AGE AND WEIGHT AT PUBERTY OF PUREBRED AND CROSSBRED GILTS INVOLVING FOUR BREEDS AND THEIR GENETIC AND PHENOTYPIC RELATIONSHIP WITH GROWTH CHARACTERISTICS

By

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Bachelor of Science
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1975

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1980

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ACKNOWLEDGMENTS

I wish to thank the Oklahoma State University Animal Science Department for giving me the opportunity to continue my education. I would also like to thank Dr. R. K. Johnson for his excellent guidance and encouragement during the initial part of my program.

I also wish to give special thanks to Dr. R. L. Hintz whose unending assistance and guidance made it possible for the formulation and preparation of this manuscript.

Special thanks is also extended to my wife, Esther, whose love and understanding made attendance of graduate school possible.

Acknowledgment is also extended to fellow graduate students for their friendship and assistance.

I would also like to thank the Hutchens and Redshirt family for their support and encouragement.

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CHAPTER I

INTRODUCTION

In the past, little effort was made toward improvement of reproductive traits since heritability estimates of these traits are low. However as swine production has intensified and operations have become larger, even small improvements in reproductive traits are of large economic importance.

Reduction in the age at puberty would be expected to improve overall reproductive efficiency, provided this reduction is not associated with detrimental effects on other aspects of reproduction. Gilts reaching puberty at younger ages would be expected to be younger at conception and therefore reduce the variable and fixed costs required to bring replacements into production.

Environmental factors such as boar exposure, nutrition level, housing and hormonal therapy can influence the age at first estrus. In addition, the importance of non-additive gene action has been shown by the fact that crossbred gilts reach puberty consistently younger than purebreds. Breed differences are also important factors which determine the age and weight at which gilts reach puberty.

The knowledge of genetic differences for pubertal characteristics and other biologically important traits will be helpful in identifying mating systems that will maximize total production efficiency under specifically designed management systems.

To determine the opportunities for selection of pubertal characteristics, accurate estimates of heritability and the genetic correlations of pubertal characteristics with other economically important traits are needed.

The objective of this study were: 1) to estimate the heritability of pubertal characteristics and their genetic and phenotypic correlations with individual pig growth characteristics; 2) and to investigate breed differences and heterosis for pubertal traits involving Duroc, Yorkshire, Spot and Landrace breeds.

CHAPTER II

REVIEW OF LITERATURE

Heritability and Correlation Estimates for Growth and Pubertal Characteristics

Heritability and correlation estimates for growth and pubertal characteristics have been obtained using a variety of statistical methods for various sexes and breeds of swine. A set of tables have been developed to present the heritability and correlation estimates for birth weight, weaning weight, postweaning daily gain, age at constant weight, backfat at 90.7 kg, age at puberty and weight at puberty. Symbols and abbreviations have been used to identify different breeds, sexes and statistical terms (Table I) in the tables.

Heritabilities

Birth Weight. The heritability estimates for birth weight ranged from -.38 to .54 (Table II). A weighted average of heritability estimates (weighted by number of offspring) for birth weight is .19 which indicates birth weight is lowly to moderately heritable.

Weaning Weight. The heritability estimates for weaning weight ranged from -.15 to .63 with the weighted average of all estimates for weaning weight being .18 (Table III), indicating weaning weight is lowly to moderately heritable.

TABLE I

SYMBOLS AND ABBREVIATIONS USED IN HERITABILITY AND CORRELATION TABLES

Statistical abbreviations and symbols

h^2 - Heritability
N_l - Number of litters
N_o - Number of offspring
N_s - Number of sires
r_g - Genetic correlation
r_p - Phenotypic correlation
SE - Standard error of the estimate

Abbreviations of methods used to obtain heritability and genetic correlation estimates

AMP - Average of maternal and paternal half-sib correlations
COP - Correlation between a parents progeny test and the progeny test of their offspring, each based on a group of full-sibs
FS - Full-sib correlation
IC1 - Modified paternal half-sib correlation (corrected for inbreeding)
IC2 - Modified paternal half-sib correlation (corrected for the average relationship between mates of a sire)
IC3 - Modified paternal half-sib correlation (corrected for increased genetic likeness of sows within a herd)
ISOD - Intra-sire regression of offspring on dam
MID - Modified intra-sire regression of offspring on dam (corrected for inbreeding)
MOP - Modified regression of offspring on midparent (corrected for inbreeding)
MHS - Maternal half-sib correlation
PHS - Paternal half-sib correlation
REAL - Realized estimated from selection
ROD - Regression of offspring on dam

TABLE I (Continued)

ROS - Regression of offspring on sire
ROP - Regression of offspring on midparent average

Abbreviations for sex of animal

B - Barrow (male castrate)
BO - Boar
G - Gilt
M - Mixed

Abbreviations used to describe the breeds of lines

B - Berkshire
BL - British Landrace
BT - Beltsville
CIW - Czechoslavakian Improved White
COP - Control population composed of several breeds
CW - Chester White
D - Duroc
DJ - Duroc Jersey
DL - Danish Landrace
FX - Animals involved were inbred e.g. FX (D) = a population of Durocs with some degree of inbreeding
FS - Animals involved were selected for backfat thickness e.g. FS (Y) = Yorkshires selected for backfat
GIL - German Improved Landrace
GL - German Landrace
GS - Animals involved were selected for growth rate e.g. GS (H) = Hampshires selected for growth rate
H - Hampshire
ILW - Irish Large White
KH - Kazah Hybrids
L - Landrace
LB - Large Black

TABLE I (Continued)

LC - Lacombe
LW - Large White
LX - Animals involved were produced from line crosses
MG - Managara
MIXED - Three or more breeds involved
MN - Minnesota synthetics
NGP - Nebraska Gene Pool (a synthetic developed from 14 breeds)
PB - Animals involved were purebreds e.g. PB (D,Y) = purebred Durocs and Yorkshires
PC - Poland China
RLW - Russian Large White
SL - Swedish Landrace
SSL - Synthetic Sire Line
XB - Animals involved were crossbreds e.g. XB (D,Y+H) refers to a population of Duroc, Yorkshire and Hampshire crossbreds
Y - Yorkshire

TABLE II

SUMMARY OF HERITABILITY ESTIMATES FOR BIRTH WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Lush et al., 1934	3,639	506	--	M	Mix	PHS	.02	--
Baker et al., 1943	999	259	62	M	FX (D)	IC1	.00	--
Nordskog et al., 1944	2,396	340	110	M	FX	MID	.14	--
Krider et al., 1946	749	98	41	M	GS (H)	PHS	.05	--
Dickerson & Grimes, 1947	547	87	--	M	D	ROS	-.38	--
						ROD	.12	--
						ROP	-.23	.13
Craig et al., 1956[a]	2,036	288	124	M	GS (H)	IC1	.28	--
Noland et al., 1966	3,360	411	106	-	PC	ROS	.24	.10
Louca & Robison, 1967	674	--	--	BO	PB (D+Y)	PHS	.09	.29
	735	--	--	G	PB (D+Y)	PHS	.05	.20
	3,275	--	--	B	XB (D+Y)	PHS	.01	.05
	3,357	--	--	G	XB (D+Y)	PHS	.03	.05
Roy et al., 1968	1,246	--	--	M	MG	PHS	.10	.15
Vangelov, 1969	10,309	--	--	-	LW	--	.46	--
Fahmy & Bernard, 1970	6,846	--	161	M	Y	IC1	.07	.35
						ROP	.27	.06
Edwards & Omtvedt, 1971	3,760	--	353	M	COP	ROS	.04	.04
						ROD	-.04	.04
						ROP	.00	.03
Berruecos et al., 1970	483	--	55	M	FS (XB)	--	.21[b]	--
Legault, 1970	--	11,266	760	-	LW	--	.07	--
Quijandri & Montalvan, 1971	2,351	--	--	-	D + LW	--	.28	--
Hetzer & Miller, 1972	2,539	--	--	M	FS (D)	ROP	.05	.04
	2,236	--	--	M	FS (Y)	ROP	.12	.04
Johar & Saibaba, 1973	1,826	--	--	-	MW	PHS	.13	.06

TABLE II (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Li et al., 1973	--	--	--	-	KH	PHS	.09	--
						MHS	.24	--
Popescu-Vifor, 1974	--	2,118	--	-	L	--	.16	--
Arganosa et al., 1974/75	--	737	231	M	D, L+Y	--	.07	--
Vechionacce et al., 1976	1,134	--	--	M	PB+XB (L+LW)	--	.54	--
	1,094	--	--	M	XB	--	.21	--
Webb & King, 1976	3,600	--	--	M	SSL	PHS	.31	.13
Young et al., 1977	531	--	--	G	PB+XB (D,Y+H)	PHS	.07	.19
Young et al., 1978	2,095	--	292	G	NGP	PHS	.16	.16
		Weighted average (24 estimates)					.19	

[a] Krider et al. (1946) obtained estimates from a portion of these data.

