

COMPARISON OF DIFFERENT BREEDING PLANS FOR EVALUATING
SIRE AND MATING SYSTEMS IN SWINEB. W. KENNEDY,¹ J. E. MOXLEY,¹ and RUTH SAISON²¹*Department of Animal Science, Macdonald College, Quebec, and* ²*Department of Biomedical Sciences, Ontario Veterinary College, Guelph, Ontario. Received 9 Oct. 1973, accepted 11 June 1974.*KENNEDY, B. W., MOXLEY, J. E. AND SAISON, RUTH. 1974. Comparison of different breeding plans for evaluating sires and mating systems in swine. *Can. J. Anim. Sci.* **54**: 265-276.

The effects of sires and mating systems on growth and carcass traits were investigated using within-litter (double mating), within-dam (sequential mating) and between-litter (random mating) comparisons. All three breeding plans were studied at a research station and, in addition, random matings were studied in the field. The experimental data consisted of 80 double mating litters (697 pigs), 302 sequential mating litters and 718 random mating litters whereas the field data comprised 622 random mating litters. Sire effects were important for postweaning growth and carcass merit whereas mating system differences were important only for postweaning growth. Based on estimates of the number of litters required to detect significant differences between sires or mating systems, double mating was the most efficient breeding plan. This advantage was most pronounced for the early growth traits.

Les effets du mâle et du système d'accouplement sur la croissance et sur les caractéristiques de la carcasse furent étudiés en utilisant des accouplements intra-portée (accouplement double), intra-femelle (accouplement séquentiel) et entre-portée (accouplement au hasard). Ces trois types d'accouplement ont été observés dans une station de recherche, et de plus, l'accouplement au hasard a aussi été observé dans le champ. Les données proviennent des accouplements observés en station, soit 80 accouplements doubles (697 porcs), 302 accouplements séquentiels et 718 accouplements au hasard et ceux observés dans le champ, soit 622 accouplements au hasard. Les effets du mâle furent plus importants pour la croissance après le sevrage et les caractéristiques des carcasses, tandis que les effets du système d'accouplement ne furent importants que pour la croissance après le sevrage. L'accouplement double fut la technique d'évaluation la plus efficace si on se base sur le nombre de croisements requis pour découvrir les différences significatives entre des mâles ou systèmes d'accouplement. Cet avantage fut le plus marqué pour la croissance avant le sevrage.

Genetic improvement in livestock populations is accomplished through the selective breeding of genetically superior animals and the manipulation of mating systems; that is, the exploitation of purebreeding and various forms of crossbreeding. The identification of genetically superior animals and crosses is usually complicated by the presence of environmental influences which often mask true genetic differences. Breeding plans de-

Can. J. Anim. Sci. **54**: 265-276 (Sept. 1974)

signed for genetic evaluation, therefore, should reduce and control extraneous environmental influences as much as is practicable.

Several alternative breeding plans, which differ in their respective abilities to control variation caused by dam and litter effects, can be used to evaluate sires and mating systems in swine. The simplest plan involves the mating of boars at random, except for the avoidance of close inbreeding, to the fe-

male breeding population at large. With random mating, sire or mating system comparisons are made on a between-litter basis and no control is exerted over dam and litter influences.

Sequential mating, a variation on polyallelic mating (Lush 1945), provides an alternative breeding plan whereby some control is exerted over dam influences. With sequential mating, each dam produces two litters; each litter is sired by a different boar. Sequential mating is designed to reduce the effects of maternal differences by providing sire or mating system comparisons on a within-dam basis. Litter effects, however, are not controlled.

The use of double matings or split litters (Roberts and Carroll 1939; Lush et al. 1939) affords sire or mating system comparisons on a within-litter basis, with each litter having progeny of two boars represented. Within-litter comparisons are free of both dam and litter influences.

This study compares the three breeding plans — random, sequential and double mating — for their relative efficiency in evaluating the effects of sires and mating systems on growth and carcass traits in swine. Additionally, two types of data involving random matings, field and experimental, are compared.

MATERIALS AND METHODS

Two sources of data were used for the study. Random mating field data were obtained from Newfoundland, through the cooperation of the Central Swine Breeding Station at St. John's, and experimental data, which involved random, sequential and double matings, were obtained from the Macdonald College swine herd (Table 1).

