PRODUCT )":PRINT
9590 PRINT STRING$(48,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
9600 DATA DxYL,DxYS,DxLS,YxDL,YxDS,YxLS,LxDY,LxDS,LxYS,SxDY,SxDL,SxYL
9610 FOR I=1 TO 12
9620 PRINT USING "³    ³
###.####";B$(I),SE3BC(I):NEXT I
9630 PRINT:INPUT "PRESS ENTER ";Z$:CLS
9640 'OPEN "O",1,"SE4BC.PRN"
9650 '
9660 PRINT:PRINT:PRINT "     TERMINAL SIRE BREED X 3 BREED ROTATION
FEMALES":PRINT
9670 PRINT "BREEDS           EFFICIENCY ( COST / KG PRODUCT )":PRINT
9680 'PRINT #1,STRING$(48,"-"):FOR I=1 TO 4:READ B$(I):NEXT I
9690 PRINT STRING$(48,"-"):FOR I=1 TO 4:READ B$(I):NEXT I
9700 DATA DxYLS,YxDLS,LxDYS,SxDYL
9710 FOR I=1 TO 4
9720 PRINT USING "³    ³
###.####";B$(I),SE4BC(I):NEXT I
9730 'CLOSE
9740 'PRINT:INPUT "PRESS ENTER ";Z$:CLS
```

APPENDIX B

STATIC CROSSBREEDING SIMULATION PROGRAM

```
10 'SAVE "STATIC",A
20 '
30 ' PERFORMANCE VARIABLES ARE INDICATED BY THE FOLLOWING PREFIXES
THROUGHOUT THE PROGRAM:
40 '
50 'CR - FIRST SERVICE CONCEPTION RATE (%)
60 'SUR - SURVIVAL TO 42 d (%)
70 'LSB - LITTER SIZE BORN
80 'LSW - LITTER SIZE WEANED ( = LSB*SUR/100 )
90 'LSFE - LITTER SIZE WEANED / FEMALE EXPOSED ( =LSW*CR/100 )
100 'ADG - POSTWEANING AVERAGE DAILY GAIN (kg/d)
110 'FG - FEED TO GAIN RATIO
120 'BF - CARCASS BACKFAT (mm)
130 '
140 ' THE FOLLOWING SUFFIXES INDICATE THE DIFFERENT BREEDING SYSTEMS:
150 '
160 'P - PUREBRED
170 'AXB - 2 BREED SPECIFIC CROSS
180 'AXAB - BACKCROSS
190 'CXAB - 3 BREED SPECIFIC CROSS
200 'CDXAB - 4 BREED SPECIFIC CROSS
210 '
220 ' THE FOLLOWING SUFFIXES REFER TO GENETIC PARAMETERS:
230 '
240 'MU - CONSTANT
250 'GIM - DIRECT AVERAGE BREED + MATERNAL EFFECTS
260 'GI - DIRECT AVERAGE BREED EFFECT
270 'GM - DIRECT AVERAGE MATERNAL EFFECT
280 'HI - INDIVIDUAL HETEROSIS
290 'HM - MATERNAL HETEROSIS
300 'HP - PATERNAL HETEROSIS
310 '
320 'DIMENSIONING ARRAYS
330 '
340 CLS:PRINT:PRINT:PRINT "STATIC.BAS":PRINT
350 DIM
CRGIM(4),CRHM(6),CRHP(6),CRP(4),CRAXB(12),CRAXAB(12),CRCXAB(12),CRCDXAB(
6)
360 DIM
LSBGIM(4),LSBHI(6),LSBHM(6),LSBHP(6),LSBP(4),LSBAXB(12),LSBAXAB(12),LSBC
XAB(12),LSBCDXAB(6)
370 DIM
SURGI(4),SURGM(4),SURHI(6),SURHM(6),SURHP(6),SURP(4),SURAXB(12),SURAXAB(
12),SURCXAB(12),SURCDXAB(6)
380 DIM
ADGGI(4),ADGGM(4),ADGHI(6),ADGHM(6),ADGHP(6),ADGP(4),ADGAXB(12),ADGAXAB(
12),ADGCXAB(12),ADGCDXAB(6)
390 DIM
BFGI(4),BFGM(4),BFHI(6),BFHM(6),BFHP(6),BFP(4),BFAXB(12),BFAXAB(12),BFCX
AB(12),BFCDXAB(6)
400 DIM
FGGI(4),FGGM(4),FGHI(6),FGHM(6),FGHP(6),FGP(4),FGAXB(12),FGAXAB(12),FGCX
AB(12),FGCDXAB(6)
410 DIM LSWP(4),LSWAXB(12),LSWAXAB(12),LSWCXAB(12),LSWCDXAB(6),LSFEP(4)
```

```
420 'THE FOLLOWING VARIABLES ARE DEFINED AS THEY OCCUR IN THE PROGRAM
430 DIM
FMP(4),FFP(4),STRAXB(12,3),STRCXAB(12,5),STRAXAB(12,4),FMAXB(12),FFAXB(1
2),STRCDXAB(6,7)
440 DIM BCIP(4),BCIAXB(12),BCIAXAB(12),BCICXAB(12),BCICDXAB(6)
450 DIM CGP(4),CGAXB(12),CGAXAB(12),CGCXAB(12),CGCDXAB(6)
460 DIM CBP(4),CBAXB(12),CBAXAB(12),CBCXAB(12),CBCDXAB(6)
470 DIM CP(4),CAXB(12),CAXAB(12),CCXAB(12),CCDXAB(6)
480 DIM PGP(4),PGAXB(12),PGCXD(12),PGAXAB(12),PGCXAB(12),PGCDXAB(6)
490 DIM PBP(4),PBAXB(12),PBAXAB(12),PBCXAB(12),PBCDXAB(6)
500 DIM PP(4),PAXB(12),PCXD(12),PAXAB(12),PCXAB(12),PCDXAB(6)
510 DIM
EP(4),EAXB(12),ECXD(12),EAXAB(12),ECXAB(12),ECDXAB(6),XP(4),B$(12)
520 DIM SEP(4),SEAXB(12),SEAXAB(12),SECXAB(12),SECDXAB(6)
530 DIM RVP(4),RVAXB(12),RVAXAB(12),RVCXAB(12),RVCDXAB(6)
540 '
550 ' READING GENETIC PARAMETER VALUES
560 '
570 'GI, GM, GIM DATA ARE READ IN ORDER :
580 ' I=1 : DUROC
590 ' I=2 : YORK
600 ' I=3 : LAND
610 ' I=4 : SPOT
620 'HI, HM, HP DATA ARE READ IN ORDER :
630 ' I=1 : DUROC-YORK
640 ' I=2 : DUROC-LAND
650 ' I=3 : DUROC-SPOT
660 ' I=4 : YORK-LAND
670 ' I=5 : YORK-SPOT
680 ' I=6 : LAND-SPOT
690 '
700 CRMU=69.76
710 FOR I=1 TO 4: READ CRGIM(I): NEXT I
720 FOR I=1 TO 6: READ CRHM(I): NEXT I
730 FOR I=1 TO 6: READ CRHP(I): NEXT I
740 '
750 'DATA -
10.01,1.34,8.62,.05,2.8,2.8,2.8,2.8,2.8,2.8,7.31,9.39,4.25,4.23,3.7,9.33
760 'PRINT "THIS RUN ASSUMES BOARS USED FOR 2 MATING SEASONS"
770 DATA -
10.01,1.34,8.62,.05,2.8,2.8,2.8,2.8,2.8,2.8,6.22,6.22,6.22,6.22,6.22,6.2
2
780 PRINT" THIS RUN ASSUMES AVERAGE HP FOR CR OF 6.22"
790 'DATA -10.01,1.34,8.62,.05,2.8,2.8,2.8,2.8,2.8,2.8,0,0,0,0,0,0
800 'PRINT "THIS RUN ASSUMES BOARS USED CONTINUOUSLEY, I.E. HP FOR CR =
0"
810 '
820 LSBMU=10.58
830 FOR I=1 TO 4: READ LSBGIM(I): NEXT I
840 FOR I=1 TO 6: READ LSBHI(I): NEXT I
850 FOR I=1 TO 6: READ LSBHM(I): NEXT I
860 FOR I=1 TO 6: READ LSBHP(I): NEXT I
```

```
870 'DATA .35,.78,.07,-
1.2,.23,.23,.23,.23,.23,.23,.93,.93,.93,.93,.93,.93,.09,-.09,.71,-
.05,.61,-.23
880 DATA .35,.78,.07,-
1.2,.23,.23,.23,.23,.23,.23,.93,.93,.93,.93,.93,.93,0,0,0,0,0,0
890 PRINT:PRINT "                    LSB, HP=0"
900 '
910 SURMU=70.81
920 FOR I=1 TO 4: READ SURGI(I): NEXT I
930 FOR I=1 TO 4: READ SURGM(I): NEXT I
940 FOR I=1 TO 6: READ SURHI(I): NEXT I
950 FOR I=1 TO 6: READ SURHM(I): NEXT I
960 FOR I=1 TO 6: READ SURHP(I): NEXT I
970 'DATA -.88,-4.48,5.05,-.31,-2.13,-
2.12,1.12,3.13,4.31,5.73,7.86,9.88,6.41,-.18,0,0,0,0,0,0,1.92,-.41,-
3.58,-1.71,-8.72,-1.60
980 DATA -.88,-4.48,5.05,-.31,-2.13,-
2.12,1.12,3.13,4.31,5.73,7.86,9.88,6.41,-.18,0,0,0,0,0,0,0,0,0,0,0,0
990 PRINT:PRINT "                    SUR, HP=0"
1000 '
1010 ADGMU=.6504
1020 FOR I=1 TO 4: READ ADGGI(I): NEXT I
1030 FOR I=1 TO 4: READ ADGGM(I): NEXT I
1040 FOR I=1 TO 6: READ ADGHI(I): NEXT I
1050 FOR I=1 TO 6: READ ADGHM(I): NEXT I
1060 FOR I=1 TO 6: READ ADGHP(I): NEXT I
1070 'DATA .0148,-.0111,-.0215,.0178,-.0026,-.0010,.0062,-
.0026,.0796,.0736,.0712,.0545,.0622,.0705,0,0,0,0,0,0,.015,.020,.016,-
.001,-.021,-.004
1080 DATA .0148,-.0111,-.0215,.0178,-.0026,-.0010,.0062,-
.0026,.0796,.0736,.0712,.0545,.0622,.0705,0,0,0,0,0,0,0,0,0,0,0,0
1090 PRINT:PRINT "                    ADG, HP=0"
1100 '
1110 BFMU=32.43
1120 FOR I=1 TO 4: READ BFGI(I): NEXT I
1130 FOR I=1 TO 4: READ BFGM(I): NEXT I
1140 FOR I=1 TO 6: READ BFHI(I): NEXT I
1150 FOR I=1 TO 6: READ BFHM(I): NEXT I
1160 FOR I=1 TO 6: READ BFHP(I): NEXT I
1170 'DATA -6.55,2.48,-.08,4.16,3.19,-1.88,1.12,-2.43,1.96,.90,.79,.98,-
1.28,-.70,0,0,0,0,0,0,.11,.39,-.89,1.58,-.78,1.03
1180 DATA -6.55,2.48,-.08,4.16,3.19,-1.88,1.12,-2.43,1.96,.90,.79,.98,-
1.28,-.70,0,0,0,0,0,0,0,0,0,0,0,0
1190 PRINT:PRINT "                    BF, HP=0"
1200 '
1210 FGMU=3.212
1220 FOR I=1 TO 4: READ FGGI(I): NEXT I
1230 FOR I=1 TO 4: READ FGGM(I): NEXT I
1240 FOR I=1 TO 6: READ FGHI(I): NEXT I
1250 FOR I=1 TO 6: READ FGHM(I): NEXT I
1260 FOR I=1 TO 6: READ FGHP(I): NEXT I
1270 'DATA -.210,-
.027,.020,.217,0,0,0,0,.009,.009,.009,.009,.009,.009,0,0,0,0,0,0,-.008,-
.008,-.008,-.008,-.008,-.008
```