[b] Weighted average of estimates obtained with ROD, ROS, ROP, PHS, MHS and FS methods.

TABLE III

SUMMARY OF HERITABILITY ESTIMATES FOR WEANING WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Bywaters, 1937	1,633	271	20	M	PC	PHS	.04	--
Baker et al., 1943	994	259	62	M	FX (D)	ICl	.15	--
Krider et al., 1946	749	98	41	M	GS (H)	PHS	.14	--
Dickerson & Grimes, 1947	567	87	--	M	D	ROP	.09	.12
						ROS	.16	.09
						ROD	.04	.09
McClung, 1953	1,054	--	--	-	FX (D)	ROD	.14	.06
Blunn et al., 1954[a]	446	--	17	-	XB (Mix)	ISOD	.11	--
	572	105	17	-	XB (Mix)	ICl	.02	--
	2,176	450	105	-	FX (D)	ICl	.22	--
Craig et al., 1956[b]	2,036	288	124	M	GS (H)	ICl	.24	--
Broderick, 1960	582	--	--	M	ILW	--	.17	--
Zoellner et al., 1963	300	--	17	M	FX (PC)	MID	-.15	--
						MOP	-.06	.06
Ward et al., 1964	2,693	357	129	M	MN #2+MN #3	PHS	.14	.11
						ROS	.13	.06
						ISOD	.27	.07
Kripple et al., 1965	1,328	--	--	-	GIL	--	.63	--
Sviben, 1965	--	356	--	-	SL	--	.16	--
Noland et al., 1966	3,360	411	106	-	FX (PC)	ROS	.12	.13
Stanislaw, 1966	3,609	457	99	M	PB (D,BT #1+H)	PHS	.03	.06
	3,077	347	99	M	XB (D,BT #1+H)	PHS	.19	.09
Reutzel & Sumption, 1968	1,192	--	123	G	NGP	PHS	.33	.07
	800	--	--	G	NGP	ISOD	.21	.07
Berruecos, 1970	483	--	55	M	FS (XB)	--	.21[c]	.15
Fahmy & Bernard, 1970	4,428	780	161	M	Y	PHS	.08	.27
						ROP	.19	.06
Biedermann et al., 1971	3,344	--	--	-	GL	--	.53	--

TABLE III (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Edwards & Omtvedt, 1971	2,956	--	349	M	COP	ROS	.08	.04
						ROD	.02	.04
						ROP	.05	.03
Siers & Thompson, 1972	1,348	--	--	M	PB	PHS	.16	.06
Quijandria & Montalvan, 1971	2,351	--	--	-	D+LW	--	.26	--
Hetzer & Miller, 1972	2,539	--	--	M	FS (D)	ROP	.09	.03
	2,236	--	--	M	FS (Y)	ROP	.07	.04
Rahnefield, 1973	2,912	--	--	M	LC+Y	PHS	.14	.03
Popescu-Vifor, 1974	--	2,118	--	-	L	--	.18	--
Arganosa et al., 1974/75	--	737	231	M	D, L+Y	--	.40	--
Vechionacce et al., 1976	1,134	--	--	M	PB+XB (L+LW)	--	.18	--
	1,094	--	--	M	XB	--	.17	--
Webb & King, 1976	2,972	--	--	M	SSL	PHS	.30	.15
Young et al., 1977	531	--	--	G	PB+XB (D,H+Y)	PHS	.12	.19
Young et al., 1978	2,095	--	292	G	NGP	PHS	.18	.15
		Weighted average (30 estimates)					.18	

[a] Estimates involve different animals.

[b] Krider et al. (1946) obtained estimates from a portion of these data.

[c] Weighted average of estimates obtained with ROD, ROS, ROP, PHS, MHS and FS methods.

Postweaning Daily Gain. The heritability estimate for postweaning daily gain ranged between -.12 to 1.11 with the majority of estimates lying between .2 and .5 (Table IV). The weighted average of all estimates was .38 which suggest that growth rate measured after weaning is moderately to highly heritable.

Age at a Constant Weight. There are relatively few estimates of heritability in the literature for growth rate measured as the age to a constant weight, as compared to postweaning daily gain. The weighted average of the heritability estimates for this trait was .55, with estimates ranging from -.07 to 1.79 (Table V). This suggests that growth rate measured in this manner may be moderate to highly heritable.

Live Backfat. The weighted average for backfat was .41 (Table VI), which agrees with the simple average of .41 which Young et al. (1978) obtained from a review of heritability estimates. These estimates suggest that live backfat is moderately to highly heritable.

Age and Weight at Puberty. The heritability estimates ranged from -.28 to .64 for age at puberty and .17 to .52 for weight at puberty (Table VII). Weighted averages of .34 and .32 were obtained for age and weight at puberty, respectively.

Correlations

Birth Weight With Weaning Weight. The weighted average of correlation estimates (Table VIII) indicates a low to moderate genetic correlation (.30) between these traits. The phenotypic correlation was higher (.53) suggesting a favorable environmental correlation for pigs

TABLE IV

SUMMARY OF HERITABILITY ESTIMATES FOR POSTWEANING DAILY GAIN

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	H^2	SE
Lush, 1936	--	287	83	M	L+Y	--	.24[a]	--
Comstock et al., 1942	178	--	--	-	PC+MN #1	ISOD	.31	--
Nordskog et al., 1944	2,396	340	110	-	FX	ICl	.40	--
	312	--	--	-	--	MID	.21	.24
Dickerson, 1947	746	--	--	M	PB+XB (PC+DL)	ICl	.31	--
Dickerson & Grimes, 1947	567	87	--	M	D	ROP	.43	.10
						ROS	.44	--
						ROD	.58	--
Blunn & Baker, 1947	358	--	--	M	DJ	ICl	.18	--
Johansson & Korkman, 1951	12,144	--	1,693	M	LW+SL	PHS	.26	--
Reddy et al., 1956	436	--	12	-	XB (L+PC)	ISOD	.04	.10
Cox, 1959	--	--	--	-	--	--	.33	--
Fowler & Ensminger, 1960	1,705	--	--	M	GSP	REAL	.51	--
Broderick, 1960	582	--	--	M	ILW	--	.15	--
Locniskar, 1960	936	--	--	M	GIL	--	.39	--
El-Issawi & Rempel, 1961	--	--	--	-	MN #1, #2+#3	ISOD	.14	.10
						ROD	.28	.06
Smith et al., 1962	1,976	494	200	M	LW	PHS	.41	.10
Jonsson & King, 1962	5,996	--	935	M	DL	PHS	.45	--
Zoellner et al., 1963	330	--	17	M	FX (PC)	ISOD	.16	--
						ROP	.22	.13
Ward et al., 1964	2,693	357	129	M	MN #2+#3	PHS	.26	.10
						ROS	.30	.11
						ISOD	.38	.09
Kripple et al., 1965	1,328	--	--	-	GIL	--	.14	--