The Newfoundland field data involved 622 litters farrowed at the Central Swine Breeding Station from 1965 to 1966. Thirty boars from three breeds, Landrace, Yorkshire and Lacombe, were involved. Both purebred and crossbred dams were represented. Purebred dams were primarily Landrace, although a few York-

Table 1. Distribution of field, random and sequential mating litters by mating system

Breed of sire	Mating system				Total
	Purebred dam		Crossbred dam		
	Purebred	Single cross	Backcross	Three-breed cross	
	<i>Field</i>				
Yorkshire	5	78	11	68	162
Landrace	200	1	80	152	433
Lacombe	0	23	0	4	27
Total	205	102	91	224	622
	<i>Random</i>				
Yorkshire	147	59	90	16	312
Landrace	79	88	82	20	269
Lacombe	23	36	12	31	102
Large Black	2	9	0	7	18
Hampshire	0	7	0	10	17
Total	251	199	184	84	718
	<i>Sequential</i>				
Yorkshire	57	29	50	7	143
Landrace	24	41	42	7	114
Lacombe	4	15	7	11	37
Large Black	0	0	0	2	2
Hampshire	0	4	0	2	6
Total	85	89	99	29	302

shire dams were also included, whereas crossbred dams involved various combinations of Landrace, Yorkshire and Lacombe breeding. The Newfoundland herd was greatly influenced by the Landrace breed. Landrace boars sired more than two-thirds of the litters while about 45% of the litters were from Landrace dams.

Baby pigs were weaned at approximately 8 wk of age and shipped to farmers cooperating with the project. The participating farmers raised the pigs to market weight and shipped the finished pigs to a central abattoir where carcass measurements were obtained.

The Newfoundland field data provided two growth and three carcass traits for study. The growth traits considered were age at market and daily gain measured as carcass weight per day of age. The carcass traits studied were maximum depth of shoulder and loin backfat and the weight of commercially trimmed loin (left-side).

The Macdonald College experimental data consisted of 6,000 pigs from 798 litters farrowed over a 12-yr period from 1957 to 1968. Five breeds, Landrace, Yorkshire, Lacombe, Large Black and Hampshire, were involved, but only the Yorkshire and Landrace breeds were used during the first 5 yr of the study. The Lacombe breed entered the herd in 1962, and Large Black breeding stock was introduced in

late 1966. A Hampshire boar entered service in 1967. Although boars of all five breeds were used, Hampshire breeding was not present in the sow herd.

Male market pigs were castrated within 2 wk following birth, and baby pigs were weaned at 21 days and raised on the Macdonald College Farm to a market weight normally ranging between 80 and 90 kg liveweight. Market pigs were slaughtered and measured for carcass traits at a Montreal abattoir.

The random mating data consisted of 718 litters sired by 61 boars. Random mating litters were farrowed during all years of the study.

The sequential mating data were selected as a subset of the random mating data such that only dams whose first and second litters were sired by different boars were considered. A total of 302 litters met this criterion of sequential mating, of which 188 contributed to mating system comparisons, since only 94 of the dams had first and second litters sired by boars of appropriately different breeds. The remaining 114 litters were included for sire comparison purposes. Forty-four boars were involved.

The double mating data involved 697 pigs from a total of 80 litters farrowed from 1965 to 1968 (Table 2). A litter was classified as double-mated if progeny from two sires were represented. Twenty boars were involved.

Table 2. Distribution of double mating litters by breed

Breed of sire pairs	Breed of dam							Total
	Purebred			Crossbred				
	Yorkshire	Landrace	Lacombe	York- Land	York- Lac	Land- Lac	Lac- L.B.	
Yorkshire Landrace	5	6	2	2	2	1	0	18
Yorkshire Lacombe	3	3	1	2	3	2	0	14
Landrace Lacombe	8	2	1	2	3	0	0	16
Yorkshire Large Black	4	2	2	3	1	2	2	16
Landrace Large Black	4	0	0	3	0	0	0	7
Lacombe Large Black	0	0	0	0	2	0	0	2
Yorkshire Hampshire	1	0	0	0	2	0	0	3
Landrace Hampshire	2	1	0	1	0	0	0	4
Total	27	14	6	13	13	5	2	80

Forty-seven double mating litters, totalling 404 pigs, were farrowed by purebred dams. However, only 24 of the litters contributed to mating system differences. Purebred and single cross progeny totalled 102 and 302 pigs, respectively. Crossbred females farrowed 293 pigs in 33 litters, of which 26 contributed to mating system differences. Backcrosses numbered 160 pigs whereas three-breed crosses totalled 133 pigs.

Double matings were performed by the artificial insemination of mixed semen from two boars based on equal volumes or equal concentrations of semen. The progeny of each sire were identified by color marker or blood type. Details of blood type identification system have been previously described by Saison and Moxley (1966).

