ECONOMICS OF SWINE CROSSBREEDING SYSTEMS

Randall A. Merrell, C. Richard Shumway, James O. Sanders, and T. D. Tanksley, Jr.

Crossbreeding in commercial hog operations is widely practiced and has increased substantially in recent years. Perhaps the most important positive feature of crossbreeding is heterosis, i.e., the performance of crossbred progeny is superior to the average performance of the parents. In addition, producers have much wider options in breeding for desired carcass traits and sire and dam characteristics when blending breeds than when making genetic selection within any single breed. The costs to the firm are primarily managerial because of the necessity of buying replacements, frequently rotating boar breed, or maintaining miniherds to produce replacements for the breeding herd. Over the long run there is also a potential cost to the industry of reducing the number of purebred lines from which the crossbreds are derived and thus slowing genetic improvements within breeds.

Although crossbreeding has become increasingly popular in commercial swine operations, crossbreeding systems vary greatly. Which system is best has not been clearly established. In fact, literature evaluating the economic merits of alternative systems appears to be totally lacking. The objective of this article is to partially fill this void by comparing expected before-tax profits of selected purebred and crossbred swine systems where system performance is based on a synthesis of available production experiments.

ALTERNATIVES CONSIDERED

A three-breed rotational crossbreeding system of Durocs, Hampshires, and Yorkshires is commonly used in commercial pork production. In breed equilibrium, females have blood of the three breeds in 4/7, 2/7, and 1/7 proportions.[1] Purebred boars are typically purchased and rotated each generation so that females are always bred to a boar of their least dominant breed.

Except for the four-breed crossbreeding system (which includes the Landrace breed), all systems evaluated in this study are limited to the aforementioned breeds. Three purebred (one for each of the three major breeds) and 15 crossbred systems are evaluated (see Table 1 for a description of each). The crossbred systems include six two-breed, eight three-breed, and one four-breed options.

Each of the two-breed systems are rotational crosses in which two breeds of boars are bred (in a fixed continuous rotation) to crossbred females produced within the system. Offspring have the same blood proportions as the dam but with breeds transposed. Two of the systems are Duroc-Hampshire, two are Duroc-Yorkshire, and two are Hampshire-Yorkshire. One of each pair has two equal-size miniherds of females; e.g., in the Duroc-Hampshire (DH) system, 50 percent of sows are 2/3D and 1/3H and 50 percent are 1/3D and 2/3H. In the second system of each pair, optimal (profit maximizing) miniherd sizes (i.e., the mating mix or proportion of mating types in the herd) are sought through a grid search of all possible combinations of 16-sow units.

Four of the three-breed systems are also continuous rotational crosses in which replacements are raised from the same herd that produces the three-breed market hogs. In system 10, the most common crossbreeding system, the entire breeding herd has the same breed structure at any point in time but the boar breed is rotated each generation. System 11 has three equal-size miniherds of the three female breed structures. Optimal miniherd sizes are sought in systems 12 and 13 by the same procedure as used for system 10. The breeding order is the same in the first three of these systems but is reversed in the last.

Randall A. Merrell is former Graduate Assistant in Agricultural Economics, C. Richard Shumway is Associate Professor of Agricultural Economics, James O. Sanders is Assistant Professor of Animal Science, and T. D. Tanksley, Jr., is Professor of Animal Science, Texas A&M University.

[1]Breed equilibrium refers here to the limit of blood proportions that would be obtained from a given crossbreeding system as time approaches infinity. In practice, these blood proportions are closely approximated within six generations.