```
1280 DATA -.210,-
.027,.020,.217,0,0,0,0,.009,.009,.009,.009,.009,.009,0,0,0,0,0,0,0,0,0
,0,0
1290 PRINT:PRINT "                    FG, HP=0"
1300 PRINT:INPUT "PRESS ENTER ";Z$:CLS
1310 '
1320 'CALCULATING PREDICTED PERFORMANCE FOR TERMINAL OFFSPRING OF
ALTERNATIVE                              CROSSBREEDING SYSTEMS
1330 '
1340 'NOTE THAT CR IS ASSUMED TO BE A FUNCTION OF DAM BREED EFFECTS,
PLUS THE
1350 'EFFECT OF USING A CROSSBRED SIRE IN THE CDXAB SYSTEM. EXPANSION OF
THE
1360 'PROGRAM TO INCLUDE HAMPSHIRE SIRES WILL REQUIRE PROGRAM
MODIFICATIONS
1370 '
1380 'PUREBREDS
1390 FOR I=1 TO 4
1400 CRP(I)=CRMU+CRGIM(I)
1410 LSBP(I)=LSBMU+LSBGIM(I)
1420 SURP(I)=SURMU+SURGI(I)+SURGM(I)
1430 LSWP(I)=LSBP(I)*SURP(I)/100
1440 LSFEP(I)=LSWP(I)*CRP(I)/100
1450 ADGP(I)=ADGMU+ADGGI(I)+ADGGM(I)
1460 BFP(I)=BFMU+BFGI(I)+BFGM(I)
1470 FGP(I)=FGMU+FGGI(I)+FGGM(I)
1480 NEXT I:I=0
1490 PRINT:PRINT:PRINT "PUREBREDS":PRINT
1500 PRINT "PREDICTED DRIVING VARIABLES ":PRINT
1510 PRINT STRING$(70,"-"):B$(1)="D":B$(2)="Y":B$(3)="L":B$(4)="S"
1520 PRINT "BREED   CR     LSB     SUR      LSW    LSFE     ADG     BF
FG":PRINT STRING$(70,"-")
1530 FOR I=1 TO 4
1540 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#    ##.#    .###
##.#    #.##
";B$(I),CRP(I),LSBP(I),SURP(I),LSWP(I),LSFEP(I),ADGP(I),BFP(I),FGP(I):NE
XT I: PRINT STRING$(70,"-")
1550 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
1560 '
1570 '2 BREED STATIC
1580 FOR J=1 TO 4: FOR K=1 TO 4
1590 IF J=K GOTO 1740
1600 I=I+1
1610 IF J=1 AND K=2 OR J=2 AND K=1 THEN L=1  'DY
1620 IF J=1 AND K=3 OR J=3 AND K=1 THEN L=2  'DL
1630 IF J=1 AND K=4 OR J=4 AND K=1 THEN L=3  'DS
1640 IF J=2 AND K=3 OR J=3 AND K=2 THEN L=4  'YL
1650 IF J=2 AND K=4 OR J=4 AND K=2 THEN L=5  'YS
1660 IF J=3 AND K=4 OR J=4 AND K=3 THEN L=6  'LS
1670 CRAXB(I)=CRMU+CRGIM(K)
1680 LSBAXB(I)=LSBMU+LSBGIM(K)+LSBHI(L)
1690 SURAXB(I)=SURMU+.5*(SURGI(J)+SURGI(K))+SURGM(K)+SURHI(L)
1700 LSWAXB(I)=LSBAXB(I)*SURAXB(I)/100
1710 ADGAXB(I)=ADGMU+.5*(ADGGI(J)+ADGGI(K))+ADGGM(K)+ADGHI(L)
```

```
1720 BFAXB(I)=BFMU+.5*(BFGI(J)+BFGI(K))+BFGM(K)+BFHI(L)
1730 FGAXB(I)=FGMU+.5*(FGGI(J)+FGGI(K))+FGGM(K)+FGHI(L)
1740 NEXT K,J:I=0
1750 PRINT:PRINT:PRINT "2 BREED STATIC":PRINT
1760 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
1770 PRINT STRING$(62,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
1780 DATA DxY,DxL,DxS,YxD,YxL,YxS,LxD,LxY,LxS,SxD,SxY,SxL
1790 PRINT "BREED   CR     LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
1800 FOR I=1 TO 12
1810 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRAXB(I),LSBAXB(I),SURAXB(I),LSWAXB(I),ADGAXB(I),BFAXB(I),FGAXB(
I):NEXT I: PRINT STRING$(62,"-")
1820 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
1830 '
1840 'BACKCROSS
1850 FOR II=1 TO 4:FOR J=1 TO 4: FOR K=1 TO 4
1860 IF J=K GOTO 2080
1870 IF II§¶K AND II§¶J THEN 2080
1880 IF LSFEP(K)§LSFEP(J) THEN 2080
1890 IF LSFEP(K)=LSFEP(J) AND J¶K THEN 2080
1900 IF J=1 AND K=2 OR J=2 AND K=1 THEN L=1  'DY & YD CROSSBRED DAM GRP
1910 IF J=1 AND K=3 OR J=3 AND K=1 THEN L=2  'DL & LD
1920 IF J=1 AND K=4 OR J=4 AND K=1 THEN L=3  'DS & SD
1930 IF J=2 AND K=3 OR J=3 AND K=2 THEN L=4  'YL & LY
1940 IF J=2 AND K=4 OR J=4 AND K=2 THEN L=5  'YS & SY
1950 IF J=3 AND K=4 OR J=4 AND K=3 THEN L=6  'LS & SL
1960 I=I+1
1970 CRAXAB(I)=CRMU+.5*(CRGIM(J)+CRGIM(K))+CRHM(L)
1980 LSBAXAB(I)=LSBMU+.5*(LSBGIM(J)+LSBGIM(K))+.5*LSBHI(L)+LSBHM(L)
1990 IF II=J THEN
SURAXAB(I)=SURMU+.25*(3*SURGI(J)+SURGI(K))+.5*(SURGM(J)+SURGM(K))+.5*SUR
HI(L)+SURHM(L)
2000 IF II=K THEN
SURAXAB(I)=SURMU+.25*(3*SURGI(K)+SURGI(J))+.5*(SURGM(J)+SURGM(K))+.5*SUR
HI(L)+SURHM(L)
2010 LSWAXAB(I)=LSBAXAB(I)*SURAXAB(I)/100
2020 IF II=J THEN
ADGAXAB(I)=ADGMU+.25*(3*ADGGI(J)+ADGGI(K))+.5*(ADGGM(J)+ADGGM(K))+.5*ADG
HI(L)+ADGHM(L)
2030 IF II=K THEN
ADGAXAB(I)=ADGMU+.25*(3*ADGGI(K)+ADGGI(J))+.5*(ADGGM(J)+ADGGM(K))+.5*ADG
HI(L)+ADGHM(L)
2040 IF II=J THEN
BFAXAB(I)=BFMU+.25*(3*BFGI(J)+BFGI(K))+.5*(BFGM(J)+BFGM(K))+.5*BFHI(L)+B
FHM(L)
2050 IF II=K THEN
BFAXAB(I)=BFMU+.25*(3*BFGI(K)+BFGI(J))+.5*(BFGM(J)+BFGM(K))+.5*BFHI(L)+B
FHM(L)
2060 IF II=J THEN
FGAXAB(I)=FGMU+.25*(3*FGGI(J)+FGGI(K))+.5*(FGGM(J)+FGGM(K))+.5*FGHI(L)+F
GHM(L)
```

```
2070 IF II=K THEN
FGAXAB(I)=FGMU+.25*(3*FGGI(K)+FGGI(J))+.5*(FGGM(J)+FGGM(K))+.5*FGHI(L)+F
GHM(L)
2080 NEXT K,J,II:I=0
2090 PRINT:PRINT:PRINT "BACKCROSS":PRINT
2100 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
2110 PRINT STRING$(62,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
2120 DATA DxDY,DxDL,DxSD,YxDY,YxYL,YxSY,LxDL,LxYL,LxSL,SxSD,SxSY,SxSL
2130 PRINT "BREED   CR     LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
2140 FOR I=1 TO 12
2150 PRINT USING "³  ³   ##.#    ##.#    ##.#    ##.#    .###    ##.#
#.##
";B$(I),CRAXAB(I),LSBAXAB(I),SURAXAB(I),LSWAXAB(I),ADGAXAB(I),BFAXAB(I),
FGAXAB(I):NEXT I: PRINT STRING$(62,"-")
2160 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
2170 '
2180 '3 BREED STATIC
2190 FOR J=1 TO 4: FOR K=1 TO 4: FOR L=1 TO 4
2200 IF J=K OR J=L OR K=L GOTO 2500
2210 IF LSFEP(L)§LSFEP(K) THEN 2500
2220 IF LSFEP(L)=LSFEP(K) AND K¶L THEN 2500
2230 IF K=1 AND L=2 OR K=2 AND L=1 THEN M=1   'M = CROSSBRED DAM GRP
(KxL)
2240 IF K=1 AND L=3 OR K=3 AND L=1 THEN M=2   'J = BREED OF SIRE
2250 IF K=1 AND L=4 OR K=4 AND L=1 THEN M=3   'N,O REQUIRED TO INDEX
2260 IF K=2 AND L=3 OR K=3 AND L=2 THEN M=4       'SPECIFIC HETEROSIS
2270 IF K=2 AND L=4 OR K=4 AND L=2 THEN M=5
2280 IF K=3 AND L=4 OR K=4 AND L=3 THEN M=6
2290 '
2300 IF J=1 AND K=2 OR J=2 AND K=1 THEN N=1
2310 IF J=1 AND K=3 OR J=3 AND K=1 THEN N=2
2320 IF J=1 AND K=4 OR J=4 AND K=1 THEN N=3
2330 IF J=2 AND K=3 OR J=3 AND K=2 THEN N=4
2340 IF J=2 AND K=4 OR J=4 AND K=2 THEN N=5
2350 '
2360 IF J=1 AND L=2 OR J=2 AND L=1 THEN O=1
2370 IF J=1 AND L=3 OR J=3 AND L=1 THEN O=2
2380 IF J=1 AND L=4 OR J=4 AND L=1 THEN O=3
2390 IF J=2 AND L=3 OR J=3 AND L=2 THEN O=4
2400 IF J=2 AND L=4 OR J=4 AND L=2 THEN O=5
2410 IF J=3 AND L=4 OR J=4 AND L=3 THEN O=6
2420 I=I+1
2430 CRCXAB(I)=CRMU+.5*(CRGIM(K)+CRGIM(L))+CRHM(M)
2440
LSBCXAB(I)=LSBMU+.5*(LSBGIM(K)+LSBGIM(L))+.5*(LSBHI(N)+LSBHI(O))+LSBHM(M
)
2450
SURCXAB(I)=SURMU+.25*(2*SURGI(J)+SURGI(K)+SURGI(L))+.5*(SURGM(K)+SURGM(L
))+.5*(SURHI(N)+SURHI(O))+SURHM(M)
2460 LSWCXAB(I)=LSBCXAB(I)*SURCXAB(I)/100
2470
ADGCXAB(I)=ADGMU+.25*(2*ADGGI(J)+ADGGI(K)+ADGGI(L))+.5*(ADGGM(K)+ADGGM(L
))+.5*(ADGHI(N)+ADGHI(O))+ADGHM(M)
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2480
BFCXAB(I)=BFMU+.25*(2*BFGI(J)+BFGI(K)+BFGI(L))+.5*(BFGM(K)+BFGM(L))+.5*(
BFHI(N)+BFHI(O))+BFHM(M)
2490
FGCXAB(I)=FGMU+.25*(2*FGGI(J)+FGGI(K)+FGGI(L))+.5*(FGGM(K)+FGGM(L))+.5*(
FGHI(N)+FGHI(O))+FGHM(M)
2500 NEXT L,K,J:I=0
2510 PRINT:PRINT:PRINT "3 BREED STATIC":PRINT
2520 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
2530 PRINT STRING$(62,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
2540 DATA DxYL,DxSY,DxSL,YxDL,YxSD,YxSL,LxDY,LxSD,LxSY,SxDY,SxDL,SxYL
2550 PRINT "BREED   CR     LSB     SUR     LSW     ADG     BF
FG":PRINT STRING$(62,"-")
2560 FOR I=1 TO 12
2570 PRINT USING "³  ³    ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRCXAB(I),LSBCXAB(I),SURCXAB(I),LSWCXAB(I),ADGCXAB(I),BFCXAB(I),
FGCXAB(I):NEXT I: PRINT STRING$(62,"-")
2580 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
2590 '
2600 '4 BREED STATIC
2610 FOR K=1 TO 4: FOR J=1 TO 4: FOR M=1 TO 4: FOR L=1 TO 4
2620 IF J=K OR J=L OR J=M OR K=L OR K=M OR L=M GOTO 3160
2630 IF LSFEP(L)§LSFEP(M) THEN 3160
2640 IF LSFEP(L)=LSFEP(M) AND L¶M THEN 3160
2650 IF LSFEP(J)§LSFEP(K) THEN 3160
2660 IF LSFEP(J)=LSFEP(K) AND J¶K THEN 3160
2670 IF K=1 AND L=2 OR K=2 AND L=1 THEN N=1    ' KxJ MALES x MxL FEMALES
2680 IF K=1 AND L=3 OR K=3 AND L=1 THEN N=2
2690 IF K=1 AND L=4 OR K=4 AND L=1 THEN N=3    ' N,P,Q,R INDEX SPEC.
HETEROSIS
2700 IF K=2 AND L=3 OR K=3 AND L=2 THEN N=4    ' O = CROSSBRED SIRE GROUP
2710 IF K=2 AND L=4 OR K=4 AND L=2 THEN N=5    ' S = CROSSBRED DAM GROUP
2720 IF K=3 AND L=4 OR K=4 AND L=3 THEN N=6
2730 '
2740 IF J=1 AND K=2 OR J=2 AND K=1 THEN O=1
2750 IF J=1 AND K=3 OR J=3 AND K=1 THEN O=2
2760 IF J=1 AND K=4 OR J=4 AND K=1 THEN O=3
2770 IF J=2 AND K=3 OR J=3 AND K=2 THEN O=4
2780 IF J=2 AND K=4 OR J=4 AND K=2 THEN O=5
2790 IF J=3 AND K=4 OR J=4 AND K=3 THEN O=6
2800 '
2810 IF J=1 AND L=2 OR J=2 AND L=1 THEN P=1
2820 IF J=1 AND L=3 OR J=3 AND L=1 THEN P=2
2830 IF J=1 AND L=4 OR J=4 AND L=1 THEN P=3
2840 IF J=2 AND L=3 OR J=3 AND L=2 THEN P=4
2850 IF J=2 AND L=4 OR J=4 AND L=2 THEN P=5
2860 IF J=3 AND L=4 OR J=4 AND L=3 THEN P=6
2870 '
2880 IF J=1 AND M=2 OR J=2 AND M=1 THEN Q=1
2890 IF J=1 AND M=3 OR J=3 AND M=1 THEN Q=2
2900 IF J=1 AND M=4 OR J=4 AND M=1 THEN Q=3
2910 IF J=2 AND M=3 OR J=3 AND M=2 THEN Q=4
2920 IF J=2 AND M=4 OR J=4 AND M=2 THEN Q=5
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2930 IF J=3 AND M=4 OR J=4 AND M=3 THEN Q=6
2940 '
2950 IF K=1 AND M=2 OR K=2 AND M=1 THEN R=1
2960 IF K=1 AND M=3 OR K=3 AND M=1 THEN R=2
2970 IF K=1 AND M=4 OR K=4 AND M=1 THEN R=3
2980 IF K=2 AND M=3 OR K=3 AND M=2 THEN R=4
2990 IF K=2 AND M=4 OR K=4 AND M=2 THEN R=5
3000 IF K=3 AND M=4 OR K=4 AND M=3 THEN R=6
3010 '
3020 IF L=1 AND M=2 OR L=2 AND M=1 THEN S=1
3030 IF L=1 AND M=3 OR L=3 AND M=1 THEN S=2
3040 IF L=1 AND M=4 OR L=4 AND M=1 THEN S=3
3050 IF L=2 AND M=3 OR L=3 AND M=2 THEN S=4
3060 IF L=2 AND M=4 OR L=4 AND M=2 THEN S=5
3070 IF L=3 AND M=4 OR L=4 AND M=3 THEN S=6
3080 I=I+1
3090 CRCDXAB(I)=CRMU+.5*(CRGIM(L)+CRGIM(M))+CRHM(S)+CRHP(O)
3100
LSBCDXAB(I)=LSBMU+.5*(LSBGIM(L)+LSBGIM(M))+.25*(LSBHI(P)+LSBHI(N)+LSBHI(
Q)+LSBHI(R))+LSBHM(S)+LSBHP(O)
3110
SURCDXAB(I)=SURMU+.25*(SURGI(J)+SURGI(K)+SURGI(L)+SURGI(M))+.5*(SURGM(L)
+SURGM(M))+.25*(SURHI(P)+SURHI(N)+SURHI(Q)+SURHI(R))+SURHM(S)+SURHP(O)
3120 LSWCDXAB(I)=LSBCDXAB(I)*SURCDXAB(I)/100
3130
ADGCDXAB(I)=ADGMU+.25*(ADGGI(J)+ADGGI(K)+ADGGI(L)+ADGGI(M))+.5*(ADGGM(L)
+ADGGM(M))+.25*(ADGHI(P)+ADGHI(N)+ADGHI(Q)+ADGHI(R))+ADGHM(S)+ADGHP(O)
3140
BFCDXAB(I)=BFMU+.25*(BFGI(J)+BFGI(K)+BFGI(L)+BFGI(M))+.5*(BFGM(L)+BFGM(M
))+.25*(BFHI(P)+BFHI(N)+BFHI(Q)+BFHI(R))+BFHM(S)+BFHP(O)
3150
FGCDXAB(I)=FGMU+.25*(FGGI(J)+FGGI(K)+FGGI(L)+FGGI(M))+.5*(FGGM(L)+FGGM(M
))+.25*(FGHI(P)+FGHI(N)+FGHI(Q)+FGHI(R))+FGHM(S)+FGHP(O)
3160 NEXT L,M,J,K:I=0
3170 PRINT:PRINT:PRINT "4 BREED STATIC":PRINT
3180 PRINT "PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING ":PRINT
3190 PRINT STRING$(63,"-"):FOR I=1 TO 6:READ B$(I):NEXT I
3200 DATA DYxSL,DLxSY,YLxSD,SDxYL,SYxDL,SLxDY
3210 PRINT "BREED    CR     LSB     SUR      LSW      ADG     BF
FG":PRINT STRING$(62,"-")
3220 FOR I=1 TO 6
3230 PRINT USING "³   ³   ##.#    ##.#    ##.#    ##.#     .###    ##.#
#.##
";B$(I),CRCDXAB(I),LSBCDXAB(I),SURCDXAB(I),LSWCDXAB(I),ADGCDXAB(I),BFCDX
AB(I),FGCDXAB(I):NEXT I: PRINT STRING$(63,"-")
3240 PRINT:INPUT "PRESS ENTER ";Z$:CLS:I=0
3250 '
3260 '
3270 PRINT " PREDICTED CONCEPTION RATE":PRINT " HOW DO THESE COMPARE TO
CONCEPTION RATES REPORTED BY BUCHANAN & JOHNSON ?":PRINT:PRINT "
PREDICTED CR FOR 3 BREED CROSSES"
3280 FOR I=1 TO 12:READ B$(I):PRINT USING "    ³  ³
##.#";B$(I),CRCXAB(I):NEXT I
3290 DATA DxYL,DxSY,DxSL,YxDL,YxSD,YxSL,LxYD,LxSD,LxSY,SxDL,SxYD,SxYL
```