Fourteen growth and carcass traits were available for study in the Macdonald College experimental data. Pig weight was recorded at birth, 21 days (weaning), 56 days and 154 days of age. Two additional traits, age at market and daily gain measured as liveweight per day of age, were also recorded.

Following slaughter, eight carcass traits were recorded. These included maximum backfat depth measured at the shoulder and loin, carcass length and loin eye area. Also, the left side of each carcass was butchered into trimmed commercial cuts and the weights of the trimmed ham, shoulder and loin were individually recorded. The sum of the weights of the three left-side trimmed cuts was doubled to provide an estimate of total lean-cut yield.

Raw means and standard deviations of the growth and carcass traits were calculated for the Newfoundland field data and the Macdonald College random, sequential and double mating data (Table 3).

As the random and sequential mating breeding plans involve sire and mating system comparisons on a between-litter basis, litter averages were computed for the field, random and sequential mating data. When computing the litter averages, adjustments were made for sex differences. In addition, all field data litter averages as well as random and sequential mating carcass data litter averages were adjusted for carcass weight differences. Least squares methods for unbalanced data were then used to analyze the field, random and sequential mating data on a between-litter basis according to the following models:

$$\text{Field: } y_{ijkn} = \mu + t_i + s_j + m_k + e_{ijkn}$$

$$\text{Random: } y_{ijkln} = \mu + t_i + s_j + m_k + p_l + e_{ijkln}$$

$$\text{Sequential: } y_{ijklmn} = \mu + t_i + s_j + m_k + p_l + d_m + e_{ijklmn}$$

where $y_{ijk(lm)n}$ = the appropriate growth or carcass trait average measured on the n^{th} litter

μ = the population mean

t_i = the effect of the i^{th} period of time

s_j = the effect of the j^{th} sire

m_k = the effect of the k^{th} mating system

p_l = the effect of the l^{th} parity number

d_m = the effect of the m^{th} dam

$e_{ijk(lm)n}$ = the random error associated with the n^{th} litter assumed to be independently and identically distributed with the mean 0 and variance σ_e^2 .

The double mating data were analyzed on a within-litter basis according to the following model:

$$\text{Double: } y_{ijklm} = \mu + l_i + s_j + m_k + x_l + e_{ijklm}$$

where y_{ijklm} = the appropriate growth or carcass trait measured on the m^{th} pig

μ = the population mean

l_i = the effect of the i^{th} litter

s_j = the effect of the j^{th} sire

m_k = the effect of the k^{th} mating system

x_l = the effect of the l^{th} sex

e_{ijklm} = the random error associated with the m^{th} pig assumed to be independently and identically distributed with mean 0 and variance σ_e^2 .

The field and random mating models differed only by the inclusion of the effects of parity number in the random mating model. Parity number was not available in the field data. Parity effects were classified as first litter, second and third or more. The mating system classifications were purebred, single cross, backcross and three-breed cross. Time periods consisted of consecutive 6-mo intervals.

The sequential mating analysis differed somewhat from the field and random mating analyses. Dam effects were added to the sequential mating model while the effects of time, because of computational limitations, were classified simply as spring and fall seasons rather than as consecutive 6-mo periods.

For the double mating analysis, a litter term was included in the model, as sire and mating system comparisons are made on a within-litter basis. The effects of sex were also included.

Table 3. Means and standard deviations of growth and carcass traits

Traits	Newfoundland Field data	Macdonald College experimental data		
		Random	Sequential	Double
<i>Growth</i>				
Birth wt (kg)		1.30± .27	1.29± .27	1.31± .26
21 day wt (kg)		5.40±1.31	5.59±1.26	5.19±1.33
56 day wt (kg)		14.2± 4.1	13.9± 3.9	15.7± 3.9
154 day wt (kg)		74.2±11.1	73.0±11.2	80.9± 9.5
Age at market (days)	193.9±19.2	174.9±18.8	175.9±18.1	164.9±17.9
Daily gain (kg/day)†	.373±.039	.507±.056	.504±.055	.537±.054
<i>Carcass</i>				
Length (mm)		777±20.9	777±21.5	767±23.8
Shoulder backfat (mm)	39.9± 4.5	39.1± 5.9	39.1± 6.0	39.5± 5.8
Loin backfat (mm)	33.8± 5.0	32.8± 5.6	32.8± 5.4	32.4± 5.7
Loin eye area (mm ²)		2655± 348	2622± 338	2735± 321
Trimmed ham (kg)		7.05± .50	7.03± .51	7.08± .46
Trimmed shoulder (kg)		5.81± .57	5.79± .57	5.78± .51
Trimmed loin (kg)	6.92± .57	5.22± .49	5.21± .47	5.23± .43
Lean cut yield (kg)		36.1± 2.4	36.1± 2.3	36.2± 2.1

†Daily gain is expressed as kg carcass weight per day of age in the field data and as kg liveweight per day of age in the experimental data.