TABLE IV (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Smith et al., 1965	2,296	574	250	M	BL	PHS	.41	--
Biswas et al., 1966	185	--	33	M	XB (D+Y)	PHS	.77	.37
Stanislaw, 1966	3,087	--	99	M	PB (D,H+BT #1)	PHS	.28	.06
	2,570	--	99	M	XB (D,H+BT #1)	PHS	.39	.10
Stockhouser & Boylan, 1966	978	--	--	G	MG	ROD	.30	.06
	334	--	--	G	MG	ROS	-.12	.12
	641	--	--	B	MG	ROD	.28	.09
	156	--	--	B	MG	ROS	.36	.15
	207	--	--	BO	MG	ROD	.29	.16
	127	--	--	BO	MG	ROS	.26	.21
Roy et al., 1968	1,246	--	--	M	MG	PHS	.33	.14
Zeek, 1968	12,425	--	--	M	GIL	--	.60	--
Reutzel & Sumption, 1968	1,192	--	123	G	NGP	PHS	.34	.17
	800	--	--	G	NGP	ISOD	.22	.09
Fahmy & Bernard, 1970	4,428	--	161	M	Y	PHS	.16	.27
						ROP	-.02	.09
Flock, 1970	28,480	--	--	M	DL+GL	IC2	.45	.05
						COP	.24	.04
Edwards & Omtvedt, 1971	1,244	--	340	G	COP	ROS	.29	.06
						ROD	.18	.08
Biederman et al., 1971	3,344	--	--	-	GL	--	.42	--
Sidor & Mojto, 1971	336	--	67	-	CIW	PHS	.98	--
						MHS	.80	--
Pavlik et al., 1971	1,544	--	144	-	LB	--	.80	--
	3,456	--	263	-	L	--	.81	--
Hetzer & Miller, 1972	2,539	--	--	M	FS (D)	ROP	.17	.04
	2,236	--	--	M	FS (Y)	ROP	.33	.04
Robison & Berruecos, 1973[a]	321	--	62	B	--	PHS	1.11	.27
Molenat, 1973	1,043	--	126	BO	LW	ROS	.30	.08

TABLE IV (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Pochernyayer, 1974	--	--	--	-	RLW	--	.35	--
Marquardt, 1974	1,600	--	--	M	GL	--	.20	--
Clarke et al., 1975	668	--	182	BO	LW+L	PHS	1.02	.29
Pumfrey et al., 1975	1,632	--	--	G	NGP	ROD	.17	.06
						ROS	.13	.04
Rahnefield & Garnett, 1976	--	--	--	M	LC+Y	--	.33[b]	.03
Webb & King, 1976	1,068	--	--	M	SSL	PHS	.26	.13
Gajic, 1976	8,590	--	--	G	Mix	--	.39	--
Young et al., 1977	531	--	--	G	PB+XB (D,H+Y)	PHS	1.03	.21
Young et al., 1978[c]	2,095	--	292	G	NGP	PHS	.30	.12
McPhee et al., 1979	1,702	--	118	BO	LW+L	--	.36	.10
	Weighted average (44 estimates)						.38	

[a] Average of estimates obtained with MHS, PHS and COP methods.

[b] Average of estimates obtained with REAL, PHS, ROD and ROS.

[c] Pumfrey et al. (1975) obtained estimates from a portion of these data.

TABLE V

SUMMARY OF HERITABILITY ESTIMATES FOR AGE AT A CONSTANT WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Johansson & Korkman, 1951	12,144	--	1,693	M	LW+SL	PHS	.57	--
Fredeen, 1953	6,876	1,719	644	M	Y	IC3	.55	--
Broderick, 1960	582	--	--	M	ILW	--	.45	--
Nowicki, 1960	--	--	--	-	LW	--	.45	--
Sviben, 1965	--	--	--	B	SL	--	-.07	--
Arganosa, 1968	210	--	--	B	PB+XB (Mix)	PHS	.26	.26
	210	--	--	G	PB+XB (Mix)	PHS	.15	.24
Zeck, 1968	12,425	--	--	M	GIL	--	.87	--
Biederman et al., 1971	3,344	--	--	-	GL	--	.14	--
Edwards & Omtvedt, 1971	1,244	--	340	G	COP	ROS	.34	.07
						ROD	.19	.12
Klusak, 1972	254	--	19	-	CIW	PHS	.23	--
						MHS	1.79	--
Bus'ko, 1973	97	--	8	-	--	PHS	.27	--
						MHS	.54	--
Pochernyayer, 1974	--	--	--	-	RLW	--	.50	--
Moskal, 1975	--	--	--	M	CIW+L	PHS	.68	--
Gajic et al., 1976	8,590	--	--	G	Mix	--	.34	--
Young et al., 1977	531	--	--	G	PB+XB (D,H+Y)	PHS	.70	.21
Swiger et al., 1979	5,952	--	--	M	MIX	PHS	.40	.07
Weighted average (13 estimates)							.55	

TABLE VI

SUMMARY OF HERITABILITY ESTIMATES OF LIVE BACKFAT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Reddy et al., 1959	436	--	--	M	XB (L+PC)	ISOP	.35	--
						ROP	.20	--
Dillard et al., 1962	419	--	--	M	FX	REAL	.49	--
						PHS	.09	--
						MHS	.81	--
						AMP	.45	--
Zoellner et al., 1963	679	--	17	M	FX (PC)	REAL	.74	--
	330	--	13	M	FX (PC)	MID	.93	--
	330	--	--	M	FX (PC)	ROP	.83	.14
Cox, 1964	7,642	--	--	M	D+H	IC2	.25	.06
						ROD	.22	.02
Gray et al., 1964	441	--	18	M	FX (PC)	IC1	.35	.16
Gray et al., 1965	--	--	--	M	PC	REAL	.49	--
						ISOD	.41	.06
Stanislaw, 1966	1,230	--	89	M	PB	PHS	.55	.12
	2,569	--	99	M	XB	PHS	.47	.13
Stockhauser & Boylan, 1966	558	--	--	G	MG	PHS	.53	.68
	334	--	--	G	MG	ROD	.13	.09
	334	--	--	G	MG	ROS	.10	.08
	335	--	--	B	MG	PHS	-.07	.22
	156	--	--	B	MG	ROD	.17	.13
	156	--	--	B	MG	ROS	-.05	.11
	209	--	--	BO	MG	PHS	.56	.44
	127	--	--	BO	MG	ROD	.25	.15
	127	--	--	BO	MG	ROS	.12	.14

TABLE VI (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Louca & Robison, 1967	293	--	--	BO	PB (D+Y)	PHS	.35	.34
	381	--	--	B	PB (D+Y)	PHS	.14	.15
	735	--	--	G	PB (D+Y)	PHS	.33	.18
	3,275	--	--	B	XB (D+Y)	PHS	.22	.06
	3,357	--	--	G	XB (D+Y)	PHS	.09	.05
Hetzer & Harvey, 1967	1,929	313	189	M	FS (D)	ROP	.55	--
						REAL	.48	--
	1,627	252	157	M	FS (Y)	ROP	.60	--
						REAL	.41	--
Gray et al., 1968	1,828	--	67	M	PC	REAL	.32	.09
						ROD	.56	.09
Reutzel & Sumption, 1968	1,192	--	123	G	NGP	PHS	.27	.16
	800	--	--	G	NGP	ISOD	.33	.07
Arganosa, 1968	652	--	--	M	PB+XB (Mix)	PHS	.62	.19
Berruecos et al., 1970	483	--	55	M	FS (XB)	--	.38[a]	.02
						REAL	.27	.09
Edwards & Omtvedt, 1971	1,108	--	314	G	COP	ROS	.30	.07
						ROD	.30	.06
Hetzer & Miller, 1972[b]	2,539	--	--	M	FS (D)	ROP	.56	.04
	2,236	--	--	M	FS (Y)	ROP	.50	.05
Molenat, 1973	1,097	--	126	BO	LW	ROS	.70	.07
Marquardt, 1974	1,600	--	--	M	GL	--	.35	--
MiKami et al., 1974	187	--	13	-	L	ISOD	.50	--
Pumfrey et al., 1975	1,253	--	--	G	NGP	ROD	.46	.05
						ROS	.61	.08
						ROP	.53	.07
Clarke et al., 1975	658	--	182	BO	L+LW	PHS	.86	.28