TABLE 1. ALTERNATIVE BREEDING SYSTEMS

System Class	System Number	Breeds[a]	Blood Proportions by Mating Type			Primary Purpose of Offspring[b]	Proportion of Mating Type in Herd	Replacement Procedure
			Dam	Sire	Offspring			
Purebred	1	D	D	D	D	M,R	1.0	Raise
	2	H	H	H	H	M,R	1.0	Raise
	3	Y	Y	Y	Y	M,R	1.0	Raise
Two-breed rotational	4	DH	2/3H, 1/3D	D	2/3D, 1/3H	M,R	0.5	Raise
			2/3D, 1/3H	H	2/3H, 1/3D	M,R	0.5	
	5		—————————same as system 4—————————				Optimal[d]	Raise
	6	DY	2/3Y, 1/3D	D	2/3D, 1/3Y	M,R	0.5	Raise
			2/3D, 1/3Y	Y	2/3Y, 1/3D	M,R	0.5	
	7		—————————same as system 6—————————				Optimal	Raise
	8	HY	2/3Y, 1/3H	H	2/3H, 1/3Y	M,R	0.5	Raise
			2/3H, 1/3Y	Y	2/3Y, 1/3H	M,R	0.5	
	9		—————————same as system 8—————————				Optimal	Raise
Three-breed rotational	10[c]	DHY	4/7Y, 2/7H, 1/7D	D	4/7D, 2/7Y, 1/7H	M,R	e	Raise
			4/7D, 2/7Y, 1/7H	H	4/7H, 2/7D, 1/7Y	M,R	e	Raise
			4/7H, 2/7D, 1/7Y	Y	4/7Y, 2/7H, 1/7D	M,R	e	Raise
	11		—————————same as system 10—————————				0.33	Raise
	12		—————————same as system 10—————————				Optimal	Raise
	13	DHY	4/7Y, 2/7D, 1/7H	H	4/7H, 2/7Y, 1/7D	M,R	Optimal	Raise
			4/7H, 2/7Y, 1/7D	D	4/7D, 2/7H, 1/7Y	M,R		
			4/7D, 2/7H, 1/7Y	Y	4/7Y, 2/7D, 1/7H	M,R		
Three-breed specific	14	DHY	1/2H, 1/?Y	D	1/2D, 1/4H, 1/4Y	M	1.0	Buy F1
	15	DHY	Y	H	1/2H, 1/2Y	R	Optimal	Buy Y, raise F1
			1/2H, 1/2Y	D	1/2D, 1/4H, 1/4Y	M		
	16	DHY	Y	Y	Y	R	Optimal	Raise
			Y	H	1/2H, 1/2Y	R		
			1/2H, 1/2Y	D	1/2D, 1/4H, 1/4Y	M		
Three-breed criss-outcross	17	DHY	2/3H, 1/3Y	Y	2/3Y, 1/3H	R	Optimal	Raise
			2/3Y, 1/3H	H	2/3H, 1/3Y	R		
			2/3H, 1/3Y	D	1/2D, 1/3H, 1/6Y	M		
			2/3Y, 1/3H	D	1/2D, 1/3Y, 1/6H	M		
Four-breed modified criss-outcross	18	DYHL	4/7L, 2/7H, 1/7Y	Y	4/7Y, 2/7L, 1/7H	R	Optimal	Raise
			4/7Y, 2/7L, 1/7H	H	4/7H, 2/7Y, 1/7L	R		
			4/7H, 2/7Y, 1/7L	L	4/7L, 2/7H, 1/7Y	R		
			4/7Y, 2/7L, 1/7H	D	1/2D, 2/7Y, 1/7L, 1/14H	M		
			4/7H, 2/7Y, 1/7L	D	1/2D, 2/7H, 1/7Y, 1/14L	M		
			4/7L, 2/7H, 1/7Y	D	1/2D, 2/7L, 1/7H, 1/14Y	M		

[a]Breed codes: D is Duroc, H is Hampshire, Y is Yorkshire, L is Landrace.

[b]Offspring purpose codes: M is market, R is replacement.

[c]This is the most popular commercial swine crossbreeding system in current use [1].

[d]Optimal means that proportions are selected to maximize profits for the system.

[e]At any point in time, all dams have the same blood proportions; breed of sire is rotated each generation.

Three of the three-breed systems are labeled "specific crosses" in which replacement females are produced by a Hampshire-Yorkshire first-cross mating and are known as Fl's. They are then bred to a Duroc boar to produce a terminal cross from which no replacements are kept. The three systems differ only in the method used to obtain replacement gilts: in system 14 all F1 replacement gilts are purchased, in system 15 Yorkshire replacement gilts are purchased and F1 replacements gilts are raised, and in system 16 all replacement gilts are raised. The optimal mating mix is sought in the latter two options.