Carcass traits were adjusted for carcass weight differences by the inclusion of carcass weight as a covariate.

The four mating systems were considered simultaneously in the field and random mating analyses. However, the sequential and double mating studies were divided into two separate analyses, analysis A which compared purebreds to single crosses and analysis B which compared backcrosses to three-breed crosses. This division was necessary with the sequential and double mating breeding plans, as only these comparisons are possible on a within-dam basis.

With all four models, all effects, except for the random error, were treated as fixed. All interactions were assumed absent. This assumption was based in part on the results of an analysis of a subset of these data by Roache and Moxley (1964). For purposes of hypothesis testing, the random errors were assumed to be normally distributed.

The criterion of the number of litters required to detect given differences between sires or mating systems for a given trait was chosen as a measure of the relative efficiency of the breeding plans. Tukey's method (Steel and Torrie 1960) was used to estimate the number of observations required to detect specified differences between two or more sires or mating systems based on parameter estimates obtained from the least squares analyses. The estimates were based on a 90% assurance of detecting the given difference at the 5% level of significance.

As double mating provides within-litter comparisons, the number of observations required to detect differences was calculated in units of pigs rather than litters, as was the case with the other breeding plans that use between-litter comparisons. Estimates of the number of litters required with double mating were based on six pigs per litter for the early growth traits and four pigs per litter for the late growth and carcass traits being available for comparison purposes. At first consideration, these estimates may appear conservative. However, as only approximately two-thirds of double matings performed are successful in producing mixed litters, the estimates as computed probably provide a realistic measure of the efficiency of the breeding plan.

RESULTS AND DISCUSSION

Sire Evaluation

F-values and their probabilities (Table 4) were computed to test for significant sire differences for growth and carcass performance.

In neither the random nor sequential mating studies were significant sire effects on pig weight at birth or 21 days of age detected. The double mating study also did not observe significant sire differences for birth weight among backcross and three-breed cross pigs (analysis B) or for 21-day weight among purebreds and single crosses (analysis

Table 4. Effect of sire on growth and carcass traits as evaluated from field, random, sequential and double mating data (expressed as probability of obtaining observed *F*-value by chance)

Trait	Field	Random	Breeding plan			
			Sequential		Double	
			A†	B‡	A	B
<i>Early Growth</i>						
No. litters		718	174	128	47	33
Birth wt		.097	.304	.304	.020*	.483
21 day wt		.152	.387	.532	.469	.037*
56 day wt		<.001**	.102	.023*	.011*	.353
<i>Late Growth</i>						
No. litters	622	680	162	124	40	29
154 day wt		<.001**	.214	.308	.098	.015*
Age at market	<.011**	<.001**	.120	.315	.145	<.001**
Daily gain	.003**	<.001**	.341	.380	.087	.037*
<i>Carcass</i>						
No. litters	622	692	166	116	33	25
Length		<.001**	.017*	.597	<.001**	<.001**
Shoulder backfat	<.001**	<.001**	.081	.036*	.064	.040*
Loin backfat	.166	<.001**	.021*	.151	.031*	.004**
Loin eye area		<.001**	.144	.174	.134	.033*
Trimmed ham		<.001**	.062	.020*	.057	.337
Trimmed shoulder		<.001**	.669	.174	.350	.827
Trimmed loin	.790	<.001**	.190	.303	.035*	.216
Lean cut yield		<.001**	.203	.225	.005**	.346

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

†A, purebreds and single crosses.

‡B, backcrosses and three-breed crosses.

A). However, significant ($P < 0.05$) sire effects were detected for birth weight among purebred and single cross pigs (analysis A) and for 21-day weight among backcross and three-breed cross pigs (analysis B). Results for 56-day weight were more consistent, as significant sire effects were noted in the random mating analysis ($P < 0.01$), sequential mating analysis B ($P < 0.05$) and double mating analysis A ($P < 0.05$).

Significant sire effects on all late growth traits were observed in the field, random and double mating B studies but were not detected in either of the two sequential mating analyses or in double mating analysis A. Nonetheless, *F*-test probabilities were low in double mating analysis A.