TABLE VI (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method	h^2	SE
Kupriyanova & Leshchenya, 1975	547	--	--	G	--	REAL	.33	--
Webb & King, 1976	1,727	--	--	M	SSL	PHS	.63	.13
Gajic et al., 1976	8,590	--	--	G	MIX	--	.41	--
Walters et al., 1977	3,583	--	--	G	LW	PHS	.49	--
	2,810	--	--	G	L	PHS	.51	--
	5,081	--	--	G	XB	PHS	.45	--
Young et al., 1978[c]	2,095	--	292	G	NGP	PHS	.89	.13
Weighted average (33 estimates)							.41	

[a] Weighted average of estimates obtained with ROS, ROD, ROP, FS, MHS, PHS methods.

[b] Hetzer & Harvey (1967) obtained estimates from a portion of these data.

[c] Pumfrey et al. (1975) obtained estimates from a portion of these data.

TABLE VII

SUMMARY OF HERITABILITY ESTIMATES FOR AGE AND WEIGHT AT PUBERTY IN GILTS

Adapted From	N_o	N_1	N_s	Breed or Line	Method	Age h^2	Age SE	Weight h^2	Weight SE
Reutzel & Sumption, 1968	1,192	312	123	NGP	PHS	-.20	.14	.17	.14
	800	--	--	NGP	ISOD	.49	.11	.52	.08
Legault, 1973	304	--	65	L+LW	PHS	.46	--	.44	--
Cunningham et al., 1974[a]	137	--	--	NGP	ROD	.64	.30	--	--
	68	--	--	NGP	ROD	-.28	.36	--	--
Pumfrey et al., 1975	1,609	--	--	NGP	ROD	.38	.04	.34	.06
Young et al., 1978[b]	2,095	--	292	NGP	PHS	.53	.13	.27	.12
				Weighted average[c]		(5) .34		(3) .32	

[a] Estimates involve different animals.

[b] Pumfrey et al. (1975) obtained estimates from a portion of these data.

[c] Number of estimates utilized are in parenthesis.

TABLE VIII

SUMMARY OF CORRELATION ESTIMATES BETWEEN BIRTH WEIGHT AND WEANING WEIGHT

Adapted From	N_o	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Lush et al., 1931	--	--	-	--	--	--	.51
Dickerson & Grimes, 1947	567	87	M	--	--	.29	--
Blunn et al., 1954	1,894	--	M	PB+XB	--	--	.46
Noland et al., 1966[b]	451	23	M	PC	ROS	.68	--
	240	19	M	PC	ROS	.36	--
Omtvedt et al., 1966	3,775	--	M	PB+XB (Mix)	--	--	.54
Jensen et al., 1968	16,000	429	M	D+H	--	--	.49
Fahmy & Bernard, 1970	5,120	--	M	Y	PHS	.51	.70
					ROP	.55	--
Edwards & Omtvedt, 1971	1,108	--	G	COP	ROD	.14	.51
					ROP	-.10	--
Fahmy & Bernard, 1972	704	--	M	Y	--	--	.42
Revelle & Robison, 1973	180	--	G	PB+XB (D+Y)	--	--	.36
Young et al., 1974	241	--	G	PB (D,H+Y)	--	--	.38
	103	--	G	XB (D,H+Y)	--	--	.39
Young et al., 1977[c]	531	--	G	PB+XB (D,H+Y)	PHS	-1.94	.38
Young et al., 1978	2,095	292	G	NGP	PHS	.36	.56
		Weighted average[d]			(7)	.30	(9) .53

[a] Utilized to obtain genetic variance and covariance.

[b] Estimates involve different animals.

[c] Young et al. (1974) published estimates from a portion of these data.

[d] Number estimates utilized are in parenthesis.

heavier at birth.

Birth Weight With Postweaning Daily Gain. The estimates of the genetic correlation between these traits ranged from -.95 to .87 with most estimates being positive (Table IX). The weighted average was .27, suggesting a low correlation among these traits. The weighted average of phenotypic correlation estimates between birth weight and postweaning daily gain was .58, indicating that pigs heavier at birth tend to have faster post-weaning growth.

Birth Weight With Age at a Constant Weight. The estimates of genetic correlation were quite variable ranging from -.96 to 1.19 with a weighted average of -.56 (Table X) suggesting a moderate to high genetic correlation. However, the phenotypic correlation was consistently negative, with a weighted average of -.13, indicating little phenotypic association between these traits.

Birth Weight With Live Backfat. Estimates of the genetic correlation between these traits were mostly negative ranging from <-1.00 to .17 (Table XI). The weighted average of the genetic correlation estimates was -.39, suggesting many of the genes affecting larger birth weights may also be involved with a reduction in live backfat. The weighted average of the phenotypic correlation estimates was -.13 indicating very little if any association between the birth weight of pigs and their final live backfat.

Weaning Weight With Postweaning Daily Gain. The weighted average of the genetic correlation estimates between these traits was .47 (Table XII), indicating pigs heavier at weaning tend to be genetically

TABLE IX

SUMMARY OF CORRELATION ESTIMATES BETWEEN BIRTH WEIGHT AND POSTWEANING DAILY GAIN

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Dickerson & Grimes, 1947	567	87	--	M	D	FS	.02	--
Roy et al., 1968	469	--	--	M	MG	PHS	.07	.15
Fahmy & Bernard, 1970	4,428	--	154	M	Y	IC1	.29	.90
						MOP	.34	--
Edwards & Omtvedt, 1971	1,244	--	308	G	COP	ROD	-.95	.27
						ROP	-.45	--
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	.22
	241	--	--	G	PB (D,H+Y)	--	--	.19
Young et al., 1977[b]	531	--	--	G	PB+XB (D,H+Y)	PHS	.25	.20
Young et al., 1978	2,095	--	292	G	NGP	PHS	.87	.29
		Weighted average[c]					(6) .27	(5) .58

[a] Method utilized to obtain genetic components of variance and covariance.

[b] Young et al. (1974) obtained estimates from a portion of these data.

[c] Number of estimates utilized are in parenthesis.

TABLE X

SUMMARY OF CORRELATION ESTIMATES BETWEEN BIRTH WEIGHT AND AGE AT A CONSTANT WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Fahmy & Bernard, 1970	4,428	--	154	M	Y	IC1	-.96	-.04
Edwards & Omtvedt, 1971	1,244	--	340	G	COP	ROD	1.19	-.36
						ROP	.43	--
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	-.16
	241	--	--	G	PB (D,H+Y)	--	--	-.31
Young et al., 1977[b]	531	--	--	G	PB+XB (D,H+Y)	PHS	-.39	-.30
		Weighted average[c]				(3)	-.56	(3)-.13

[a] Method utilized to obtain genetic components of variance and covariances.

[b] Young et al. (1974) obtained estimates from a portion of these data.

[c] Number of estimates utilized are in parenthesis.