The final three-breed system evaluated is the criss-outcross in which rotational and terminal crossbreeding systems are combined. Replacement gilts are produced from a continuous Hampshire-Yorkshire rotational cross, and market hogs are produced by a terminal cross to a Duroc boar.

The only four-breed cross evaluated is the modified criss-outcross system. Replacement gilts are produced from the continuous three-breed rotational system using Yorkshire, Hampshire, and Landrace; market hogs are produced by a terminal cross to a Duroc boar.

MANAGEMENT SYSTEM

Physical Parameters

The common total-confinement continuous (or year-round) farrowing system is treated as a common denominator in the comparisons. Each system is comparable in size of breeding herd. Facilities are designated for a warm climate to accommodate a 320-sow equivalent breeding herd (i.e., enough gilts are kept to replace the number of litters that culled sows would have produced). This herd is larger than average and captures most economies of size in hog production [7, p. 67].

Typical conception rates for sows and gilts are estimated to be 87 percent and 81 percent, respectively, allowing three estrous cycles

before gilts are culled [8].[2] Sows wean approximately 0.3 more pigs per litter than first-litter gilts of like breeding. As is done by better managers, 50 percent of sows are culled each year because of age, poor performance, and/or failure to conceive. In systems for which replacement females are raised within the herd, no more than 62 percent of the gilt pigs from any litter are kept for replacement; however, no genetic improvement is assumed in the calculations. One boar is required for 16 sow equivalents. Purebred boars are purchased from outside herds.

If conception rate is accounted for, producing sows average 2.11 litters per year, and thus a total of 677 litters are farrowed each year. Pigs are weaned at four weeks of age and are put in a nursery for five weeks before being placed in a finishing unit. Hogs are marketed at a conventional weight of 100 kg (220.46 lb), and a 4 percent shrink is assumed in transportation to market. It is also assumed that 50 percent of the pigs of the average litter are male and 50 percent are female. A 2 percent death loss from weaning to market weight is expected.

Economic Parameters

Prices. On the assumption of no important quality differences among these systems, all market pigs are sold at early 1979 hog prices, i.e., 99.21¢ per kg (45¢ per lb). Replacement gilts that do not conceive within three estrous cycles are marketed at a weight of 134 kg (295 lb) for 94.80¢ per kg (43¢ per lb). Cull sows are marketed at a weight of 159 kg (350 lb) for 77.16¢ per kg (35¢ per lb). Revenue from cull boars is treated as a salvage value and subtracted from depreciation (see Table 2). These are the only sources of revenue.

Fixed costs. The total confinement facility consists of 15 acres of land, breeding barn, gestation barn, five 14-crate farrowing houses, five-week-capacity nursery, finishing unit, office, waste handling facility, feed handling and grinding facility, and well and water facilities. Twenty boars are part of the fixed investment. In systems that raise their own replacement gilts, the sow herd is also a fixed investment. The investment in depreciable assets, expected useful life, and average annual depreciation are listed in Table 2. The size of the nursery and finishing unit depends on the expected number of pigs weaned per week and expected average days to 100 kg.

Twelve percent interest is charged on the land investment, sow herd, and average value of depreciable assets. Other fixed costs include

repairs, property taxes, and insurance charged at rates of 3.0, 0.5, and 0.3 percent, respectively, of fixed investment.

Variable costs. Variable cost items include feed, labor, veterinary service, utilities, interest on operating capital, and supplies and miscellaneous expense; if replacement gilts are purchased, the purchase price ($150 per gilt for crossbreds and $250 for purebreds) is also considered to be a variable cost. Table 3 shows the feed cost makeup in terms of boar feed, post-finishing gilt feed, gestation feed, lactation feed, nursery feed, and finishing feed. Cost of finishing feed is variable because of differences in feed/gain ratios of the systems.