With the field data carcass traits, significant sire differences were only found for shoulder backfat depth ($P < 0.01$). However, sire effects were significant ($P < 0.01$) for all carcass traits considered in the

random mating study. In the sequential mating analyses, significant ($P < 0.05$) sire effects were only observed for carcass length and loin backfat in analysis A, and for shoulder backfat trimmed ham weight in analysis B. Significant sire differences were detected for length ($P < 0.01$), loin backfat ($P < 0.05$), trimmed loin weight ($P < 0.05$) and lean cut yield ($P < 0.01$) in double mating analysis A, and length ($P < 0.01$), shoulder backfat ($P < 0.05$), loin backfat ($P < 0.01$), and loin eye area ($P < 0.05$) in double mating analysis B.

The ability to detect significant sire differences for postweaning growth and carcass merit and the failure to detect sire differences for preweaning growth, as found in the random mating study, is consistent with other reports (Baker et al. 1943; Duckworth et al. 1961). The results of the random mating study, therefore, support the contention that sire influences are most important for

traits that are expressed later in life, and are of lesser importance for those traits that are expressed at an earlier age when litter and maternal influences are of overriding importance.

The field study failed to detect significant sire differences for two of the three carcass traits considered, although significant sire differences were noted for both measures of postweaning growth. Approximately the same number of litters were involved in the field and random mating studies. The relative lack of sensitivity of the use of field data in detecting sire effects on carcass performance may reflect an overriding influence of different farm environments on the expression of these traits or, at least in the case of trimmed loin weight, a lack of consistency in butchering procedures with the field data. Additionally, the boars which were represented in the field data were not, for the most part, the same as those represented in the experimental data. The detection of sire differences in the field data would be more difficult if the Newfoundland boars were genetically more homogeneous than the Macdonald boars. This is a possibility, as only Landrace, Yorkshire and Lacombe boars were represented in the field data, whereas two additional breeds, Large Black and Hampshire, were included in the experimental data.

The sequential mating analysis failed to detect significant sire differences for most growth and carcass traits considered. Less than one-half the number of litters employed in the random mating study were used in the sequential mating study. Additionally, these litters were split into two separate analyses, one comprising purebreds and single crosses and another comprising backcrosses and three-breed crosses. Therefore, approximately one-fourth the number of litters employed in the random mating study were used in each of the two sequential mating analyses. Removal of variation due to dam differences by sequential mating was not sufficient to compensate for the smaller number of litters.

The double mating analysis, which involved less than one-eighth the number of litters used in the random mating study, was more successful. Significant sire differences were observed for all growth traits in at least

one of the two analyses performed. Of particular interest, the analysis detected sire differences for the preweaning growth traits of birth weight and 21-day weight which the random mating study failed to do. The success of double mating in detecting sire effects on growth, and in particular early growth, reflects the inherent ability of this breeding plan to control variation due to dam and litter influences, both prenatal and postnatal. The removal of dam and litter effects afforded by the within-litter comparisons compensated for the very small number of litters used.

Double mating was not as successful in detecting sire effects on carcass merit, as significant sire differences were observed only for six of the eight carcass traits. This most likely reflects the decreased importance of maternal and litter influences on the expression of carcass traits.

Mating System Evaluation

The effects of mating system on growth (Table 5) and carcass performance (Table 6), expressed as the mean plus the least squares estimate of the deviation from the mean, were estimated from the field, random, sequential and double mating data.

No significant mating system differences were observed for early growth traits in any of the analyses. Significant ($P < 0.01$) differences were observed for all late growth traits in both the field and random mating studies. The sequential mating study also found significant ($P < 0.01$) differences between purebreds and single crosses for the three late growth traits. Similar effects were noted in the double mating study where single cross pigs were superior ($P < 0.05$) to purebreds for weight at 154 days and age at market although differences for daily gain were not significant. In both the sequential and double mating analyses, no significant differences between backcrosses and three-breed crosses were observed for any late growth trait.

Fredeen (1957), reviewing crossbreeding research, stated that although statistically significant differences are rarely observed in individual experiments, the effects of heterosis appear greatest for traits expressed early in life and become less important as the

animal develops. The results of this study, however, indicate that the effects of heterosis are relatively more important for late growth than for early growth.

It could be argued that maternal and litter effects are masking real mating systems differences for early growth and these differences become evident only when litter and maternal influences diminish with increasing age. If this were so, significant differences for early growth should have been observed in the sequential or double mating analyses. It must be concluded that, for the breed strains used in this study, crossbred superiority for growth rate is manifested primarily in the later stages of growth.

In addition, examination of the least squares estimates from the field and random

mating data and the results of the sequential and double mating studies indicate a simple superiority of crossbreds over purebreds for growth to market weight. No evidence of additional heterotic benefits through backcrosses or three-breed crosses was observed.