TABLE XI

SUMMARY OF CORRELATION ESTIMATES BETWEEN BIRTH WEIGHT AND LIVE BACKFAT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Louca & Robison, 1967	293	--	--	BO	PB (D+Y)	PHS	> 1.00	-.38
	381	--	--	B	PB (D+Y)	PHS	<-1.00	-.10
	735	--	--	G	PB (D+Y)	PHS	-.22	-.19
	3,275	--	--	B	XB (D+Y)	PHS	-.49	-.06
	3,357	--	--	G	XB (D+Y)	PHS	<-1.00	-.11
Roy et al., 1968	469	--	--	M	MG	PHS	.17	-.20
Jensen et al., 1968	16,000	2,000	429	M	D+H	--	--	-.13
Edwards & Omtvedt, 1971	1,108	--	314	G	COP	ROD	-.26	-.18
						ROP	-.73	
Hetzer & Miller, 1972	2,539	--	--	M	FS (D)	REAL	-.63	-.15
						ROP	-.46	
	2,236	--	--	M	FS (Y)	REAL	-.17	-.15
						ROP	-.37	
Revelle & Robison, 1973	180	--	--	G	PB+XB (D+Y)	--	--	-.09
Young et al., 1974	103	--	--	G	XB (D,Y+H)	--	--	-.23
	241	--	--	G	PB (D,Y+H)	--	--	-.12
Young et al., 1978	2,095	--	292	G	NGP	PHS	-.28	-.05
		Weighted average[b]				(7)	-.39	(14) -.12

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates utilized are in parenthesis.

TABLE XII

SUMMARY OF CORRELATION ESTIMATES BETWEEN WEANING WEIGHT AND POSTWEANING DAILY GAIN

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Bennett & Coles, 1946	220	--	--	B	Y	--	--	.32
	181	--	--	G	Y	--	--	.16
Dickerson & Grimes, 1947	567	87	--	M	D	FS	.65	.44
Warren & Dickerson, 1952	527	--	--	M	MIX	--	--	.38
Zoellner, et al, 1963	341	--	--	M	PC	ROP	--	.40
Ward et al., 1964	2,693	357	129	M	MN #2+MN #3	ROS	.49	.37
						ISOD	.84	
						PHS	.58	
Stanislaw, 1966	3,087	443	99	M	PB (H,D+BT #1)	PHS	.29	--
	2,570	335	99	M	XB (D,D+BT #1)	PHS	.20	--
Reutzel & Sumption, 1968	1,192	--	123	G	NGP	PHS	.04	.08
Fahmy & Bernard, 1970	4,428	--	161	M	Y	PHS	.40	.73
						ROP	.13	
Edwards & Omtvedt, 1971	1,244	--	340	G	COP	ROS	1.47	.32
						ROD	-1.09	
						ROP	.69	
Rahnefield, 1973	2,912	--	--	M	LC+Y	PHS	1.29	--
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	.34
	241	--	--	G	PB (D,H+Y)	--	--	.29
Siers et al., 1975a	114	--	--	M	Y	--	--	.31

TABLE XII (Continued)

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Young et al., 1977[b]	531	--	--	G	PB+XB (D,H+Y)	PHS	.82	.30
Young et al., 1978	2,095	--	292	G	NGP	PHS	.34	.35
		Weighted average[c]				(10)	.47	(12) .45

[a] Method utilized to obtain genetic variances and covariances.

[b] Young et al. (1974) obtained estimates from a portion of these data.

[c] Number of estimates are in parenthesis.

superior for postweaning daily gain. The weighted average of phenotypic correlation estimates between these traits was .45. These estimates suggest moderate genetic and phenotypic correlation between weaning weight and postweaning daily gain.

Weaning Weight With Age at a Constant Weight. A weighted average of the three estimates in the literature (Table XIII) was -.85 suggesting a high genetic relationship between these traits. Which is considerably larger than the estimated genetic relationship between weaning weight and postweaning daily gain.

The weighted average of phenotypic correlations was also relatively high (-.62). These estimates suggest high genetic and phenotypic relationship among these traits, however these weighted averages are based on only a few estimates.

Weaning Weight With Live Backfat. The estimate of the genetic correlation between weaning weight and live backfat were quite variable with estimates ranging from -.77 to .44 (Table XIV). The weighted average was -.20, suggesting a low genetic relationship between weaning weight and live backfat. Estimates of the phenotypic correlation among these traits were more consistent ranging from .00 to -.29 with a weighted average of -.09 suggesting little if any phenotypic relationship between these traits.

Postweaning Daily Gain With Age at a Constant Weight. Few researchers have estimated the relationship between postweaning daily gain and growth measured as age to constant weight, however the estimates were all in relative agreement (Table XV). Genetic correlation estimates ranged from -.80 to -1.01 with a weighted average of -.88 suggesting

TABLE XIII

SUMMARY OF CORRELATION ESTIMATES BETWEEN WEANING WEIGHT AND AGE AT A CONSTANT WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Fahmy & Bernard, 1970	4,428	--	161	M	Y	ICl	-.97	-.65
Edwards & Omtevdt, 1971	1,244	--	340	G	COP	ROS	-1.54	-.54
						ROD	1.32	
						ROP	-.80	
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	-.52
	241	--	--	G	PB (D,H+Y)	--	--	-.53
Young et al., 1977[b]	531	--	--	G	PB+XB (D,H+Y)	PHS	-1.02	-.54
			Weighted average[c]			(3)	-.85	(3) -.62

[a] Method utilized to obtain genetic variances and covariances.

[b] Young et al. (1974) obtained estimates utilizing a portion of these data.

[c] Number of estimates are in parenthesis.

TABLE XIV

SUMMARY OF CORRELATION ESTIMATES BETWEEN WEANING WEIGHT AND LIVE BACKFAT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method^a	r_g	r_p
Zoellner et al., 1963	330	--	--	M	FX (PC)	ROP	--	-.24
Stanislaw, 1966	2,157	--	98	M	PB	PHS	-.05	--
	1,229	--	88	M	XB	PHS	-.61	--
Jensen et al., 1968	16,000	2,220	429	M	D+H	--	--	-.08
Reutzel & Sumption, 1968	1,192	312	123	G	NGP	PHS	-.77	-.29
Edwards & Omtvedt, 1971	1,108	--	314	M	COP	ROS	.44	-.08
						ROD	.00	
						ROP	.22	
Hetzer & Miller, 1972	2,539	--	--	M	FS (D)	REAL	-.40	-.09
						ROP	-.31	
	2,236	--	--	M	FS (Y)	REAL	-.06	-.08
						ROP	-.22	
Revelle & Robison, 1973	180	--	--	G	PB+XB (D+Y)	--	--	-.02
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	-.03
	241	--	--	G	PB (D,H+Y)	--	--	.00
Young et al., 1978	2,095	--	292	G	NGP	PHS	.11	-.07
			Weighted average^b			(7)	-.20	(10) -.09

---

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates are in parenthesis.

TABLE XV

SUMMARY OF CORRELATION ESTIMATES BETWEEN POSTWEANING DAILY GAIN AND AGE AT A CONSTANT WEIGHT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Fahmy & Bernard, 1970	4,428	--	154	M	Y	ICl	-1.01	-.86
Edwards & Omtvedt, 1971	1,244	--	340	G	COP	ROS	-.98	-.91
						ROD	-1.01	
						ROP	-.98	
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	-.96
	241	--	--	G	PB (D,H+Y)	--	--	-.91
Siers, 1975a	114	--	10	M	Y	--	--	-.81
Siers, 1975b	66	--	--	M	Y	--	--	-.85
Gajic, 1976	8,590	--	--	G	MIX	--	-.80	--
Young et al., 1977[b]	531	--	--	G	XB+PB (D,H+Y)	PHS	-.96	-.89
		Weighted average[c]					(4) -.88	(5)-.87

[a] Method utilized to obtain genetic variances and covariances.

[b] Young et al. (1974) obtained earlier estimates from a portion of these data.

[c] Number of estimates utilized are in parenthesis.

that many of the same genes influence both traits. The phenotypic correlations tended to be lower ranging from -.81 to -.96 with a weighted average of -.87.