```
3300 PRINT:PRINT " PREDICTED CR FOR 4 BREED CROSSES"
3310 FOR I=1 TO 6:READ B$(I):PRINT USING "    3   3
##.#";B$(I),CRCDXAB(I):NEXT I
3320 DATA SDxYL,DYxSL,SYxDL,DLxSY,YLxSD,SLxDY
3330 INPUT "PRESS ENTER ";Z$:I=0
3340 '
3350 '-----------------------------------------------------------------
------
3360 '
3370 ' CALCULATING THE NUMBER OF FEMALES FARROWING IN EACH SUB-SYSTEM
3380 '
3390 '   T - TOTAL NUMBER FEMALES FARROWING IN THE SYSTEM
3400 ' FMR - NUMBER OF FEMALES / MALE IN BREEDING HERD
3410 ' PSP - PROBABILITY OF SURVIVING FROM WEANING (42d) TO 100KG
(PUREBREDS)
3420 ' PSC - PROBABILITY OF SURVIVING FROM WEANING (42d) TO 100KG
(CROSSBREDS)
3430 '  NOTE: POSTWEANING SURVIVAL SHOULD REALLY BE CALCULATED FOR EACH
SYSTEM,
3440 '        AS FOR THE OTHER TRAITS. LACK OF LITERATURE PARAMETER
ESTIMATES
3450 '        AND THE RELATIVELY SMALL EXPECTED DIFFERENCES BETWEEN
DIFFERENT
3460 '        CROSSBREEDING SYSTEMS MAKE THIS SIMPLIFYING ASSUMPTION
REASONABLE.4440 '        REASONABLE
3470 ' FRP - PROPORTION OF FEMALES REPLACED EACH BREEDING CYCLE
(PUREBREDS)            ' FRC - PROPORTION OF FEMALES REPLACED EACH
BREEDING CYCLE (CROSSBREDS)
3480 ' MRP - PROPORTION OF MALES REPLACED EACH BREEDING CYCLE (PUREBRED
HERDS)
3490 ' MRC - PROPORTION OF MALES REPLACED EACH BREEDING CYCLE (CROSSBRED
HERDS)
3500 '  FS - PROPORTION OF FEMALE OFFSPRING SELECTED AS REPLACEMENTS IN
HERDS                 GENERATING FEMALE REPLACEMENTS
3510 '  MS - PROPORTION OF MALE OFFSPRING SELECTED AS REPLACEMENTS IN
HERDS                  GENERATING MALE REPLACEMENTS
3520 '
3530 T=10000
3540 FMR=10
3550 PSP=.97
3560 PSC=.98
3570 FRP=.5          ' .15 ? PROBABLY MORE REASONABLE IN PRACTISE,
HOWEVER SEE
3580 FRC=.5          '       NOTE WITH FIB IN ECONOMIC CALCULATIONS BELOW
3590 MRP=.5
3600 MRC=.5
3610 FS=.8
3620 MS=.6
3630 '
3640 '
3650 'The next section calculates FM and FF for purebreds and 2 breed
terminals.These are the only ones necessary for these calculations.'
3660 'FM =( # FEMALES REQUIRED TO PRODUCE NEEDED BOARS) / (TOTAL #
FEMALES                IN SUB-SYSTEMS THE BOARS ARE USED IN)
```

```
3670 'FF =( # FEMALES REQUIRED TO PRODUCE NEEDED GILTS) / (TOTAL #
FEMALES                IN SUB-SYSTEMS THE GILTS ARE USED IN)
3680 CLS
3690 PRINT "FM and FF for purebreds"
3700 FOR I = 1 TO 4
3710 FMP(I) = 2*MRP/FMR/MS/PSP/LSWP(I)
3720 FFP(I) = 2*FRP/FS/PSP/LSWP(I)
3730 PRINT USING "##########.#####";FMP(I),FFP(I)
3740 NEXT I
3750 PRINT
3760 PRINT "FM and FF for 2 breed terminals"
3770 FOR L = 1 TO 12
3780 FMAXB(L) = 2*MRC/FMR/MS/PSC/LSWAXB(L)
3790 FFAXB(L) = 2*FRC/FS/PSC/LSWAXB(L)
3800 PRINT USING "##########.#####";FMAXB(L),FFAXB(L)
3810 NEXT L
3820 INPUT "PRESS ENTER ";Z$
3830 CLS
3840 PRINT
3850 'This section calculates the structure for the 2 BREED TERMINALS.
There are12 of these. The screen output shows the two breeds and the
numbers for PurebredA, Purebred B and the AB crossbred.'
3860 PRINT "     STRUCTURE FOR 2 BREED STATIC":PRINT
3870 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(42,"-
")
3880 PRINT "     A     B     #A    #B    #AxB":PRINT STRING$(42,"-")
3890 L=0
3900 FOR I=1 TO 4: FOR J=1 TO 4
3910 IF I = J GOTO 3970
3920 L=L+1
3930 STRAXB(L,3) = T/((FMP(I)/(1-FMP(I)))+(FFP(J)/(1-FFP(J)))+1)
'Crossbred AxB
3940 STRAXB(L,1) = FMP(I)*STRAXB(L,3)/(1-FMP(I))                   '
Purebred A
3950 STRAXB(L,2) = FFP(J)*STRAXB(L,3)/(1-FFP(J))                   '
Purebred B
3960 PRINT USING "######.";I,J,STRAXB(L,1),STRAXB(L,2),STRAXB(L,3)
3970 NEXT J,I
3980 PRINT:INPUT "PRESS ENTER ";Z$
3990 CLS
4000 PRINT
4010 'This section calculates the structure for the 3 BREED TERMINALS.
4020 'The cross is chosen so that the dam of the dam is from a breed
with a larger litter size weaned / female exposed than the breed of the
sire of the dam.
4030 'The screen output shows the 3 breeds (C, A, B) and the numbers for
Purebred A, Purebred B, Purebred C, Crossbred AB and Crossbred CxAB.'
4040 PRINT "     STRUCTURE FOR 3 BREED STATIC":PRINT
4050 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(54,"-
")
4060 PRINT "     C     A     B     #A     #B     #C   #AxB   #CxAB":PRINT
STRING$(54,"-")
4070 L=0
4080 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
```

```
4090 IF I=J OR I=K OR J=K GOTO 4310
4100 IF LSFEP(K) § LSFEP(J) GOTO 4310
4110 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 4310
4120 L=L+1
4130 IF J = 1 AND K = 2 THEN M = 1
4140 IF J = 1 AND K = 3 THEN M = 2
4150 IF J = 1 AND K = 4 THEN M = 3
4160 IF J = 2 AND K = 1 THEN M = 4
4170 IF J = 2 AND K = 3 THEN M = 5
4180 IF J = 2 AND K = 4 THEN M = 6
4190 IF J = 3 AND K = 1 THEN M = 7
4200 IF J = 3 AND K = 2 THEN M = 8
4210 IF J = 3 AND K = 4 THEN M = 9
4220 IF J = 4 AND K = 1 THEN M = 10
4230 IF J = 4 AND K = 2 THEN M = 11
4240 IF J = 4 AND K = 3 THEN M = 12
4250 STRCXAB(L,5) = T / ((FMP(J)*FFAXB(M)/(1-
FMP(J)))+(FFP(K)*FFAXB(M)/(1-FFP(K)))+(FMP(I)/(1-FMP(I)))+FFAXB(M)+1)
' Crossbred CxAB
4260 STRCXAB(L,4) = FFAXB(M)*STRCXAB(L,5)                           '
Crossbred AxB
4270 STRCXAB(L,3) = FMP(I)*STRCXAB(L,5)/(1-FMP(I))                  '
Purebred C
4280 STRCXAB(L,2) = FFP(K)*FFAXB(M)*STRCXAB(L,5)/(1-FFP(K))         '
Purebred B
4290 STRCXAB(L,1) = FMP(J)*STRCXAB(L,4)/(1-FMP(J))                  '
Purebred A
4300 PRINT USING
"######.";I,J,K,STRCXAB(L,1),STRCXAB(L,2),STRCXAB(L,3),STRCXAB(L,4),STRC
XAB(L,5)
4310 NEXT K,J,I
4320 PRINT:INPUT "PRESS ENTER ";Z$
4330 CLS
4340 PRINT
4350 'This section calculates the structure for the 4 BREED TERMINALS.
Breeds  are chosen similar to the manner for the 3 breed terminal
crosses. The breeds  for the sire are also paired so that the breed of
the dam of the sire is larger
4360 'The screen output shows the breeds (in order C,D,A,B) and the
numbers for the 4 purebreds (C,D,A,B), the two crossbreds (CxD and AxB)
and the terminal   cross (CDxAB)
4370 ' The N and O variables are used to recall FF and FM for the
various two breed crosses'
4380 PRINT "     STRUCTURE FOR 4 BREED STATIC":PRINT
4390 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(61,"-
")
4400 PRINT "   C   D   A   B   #C   #D   #A  #B  #CxD #AxB
#CDxAB":PRINT STRING$(61,"-")
4410 L=0
4420 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4: FOR M=1 TO 4
4430 IF I=J OR I=K OR I=M OR J=K OR J=M OR K=M GOTO 4810
4440 IF LSFEP(J) § LSFEP(I) GOTO 4810
4450 IF LSFEP(J) = LSFEP(I) AND I ¶ J GOTO 4810
4460 IF LSFEP(M) § LSFEP(K) GOTO 4810
```