No consistent effects of mating system on carcass performance were observed. The field study failed to detect significant mating system differences for any of the three traits considered. Mating system had a significant ($P < 0.05$) effect on loin eye area and trimmed ham weight in the random mating analysis. The sequential mating study found purebreds superior ($P < 0.05$) to single crosses for loin eye area, trimmed ham weight and lean cut yield, but no significant differences between backcrosses and three-

Table 5. Effect of mating system on growth as evaluated from field, random, sequential and double mating data (expressed as the mean plus least squares estimate of deviation from mean)

Trait	Analysis	No. litters	Mating system			
			Purebred	Single cross	Back-cross	3-breed cross
<i>Early growth</i>						
Birth wt (kg)	Random	718	(1.29	1.31	1.33	1.32)
	Sequential	302	(1.28	1.27)†	(1.34	1.32)‡
	Double	80	(1.30	1.27)	(1.34	1.37)
21 day wt (kg)	Random	718	(5.52	5.33	5.58	5.50)
	Sequential	302	(5.44	5.62)	(6.03	5.52)
	Double	80	(5.27	5.13)	(5.18	5.17)
56 day wt (kg)	Random	718	(14.2	14.3	14.7	14.6)
	Sequential	302	(13.3	14.4)	(15.2	13.8)
	Double	80	(15.6	15.7)	(15.9	15.7)
<i>Late growth</i>						
154 day wt (kg)	Random	680	(71.8	76.0	75.8	77.3)**
	Sequential	286	(69.9	76.0)**	(74.2	77.0)
	Double	69	(77.2	83.9)*	(81.4	81.4)
Age at market (days)	Field	622	(200.2	190.6	195.3	194.3)**
	Random	680	(178.8	172.3	173.1	169.6)**
	Sequential	286	(181.5	171.0)**	(172.6	171.1)
	Double	69	(170.5	159.7)*	(164.1	165.4)
Daily gain§ (kg/day)	Field	622	(.359	.377	.369	.370)**
	Random	680	(.492	.514	.511	.519)**
	Sequential	286	(.486	.517)**	(.509	.517)
	Double	69	(.522	.551)	(.536	.539)

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

†Purebred vs. single cross comparison.

‡Backcross vs. three-breed cross comparison.

§Daily gain is expressed as kg carcass weight per day of age in the field data and as kg liveweight per day of age in the random, sequential and double mating data.

breed crosses were observed for any carcass trait. In the double mating analyses, back-cross pigs had heavier ($P < 0.05$) trimmed loins than three-breed crosses.

Carcass traits tend to exhibit little heterosis (Fredeen 1957; Hazel 1963). The results of this study support this contention.

Comparison of Breeding Plans

Estimates were made of the relative efficiencies of the field, random, sequential and double mating breeding plans for detecting sire differences in growth and carcass merit (Table 7). The relative efficiency of each breeding plan was measured as the ratio of

the estimated number of litters required to detect significant differences between two sires by that breeding plan to the estimated number of litters required by random mating.

The relative efficiencies of field data and random mating experimental data were not consistent across all traits. For age at market, almost twice as many litters would be required to detect significant differences between sires with field data than with random mating experimental data. For daily gain, the results indicated that field data are relatively more efficient. However, daily gain was not measured in the same manner in both studies. Daily gain was expressed as

Table 6. Effects of mating system on carcass traits as evaluated from field, random, sequential and double mating data (expressed as the mean plus least squares estimate of deviation from mean)

Trait	Analysis	No. litters	Mating system			
			Purebred	Single cross	Back-cross	3-breed cross
Length (mm)	Random	692	(775	776	774	773)
	Sequential	282	(777	777) [†]	(774	778) [‡]
	Double	58	(770	771)	(770	765)
Shoulder backfat (mm)	Field	622	(39.5	39.9	39.7	39.8)
	Random	692	(39.0	38.7	38.7	39.0)
	Sequential	282	(38.8	38.9)	(39.1	38.3)
	Double	58	(40.7	38.8)	(39.7	38.7)
Loin backfat (mm)	Field	622	(33.8	33.7	38.5	33.9)
	Random	692	(32.0	32.6	32.3	32.8)
	Sequential	282	(32.3	32.7)	(33.6	31.9)
	Double	58	(33.2	33.5)	(31.3	30.7)
Loin eye area (mm ²)	Random	692	(2677	2650	2686	2599)*
	Sequential	282	(2682	2570)*	(2588	2669)
	Double	58	(2750	2755)	(2723	2699)
Trimmed ham (kg)	Random	692	(7.07	7.00	7.09	7.07)*
	Sequential	282	(7.13	6.98)*	(7.09	7.05)
	Double	58	(6.94	7.10)	(7.16	7.18)
Trimmed shoulder (kg)	Random	692	(5.82	5.78	5.82	5.77)
	Sequential	282	(5.87	5.75)	(5.86	5.76)
	Double	58	(5.62	5.90)	(5.84	5.77)
Trimmed loin (kg)	Field	622	(6.88	6.94	6.90	6.91)
	Random	692	(5.21	5.23	5.25	5.14)
	Sequential	282	(5.26	5.21)	(5.10	5.29)
	Double	58	(5.24	5.22)	(5.35	5.11)*
Lean cut yield (kg)	Random	692	(36.2	36.0	36.3	35.9)
	Sequential	282	(36.5	35.9)*	(35.9	36.3)
	Double	58	(35.6	36.4)	(36.7	36.1)