Interest on operating capital is charged at an annual rate of 12 percent for the average length of time capital is tied up in each variable cost item. Labor requirements are expected to

TABLE 2. DEPRECIABLE ASSETS, 320 SOW EQUIVALENT HERD

Item	Cost	Expected Years Useful Life	Average Annual Depreciation
Breeding barn	$ 35,000	10	$ 3,500
Gestation barn	112,000	10	11,200
Farrowing houses	120,000	10	12,000
Nursery	a	10	a
Finishing unit	a	10	a
Office	4,000	10	400
Mill and augers	15,000	5	3,000
Grain storage	15,000	10	1,500
Lagoon and aerator	10,000	5	2,000
Well and water facilities	5,000	5	1,000
Boars	10,000	2	4,165[b]

[a]Costs of the nursery and finishing unit are variable because the number of pigs produced by the herd varies between systems, thus resulting in different requirements for these facilities. Among the systems considered here, costs range from $27,000 to $35,000 for the nursery and from $182,000 to $221,000 for the finishing work.

[b]Cull boars are presumed to have a salvage value of $83.50 each, or $1670 for the 20 boars.

TABLE 3. FEED COSTS

Feed Type	Price	Quantity	Days Fed per Unit	Cost per Animal Unit	Unit
	(¢/kg)	(kg/day)		($)	
Boar feed	13.2	2.04	365	98.55	year
Post-finishing gilt feed	13.2	3.40	50	22.50	replacement
Sow gestation feed	13.2	2.04	120	32.31	litter
Sow lactation feed	13.2	5.44	30	45.66	litter
Nursery feed[a]	17.6	0.97	35	6.00	weaned pig
Finishing feed	13.2	2.33	115	b	market pig

[a]Also includes feed for pig from birth to 30 days of age.

[b]Actual cost per animal for the finishing feed varies because the number of days in the finishing unit and quantity of feed consumed daily varies between systems. Among the systems considered, finishing feed cost ranged from $34.57 to $35.52 per pig marketed.

[1]Johnson, Omtvedt, and Walters [4, p. 74] report differences in conception rate between breeds. They report a higher conception rate for Hampshires and lower rate for Yorkshires than used here. If their data are representative, the analysis performed here would overestimate net returns to Yorkshire-dominated systems and underestimate net returns to Hampshire-dominated systems because breed differences in conception rate are ignored.

average two hours per pig marketed and are charged at a rate of $3.50 per hour. Veterinary services, utility costs, and supplies and miscellaneous expenses are each assumed to be $1.00 per pig marketed.

Net before-tax income. All costs (fixed and variable) are subtracted from all revenues to get net before-tax income. Income from the sale of cull sows would be treated as long-term capital gains for income taxation purposes in systems where replacement gilts are raised.

PERFORMANCE DATA

Profitability of alternative systems depends on animal performance traits as well as on the physical and economic parameters [5]. Expected performance of alternative breeding systems is evaluated in this study in terms of four physical variables: pigs weaned per litter, 63-day weight, feed/gain ratio from 63 days to 100 kg, and days to 100 kg.

Purebred Performance

Two sources provide the data used for these measures on the purebred systems.
1. Data on mean performance with respect to the stated variables of Durocs, Yorkshires, and Hampshires are available from a long-term series of breeding experiments at the Oklahoma Agricultural Experiment Station [8, 9].
2. Relative performance of each of the four breeds based on most of the recent swine breeding research in the United States and Canada is assessed by Christians and Johnson [1].

Because the data in the second source are based on a larger set of experiments than those in the first, they are treated in this study as the more accurate representation of relative breed performance. Unfortunately, performance levels are not reported in that source. Therefore, the data in the first source are used to derive estimated performance levels by (1) taking the mean performance of Durocs in that source as a base and calculating the performance of the other three breeds from the expected relative performance indices of the latter source, (2) repeating this procedure twice using mean performance of Yorkshires and Hampshires, respectively, from the first source as the base, and (3) averaging the three values thus obtained for each breed. This derived set of estimated performance levels is reported in Table 4. Performance levels were calculated in an at-

TABLE 4. EXPECTED PERFORMANCE OF DUROCS, YORKSHIRES, HAMPSHIRES AND LANDRACES FOR SELECTED TRAITS[a]

| Breed | Trait | | | |
	Pigs Weaned/ Gilt Litter	Wt. at 63 Days	Feed/Gain, Finishing	Age at 100 kg (220.46 lb)
		(kg)		(days)
Duroc	5.83	16.450	3.1944	185.7
Yorkshire	6.78	16.277	3.2267	188.4
Hampshire	5.69	16.623	3.2596	187.9
Landrace	6.04	17.316	3.5493	193.4

[a]Based on [1, 8, 9].

tempt to determine realistic purebred performance levels from which to calculate expected crossbred performance. See [6, pp. 4-8] for the specific calculations.