```
4470 IF LSFEP(M) = LSFEP(K) AND K ¶ M GOTO 4810
4480 L=L+1
4490 IF I = 1 AND J = 2 THEN N = 1    'I=BREED OF SIRE OF SIRE
4500 IF I = 1 AND J = 3 THEN N = 2    'J=BREED OF DAM OF SIRE
4510 IF I = 1 AND J = 4 THEN N = 3    'K=BREED OF SIRE OF DAM
4520 IF I = 2 AND J = 1 THEN N = 4    'M=BREED OF DAM OF DAM
4530 IF I = 2 AND J = 3 THEN N = 5    'N=CROSSBRED SIRE GROUP (1-12)
4540 IF I = 2 AND J = 4 THEN N = 6    'O=CROSSBRED DAM GROUP (1-12)
4550 IF I = 3 AND J = 1 THEN N = 7    'L=SYSTEM ID # (1-12)
4560 IF I = 3 AND J = 2 THEN N = 8
4570 IF I = 3 AND J = 3 THEN N = 9
4580 IF I = 4 AND J = 1 THEN N = 10
4590 IF I = 4 AND J = 2 THEN N = 11
4600 IF I = 4 AND J = 3 THEN N = 12
4610 IF K = 1 AND M = 2 THEN O = 1
4620 IF K = 1 AND M = 3 THEN O = 2
4630 IF K = 1 AND M = 4 THEN O = 3
4640 IF K = 2 AND M = 1 THEN O = 4
4650 IF K = 2 AND M = 3 THEN O = 5
4660 IF K = 2 AND M = 4 THEN O = 6
4670 IF K = 3 AND M = 1 THEN O = 7
4680 IF K = 3 AND M = 2 THEN O = 8
4690 IF K = 3 AND M = 4 THEN O = 9
4700 IF K = 4 AND M = 1 THEN O = 10
4710 IF K = 4 AND M = 2 THEN O = 11
4720 IF K = 4 AND M = 3 THEN O = 12
4730 STRCDXAB(L,7) = T/ ((FMP(K)*FFAXB(O) /(1-
FMP(K))+FFP(M)*FFAXB(O)/(1-FFP(M)))+(FMP(I)*FMAXB(N)/(1-
FMP(I)))+(FFP(J)*FMAXB(N)/(1-FFP(J)))+FFAXB(O)+FMAXB(N)+1)
4740 STRCDXAB(L,6)=FFAXB(O)*STRCDXAB(L,7)
4750 STRCDXAB(L,5)=FMAXB(N)*STRCDXAB(L,7)
4760 STRCDXAB(L,4)=FFP(M)*STRCDXAB(L,6)/(1-FFP(M))
4770 STRCDXAB(L,3)=FMP(K)*STRCDXAB(L,6)/(1-FMP(K))
4780 STRCDXAB(L,2)=FFP(J)*STRCDXAB(L,5)/(1-FFP(J))
4790 STRCDXAB(L,1)=FMP(I)*STRCDXAB(L,5)/(1-FMP(I))
4800 PRINT USING
"#####.";I,J,K,M,STRCDXAB(L,1),STRCDXAB(L,2),STRCDXAB(L,3),STRCDXAB(L,4)
,STRCDXAB(L,5),STRCDXAB(L,6),STRCDXAB(L,7)
4810 NEXT M,K,J,I
4820 PRINT:INPUT "PRESS ENTER ";Z$
4830 CLS
4840 PRINT
4850 'This section calculates the structure for the BACKCROSSES. Treated
as     special cases of 3 breed crosses, the combination used for the
dam is chosen as that for the 3 breed crosses. Both possibilities for
sire breed are used.
4860 'This involves another decision since AxAB, AxBA, BxAB and BxBA
require rather different structures. If the sire is the same as the dam
of the dam the critical needs are dependant upon the reproductive
performance of the various purebreds'
4870 'The screen output shows the breed combination and the numbers for
Purebred A, Purebred B, Crossbred AB and Crossbred AxAB'
4880 PRINT "    STRUCTURE FOR BACKCROSS":PRINT
```

```
4890 PRINT "     (1=DUROC, 2=YORK, 3=LAND, 4=SPOT)":PRINT STRING$(48,"-
")
4900 PRINT "     A     A     B    #A     #B    #AxB   #AxAB":PRINT
STRING$(48,"-")
4910 L=0
4920 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
4930 IF J=K GOTO 5280
4940 IF I §¶ K AND I §¶ J GOTO 5280
4950 IF LSFEP(K) § LSFEP(J) GOTO 5280
4960 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 5280
4970 L=L+1
4980 IF J = 1 AND K = 2 THEN M = 1   'I=BREED OF TERMINAL SIRE
4990 IF J = 1 AND K = 3 THEN M = 2   'J=BREED OF SIRE OF DAM
5000 IF J = 1 AND K = 4 THEN M = 3   'K=BREED OF DAM OF DAM
5010 IF J = 2 AND K = 1 THEN M = 4   'M=CROSSBRED DAM GROUP
5020 IF J = 2 AND K = 3 THEN M = 5   'L=SYSTEM ID #
5030 IF J = 2 AND K = 4 THEN M = 6
5040 IF J = 3 AND K = 1 THEN M = 7
5050 IF J = 3 AND K = 2 THEN M = 8
5060 IF J = 3 AND K = 4 THEN M = 9
5070 IF J = 4 AND K = 1 THEN M = 10
5080 IF J = 4 AND K = 2 THEN M = 11
5090 IF J = 4 AND K = 3 THEN M = 12
5100 IF I = K GOTO 5180
5110 ' These formulas calculate the structure when the sire breed is the
same as the sire of the dam'
5120 STRAXAB(L,4) = T / ((FMP(J)*(1+FFAXB(M))/(1-
FMP(J)))+(FFP(K)*FFAXB(M)/(1-FFP(K)))+FFAXB(M)+1)
' Crossbred AxAB
5130 STRAXAB(L,3) = FFAXB(M)*STRAXAB(L,4)                'Crossbred AxB
5140 STRAXAB(L,2) = FFP(J)*STRAXAB(L,3)/(1-FFP(J))      ' Purebred B
5150 STRAXAB(L,1) = (FMP(J)*STRAXAB(L,4)+FMP(J)*STRAXAB(L,4))/(1-FMP(J))
'      Purebred A
5160 GOTO 5270
5170 'The next four lines determine the critical needs for the situation
where the sire breed is the same as the dam of the dam'
5180 FFB = FFP(K)*FFAXB(M)/(1-FFP(K))
5190 FMB = FMP(K)/(1-FMP(K))
5200 IF FFB § FMB THEN FB = FFB
5210 IF FFB ¶= FMB THEN FB = FMB
5220 'These formulas calculate the structure when the sire breed is the
same as the dam of the dam'
5230 STRAXAB(L,4) = T/((FMP(J)*FFAXB(M)/(1-FMP(J)))+FB+FFAXB(M)+1)
'Cross AxBA
5240 STRAXAB(L,3) = FFAXB(M)*STRAXAB(L,4)
'Cross BxA
5250 STRAXAB(L,2) = FB*STRAXAB(L,4)
'Purebred B
5260 STRAXAB(L,1) = FMP(J)*STRAXAB(L,3)/(1-FMP(J))
'Purebred A
5270 PRINT USING
"######.";I,J,K,STRAXAB(L,1),STRAXAB(L,2),STRAXAB(L,3),STRAXAB(L,4)
5280 NEXT K,J,I
5290 PRINT:INPUT "PRESS ENTER ";Z$
```

```
5300 '
5310 ' CALCULATING BREEDING TO REBREEDING INTERVAL
5320 '
5330 'NOTE: 160 = 113d GESTATION + 42d LACTATION + 5d TO FIRST ESTRUS
5340 'FEMALES THAT FAIL TO CONCEIVE BY SECOND ESTRUS ARE CULLED.
THEREFORE:
5350 '
5360 FOR I=1 TO 4
5370 BCIP(I)=160+(1-CRP(I)/100)*21
5380 NEXT I:I=0
5390 FOR I=1 TO 6
5400 BCICDXAB(I)=160+(1-CRCDXAB(I)/100)*21
5410 NEXT I:I=0
5420 FOR I=1 TO 12
5430 BCIAXB(I)=160+(1-CRAXB(I)/100)*21
5440 BCIAXAB(I)=160+(1-CRAXAB(I)/100)*21
5450 BCICXAB(I)=160+(1-CRCXAB(I)/100)*21
5460 NEXT I
5470 '
5480 '------------------------------------------------------------------
------
5490 '
5500 ' CALCULATE EFFICIENCY FOR EACH SUB-SYSTEM
5510 '
5520 ' NOTE : EFFICIENCY = (LIFETIME COSTS/DAM) / (LIFETIME PRODUCT/DAM)
E () = C () / P ()
5530 '
5540 ' BCI() - BREEDING TO REBREEDING INTERVAL (DAYS)
5550 ' CONSTANTS :
5560 ' LOCG - GROWING-FINISHING LABOR & OVERHEAD COSTS FROM 40-220lb/
5570 '                                                           MARKET
PIG/DAY ($)
5580 ' LOCR - LABOR & OVERHEAD COSTS OF REPRODUCTION/SOW FARROWED/DAY
($)
5590 '   GP - GILT COSTS FROM 220lb TO FIRST BREEDING ($)
5600 '  FIB - BREEDING HERD (MALES, FEMALES, LITTERS) FEED
INTAKE/SOW/DAY (KG)
5610 '         (SHOULD PROBABLY BE A VARIABLE, SEE NOTE BELOW)
5620 '  FCB - COST OF BREEDING HERD RATION ($/KG)
5630 '  FCG - COST OF GROWING / FINISHING RATION. ($/KG)
5640 '
5650 ' ECONOMIC PARAMETER ESTIMATES ARE CALCULATED FROM "ESTIMATED
RETURNS FROM
5660 ' FARROWING AND FINISHING HOGS IN IOWA" FOR THE 10 YEARS 1974-1983,
5670 ' PUBLISHED BY THE IOWA STATE UNIVERSITY COOPERATIVE EXTENSION
SERVICE
5680 ' ( REPORTS  M-1171, FEB 1974;  M-1198(REV), JUNE 1980;  M-1231,
JAN 1983 )5408 '
5690 LOCG=.136
5700 LOCR=.867
5710 GP=30!        ' CALC. AS 110% OF TOTAL FINISHING COSTS FOR 60 DAY
PERIOD
5720 FIB=3.728     ' NOTE: FIB SHOULD REALLY BE TREATED AS VARIABLE. THE
IOWA
```

```
5730              '       FIGURES ARE BASED ON REPLACING SOWS AFTER 2
LITTERS,
5740              '       i.e. FIB DEPENDS UPON FR, AS WELL AS LSW,
ETC.
5750 FCB=.129
5760 FCG=.126
5770 '
5780 CLS:PRINT:PRINT:PRINT "     ECONOMIC CONSTANTS ASSUMED":PRINT
5790 PRINT "     LOCG      LOCR      GP        FIB       FCB
FCG":PRINT
5800 PRINT USING "     .###      .###      ##.#      #.###      .###
.###";LOCG,LOCR,GP,FIB,FCB,FCG:PRINT
5810 PRINT"LOCG - GROWING-FINISHING LABOR & OVERHEAD COSTS FROM 40-
220lb/"
5820 PRINT"                                                   MARKET
PIG/DAY ($)"
5830 PRINT"LOCR - LABOR & OVERHEAD COSTS OF REPRODUCTION/SOW
FARROWED/DAY ($)"
5840 PRINT"  GP - GILT COSTS FROM 220lb TO FIRST BREEDING ($)"
5850 PRINT" FIB - BREEDING HERD (MALES, FEMALES, LITTERS) FEED
INTAKE/SOW/DAY (KG)"
5860 PRINT" FCB - COST OF BREEDING HERD RATION ($/KG)"
5870 PRINT" FCG - COST OF GROWING / FINISHING RATION. ($/KG)"
5880 PRINT:INPUT "PRESS ENTER ";Z$
5890 PRINT:PRINT "TAKES ABOUT A MINUTE NOW"
5900 '
5910 ' CALCULATING CG (COST OF POSTWEANING GROWTH / DAM / LITTER)
5920 '
5930 ' CG = [ (1+PS)/2 * LSW ] * [ (final - wean wt)/ADG * (LOCG +
FCG*ADG*FG) ]9745 ' CG = [ pigs/dam/litter ]*[ costs/pig ]
5940 CLS:PRINT:PRINT " CGP(I)":PRINT
5950 FOR I=1 TO 4
5960 CGP(I)=(1+PSP)/2*LSWP(I)*81.64701/ADGP(I)*(LOCG+FCG*ADGP(I)*FGP(I))
5970 PRINT CGP(I)
5980 NEXT I
5990 PRINT:PRINT:PRINT " CGCDXAB(I)":PRINT
6000 FOR I=1 TO 6
6010
CGCDXAB(I)=(1+PSC)/2*LSWCDXAB(I)*81.64701/ADGCDXAB(I)*(LOCG+FCG*ADGCDXAB
(I)*FGCDXAB(I))
6020 PRINT CGCDXAB(I)
6030 NEXT I
6040 PRINT:INPUT " PRESS ENTER ";Z$
6050 CLS:PRINT:PRINT " CGAXB(I)       CGAXAB(I)     CGCXAB(I)":PRINT
6060 FOR I=1 TO 12
6070
CGAXB(I)=(1+PSC)/2*LSWAXB(I)*81.64701/ADGAXB(I)*(LOCG+FCG*ADGAXB(I)*FGAX
B(I))
6080
CGAXAB(I)=(1+PSC)/2*LSWAXAB(I)*81.64701/ADGAXAB(I)*(LOCG+FCG*ADGAXAB(I)*
FGAXAB(I))
6090
CGCXAB(I)=(1+PSC)/2*LSWCXAB(I)*81.64701/ADGCXAB(I)*(LOCG+FCG*ADGCXAB(I)*
FGCXAB(I))
```