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

[†]Purebred vs. single cross comparison.

[‡]Backcross vs. three-breed cross comparison.

Table 7. Relative efficiencies of the field, random, sequential and double mating breeding plans for detecting sire differences in growth and carcass merit (expressed as a ratio of the number of litters required to detect significant differences between two sires† for the breeding plan concerned relative to the number of litters required by random mating)

Breeding plan	Growth traits					Carcass traits								
	Birth wt	21-day wt	56-day wt	154-day wt	Age at market	Daily gain	Length	Shoulder backfat	Loin backfat	Loin eye area	Trimmed ham	Trimmed shoulder	Trimmed loin	Lean cut yield
Field					1.86	0.78		0.62	0.94				2.20	
Random	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sequential	0.70	1.24	1.24	1.31	1.09	1.43	0.98	1.07	0.91	1.29	0.74	2.07	1.08	1.32
Double‡	0.15	0.23	0.21	0.33	0.35	0.40	0.36	0.47	0.44	0.42	0.32	0.63	0.50	0.56

†Based on a 90% assurance of detecting a given difference at the 5% significance level.

‡Double mating estimates of litters required were based on six pigs per litter for the early growth traits and four pigs per litter for the late growth and carcass traits.

Table 8. Relative efficiencies of the field, random, sequential and double mating breeding plans for detecting mating system differences in growth and carcass merit (expressed as a ratio of the number of litters required to detect significant differences between purebreds, single crosses, backcrosses and three-breed crosses† for the breeding plan concerned relative to the number of litters required by random mating)

Breeding plan	Growth traits					Carcass traits								
	Birth wt	21-day wt	56-day wt	154-day wt	Age at market	Daily gain	Length	Shoulder backfat	Loin backfat	Loin eye area	Trimmed ham	Trimmed shoulder	Trimmed loin	Lean cut yield
Field					1.81	.78		0.57	0.96				2.24	
Random	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sequential	0.44	0.75	0.76	0.80	0.65	0.85	0.60	0.68	0.58	0.78	0.44	1.28	0.66	0.79
Double‡	0.09	0.14	0.13	0.20	0.21	0.24	0.22	0.30	0.29	0.25	0.19	0.39	0.31	0.33

†Based on a 90% assurance of detecting a given difference at the 5% significance level.

‡Double mating estimates of litters required were based on six pigs per litter for the early growth traits and four pigs per litter for the late growth and carcass traits.

liveweight per day of age in the experimental data and as carcass weight per day of age in the field data. This latter measurement is subject to considerably less variation; thus the relatively greater efficiency of field data is not surprising. Little difference in the relative efficiencies between the two breeding plans was detected for loin backfat depth, whereas field data appeared to be more efficient for shoulder backfat depth. In contrast, the number of field litters required to detect sire differences for trimmed loin weight was over twice the random mating number.

For most traits, sequential mating was relatively less efficient than random mating. One notable exception was birth weight. It was estimated that sequential mating would require about two-thirds the number of litters that would be required by random mating to detect sire differences for birth weight. However, sequential mating appeared to be less efficient than random mating for all subsequent growth traits and offered no consistent advantage for carcass traits.

The relative efficiency of double mating was vastly superior to both sequential mating and random mating for all traits considered. This superiority was most pronounced for birth weight and, to a lesser extent, the other early growth traits. As the age at which growth was measured increased, the relative efficiency of double mating decreased. The relative efficiency estimates of double mating for carcass traits tended to be similar to, or slightly less than, those observed for the late growth traits.