Heterosis Estimates

Heterosis measures the relative superiority of crossbred performance over the average performance of the parents. The amount of heterosis may vary between breeds. However, because the specific differences have not been reliably documented, average heterosis estimates across breeds are used in this study. The maximum heterosis advantages that can be achieved by any crossbreeding system, based on the averages across breeds, are estimated to be: 24 percent for pigs weaned per litter (14 percent due to increased litter size of the sow and 10 percent due to increased survivability of the pig), 4 percent for 63-day weight, 1 percent for feed/gain ratio from 63 days to 100 kg, and 7 percent for days to 100 kg [1].[3]

Each of the groups of crossbreeding systems analyzed has different expected heterosis levels, because the sire and dam can contain no duplication of blood if maximum heterosis is to be achieved. The percentage of maximum heterosis in dam and pig performance that can be expected in each crossbreeding system is reported in Table 5.

When these relative expectations are used to weight the maximum percentage heterosis advantages, expected heterosis advantages presented in Table 6 are obtained for matings within each system. These estimates of percentage heterosis advantage are added to (or subtracted from) 100 percent and used to weight estimated base performance values of Durocs, Yorkshires, and Hampshires in order

[3]Heterosis for 63-day weight is calculated from heterosis estimates for other traits. Heterosis for days to 100 kg is 7.5 percent if a purebred female is used to produce the first cross.

TABLE 5. PERCENT OF MAXIMUM HETEROSIS EXPECTED IN ALTERNATIVE CROSS-BREEDING SYSTEMS IN EQUILIBRIUM[a]

Crossbreeding System	Percent of Maximum Heterosis	
	Sow Performance	Pig Performance
Two-breed rotational	67	67
Three-breed rotational	86	86
Three-breed specific		
F1	0	100
Terminal cross	100	100
Three-breed criss-outcross		
Two-breed rotational	67	67
Terminal cross	67	100
Four-breed modified criss-outcross		
Three-breed rotational	86	86
Terminal cross	86	100

[a]Source: [3].

TABLE 6. EXPECTED PERCENT HETEROSIS ADVANTAGE BY CROSSBREEDING SYSTEM FOR SELECTED TRAITS.

System	Percent Heterosis Advantage by Trait[a]			
	Pigs Weaned/ Gilt Litter	Wt. at 63 Days[a]	Feed/Gain, Finishing	Age at 100 kg (220.46 lb)
	(%)			
Two-breed rotational	16.0	2.7	0.7	4.7
Three-breed rotational	20.6	3.4	0.9	6.0
Three-breed specific:				
F1	10.0[b]	1.9[c]	1.0	7.5[d]
Terminal	24.0	4.0	1.0	7.0
Three-breed criss-outcross:				
Two-breed rotational	16.0	2.7	0.7	4.7
Terminal	19.4	4.0	1.0	7.0
Four-breed modified criss-outcross				
Three-breed rotational	20.6	3.4	0.9	6.0
Terminal	22.0	4.0	1.0	7.0

[a]Derived from [1] and [3].

[b]Source: [1].

[c]Adapted from [1].

[d]Estimated from expected heterosis advantage for 21-day wt.

to estimate sow and pig performance of each mating within the alternative crossbreeding systems (see Table 7).[4] In the calculation of pigs weaned per litter, the breed makeup of the dam is used to adjust for heterosis. For the other three traits, the breed makeup of the offspring is used.