```
6100 PRINT CGAXB(I),CGAXAB(I),CGCXAB(I)
6110 NEXT I
6120 PRINT:INPUT " PRESS ENTER ";Z$
6130 '
6140 ' CALCULATING CB (REPRODUCTION COSTS / DAM / LIFETIME)
6150 '
6160 ' CB = (COST OF BREEDING STOCK (GILT + BOAR SHARE ) AT FIRST MATING
6170 '      + (# LITTERS) * BCI() * (LOCR + FCB*FIB)
6180 '
6190 '    = [1 + MR/(FMR*FR)] * [ CB()/(PS*LSW/FR) + CG()/(PS*LSW) + GP
]
6200 '      note : cb & cg values for the system replacements produced
in
6210 '      + [  1/FR   ] * BCI * [ LOCR + FCB*FIB ]
6220 '
6230 ' FOR PUREBRED SYSTEMS, CB & CB() ARE FOR THE SAME SYSTEM.
MULTIPLYING THRU       AND SIMPLIFYING RESULTS IN :
6240 ' CB = [ (1+MR/(FM*FR))*(CG/(PS*LSW)+GP) +
(1/FR)*BCI*(LOCR+(FCB*FIB))                / [ 1 - FR/(PS*LSW) -
MR/(FMR*PS*LSW) ] i.e.,
6250 '
6260 CLS:PRINT:PRINT " CBP(I)":PRINT
6270 FOR I=1 TO 4
6280
CBP(I)=((1+(MRP/(FMR*FRP)))*((100*CGP(I))/(PSP*LSWP(I)*CRP(I))+(100*GP/C
RP(I)))+((1/FRP)*BCIP(I)*(LOCR+(FCB*FIB))))/(1-
(100*FRP)/(PSP*LSWP(I)*CRP(I))-(100*MRP)/(FMR*PSP*LSWP(I)*CRP(I)))
6290 PRINT CBP(I)
6300 NEXT I
6310 '
6320 ' FOR ALL SYSTEMS REQUIRING ONLY PUREBRED MALES FROM OUTSIDE THE
SYSTEM
6330 ' (I.E. ROTATIONAL SYSTEMS), THE BOAR SHARE OF COSTS
6340 ' (CALCULATED BY THE MR/(FMR*FR) COEFFICIENT) DEPENDS UPON THE
WEIGHTED
6350 ' AVERAGE CB(I) AND CG(I) FOR THE PUREBREDS INVOLVED. THE FOLLOWING
6360 ' VARIABLE (XP) IS FIRST CALCULATED FOR EACH PUREBRED :
6370 '
6380 PRINT:PRINT:PRINT " XP(I)":PRINT
6390 FOR I=1 TO 4
6400 XP(I)=(FRP*CBP(I)+CGP(I))/(PSP*LSWP(I))
6410 PRINT XP(I)
6420 NEXT I
6430 PRINT:INPUT " PRESS ENTER ";Z$
6440 '
6450 ' THE REMAINING (STATIC) SYSTEMS REQUIRE VARIOUSLY PUREBRED AND
CROSSBRED
6460 ' MALES AND FEMALES. AGAIN, BREED OF DAM OF DAM IS CHOSEN BASED
UPON LITTER       SIZE WEANED / FEMALE EXPOSED FOR BACKCROSS AND 3 & 4
BREED STATIC SYSTEMS
6470 '
6480 '2 BREED STATIC
6490 CLS:PRINT:PRINT " CBAXB(I)":PRINT
6500 FOR I=1 TO 12
```