Postweaning Daily Gain With Live Backfat. The correlations between these two traits are of great interest because of the economic importance which is placed upon these traits. The estimated genetic correlation between postweaning daily gain and live backfat are quite varied (Table XVI) ranging from -.98 to .70, which tend to support the idea that possible breed differences may exist with respect to this genetic correlation (Hetzer and Miller, 1972). The weighted average of the genetic correlation estimates between postweaning daily gain and live backfat was -.15, which suggest little if any genetic relationships between these traits. The phenotypic correlation estimates between postweaning daily gain was generally low with the weighted average of estimates being -.02, which suggest no relationship between a pig's postweaning daily gain and live backfat.

Age at a Constant Weight With Live Backfat. Few researchers have investigated the relationship between growth rate measured as the age at a constant weight with live backfat. A weighted average of the genetic correlation estimates was .13 (Table XVII), which suggests there is little if any genetic association between these traits. This genetic correlation is similar to the desirable genetic correlation between postweaning daily gain and live backfat. The weighted average of the phenotypic correlations was -.13, which suggest little phenotypic relationship between these traits.

TABLE XVI

SUMMARY OF CORRELATION ESTIMATES BETWEEN POSTWEANING DAILY GAIN AND LIVE BACKFAT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Zoellner et al., 1963	330	--	--	M	PC	ROP	.70	.08
Stockhauser & Boylan, 1966	558	--	--	G	MG	PHS	-.54	--
	334	--	--	G	MG	ROP	-.19	--
	156	--	--	B	MG	ROP	.44	--
	209	--	--	BO	MG	PHS	-.53	--
	127	--	--	BO	MG	ROP	-.52	--
Stanislaw, 1966	2,157	416	98	M	PB	PHS	-.07	--
	1,230	241	88	M	XB	PHS	-.39	--
Roy et al., 1968	469	--	--	M	MG	--	--	.07
Reutzel & Sumption, 1968	1,192	--	123	G	NGP	PHS	-.98	-.34
Edwards & Omtvedt, 1971	1,108	--	314	G	COP	ROS	-.31	.03
						ROD	.65	
						ROP	.09	
Hetzer & Miller, 1972	2,539	--	--	M	GS (D)	REAL	-.06	.13
						ROP	.09	
	2,236	--	--	M	FS (Y)	REAL	.23	.04
						ROP	-.12	
Robison & Berruecos, 1973[b]	321	--	62	B	--	PHS	.37	--
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	.07
	241	--	--	G	PB (D,H+Y)	--	--	.16
Clarke et al., 1975	658	--	182	BO	L+LW	PHS	-.17	-.26
Young et al., 1978	2,095	--	292	G	NGP	PHS	-.32	-.07
		Weighted average[b]					(13) -.15	(10)-.02

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates utilized are in parenthesis.

TABLE XVII

SUMMARY OF CORRELATION ESTIMATES BETWEEN AGE AT A CONSTANT WEIGHT AND LIVE BACKFAT

Adapted From	N_o	N_1	N_s	Sex	Breed or Line	Method[a]	r_g	r_p
Omtvedt et al., 1967	228	--	--	M	LX (H)	--	--	-.18
Arganosa, 1968	554	--	--	M	PB+XB (Mix)	PHS	-.20	-.15
Edwards & Omtvedt, 1971	1,108	--	314	G	COP	ROS	.14	
						ROD	-.49	
						ROP	-.08	
Young et al., 1974	103	--	--	G	XB (D,H+Y)	--	--	-.07
	241	--	--	G	PB (D,H+Y)	--	--	-.07
Naveau et al., 1977	13,810	--	--	-	LW+L	--	.19	--
	725	--	--	-	H	--	-.32	--
			Weighted average[b]			(4)	.13	(4)-.13

---

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates utilized are in parenthesis.

Age at Puberty With Growth Characteristics. The only genetic correlation estimates found (Table XVIII) were those published by Young et al. (1978). Reutzel and Sumption (1968) attempted to estimate these correlations but were unable to attain estimates because of a negative sire variance obtained for age at puberty. The estimate available suggests a low genetic correlation with both birth weight and weaning weight (-.14 and -.04, respectively) and a moderate genetic correlation with postweaning daily gain (-.33). These genetic correlations suggest that selection for increased growth rate would tend to decrease the mean age at puberty. The genetic correlation of age at puberty with live backfat (.00) suggest little if any genetic association between these traits.

A weighted average of the phenotypic correlation estimates also revealed low phenotypic correlations between age at puberty and growth rate. The weighted average of the phenotypic correlation estimates was -.01 for birth weight, -.12 for weaning weight and -.17 with postweaning daily gain. Several authors have also found negative phenotypic correlations between age at puberty and 154-day weight (Robertson et al., 1951a; Robertson et al., 1951b; Self et al., 1955; Foote et al., 1956). A weighted average of the phenotypic correlation estimates between age at puberty and backfat was .07 suggesting very little genetic relationship between these traits. Generally these estimates suggest low favorable genetic and phenotypic relationship between growth and age at puberty with the highest correlation existing with postweaning daily gain.

Weight at Puberty With Growth Characteristics. Correlation estimates between weight at puberty and growth characteristics were obtained

TABLE XVIII

SUMMARY OF CORRELATION ESTIMATES BETWEEN AGE AT PUBERTY AND GROWTH CHARACTERISTICS IN GILTS

	Adapted From						
Item	Warnick et al., 1951	Reutzel & Sumption, 1968	Revelle & Robison, 1973	Cunningham et al., 1974[b]		Young et al., 1978	Weighted Average[c]
N_o	112	1,192	180	137	68	2,095	
N_1	--	312	--	--	--	--	
N_s	--	123	--	--	--	292	
Breed or line	CW+Y	NGP	PB+XB(D+Y)	NGP	NGP	NGP	
Method[a]	--	--	--	--	--	PHS	
Birth weight r_g	--	--	--	--	--	-.14	-.14
Birth weight r_p	--	--	-.21	--	--	.01	(2) -.01
Weaning weight r_g	--	--	--	--	--	-.04	-.04
Weaning weight r_p	-.54	-.10	-.23	-.25	-.32	-.09	(6) -.12
Postweaning daily gain r_g	--	--	--	--	--	-.33	-.33
Postweaning daily gain r_p	--	-.18	--	-.30	-.57	-.15	(4) -.17
Live backfat r_g	--	--	--	--	--	.00	.00
Live backfat r_p	--	.08	.22	-.11	.22	.06	(5) .07

[a] Method utilized to obtain genetic variances and covariances

[b] Estimates involve different animals.

[c] Number of estimates utilized are in parenthesis.

by Reutzel and Sumption (1968) and Young et al. (1978) which both utilized gilts from the Nebraska Gene Pool (Table XIX). However, a portion of the population utilized by Young et al. (1978) had been selected several generations for ovulation rate. The phenotypic and genetic correlation estimates between birth weight and weight at puberty were .04 and .27, respectively (Young et al., 1978); which indicates little if any association between these traits.

Estimates of the genetic correlations of weaning weight, postweaning daily gain and live backfat with weight at puberty by Reutzel and Sumption (1968) were consistently higher than those by Young et al. (1978). However, their estimates of the phenotypic correlations agreed quite well. Weighted averages of the genetic correlations of weaning weight and postweaning daily gain with weight at puberty were .26 and .49, respectively; indicating a moderate to high genetic relationship with growth rate. The weighted average of the phenotypic correlation estimates of weaning weight and postweaning daily gain with weight at puberty were .28 and .39, respectively; which are similar in magnitude to the genetic correlations for these traits.

The weighted average of the two genetic correlation estimates between backfat and weight at puberty was -.22, suggesting little genetic association between backfat and weight at puberty. The weighted average of the phenotypic correlation estimates was -.12, suggesting fatter gilts tend to be lighter at puberty; however, the magnitude of the correlation is quite low, thus suggesting very little if any relationship between these traits.