RESULTS

In nine of the 18 systems analyzed (i.e., systems 5, 7, 9, 12, 13, 15, 16, 17, 18), mating mix

TABLE 7. CALCULATED EXPECTED PERFORMANCE BY MATING WITHIN EACH CROSS-BREEDING SYSTEM

Matings within Each System[a]	Trait			
	Pigs Weaned/ Gilt Litter	Wt. at 63 Days	Feed/Gain, Finishing	Age at 100 kg (220.46 lb)
		(kg)		(days)
Two-breed rotational:[b]				
DxHD	6.65	16.95	3.195	177.7
HxDH	6.71	17.01	3.216	178.4
DxYD	7.50	16.83	3.184	177.8
YxDY	7.13	16.77	3.194	178.7
HxYH	7.44	16.95	3.227	176.3
YxHY	7.02	16.83	3.216	179.4
Three-breed rotational (Breeding order DHY):[c]				
DxYHD	7.64	16.99	3.185	175.6
HxDYH	7.35	17.09	3.207	176.1
YxHDY	7.11	16.96	3.204	176.6
Three-breed rotational (Breeding order HDY):[c]				
HxYDH	7.67	17.06	3.213	176.5
DxHYD	7.27	17.04	3.190	175.5
YxDHY	7.17	16.94	3.194	176.3
Three-breed specific:				
YxY	6.78	16.27	3.227	188.4
HxY	7.46	16.76	3.211	174.0
DxHY[d]	7.73	17.11	3.187	173.8
Three-breed criss-outcross:[b]				
YxHY	7.02	16.83	3.216	179.4
HxYH	7.44	16.95	3.227	176.3
DxHY	7.23	17.14	3.189	173.8
DxYH	7.68	17.08	3.184	173.9
Four-breed modified criss-outcross[c]				
YxLHY	7.30	17.19	3.294	178.4
HxYLH	7.73	17.19	3.262	177.5
LxHYL	7.30	17.55	3.390	179.6
DxYLH	7.82	17.20	3.226	174.6
DxHYL	7.38	17.20	3.211	174.2
DxLHY	7.38	17.38	3.274	175.2

[a]The first letter in the mating code identifies boar breed. Letters to the right of "x" identify female breed make-up: D is Duroc, H is Hampshire, Y is Yorkshire, and L is Landrace.

[b]Breed make-up of females is in ratio of 2/3, 1/3 (e.g., HD=2/3H, 1/3 D).

[c]Breed make-up of females is in 4/7, 2/7, 1/7 proportions (e.g., YHD=4/7 Y, 2/7 H, 1/7 D).

[d]Breed make-up of crossbred females is 1/2 H, 1/2 Y.

(relative sizes of miniherds) is not predetermined. For these ten, an exhaustive mathematical grid search [2, ch. 5] was made of all possible combinations of 16-sow units in the 320-sow equivalent herd to determine the mating mix that maximizes expected beforetax profit for each system.[5] The nonlinear objective function necessitates use of the grid search rather than linear programming.[6] After an optimal (i.e., profit maximizing) mating mix was determined, the 16-sow unit restriction was relaxed and a secondary search in single-sow units was made covering 16 sows in each direction from the initial optimum. Because additional boar(s) were required for the latter

[4]Percentage heterosis advantage is added to 100 percent for pigs weaned per litter and 63-day weight and subtracted for feed/gain and age at 100 kg.

[5]Using after-tax profit could affect the ranking of only two systems, the three-breed specific systems in which all or part of the replacement gilts are purchased. All other systems would be treated comparably in terms of capital gains.

[6]The objective function reduces to the following nonlinear form:

$$\text{Max } Z = A + \sum_i (B_{1i} X_{1i} + B_{2i} X_{2i} + B_{3i} X_{1i} X_{3i} + B_{4i} X_{1i} X_{3i} X_{4i})$$

where A is the negative of fixed costs, X_1 is number of pigs weaned, X_2 is age at 100 kg, X_3 is feed/gain ratio in the finishing unit, X_4 is average 63-day weight of pigs from all mating types, i is mating type, and Z is net returns.

solutions, the increase in expected profits proved to be very small. Thus, it is concluded that boars should generally be used to capacity.

The optimal mating mix with 16-sow units is reported for the nine systems in Table 8. The reason one mating type dominates each system is that it best combines performance in the two most economically important traits—pigs weaned per litter and feed required per unit gain. Other mating types may demonstrate better performance than the dominant type on at least one of the four traits, but overall performance is not as good. These mating types are included in the systems only to ensure sufficient replacements for the breeding herd.