```
6510 IF I=1 THEN J=1:K=2        ' J INDEXES THE BREED OF SIRE
6520 IF I=2 THEN J=1:K=3        ' K INDEXES THE BREED OF DAM
6530 IF I=3 THEN J=1:K=4
6540 IF I=4 THEN J=2:K=1
6550 IF I=5 THEN J=2:K=3
6560 IF I=6 THEN J=2:K=4
6570 IF I=7 THEN J=3:K=1
6580 IF I=8 THEN J=3:K=2
6590 IF I=9 THEN J=3:K=4
6600 IF I=10 THEN J=4:K=1
6610 IF I=11 THEN J=4:K=2
6620 IF I=12 THEN J=4:K=3
6630
CBAXB(I)=XP(K)+(1+MRC/(FMR*FRC))*(100*GP/CRP(K))+(MRC/(FMR*FRC))*XP(J)+(
1/FRC)*BCIAXB(I)*(LOCR+FCB*FIB)
6640 PRINT CBAXB(I)
6650 NEXT I
6660 PRINT:INPUT " PRESS ENTER ";Z$
6670 '
6680 'BACKCROSS
6690 CLS:PRINT:PRINT " CBAXAB(I)":PRINT
6700 L=0
6710 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
6720 IF J=K GOTO 6910
6730 IF I §¶ K AND I §¶ J GOTO 6910
6740 IF LSFEP(K) § LSFEP(J) GOTO 6910
6750 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 6910
6760 L=L+1
6770 IF J = 1 AND K = 2 THEN M = 1   'I=BREED OF TERMINAL SIRE
6780 IF J = 1 AND K = 3 THEN M = 2   'J=BREED OF SIRE OF DAM
6790 IF J = 1 AND K = 4 THEN M = 3   'K=BREED OF DAM OF DAM
6800 IF J = 2 AND K = 1 THEN M = 4   'M=CROSSBRED DAM GROUP
6810 IF J = 2 AND K = 3 THEN M = 5   'L=SYSTEM ID #
6820 IF J = 2 AND K = 4 THEN M = 6
6830 IF J = 3 AND K = 1 THEN M = 7
6840 IF J = 3 AND K = 2 THEN M = 8
6850 IF J = 3 AND K = 4 THEN M = 9
6860 IF J = 4 AND K = 1 THEN M = 10
6870 IF J = 4 AND K = 2 THEN M = 11
6880 IF J = 4 AND K = 3 THEN M = 12
6890
CBAXAB(L)=(CBAXB(M)*FRC+CGAXB(M))/(PSC*LSWAXB(M))+(1+MRC/(FMR*FRC))*(100
*GP/CRAXB(M))+(MRC/(FMR*FRC))*XP(I)+(1/FRC)*BCIAXAB(L)*(LOCR+FCB*FIB)
6900 PRINT CBAXAB(L)
6910 NEXT K,J,I
6920 PRINT:INPUT " PRESS ENTER ";Z$
6930 '
6940 '3 BREED STATIC
6950 CLS:PRINT:PRINT " CBCXAB(I)":PRINT
6960 L=0
6970 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
6980 IF I=J OR I=K OR J=K GOTO 7160
6990 IF LSFEP(K) § LSFEP(J) GOTO 7160
7000 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 7160
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7010 L=L+1
7020 IF J = 1 AND K = 2 THEN M = 1     ' I,J,K,M,L AS FOR THE BACKCROSS
ABOVE
7030 IF J = 1 AND K = 3 THEN M = 2
7040 IF J = 1 AND K = 4 THEN M = 3
7050 IF J = 2 AND K = 1 THEN M = 4
7060 IF J = 2 AND K = 3 THEN M = 5
7070 IF J = 2 AND K = 4 THEN M = 6
7080 IF J = 3 AND K = 1 THEN M = 7
7090 IF J = 3 AND K = 2 THEN M = 8
7100 IF J = 3 AND K = 4 THEN M = 9
7110 IF J = 4 AND K = 1 THEN M = 10
7120 IF J = 4 AND K = 2 THEN M = 11
7130 IF J = 4 AND K = 3 THEN M = 12
7140
CBCXAB(L)=(CBAXB(M)*FRC+CGAXB(M))/(PSC*LSWAXB(M))+(1+MRC/(FMR*FRC))*(100
*GP/CRAXB(M))+(MRC/(FMR*FRC))*XP(I)+(1/FRC)*BCICXAB(L)*(LOCR+FCB*FIB)
7150 PRINT CBCXAB(L)
7160 NEXT K,J,I
7170 PRINT:INPUT " PRESS ENTER ";Z$
7180 '
7190 '4 BREED STATIC
7200 CLS:PRINT:PRINT " CBCDXAB(I)":PRINT
7210 L=0
7220 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4: FOR M=1 TO 4
7230 IF I=J OR I=K OR I=M OR J=K OR J=M OR K=M GOTO 7550
7240 IF LSFEP(J) § LSFEP(I) GOTO 7550
7250 IF LSFEP(J) = LSFEP(I) AND I ¶ J GOTO 7550
7260 IF LSFEP(M) § LSFEP(K) GOTO 7550
7270 IF LSFEP(M) = LSFEP(K) AND K ¶ M GOTO 7550
7280 L=L+1
7290 IF I = 1 AND J = 2 THEN N = 1     'I=BREED OF SIRE OF SIRE
7300 IF I = 1 AND J = 3 THEN N = 2     'J=BREED OF DAM OF SIRE
7310 IF I = 1 AND J = 4 THEN N = 3     'K=BREED OF SIRE OF DAM
7320 IF I = 2 AND J = 1 THEN N = 4     'M=BREED OF DAM OF DAM
7330 IF I = 2 AND J = 3 THEN N = 5     'N=CROSSBRED SIRE GROUP (1-12)
7340 IF I = 2 AND J = 4 THEN N = 6     'O=CROSSBRED DAM GROUP (1-12)
7350 IF I = 3 AND J = 1 THEN N = 7     'L=SYSTEM ID # (1-12)
7360 IF I = 3 AND J = 2 THEN N = 8
7370 IF I = 3 AND J = 3 THEN N = 9
7380 IF I = 4 AND J = 1 THEN N = 10
7390 IF I = 4 AND J = 2 THEN N = 11
7400 IF I = 4 AND J = 3 THEN N = 12
7410 IF K = 1 AND M = 2 THEN O = 1
7420 IF K = 1 AND M = 3 THEN O = 2
7430 IF K = 1 AND M = 4 THEN O = 3
7440 IF K = 2 AND M = 1 THEN O = 4
7450 IF K = 2 AND M = 3 THEN O = 5
7460 IF K = 2 AND M = 4 THEN O = 6
7470 IF K = 3 AND M = 1 THEN O = 7
7480 IF K = 3 AND M = 2 THEN O = 8
7490 IF K = 3 AND M = 4 THEN O = 9
7500 IF K = 4 AND M = 1 THEN O = 10
7510 IF K = 4 AND M = 2 THEN O = 11
```

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7520 IF K = 4 AND M = 3 THEN O = 12
7530
CBCDXAB(L)=(CBAXB(O)*FRC+CGAXB(O))/(PSC*LSWAXB(O))+(1+MRC/(FMR*FRC))*(10
0*GP/CRAXB(O))+(MRC/(FMR*FRC))*(CBAXB(N)*FRC+CGAXB(N))/(PSC*LSWAXB(N))+(
1/FRC)*BCICDXAB(L)*(LOCR+FCB*FIB)
7540 PRINT CBCDXAB(L)
7550 NEXT M,K,J,I
7560 PRINT:INPUT " PRESS ENTER ";Z$
7570 '
7580 ' CALCULATING C (LIFETIME COSTS / DAM) FROM CB, CG & # OF
LITTERS(1/FR_)
7590 '
7600 FOR I=1 TO 4
7610 CP(I)=CBP(I)+(1/FRP)*CGP(I)
7620 NEXT I:I=0
7630 FOR I=1 TO 6
7640 CCDXAB(I)=CBCDXAB(I)+(1/FRC)*CGCDXAB(I)
7650 NEXT I:I=0
7660 FOR I=1 TO 12
7670 CAXB(I)=CBAXB(I)+(1/FRC)*CGAXB(I)
7680 CAXAB(I)=CBAXAB(I)+(1/FRC)*CGAXAB(I)
7690 CCXAB(I)=CBCXAB(I)+(1/FRC)*CGCXAB(I)
7700 NEXT I
7710 '
7720 ' CALCULATING PG (GROWTH PHASE PRODUCT / DAM / PARITY)
7730 '
7740 ' PG = RELATIVE VALUE*P(SURVIVE WEAN-100kg)*LITTER SIZE
WEANED*SLAUGHTER WT
7750 '    = RV * PS * LSW * 100  (kg)
7760 ' EXCEPT FOR PUREBRED HERDS, AND HERDS PRODUCING CROSSBRED BOARS
(CXD), WHERE IT IS ASSUMED THAT 10% OF MALES ARE
7770 ' CASTRATED, AND THAT BOAR (100kg) MEAT IS WORTH 70% OF EQUIVALENT
7780 ' BARROW / GILT MARKET HOG MEAT. THEREFORE, IN THESE HERDS :
7790 ' PG = RV * (Prop. gilts & barrows + 70% prop. boars) * PS * LSW *
100(kg)
7800 '    = RV * .865 * PS * LSW * 100
7810 '
7820 ' THE FOLLOWING SET OF EQUATIONS MAY BE USED TO FIX RV = 1.00
7830 '
7840 'FOR I=1 TO 4
7850 'PGP(I)=86.5*PSP*LSWP(I)
7860 'NEXT I:I=0
7870 'FOR I=1 TO 6
7880 'PGCDXAB(I)=100*PSC*LSWCDXAB(I)
7890 'NEXT I:I=0
7900 'FOR I=1 TO 12
7910 'PGAXB(I)=100*PSC*LSWAXB(I)
7920 'PGCXD(I)=.865*PGAXB(I)
7930 'PGAXAB(I)=100*PSC*LSWAXAB(I)
7940 'PGCXAB(I)=100*PSC*LSWCXAB(I)
7950 'NEXT I
7960 '
7970 ' THE FOLLOWING EQUATIONS PAY A PREMIUM FOR LEANER HOGS, ACCORDING
TO
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7980 ' NPPC "PORK VALUE" GUIDELINES FOR 211-230 lb MARKET HOGS, I.E.,
7990 ' fat,last rib,in.:    .7     .8     .9     1.0   1.1    1.2    1.3
8000 ' av. backfat, in.:   1.0    1.1    1.2     1.3   1.4    1.5    1.6
8010 ' relative value  :   104    103    102    101    100     99     98
8020 ' NOTE: THE RELATIONSHIP "av. fat = last rib fat + .3 in." IS
ASSUMED
8030 '      NPPC USES LAST RIB FAT TO ASIGN VALUE
8040 ' THE REGRESSION OF VALUE ON AV. FAT IS:
8050 '  RELATIVE VALUE = 114 - 10. * (av. fat, in)
8060 '                 = 114 - .3937 * (av. fat, mm)
8070 ' RV IS CALCULATED FOR TERMINAL OFFSPRING OF EACH SYSTEM:
8080 '
8090 FOR I=1 TO 4
8100 RVP(I)=(114-.3937*BFP(I))/100
8110 NEXT I
8120 FOR I=1 TO 6
8130 RVCDXAB(I)=(114-.3937*BFAXAB(I))/100
8140 NEXT I
8150 FOR I=1 TO 12
8160 RVAXB(I)=(114-.3937*BFAXB(I))/100
8170 RVAXAB(I)=(114-.3937*BFAXAB(I))/100
8180 RVCXAB(I)=(114-.3937*BFCXAB(I))/100
8190 NEXT I
8200 '
8210 ' PG IS THEN CALCULATED:
8220 '
8230 CLS:PRINT:PRINT " PGP(I)":PRINT
8240 FOR I=1 TO 4
8250 PGP(I)=RVP(I)*86.5*PSP*LSWP(I)
8260 PRINT PGP(I)
8270 NEXT I
8280 PRINT:PRINT:PRINT " PGCDXAB(I)":PRINT
8290 FOR I=1 TO 6
8300 PGCDXAB(I)=RVCDXAB(I)*100*PSC*LSWCDXAB(I)
8310 PRINT PGCDXAB(I)
8320 NEXT I
8330 PRINT:INPUT " PRESS ENTER ";Z$
8340 CLS:PRINT:PRINT " PGAXB(I)      PGAXAB(I)     PGCXAB(I)":PRINT
8350 FOR I=1 TO 12
8360 PGAXB(I)=RVAXB(I)*100*PSC*LSWAXB(I)
8370 PGCXD(I)=.865*PGAXB(I)
8380 PGAXAB(I)=RVAXAB(I)*100*PSC*LSWAXAB(I)
8390 PGCXAB(I)=RVCXAB(I)*100*PSC*LSWCXAB(I)
8400 PRINT PGAXB(I),PGAXAB(I),PGCXAB(I)
8410 NEXT I
8420 PRINT:INPUT " PRESS ENTER ";Z$
8430 ' CALCULATING PB (SALVAGE PRODUCT / DAM LIFETIME)
8440 '
8450 ' PB =PRODUCT (AS % SLAUGHTER WT) * [ CULL FEMALE WT + (CULL BOAR
WT / (FMR*(MALE HERD LIFE/FEMALE HERD LIFE)) ]
8460 '
8470 ' EQUATIONS WERE DEVELOPED AS FOLLOWS :
8480 '
8490 '  SALVAGE PRODUCT CONSISTS OF SOWS CULLED AT THE END OF THEIR
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8500 '  REPRODUCTIVE LIFE ( i.e. AFTER 1/FR LITTERS, FR=PROP FEMALES
REPLACED
8510 '  EACH CYCLE ), OPEN SOWS AND GILTS AND CULL BOARS.
8520 '  EACH CYCLE ), OPEN SOWS AND GILTS AND CULL BOARS.
8530 '  FOR EVERY FEMALE CONCEIVING EACH CYCLE, (100/CR)-1 FEMALES ARE
SOLD AS
8540 '  OPEN. OVER A FEMALES LIFETIME, (1/FR)*((100/CR)-1) CULL FEMALES
HAVE
8550 '  BEEN SOLD.
8560 '
8570 '  ASSUMING THE FOLLOWING RELATIVE PRODUCT VALUES :
8580 '   2201b MARKET BARROW/GILT                      = 1.00
8590 '   OPEN GILT (2851b)                             =  .90
8600 '   OPEN/CULL SOW (2601b + 601b / PARITY ¶ 1 ) =  .85
8610 '   CULL BOAR (4001b)                             =  .65
8620 '
8630 ' PB = .85*(255+(30/FR)) + (1/FR)*((100/CR)-1) *
8640 '          cull sow       # open females/dam lifetime
8650 '
8660 '         [ .9*255*FR + .85*(255+(15/FR))*(1-FR) ] +
(.65*400)/(FM*FR/MR)
8670 '         open gilts          open sows                   cull boars
8680 '
8690 ' CONVERTING TO KG AND SIMPLIFYING GIVES THE EQUATIONS USED BELOW,
EXCEPT
8700 ' FOR THE CONSTANT MULTIPLIER OF .985, USED TO REFLECT THE ASSUMED
1.5%
8710 ' BREEDING HERD DEATH LOSS / CYCLE
8720 '
8730 CLS:PRINT:PRINT " PBP(I)":PRINT
8740 FOR I=1 TO 4
8750 PBP(I)=.985*(109.883+(23.133/FRP)+(1/FRP)*(100/CRP(I)-
1)*(116.346*FRP+(1-FRP)*(109.883+23.133/FRP))+117.934/(FMR*FRP/MRP))
8760 PRINT PBP(I)
8770 NEXT I
8780 PRINT:PRINT:PRINT " PBCDXAB(I)":PRINT
8790 FOR I=1 TO 6
8800 PBCDXAB(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRCDXAB(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8810 PRINT PBCDXAB(I)
8820 NEXT I
8830 PRINT:INPUT " PRESS ENTER ";Z$
8840 CLS:PRINT:PRINT " PBAXB(I)       PBAXAB(I)     PBCXAB(I)":PRINT
8850 FOR I=1 TO 12
8860 PBAXB(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRAXB(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8870 PBAXAB(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRAXAB(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8880 PBCXAB(I)=.985*(109.883+(23.133/FRC)+(1/FRC)*(100/CRCXAB(I)-
1)*(116.346*FRC+(1-FRC)*(109.883+23.133/FRC))+117.934/(FMR*FRC/MRC))
8890 PRINT PBAXB(I),PBAXAB(I),PBCXAB(I)
8900 NEXT I
8910 PRINT:INPUT " PRESS ENTER ";Z$
8920 '
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8930 ' CALCULATING P (LIFETIME PRODUCT / DAM) FROM PB, PG & # LITTERS
PRODUCED
8940 '
8950 FOR I=1 TO 4
8960 PP(I)=PBP(I)+(1/FRP)*PGP(I)
8970 NEXT I
8980 FOR I=1 TO 6
8990 PCDXAB(I)=PBCDXAB(I)+(1/FRC)*PGCDXAB(I)
9000 NEXT I
9010 FOR I=1 TO 12
9020 PAXB(I)=PBAXB(I)+(1/FRC)*PGAXB(I)
9030 PCXD(I)=PBAXB(I)+(1/FRC)*PGCXD(I)
9040 PAXAB(I)=PBAXAB(I)+(1/FRC)*PGAXAB(I)
9050 PCXAB(I)=PBCXAB(I)+(1/FRC)*PGCXAB(I)
9060 NEXT I
9070 '
9080 ' CALCULATING E (EFFICIENCY) FROM C & P
9090 '
9100 FOR I=1 TO 4
9110 EP(I)=CP(I)/PP(I)
9120 NEXT I:I=0
9130 FOR I=1 TO 6
9140 ECDXAB(I)=CCDXAB(I)/PCDXAB(I)
9150 NEXT I:I=0
9160 FOR I=1 TO 12
9170 EAXB(I)=CAXB(I)/PAXB(I)
9180 ECXD(I)=CAXB(I)/PCXD(I)
9190 EAXAB(I)=CAXAB(I)/PAXAB(I)
9200 ECXAB(I)=CCXAB(I)/PCXAB(I)
9210 NEXT I
9220 '
9230 ' E REPRESENTS EFFICIENCY FOR TERMINAL SUB-SYSTEMS OF EACH SYSTEM.
9240 ' TOTAL SYSTEM EFFICIENCY (SE), HOWEVER, IS THE WEIGHTED AVERAGE OF
EFFICIENCIES OF BOTH THE BREEDING STOCK GENERATORS AND TERMINAL
9250 ' CROSSES THAT COMPRISE THE 10,000 FEMALES FARROWING IN EACH
SYSTEM.
9260 ' THUS :
9270 '
9280 'PUREBREDS
9290 FOR I=1 TO 4
9300 SEP(I)=EP(I)
9310 NEXT I
9320 '
9330 '2 BREED STATIC
9340 FOR I=1 TO 12
9350 IF I=1 THEN J=1:K=2        ' J INDEXES THE BREED OF SIRE
9360 IF I=2 THEN J=1:K=3        ' K INDEXES THE BREED OF DAM
9370 IF I=3 THEN J=1:K=4
9380 IF I=4 THEN J=2:K=1
9390 IF I=5 THEN J=2:K=3
9400 IF I=6 THEN J=2:K=4
9410 IF I=7 THEN J=3:K=1
9420 IF I=8 THEN J=3:K=2
9430 IF I=9 THEN J=3:K=4
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9440 IF I=10 THEN J=4:K=1
9450 IF I=11 THEN J=4:K=2
9460 IF I=12 THEN J=4:K=3
9470
SEAXB(I)=(STRAXB(I,1)*EP(J)+STRAXB(I,2)*EP(K)+STRAXB(I,3)*EAXB(I))/10000
9480 NEXT I
9490 '
9500 'BACKCROSS
9510 L=0
9520 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
9530 IF J=K GOTO 9710
9540 IF I §¶ K AND I §¶ J GOTO 9710
9550 IF LSFEP(K) § LSFEP(J) GOTO 9710
9560 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 9710
9570 L=L+1
9580 IF J = 1 AND K = 2 THEN M = 1   'I=BREED OF TERMINAL SIRE
9590 IF J = 1 AND K = 3 THEN M = 2   'J=BREED OF SIRE OF DAM
9600 IF J = 1 AND K = 4 THEN M = 3   'K=BREED OF DAM OF DAM
9610 IF J = 2 AND K = 1 THEN M = 4   'M=CROSSBRED DAM GROUP
9620 IF J = 2 AND K = 3 THEN M = 5   'L=SYSTEM ID #
9630 IF J = 2 AND K = 4 THEN M = 6
9640 IF J = 3 AND K = 1 THEN M = 7
9650 IF J = 3 AND K = 2 THEN M = 8
9660 IF J = 3 AND K = 4 THEN M = 9
9670 IF J = 4 AND K = 1 THEN M = 10
9680 IF J = 4 AND K = 2 THEN M = 11
9690 IF J = 4 AND K = 3 THEN M = 12
9700
SEAXAB(L)=(STRAXAB(L,1)*EP(J)+STRAXAB(L,2)*EP(K)+STRAXAB(L,3)*EAXB(M)+ST
RAXAB(L,4)*EAXAB(L))/10000
9710 NEXT K,J,I
9720 '
9730 '3 BREED STATIC
9740 L=0
9750 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4
9760 IF I=J OR I=K OR J=K GOTO 9930
9770 IF LSFEP(K) § LSFEP(J) GOTO 9930
9780 IF LSFEP(K) = LSFEP(J) AND J ¶ K GOTO 9930
9790 L=L+1
9800 IF J = 1 AND K = 2 THEN M = 1    ' I,J,K,M,L AS FOR THE BACKCROSS
ABOVE
9810 IF J = 1 AND K = 3 THEN M = 2
9820 IF J = 1 AND K = 4 THEN M = 3
9830 IF J = 2 AND K = 1 THEN M = 4
9840 IF J = 2 AND K = 3 THEN M = 5
9850 IF J = 2 AND K = 4 THEN M = 6
9860 IF J = 3 AND K = 1 THEN M = 7
9870 IF J = 3 AND K = 2 THEN M = 8
9880 IF J = 3 AND K = 4 THEN M = 9
9890 IF J = 4 AND K = 1 THEN M = 10
9900 IF J = 4 AND K = 2 THEN M = 11
9910 IF J = 4 AND K = 3 THEN M = 12
```