<u>Weight at Puberty With Age at Puberty</u>. Young et al. (1978) estimated the genetic correlation between age and weight at puberty to

TABLE XIX

SUMMARY OF CORRELATION ESTIMATES BETWEEN WEIGHT AT PUBERTY AND GROWTH CHARACTERISTICS IN GILTS

	Adapted From		
Item	Reutzel & Sumption, 1968	Young et al., 1978	Weighted Average[b]
N_o	1,192	2,095	
N_1	312	--	
N_s	123	292	
Breed or line	NGP	NGP	
Method[a]	PHS	PHS	
Birth weight r_g	--	.04	.04
Birth weight r_p	--	.27	.27
Weaning weight r_g	.70	.01	(2) .26
Weaning weight r_p	.29	.28	(2) .28
Postweaning daily gain r_g	1.01	.19	(2) .49
Postweaning daily gain r_p	.43	.36	(2) .39
Live backfat r_g	-.40	-.11	(2) -.22
Live backfat r_p	-.13	-.12	(2) -.12

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates utilized are in parenthesis.

be .90 (Table XX). Phenotypic correlations estimated between these traits were moderate and positive, ranging from .45 to .68, with a weighted average of .65. These estimates suggest a high degree of relationship between age and puberty and weight at puberty, both genetically and phenotypically.

Estimates From Other Species

An objective of this study was to estimate the heritability of age and weight at puberty and the correlations between pubertal and growth characteristics. Few estimates were available in swine, however, since estimates of traits are often similar across species, these were reviewed.

Age at Puberty. In chickens the heritability of the age at sexual maturity was estimated to be .47 (Singh et al., 1972). From bidirectional selection for age at puberty in rats a realized estimate of .17 was obtained (Warren and Bogart, 1952). A weighted average of two estimates in mice of .31 suggests age at puberty in mice to be low to moderately heritable (Crane et al., 1972; Eisen, 1973). In beef cattle, the weighted average of heritability estimates of age at puberty was .28 which also suggests a low to moderate heritability (Arije and Wiltbank, 1971; Smith et al., 1976).

Weight at Puberty. Estimates in mice suggest that weight at puberty is moderately heritable. The weighted average of the heritability estimates found in mice was .34 (Crane et al., 1972; Eisen, 1973). In beef cattle the estimates were 1.09 (Arije and Wiltbank, 1971) and .44 (Smith et al., 1976) which suggests that weight at puberty is

TABLE XX

SUMMARY OF CORRELATION ESTIMATES BETWEEN AGE AT PUBERTY AND WEIGHT AT PUBERTY IN GILTS

Adapted From	N_o	N_1	N_s	Breed or Line	Method[a]	r_g	r_p
Phillips & Zeller, 1943	63	--	--	PC	--	--	.51
Gossett & Sorenson, 1959	52	--	--	D,H,PC	--	--	.45
Obannon et al., 1966	72	--	--	XB	--	--	.46
Reutzel & Sumption, 1968	1,192	312	123	NGP	PHS	--	.62
Young et al., 1978	2,095	--	292	NGP	PHS	.90	.68
		Weighted average[b]				(1) .90	(5) .65

[a] Method utilized to obtain genetic variances and covariances.

[b] Number of estimates utilized are in parenthesis.

moderate to highly heritable in beef cattle.

Age at Puberty With Birth Weight. In cattle the estimated genetic correlation between birth weight and age at puberty was .07 (Smith et al., 1976). A weighted average of the phenotypic correlations between these two traits in cattle was .02 (Smith et al., 1976; Swiestra et al., 1977). These estimates suggest little if any association between these traits.

Age at Puberty With Weaning Weight. In mice, a genetic correlation of -.41 and a phenotypic correlation of -.27 was estimated (Eisen, 1973) suggesting a favorable relationship between growth rate and age at puberty. In beef cattle the genetic correlation between weaning weight and age at puberty was -.52 (Smith et al., 1976) also suggesting a favorable genetic relationship between these traits. However, a weighted of the phenotypic correlations was .01 indicating little if any phenotypic relationship (Smith et al., 1976; Swiestra et al., 1977).

Weight at Puberty With Birth Weight. In beef cattle the genetic correlation between weight at birth and at puberty was .41 (Smith et al., 1976). While the weighted average of the phenotypic correlations between these traits in beef cattle was .39 (Smith et al., 1976; Swiestra et al., 1977). These estimates indicate moderate genetic and phenotypic associations between birth weight and weight at puberty.

Weight at Puberty With Weaning Weight. In mice a genetic correlation of .54 was obtained between weaning weight and weight at puberty, while the phenotypic correlation was only .11 (Eisen, 1973). In beef cattle the genetic correlation between weaning weight and weight at puberty was .17 (Smith et al., 1976), while the weighted average of the phenotypic correlations between these traits was .39 (Smith et al., 1976; Swiestra et al., 1977). Thus estimates in these species suggest positive genetic and phenotypic associations between weight at weaning and weight at puberty.

Age at Puberty With Weight at Puberty. In beef cattle a weighted average of genetic correlation estimates was .48 suggesting a moderate to high genetic relationship between age and weight at puberty (Arije and Wiltbank, 1971; Smith et al., 1976). The phenotypic correlations were also moderate and positive. A weighted average of the phenotypic correlations found in the literature was .49 (Arije and Wiltbank, 1971; Smith et al., 1976; Swiestra et al., 1977). In mice, a weighted average of phenotypic correlation was .43 (Bakker et al., 1977; Crane et al., 1972). The estimates suggest a moderate positive association between the age and weight at which females reach puberty.

Management Factors Affecting Pubertal Characteristics

Few investigations concerning the effect of housing type upon the onset of puberty have been reported. Space restrictions appears to have no effect upon the proportion of gilts reaching puberty by eight months of age (Ford and Teague, 1978) or mean age at puberty (Jensen et al., 1970). However, the number of infantile tracts was significantly increased in tethered gilts (Jensen et al., 1970). Utilizing 405 gilts, Christenson (1979) found 65.8 percent of the gilts reared in a totally enclosed building had regular estrous cycles at 9 months of age compared to 83.9 percent of the gilts reared in dirt lots. This detrimental effect of total confinement upon the percent cycling agrees with Rampacek and Kraeling (1978). Upon comparing gilts which had not cycled however, these authors found no differences among the groups for the percentage of gilts exhibiting "silent estrus" (ovulating without exhibiting estrus). Thus indicating that the delay in puberty caused by total confinement was not due to gilts ovulating without exhibiting estrus, but rather an actual delay in ovarian function.

Fall born gilts reached puberty at similar ages irregardless of housing type but, spring born gilts were 14 days older at puberty when grown in an enclosed building as compared to non-confinement rearing, which indicates an interaction between housing type and season for age at puberty (Christenson, 1979).

Chester White gilts when compared to Poland Chinas were 11 days older at puberty when raised on pasture ($P < .01$) however, no differences between breeds were found when grown in dry lots indicating a possible genotype by environment interaction for age at puberty (Robertson et al., 1951a). Also, a genotype by environment interaction for age at puberty in beef cattle was found when comparing different breeds fed on pasture or in drylots (Stewart et al., 1976).

Gilts which were penned in groups of 30 exhibited estrus at a significantly younger age than gilts penned individually (207.4 vs. 222.2 days). However, no effect of group size was noted for weight at puberty or the incidence of "silent estrus" (Mavrogenis and Robison, 1976).

The presence of a boar with gilts has been shown to reduce the mean age at puberty (Thompson and Savage, 1978; Brooks and Cole, 1970). Mavrogenis and Robison (1976) found that spring born gilts penned adjacent to boars at an average age of 140 days expressed estrus 25 days earlier than gilts not exposed to boars. However, boar exposure in fall born gilts was of little advantage (4.3 days). These authors also observed a significant reduction in weight at puberty (8 kg) when gilts were exposed to boars.

The response to boar stimuli appears to be related more to the age than the weight of the gilt (Hughes and Cole, 1976); generally the younger the gilts are when exposed to a boar the lesser the degree of stimulation (as indicated by the number of days of exposure until estrus). However, when gilts are exposed to boars too early, the stimulus factor may be reduced such that the mean age at puberty may increase as compared to gilts exposed at a later age (Zimmerman et al., 1969). Components of boar stimuli appears to be related to visual and auditory factors associated with the male (Kinsey et al., 1976 and Zimmerman et al., 1974).