Costs and returns for all 18 crossbreeding systems, half with predetermined and half with optimal mating mixes, are reported in Table 9. Of the alternatives considered, the three-breed specific system in which all replacements are raised on the farm (system 16) is the most profitable. The purebred systems are by far the least profitable alternatives for commercial production.

Much of the economic benefit of crossbreeding can be obtained by the two-breed rotational cross with appropriate selection of breeds. The Duroc-Yorkshire rotational cross with equal-size miniherds (system 6) offers an increase in expected profits over the best purebred system (system 3) of $18,000. Optimizing the mating mix (system 7) offers another $3,200.

The common three-breed rotational system with mating type rotated annually (system 10) is the least profitable of the three-breed systems and is less profitable than the best of the two-breed systems. Its comparative disadvantage in relation to the same system with equal-size miniherds (system 11) is due to the need for nursery and finishing units to be large enough to accommodate the most prolific mating although there is excess space in two of three years. Optimizing the mating mix (system 12) permits profits to be increased $5,200 above those of the equal-size miniherd system. There are only two alternative breeding orders in three-breed rotational systems, but mere selection of the right order can be worth $800 (compare systems 12 and 13).

Raising all replacements for the three-breed specific system (system 16) is worth $7,200 in before-tax profits over buying F1 replacements (system 14) and $1,300 over buying purebred Yorkshires and raising F1 replacements (system 15) at the specified prices. In after-tax profits, the comparative advantage of raising all replacements is even greater because more income receives capital gains tax treatment in systems where replacements are raised.

The three-breed criss-outcross (system 17) and the four-breed modified criss-outcross (sys-

TABLE 8. OPTIMAL MATING MIX FOR CROSSBREEDING ALTERNATIVES[a]

Alternative Considered	Optimal Mating Combinations by Type
Two-breed rotational:[b]	
DH	15%-DxHD, 85%-HxDH
DY	85%-DxYD, 15%-YxDY
HY	85%-HxYH, 15%-YxHY
Three-breed rotational:[c]	
Breeding order DHY	85%-DxYHD, 5%-HxDYH, 10%-YxHDY
Breeding order HDY	85%-HxYDH, 5%-DxHYD, 10%-YxDHY
Three-breed specific:[d]	
Buy Yorkshires, raise F1's	10%-HxY, 90% DxHY·
Raise Yorkshires, raise F1's	5%-YxY, 10% HxY, 85% DxHY
Three-breed criss-outcross[b]	10%-YxHY, 5%-HxYH, 5%-DxHY, 80%-DxYH
Four-breed modified criss-outcross[c]	10%-YxLHY, 5%-HxYLH, 5%-LxHYL, 80%-DxYLH, 0%-DxHYL, 0%-DxLHY

[a]Constraints: (1) sixteen sows per boar and (2) no more than 62% of female pigs weaned kept as replacements. The first letter in the mating code identifies boar breed. Letters to the right of "x" identify female breed makeup.

[b]Breed make-up of females is in ratio of 2/3, 1/3 (e.g., DH=2/3 D, 1/3 H).

[c]Breed make-up of females is in 4/7, 2/7, 1/7 proportions (e.g., YHD=4/7 Y, 2/7 H, 1/7 D).

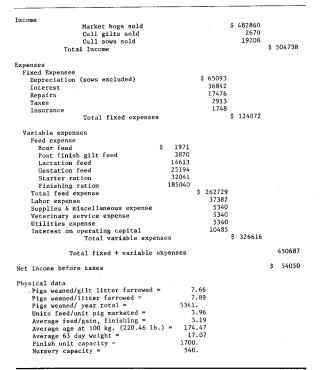[d]Breed make-up of crossbred females is 1/2 H, 1/2 Y.