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9920
SECXAB(L)=(STRCXAB(L,1)*EP(J)+STRCXAB(L,2)*EP(K)+STRCXAB(L,3)*EP(I)+STRC
XAB(L,4)*EAXB(M)+STRCXAB(L,5)*ECXAB(L))/10000
9930 NEXT K,J,I
9940 '
9950 '4 BREED STATIC
9960 L=0
9970 FOR I=1 TO 4: FOR J=1 TO 4: FOR K=1 TO 4: FOR M=1 TO 4
9980 IF I=J OR I=K OR I=M OR J=K OR J=M OR K=M GOTO 10290
9990 IF LSFEP(J) § LSFEP(I) GOTO 10290
10000 IF LSFEP(J) = LSFEP(I) AND I ¶ J GOTO 10290
10010 IF LSFEP(M) § LSFEP(K) GOTO 10290
10020 IF LSFEP(M) = LSFEP(K) AND K ¶ M GOTO 10290
10030 L=L+1
10040 IF I = 1 AND J = 2 THEN N = 1     'I=BREED OF SIRE OF SIRE
10050 IF I = 1 AND J = 3 THEN N = 2     'J=BREED OF DAM OF SIRE
10060 IF I = 1 AND J = 4 THEN N = 3     'K=BREED OF SIRE OF DAM
10070 IF I = 2 AND J = 1 THEN N = 4     'M=BREED OF DAM OF DAM
10080 IF I = 2 AND J = 3 THEN N = 5     'N=CROSSBRED SIRE GROUP (1-12)
10090 IF I = 2 AND J = 4 THEN N = 6     'O=CROSSBRED DAM GROUP (1-12)
10100 IF I = 3 AND J = 1 THEN N = 7     'L=SYSTEM ID # (1-12)
10110 IF I = 3 AND J = 2 THEN N = 8
10120 IF I = 3 AND J = 3 THEN N = 9
10130 IF I = 4 AND J = 1 THEN N = 10
10140 IF I = 4 AND J = 2 THEN N = 11
10150 IF I = 4 AND J = 3 THEN N = 12
10160 IF K = 1 AND M = 2 THEN O = 1
10170 IF K = 1 AND M = 3 THEN O = 2
10180 IF K = 1 AND M = 4 THEN O = 3
10190 IF K = 2 AND M = 1 THEN O = 4
10200 IF K = 2 AND M = 3 THEN O = 5
10210 IF K = 2 AND M = 4 THEN O = 6
10220 IF K = 3 AND M = 1 THEN O = 7
10230 IF K = 3 AND M = 2 THEN O = 8
10240 IF K = 3 AND M = 4 THEN O = 9
10250 IF K = 4 AND M = 1 THEN O = 10
10260 IF K = 4 AND M = 2 THEN O = 11
10270 IF K = 4 AND M = 3 THEN O = 12
10280
SECDXAB(L)=(STRCDXAB(L,1)*EP(I)+STRCDXAB(L,2)*EP(J)+STRCDXAB(L,3)*EP(K)+
STRCDXAB(L,4)*EP(M)+STRCDXAB(L,5)*ECXD(N)+STRCDXAB(L,6)*EAXB(O)+STRCDXAB
(L,7)*ECDXAB(L))/10000
10290 NEXT M,K,J,I
10300 SUMP=0: SUMAXB=0: SUMAXAB=0: SUMCXAB=0: SUMCDXAB=0
10310 FOR L=1 TO 4
10320 SUMP=SEP(L)+SUMP
10330 NEXT L
10340 AVGP=SUMP/4
10350 '
10360 FOR L=1 TO 12
10370 SUMAXB=SEAXB(L)+SUMAXB
10380 SUMAXAB=SEAXAB(L)+SUMAXAB
10390 SUMCXAB=SECXAB(L)+SUMCXAB
10400 NEXT L
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10410 '
10420 AVGAXB=SUMAXB/12: AVGAXAB=SUMAXAB/12: AVGCXAB=SUMCXAB/12
10430 FOR L=1 TO 6
10440 SUMCDXAB=SECDXAB(L)+SUMCDXAB
10450 NEXT L
10460 AVGCDXAB=SUMCDXAB/6
10470 '
10480 CLS:PRINT TAB(12) " NO. BREED            EFFICIENCY ( COST / KG
PRODUCT )"
10490 PRINT "SYSTEM    COMBINATIONS        MEAN           MIN
MAX"
10500 PRINT STRING$(70,"-")
10510 PRINT USING "  P          4                 #.####        ###.##
###.##";AVGP,MINP,MAXP
10520 PRINT USING " AxB        12                 #.####        ###.##
###.##";AVGAXB,MINAXB,MAXAXB
10530 PRINT USING " AxAB       12                 #.####        ###.##
###.##";AVGAXAB,MINAXAB,MAXAXAB
10540 PRINT USING " CxAB       12                 #.####        ###.##
###.##";AVGCXAB,MINCXAB,MAXCXAB
10550 PRINT USING "CDxAB        6                 #.####        ###.##
###.##";AVGCDXAB,MINCDXAB,MAXCDXAB
10560 PRINT:INPUT "PRESS ENTER";Z$:CLS
10570 '
10580 PRINT:PRINT:PRINT "     PUREBREDS":PRINT
10590 PRINT "BREEDS          EFFICIENCY ( COST / KG PRODUCT )":PRINT
10600 PRINT STRING$(48,"-"):B$(1)="D":B$(2)="Y":B$(3)="L":B$(4)="S"
10610 FOR I=1 TO 4
10620 PRINT USING "³  ³                          ###.####";B$(I),EP(I):NEXT
I
10630 PRINT:INPUT "PRESS ENTER ";Z$:CLS
10640 '
10650 PRINT:PRINT:PRINT "2 BREED STATIC":PRINT
10660 PRINT "BREEDS          EFFICIENCY ( COST / KG PRODUCT )":PRINT
10670 PRINT STRING$(48,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
10680 DATA DxY,DxL,DxS,YxD,YxL,YxS,LxD,LxY,LxS,SxD,SxY,SxL
10690 FOR I=1 TO 12
10700 PRINT USING "³  ³
###.####";B$(I),SEAXB(I):NEXT I
10710 PRINT:INPUT "PRESS ENTER ";Z$:CLS
10720 '
10730 PRINT:PRINT:PRINT "     BACKCROSS":PRINT
10740 PRINT "BREEDS          EFFICIENCY ( COST / KG PRODUCT )":PRINT
10750 PRINT "(Check!)"
10760 PRINT STRING$(48,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
10770 DATA DxDY,DxDL,DxSD,YxDY,YxYL,YxSY,LxDL,LxYL,LxSL,SxSD,SxSY,SxSL
10780 FOR I=1 TO 12
10790 PRINT USING "³  ³
###.####";B$(I),SEAXAB(I):NEXT I
10800 PRINT:INPUT "PRESS ENTER ";Z$:CLS
10810 '
10820 PRINT:PRINT:PRINT "3 BREED STATIC":PRINT
10830 PRINT "BREEDS          EFFICIENCY ( COST / KG PRODUCT )":PRINT
10840 PRINT "(Check!)"
```