Estimates were made of the relative efficiencies of the field, random, sequential and double mating breeding plans for detecting mating system differences in growth and carcass merit (Table 8). The relative efficiency of each breeding plan was measured as the ratio of the estimated number of litters required to detect significant differences between purebreds, single crosses, backcrosses and three-breed crosses by that breeding plan to the estimated number of litters required by random mating. The field and random mating breeding plans compare all four mating systems simultaneously, whereas the sequential and double mating breeding plans are restricted to two separate com-

parisons: purebreds vs. single crosses and backcrosses vs. three-breed crosses. For the sequential and double mating breeding plans, the sum of the estimates of litter numbers required by the two separate comparisons was used as the basis for measuring breeding plan efficiency relative to random mating.

The relative efficiency estimates between the use of field data and random mating experimental data for detecting mating system differences were very similar to those noted in the sire comparison study.

Sequential mating, as was also observed in the sire comparison study, was substantially more efficient than random mating for detecting mating system differences for birth weight. However, unlike the sire comparison study, sequential mating was slightly more efficient than random mating for the remaining growth traits and for all carcass traits except weight of trimmed loin. It is doubtful, however, that this slight advantage provides sufficient compensation for the inability of the sequential mating breeding plan to make comparisons between all four mating systems.

Double mating was substantially more efficient than both sequential and random mating for all traits. The relative efficiency estimates observed for double mating were similar to those of the sire comparison study.

In summary, there was little overall difference in relative efficiency, when measured as the number of litters required to detect significant sire or mating system differences, between the use of field data and experimental data based on random matings, although distinct advantages and disadvantages were observed for some traits. It must be noted, however, that the cost of obtaining data from the field is generally less than that incurred from experimental studies and the use of field data for sire and mating system evaluation may well be more efficient economically.

The sequential mating breeding plan, which provides within-dam comparisons, offered little advantage, if any, over random mating except in detecting differences for birth weight, a trait which is greatly influenced by maternal effects.

The double mating breeding plan was most efficient. Comparisons on a within-litter basis resulted in effective control over variation due to both dam and litter effects and substantially reduced the number of litters required to detect sire or mating system differences for both growth and carcass performance. This advantage was most pronounced for the early growth traits when maternal and litter influences are greatest.

Two difficulties, however, which are inherent with double mating but not with random mating, were the identification of sires in mixed litters and the inability of the double mating breeding plan to make comparisons between all four mating systems. Nonetheless, the substantial saving in time and resources afforded by double mating should offer sufficient compensation for these difficulties.

ACKNOWLEDGMENTS

The assistance of R. M. Channon of the Department of Animal Science, Macdonald College, and A. Sutherland of the College Farm, Macdonald College, is gratefully acknowledged. The authors also appreciate the cooperation of Dr. Gabriel Roy and the Central Swine Breeding Station, St. John's, Newfoundland. This study was supported by grants from the Quebec Agricultural Research Council (MCA-57-91) and the National Research Council (A-4442).

- BAKER, M. L., HAZEL, L. N. and REIN-MILLER, C. F. 1943. The relative importance of heredity and environment in the growth of pigs at different ages. *J. Anim. Sci.* **2**: 3-13.
- DUCKWORTH, J. E., COOPER, M. M., DUNKIN, A. G., TAYLOR, J. M. and HOLMES W. 1961. Progeny testing of bacon pigs at Wye College. *Anim. Prod.* **3**: 239-250.
- FREDEEN, H. T. 1957. Crossbreeding and swine production. *Anim. Breed. Abstr.* **25**: 339-347.
- HAZEL, L. N. 1963. Influence of breeding on production efficiency. *World Conf. Anim. Prod. Rome* **2**: 189-193.
- LUSH, J. L. 1945. *Animal breeding plans*. Iowa State College Press, Ames, Iowa.
- LUSH, J. L., SHEARER, P. S. and CULBERTSON, C. C. 1939. Crossbreeding hogs for pork production. *Iowa Agric. Exp. Sta. Bull.* **380**.
- ROACHE, K. L. and MOXLEY, J. E. 1964. Sire by mating system interactions in swine. *Proc. Can. Soc. Anim. Prod.* p. 90.
- ROBERTS, E. and CARROLL, W. E. 1939. A study of hybrid vigour in a cross between Poland China and Duroc Jersey swine. *J. Agric. Res.* **59**: 847-854.
- SAISON, RUTH and MOXLEY, J. E. 1966. The use of blood groups as markers in a double mating program in swine and evidence for preferential fertilization. *Proc. 10th Eur. An. Blood. Grp. Conf. Paris*. pp. 171-174.
- STEEL, R. G. D. and TORRIE, J. H. 1960. *Principles and procedures of statistics*. McGraw-Hill Book Co., New York, N.Y.