TABLE 9. INCOME SUMMARY FOR PUREBRED AND CROSSBRED SYSTEMS

System	System Number	Total Revenue	Total Cost	Net Income
			($)	
Purebred:				
Durocs	1	389,278	379,524	9,754
Hampshires	2	380,423	376,861	3,563
Yorkshires	3	449,364	422,648	26,716
Two-breed rotational:				
DH, equal mating mix	4	443,039	412,375	30,665
DH, optimal mating mix	5	444,367	413,688	30,680
DY, equal mating mix	6	483,202	438,437	44,765
DY, optimal mating mix	7	491,392	443,469	47,924
HY, equal mating mix	8	477,826	436,363	41,463
HY, optimal mating mix	9	487,123	442,255	44,868
Three-breed rotational:				
DHY, mating type rotated annually	10	486,470	441,464	45,006
DHY, equal mating mix	11	486,472	439,903	46,569
DHY, optimal mating mix	12	499,488	447,760	51,728
HDY breeding order, optimal mating mix	13	501,227	450,325	50,902
Three-breed specific:				
Buy F1's	14	525,845	478,965	46,880
Buy Yorkshires, raise F1's	15	509,382	456,590	52,792
Raise all replacements	16	504,738	450,688	54,050
Three-breed criss-outcross	17	499,930	447,516	52,414
Four-breed modified criss-outcross	18	509,924	457,180	52,743

tem 18) have about the same expected profit. Neither produces profit as high as that of the three-breed specific system raising all replacements (system 16).

A detailed income statement and supplementary physical data are shown in Table 10 for the highest profit system (system 16). Net before-tax income is a little more than 10 percent of total income. Heterosis effects cause all performance measures for this system to be better than those for the best of the purebred systems. In particular, pigs weaned per litter and feed required per unit gain in the finishing

TABLE 10. INCOME STATEMENT, THREE-BREED SPECIFIC, RAISE YORKSHIRE REPLACEMENTS, RAISE F1 REPLACEMENTS, OPTIMAL MATING MIX

Income
Market hogs sold	$ 482860	
Cull gilts sold	2670	
Cull sows sold	19208	
Total Income		$ 504738

Expenses
Fixed Expenses
Depreciation (sows excluded)	$ 65093	
Interest	36842	
Repairs	17476	
Taxes	2913	
Insurance	1748	
Total fixed expenses		$ 124072

Variable expenses
Feed expense
Boar feed	$ 1971		
Post finish gilt feed	3870		
Lactation feed	14613		
Gestation feed	25194		
Starter ration	32041		
Finishing ration	185040		
Total feed expense		$ 262729	
Labor expense		37382	
Supplies & miscellaneous expense		5340	
Veterinary service expense		5340	
Utilities expense		5340	
Interest on operating capital		10485	
Total variable expenses			$ 326616

Total fixed + variable expenses	450687

Net income before taxes	$ 54050

Physical data
Pigs weaned/gilt litter farrowed =	7.66
Pigs weaned/litter farrowed =	7.89
Pigs weaned/ year total =	5341.
Units feed/unit pig marketed =	3.96
Average feed/gain, finishing =	3.19
Average age at 100 kg. (220.46 lb.) =	174.47
Average 63 day weight =	17.07
Finish unit capacity =	1700.
Nursery capacity =	540.

operation are substantially better than in any of the purebred systems (see Table 3) and largely explain the higher expected profit. Seemingly minor improvements in productivity can have profound impact on expected profits. For example, none of the four performance measures is 15 percent better for the three-breed specific crossbred system raising all replacements than for purebred Yorkshires, but profit for the former is more than twice that for the latter.

CONCLUSIONS

The authors present evidence of substantial potential differences in expected profit among alternative swine breeding systems of comparable size. It is clear that crossbreeding is an economic technology and that the major portion of firm-level potential profits due to crossbreeding are captured in the conventionally used three-breed rotational system in which breeding type is rotated annually. However, some improvement (7 percent) could be obtained by using the simpler two-breed rotational cross with Durocs and Yorkshires in an optimal mix. A substantial increment (20 percent) could be added to profit by adopting the managerially more complex three-breed specific system in which all replacements are raised on the farm.

This study is limited to comparing profit of alternative swine systems by using mean breed values determined experimentally. Conception rates and heterosis levels are assumed to be independent of breed. Neither technical nor economic uncertainty is evaluated. Alternative enterprise sizes, prices, and managerial restrictions are not considered. Although comparisons focus only on before-tax income, the ranking of the top eight systems is unaltered by inclusion of income tax considerations.

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