```
10850 PRINT STRING$(48,"-"):FOR I=1 TO 12:READ B$(I):NEXT I
10860 DATA DxYL,DxSY,DxSL,YxDL,YxSD,YxSL,LxDY,LxSD,LxSY,SxDY,SxDL,SxYL
10870 FOR I=1 TO 12
10880 PRINT USING "3  3
###.####";B$(I),SECXAB(I):NEXT I
10890 PRINT:INPUT "PRESS ENTER ";Z$:CLS
10900 '
10910 PRINT:PRINT:PRINT "4 BREED STATIC":PRINT
10920 PRINT "BREEDS          EFFICIENCY ( COST / KG PRODUCT )":PRINT
10930 PRINT "(Check!)"
10940 PRINT STRING$(48,"-"):FOR I=1 TO 6:READ B$(I):NEXT I
10950 DATA DYxSL,DLxSY,YLxSD,SDxYL,SYxDL,SLxDY
10960 FOR I=1 TO 6
10970 PRINT USING "3    3
###.####";B$(I),SECDXAB(I):NEXT I
```

APPENDIX C

STRUCTURE FORMULAS FOR ALTERNATIVE CROSSBREEDING SYSTEMS

2 Breed Rotation (A, B)

$$A = (FM_A * AB)/(2 - 2FM_A)$$

$$B = (FM_B * AB)/(2 - 2FM_B)$$

$$AB = T/[(FM_A/(2 - 2FM_A)) + (FM_B/(2 - 2FM_B)) + 1]$$

3 Breed Rotation (A, B, C)

$$A = (FM_A * ABC)/(3 - 3FM_A)$$

$$B = (FM_B * ABC)/(3 - 3FM_B)$$

$$C = (FM_C * ABC)/(3 - 3FM_C)$$

$$ABC = T/[(FM_A/(3 - 3FM_A)) + (FM_B/(3 - 3\ FM_B)) + (FM_C/(3 - 3FM_C)) + 1]$$

4 Breed Rotation (A, B, C, D)

As above, but now include breed D and 3 becomes 4 in all equations.

2 Breed Static (A x B)

$$A = (FM_A * AB)/(1 - FM_A)$$

$$B = (FF_B * AB)/(1 - FF_B)$$

$$AB = T/[(FM_A/(1-FM_A)) + (FF_B/(1 - FF_B)) + 1]$$

3 Breed Static (C x (AxB))

$$A = (FM_A * FF_{AB} * CAB)/(1 - FM_A)$$

$$B = (FF_B * FF_{AB} * CAB)/(1 - FF_B)$$

$$C = (FM_C * CAB)/(1 - FM_C)$$

$$AB = FF_{AB} * CAB$$

$$CAB = T/[(FM_A * FF_{AB})/(1 - FM_A) + (FF_B * FF_{AB})/ (1 - FM_A) + FM_C/(1 - FM_C) + FF_{AB} + 1]$$

4 Breed Static ((CxD) x (AxB))

$$A = (FM_A * AB)/(1 - FM_A)$$

$$B = (FF_B * AB)/(1 - FF_B)$$

$$C = (FM_C * CD)/(1 - FM_C)$$

$$D = (FF_D * CD)/(1 - FF_D)$$

$$AB = FF_{AB} * CDAB$$

$$CD = FM_{CD} * CDAB$$

$$\begin{aligned} CDAB = {} & T/[(FM_A * FF_{AB})/(1 - FM_A) + (FM_B * FF_{AB})/(1 - FF_B) \\ & + (F_{MC} * FM_{CD})/(1 - FM_C) + (FF_D * FM_{CD})/(1 - FF_D) + FF_{AB} + FM_{CD} \\ & + 1] \end{aligned}$$

2 Breed Backcross (A x (AxB))

$$A = FM_A * AAB * (1 + FF_{AB})/(1 - FM_A)$$

$$B = FF_B * AAB * FF_{AB}/(1 - FF_B)$$

$$AB = FF_{AB} * AAB$$

$$\begin{aligned} AAB = {} & T/[(FM_A * (1 + FF_{AB})/(1 - FM_A)) + (FF_B * FF_{AB}/(1 - FF_B)) \\ & + FF_{AB} + 1] \end{aligned}$$

2 Breed Backcross (B x (AxB))

$$A = FM_A * BAB * FF_{AB}/(1 - FM_A)$$

$$B = FM_B * BAB/(1 - FM_B), \text{ or}$$

$$B = FF_B * BAB * FF_{AB}/(1 - FF_B), \qquad \text{(whichever is the greater)}$$

$$AB = FF_{AB} * BAB$$

$$\begin{aligned} BAB = {} & T/[(FM_A * FF_{AB}/(1 - FM_A)) + [FF_B * FF_{AB}/(1 - FF_B) \\ & \text{or } FM_B/(1 - FM_B)] + FF_{AB} + 1] \end{aligned}$$

3 Breed Combination (C x A,B)

$$A = (FM_A * FF_{AB} * CAB)/(2(1 - FM_A)(1 - FF_{AB}))$$

$$B = (FM_B * FF_{AB} * CAB)/(2(1 - FM_B)(1 - FF_{AB}))$$

$$C = (FM_C * CAB)/(1 - FM_C)$$

$$AB = (FF_{AB} * CAB)/(1 - FF_{AB})$$

$$CAB = T/[(FF_{AB}/(2 - 2FF_{AB})) * ((FM_A/(1 - FM_A)) + (FM_B/(1 - FM_B))) + FM_C/(1 - FM_C) + FF_{AB}/(1 - FF_{AB}) + 1]$$

4 Breed Combinations (D x A, B, C)

$$A = (FM_A * FF_{ABC} * DABC)/(3(1 - FM_A)(1 - FF_{ABC}))$$

$$B = (FM_B * FF_{ABC} * DABC)/(3(1 - FM_B)(1 - FF_{ABC}))$$

$$C = (FM_C * FF_{ABC} * DABC)/(3(1 - FM_C)(1 - FF_{ABC}))$$

$$D = (FM_D * DABC)/(1 - FM_D)$$

$$ABC = (FF_{ABC} * DABC)/(1 - FF_{ABC})$$

$$DABC = T/[(FF_{ABC}/(3 - 3FF_{ABC})) * ((FM_A/(1 - FM_A)) + (FM_B/(1 - FM_B)) + (FM_C/(1 - FM_C))) + FM_D/(1 - FM_D) + FF_{ABC}/(1 - FF_{ABC}) + 1]$$

APPENDIX D

PREDICTED VALUES FOR MODEL DRIVING VARIABLES

PUREBREDS

PREDICTED DRIVING VARIABLES

BREED	CR	LSB	SUR	LSW	LSFE	ADG	BF	FG
D	59.8	10.9	67.8	7.4	4.4	.663	29.1	3.00
Y	71.1	11.4	64.2	7.3	5.2	.638	33.0	3.19
L	78.4	10.7	77.0	8.2	6.4	.635	33.5	3.23
S	69.8	9.4	73.6	6.9	4.8	.666	34.2	3.43

2 BREED ROTATION

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DY	67.3	11.8	68.9	8.1	.704	32.4	3.10
DL	70.9	11.4	76.2	8.7	.698	31.9	3.12
DS	66.6	10.8	76.0	8.2	.712	32.1	3.22
YL	76.6	11.6	77.2	9.0	.673	33.9	3.21
YS	72.3	11.0	73.2	8.0	.693	32.7	3.31
LS	76.0	10.6	75.2	8.0	.697	33.3	3.34

3 BREED ROTATION

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DYL	72.1	11.8	75.4	8.9	.705	33.0	3.15
DYS	69.3	11.4	73.9	8.4	.716	32.5	3.21
DLS	71.7	11.1	76.6	8.5	.716	32.5	3.23
YLS	75.5	11.3	76.2	8.6	.700	33.3	3.29

4 BREED ROTATION

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DYLS	72.4	11.4	75.9	8.7	.714	32.8	3.22

2 BREED STATIC

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DxY	71.1	11.6	70.3	8.2	.731	30.5	3.10
DxL	78.4	10.9	79.7	8.7	.727	31.1	3.13
DxS	69.8	9.6	81.2	7.8	.735	29.6	3.22
YxD	59.8	11.2	70.3	7.8	.729	35.5	3.10
YxL	78.4	10.9	82.1	8.9	.695	35.7	3.22
YxS	69.8	9.6	78.0	7.5	.713	32.0	3.32
LxD	59.8	11.2	76.5	8.5	.718	33.2	3.13
LxY	71.1	11.6	78.9	9.1	.688	32.7	3.22
LxS	69.8	9.6	76.1	7.3	.716	31.3	3.34
SxD	59.8	11.2	75.9	8.5	.735	35.2	3.22
SxY	71.1	11.6	72.7	8.4	.715	32.6	3.32
SxL	78.4	10.9	74.1	8.1	.725	34.9	3.34

BACKCROSS

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DxDY	68.2	12.2	69.1	8.4	.697	29.8	3.05
DxDL	71.9	11.8	73.8	8.7	.695	30.1	3.06
DxSD	67.6	11.2	74.5	8.3	.699	29.3	3.11
YxDY	68.2	12.2	67.3	8.2	.684	34.3	3.14
YxYL	77.5	12.1	73.2	8.8	.667	34.4	3.20
YxSY	73.3	11.4	71.1	8.1	.676	32.5	3.25
LxDL	71.9	11.8	76.7	9.1	.677	33.3	3.18
LxYL	77.5	12.1	77.9	9.4	.661	33.1	3.22
LxSL	76.9	11.1	76.6	8.5	.676	32.4	3.29
SxSD	67.6	11.2	74.8	8.4	.700	34.7	3.33
SxSY	73.3	11.4	73.2	8.4	.690	33.4	3.37
SxSL	76.9	11.1	73.9	8.2	.695	34.5	3.38

3 BREED STATIC

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DxYL	77.5	12.2	75.0	9.1	.729	30.8	3.11
DxSY	73.3	11.5	75.8	8.7	.733	30.0	3.16
DxSL	76.9	11.2	80.5	9.0	.731	30.4	3.18
YxDL	71.9	12.0	76.2	9.1	.712	35.6	3.16
YxSD	67.6	11.3	74.1	8.4	.721	33.8	3.21
YxSL	76.9	11.2	80.0	8.9	.704	33.9	3.27
LxDY	68.2	12.3	77.7	9.6	.703	33.0	3.17
LxSD	67.6	11.3	76.3	8.6	.717	32.3	3.23
LxSY	73.3	11.5	80.4	9.3	.704	32.8	3.28
SxDY	68.2	12.3	74.3	9.1	.725	33.9	3.27
SxDL	71.9	12.0	75.0	9.0	.730	35.1	3.28
SxYL	77.5	12.2	73.4	8.9	.720	33.7	3.33

4 BREED STATIC

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DYxSL	83.1	11.2	80.3	9.0	.718	32.1	3.22
DLxSY	79.5	11.5	76.6	8.8	.718	31.0	3.22
YLxSD	83.8	12.2	74.2	9.0	.724	32.3	3.22
SDxYL	73.8	11.3	75.2	8.5	.719	33.0	3.22
SYxDL	78.1	12.0	75.6	9.0	.721	35.3	3.22
SLxDY	74.4	12.3	76.0	9.4	.714	33.4	3.22

TERMINAL SIRE BREED X 2 BREED ROTATION FEMALES

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DxYL	76.6	11.6	75.0	8.7	.729	30.8	3.11
DxYS	72.3	11.0	75.8	8.3	.733	30.0	3.16
DxLS	76.0	10.6	80.5	8.6	.731	30.4	3.18
YxDL	70.9	11.4	76.2	8.7	.712	35.6	3.16
YxDS	66.6	10.8	74.1	8.0	.721	33.8	3.21
YxLS	76.0	10.6	80.0	8.5	.704	33.9	3.27
LxDY	67.3	11.8	77.7	9.1	.703	33.0	3.17
LxDS	66.6	10.8	76.3	8.2	.717	32.3	3.23
LxYS	72.3	11.0	77.5	8.5	.702	32.0	3.28
SxDY	67.3	11.8	74.3	8.7	.725	33.9	3.27
SxDL	70.9	11.4	75.0	8.6	.730	35.1	3.28
SxYL	76.6	11.6	73.4	8.5	.720	33.7	3.33

TERMINAL SIRE BREED X 3 BREED ROTATION FEMALES

PREDICTED DRIVING VARIABLES FOR TERMINAL OFFSPRING

BREED	CR	LSB	SUR	LSW	ADG	BF	FG
DxYLS	75.5	11.3	77.1	8.7	.731	30.4	3.15
YxDLS	71.7	11.1	76.8	8.5	.712	34.4	3.21
LxDYS	69.3	11.4	77.2	8.8	.707	32.4	3.23
SxDYL	72.1	11.8	74.3	8.7	.725	34.2	3.29

APPENDIX E

ECONOMIC EFFICIENCY FOR ALTERNATIVE CROSSBREEDING SYSTEMS

PUREBREDS

BREEDS	EFFICIENCY (COST / KG PRODUCT)
D	0.8521
Y	0.9029
L	0.8800
S	0.9420

2 BREED ROTATIONS

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DY	0.7175
DL	0.7088
DS	0.7241
YL	0.7277
YS	0.7499
LS	0.7582

3 BREED ROTATIONS

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DYL	0.7098
DYS	0.7218
DLS	0.7226
YLS	0.7366

4 BREED ROTATION

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DYLS	0.7195

2 BREED STATIC

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DxY	0.7498
DxL	0.7397
DxS	0.7731
YxD	0.7422
YxL	0.7571
YxS	0.7954
LxD	0.7271
LxY	0.7502
LxS	0.7985
SxD	0.7385
SxY	0.7679
SxL	0.7789

3 BREED STATIC

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DxYL	0.7061
DxSY	0.7155
DxSL	0.7171
YxDL	0.7141
YxSD	0.7305
YxSL	0.7371
LxDY	0.7029
LxSD	0.7242
LxSY	0.7244
SxDY	0.7174
SxDL	0.7230
SxYL	0.7355

4 BREED STATIC

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DYxSL	0.7271
DLxSY	0.7260
YLxSD	0.7196
SDxYL	0.7369
SYxDL	0.7217
SLxDY	0.7148

BACKCROSS

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DxDY	0.7223
DxDL	0.7215
DxSD	0.7298
YxDY	0.7266
YxYL	0.7558
YxSY	0.7453
LxDL	0.7124
LxYL	0.7224
LxSL	0.7451
SxSD	0.7391
SxSY	0.7725
SxSL	0.7867

TERMINAL SIRE BREED X 2 BREED ROTATION FEMALES

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DxYL	0.7205
DxYS	0.7325
DxLS	0.7339
YxDL	0.7296
YxDS	0.7424
YxLS	0.7541
LxDY	0.7148
LxDS	0.7352
LxYS	0.7453
SxDY	0.7303
SxDL	0.7388
SxYL	0.7505

TERMINAL SIRE BREED X 3 BREED ROTATION FEMALES

BREEDS	EFFICIENCY (COST / KG PRODUCT)
DxYLS	0.7241
YxDLS	0.7379
LxDYS	0.7273
SxDYL	0.7360

APPENDIX F

STRUCTURE FOR ALTERNATIVE CROSSBREEDING SYSTEMS

STRUCTURE FOR 2 BREED ROTATIONS

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

A	B	#A	#B	#AB
1	2	116	118	9766
1	3	116	105	9779
1	4	116	124	9760
2	3	118	105	9777
2	4	118	124	9758
3	4	105	125	9771

STRUCTURE FOR 3 BREED ROTATIONS

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

A	B	C	#A	#B	#C	#ABC
1	2	3	77	79	70	9774
1	2	4	77	78	83	9761
1	3	4	77	70	83	9770
2	3	4	79	70	83	9769

STRUCTURE FOR 4 BREED ROTATIONS

#D	#Y	#L	#S	#DYLS
58	59	52	62	9769

STRUCTURE FOR BACKCROSS

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

A	A	B	#A	#B	#AxB	#AxAB
1	1	2	390	271	1285	8213
1	1	3	395	258	1223	8322
1	1	4	386	280	1330	8140
2	1	2	31	204	1321	8444
2	2	3	403	256	1193	8354
2	4	2	33	205	1283	8479
3	1	3	30	183	1254	8533
3	2	3	30	183	1223	8564
3	4	3	34	181	1336	8449
4	1	4	33	214	1370	8383
4	4	2	421	286	1248	8243
4	4	3	419	298	1299	8215

STRUCTURE FOR 2 BREED STATIC

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

A	B	#A	#B	#AxB
1	2	192	1733	8076
1	3	196	1541	8263
1	4	189	1831	7980
2	1	195	1705	8100
2	3	199	1541	8260
2	4	192	1830	7978
3	1	174	1709	8117
3	2	173	1736	8091
3	4	171	1834	7995
4	1	206	1703	8091
4	2	206	1730	8064
4	3	211	1539	8251

STRUCTURE FOR 3 BREED STATIC

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

C	A	B	#A	#B	#C	#AxB	#CxAB
1	2	3	29	223	198	1193	8357
1	4	2	32	268	196	1249	8255
1	4	3	33	243	195	1301	8227
2	1	3	29	228	201	1223	8319
2	1	4	32	305	196	1330	8137
2	4	3	33	243	198	1301	8225
3	1	2	31	276	176	1288	8229
3	1	4	32	306	175	1333	8155
3	4	2	32	269	177	1252	8270
4	1	2	30	275	209	1284	8201
4	1	3	29	228	212	1222	8310
4	2	3	29	222	213	1192	8345

STRUCTURE FOR 4 BREED STATIC

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

C	D	A	B	#C	#D	#A	#B	#CxD	#AxB	#CDxAB
1	2	4	3	4	37	33	242	171	1299	8213
1	3	4	2	4	30	32	268	162	1250	8255
1	4	2	3	4	42	29	222	182	1190	8332
2	3	1	4	4	29	32	305	155	1331	8144
4	2	1	3	4	36	29	228	168	1222	8313
4	3	1	2	4	32	30	275	173	1283	8201

STRUCTURE FOR TERMINAL SIRE BREED X 2 BREED ROTATION FEMALES

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

C	A	B	#C	#A	#B	#AB	#CxAB
1	2	3	199	17	15	1389	8381
1	2	4	195	19	20	1549	8218
1	3	4	195	17	20	1558	8210
2	1	3	201	17	15	1433	8334
2	1	4	199	18	19	1522	8242
2	3	4	198	17	20	1558	8208
3	1	2	177	18	19	1540	8246
3	1	4	177	18	19	1525	8261
3	2	4	176	19	20	1552	8234
4	1	2	210	18	19	1535	8218
4	1	3	212	17	15	1431	8324
4	2	3	213	17	15	1387	8368

STRUCTURE FOR TERMINAL SIRE BREED X 3 BREED ROTATION FEMALES

(1=DUROC, 2=YORK, 3=LAND, 4=SPOT)

D	A	B	C	#D	#A	#B	#C	#ABC	#DxABC
1	2	3	4	197	12	10	12	1452	8316
2	1	3	4	200	12	10	12	1462	8303
3	1	2	4	178	12	12	13	1489	8297
4	1	2	3	213	11	11	10	1402	8353

VITA 2

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Doctor of Philosophy

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