Other management techniques such as mixing gilts together or transporting gilts near the age when estrus would occur has been suggested to stimulate the onset of puberty (Zimmerman et al., 1974; Kinsey et al., 1976; Schiemann et al., 1976; Zimmerman et al., 1976).

Seasonal Influences Upon Pubertal Characteristics

Seasonal effects upon the onset of puberty has been studied in several domestic species. Pullets hatched in the winter, summer and fall matured at an earlier age than those hatched in the spring (Upp and Thompson, 1927). Spring born dairy heifers reached puberty 62 days younger (328 vs. 390 days) than fall born heifers (Menge et al., 1960). Beef heifers born earlier in the spring calving season were older and heavier at puberty than heifers born later in the calving season (Swiestra et al., 1977).

Correlations between season of birth and puberty have been used to indicate the degree of association between these traits. Gilts born in fall seasons reached puberty at an earlier age than spring born gilts as indicated from significant correlations between date of farrow and age at puberty (Robertson et al., 1951a). Gilts born later in the spring appear to reach puberty at an earlier age as indicated by a significant negative correlation between age at puberty and date of birth (Warnick et al., 1951; Robertson et al., 1951a). However a non significant correlation of .12 also was obtained in a second year of the study (Warnick et al., 1951). Self et al. (1955) found no significant relationship between the day of birth in the farrowing season and age at puberty, however they felt their data did not provide an adequate appraisal since the farrowing season was only about 30 days in length.

Ovaries of gilts slaughtered over various times of the year have been used to characterize the percentage of non-puberal gilts at market age and weight. Based on several thousand gilts, significantly more gilts exhibited evidence of ovarian activity (presence of corpus luteum or corpus albicans) during spring seasons than fall seasons, suggesting fall born gilts may reach puberty younger than spring born (Scanlon and Krishnamurphy, 1974; Wiggins et al., 1950). In order for these results to reflect seasonal differences upon age at puberty, I feel it must be assumed that there is no seasonal influences upon market age or weight.

Gilts born in September thru February were younger at first conception than gilts born in March thru August (245.9 and 277.9 days, respectively) (Sviben et al., 1969). Based upon 85 Duroc-Jersey gilts, January and February born gilts were found to be significantly older (229 vs. 206 days) and lighter (246 vs. 214 lbs) at puberty than April born gilts (Haines et al., 1958). However, Sorenson et al. (1961) found no seasonal effects upon age or weight at puberty.

Since light and temperature are components of season these factors will be discussed briefly. Gilts reared in darkness (1 hour of daylight) exhibited first estrus 11 days sooner and at similar mean weight at puberty when compared to gilts reared with normal summer daylength. However the variation in temperature was greater in gilts exposed to normal daylength (Dufour, 1968). In contrast, Hacker et al. (1974) and Ntunde et al. (1979) suggest that absence of light may delay the onset of puberty in gilts. Furthermore Ntunde et al. (1979) also found the absence of light would significantly increase the mean weight at puberty. Therefore, the effect of light upon the mean age at puberty in gilts is unclear.

Gilts exposed to high temperatures (33.3 to 35.5 C) continuously, have a retarded expression of estrus (Jensen et al., 1970). In beef heifers, age at puberty was delayed in Shorthorn and Brahman heifers when exposed to a constant 80 F, while Santa Gertrudes heifers were unaffected (Homer et al., 1959).

Certain factors may interact with seasonal influences on pubertal characteristics. Chester Whites born in the spring were 12.2 days younger than fall born. While, Poland China gilts born in the spring were 13.3 days older at puberty than fall born gilts (Zimmerman et al., 1960). Spring born gilts were younger at puberty than fall born gilts reared in dirt lots (201 vs 187 days, respectively). However if gilts were raised in an enclosed building no seasonal differences for mean age at puberty were noted (Christenson, 1979).

The effect of season has also been shown to be influenced by whether or not gilts were exposed to a teaser boar (Mavrogenis and Robison, 1976). If not exposed to boars, gilts born in the fall were 21.9 days younger than spring born gilts at puberty. On the other hand, if mature boars were placed in adjacent pens when gilts averaged 140 days of age no seasonal influences were apparent.

Genetic Differences for Pubertal Characteristics

Genetic differences between lines of breeds for pubertal characteristics in females have been observed in many species. Differences between various lines of mice exist for age and weight at puberty (Eisen, 1973; Crane et al., 1972; Montenier and Falconer, 1966; Synenki et al., 1972; Bakker et al., 1977). In addition, after three generations of bi-directional selection for age at vaginal opening in rats, Warren and Bogart (1952) found a significant difference between lines. In beef heifers, a significant difference between breeds was found for age at puberty but not for weight at puberty (Wiltbank et al., 1969). Breed of sire has been shown to influence both age and weight at puberty in beef heifers (Swiestra et al., 1977; Laster et al., 1976). Furthermore, Swiestra et al. (1977) and Laster et al. (1976) found breed of dam to significantly influence age at puberty. However Laster et al. (1976) also indicated breed of dam influenced weight at puberty, which disagrees with Swiestra et al. (1977) who indicated no significant influence due to breed of dam.

Breed differences have an important role upon the age and weight at which ewe lambs reach puberty (Hafez, 1953). Breed of sire and breed of dam both significantly affected the percentage of ewe lambs reaching puberty by November 10th and the mean weight at puberty of ewes expressing estrus by this date. However, only breed of sire significantly influenced the mean age at puberty of the ewe lambs which reached puberty by November 10th (Dickerson, 1975). Wiggins et al. (1970) in comparing fall born ewe lambs found no differences between lines or breeds for mean age at puberty.

Breed and line differences for pubertal characteristics in swine has been indicated. Poland China gilts were significantly heavier at puberty than Chester White gilts (224 vs 212 lbs). However no significant differences for age at puberty were observed (Robertson et al., 1951a). In a comparison of mating systems, utilizing six inbred lines (four Chester White, one Yorkshire and one line originating from a Chester White by Yorkshire cross) no significant effect due to line of dam was found upon age at puberty. In an additional segment of the study, purebred Yorkshire and Durocs were not significantly different for mean age at puberty, but were significantly older than Poland China gilts at puberty (Foote et al., 1956). Poland China gilts were also found to be younger at puberty than Yorkshire in a different study (Clark et al., 1970). An investigation of weight at puberty of Landrace, Lacombe, Hampshire, Duroc, Berkshire and Large Black gilts found neither breed of sire nor breed of dam to be an important factor (Fahmy et al., 1971). In a second phase of this experiment, the percentage of gilts exhibiting estrus by 300 days of age was significantly affected by breedtype (28 various crossbred types among 1013 crossbred gilts) (Holtman et al., 1975). The effect of breed type was also significant for age at puberty with crosses involving Yorkshires and Tamworths significantly younger at puberty than gilts of the other six breeds (Landrace, Lacombe, Hampshire, Duroc, Large Black and Berkshire) (Holtman et al., 1975). In a recent study the percentage of Landrace gilts exhibiting regular estrous cycles at 6 months of age was greater ($P < .01$) than for Hampshire, Large White, Yorkshire and Duroc gilts (69 vs 11, 4, 3, 0 percent, respectively)(Christenson and Young, 1978). At breeding age (8.5 months) estrous activity for the five breeds had reached a maximum and a greater percentage of Landrace, Large White, Hampshire, and Duroc gilts were exhibiting regular estrous cycles than were Yorkshires gilts (78, 86, 71, 71 vs 56 percent, respectively).

Chester White gilts reached puberty 12.2 days earlier than Poland China in fall born and 13.3 days later in spring born gilts indicating a significant interaction between breeds and season of the year (Zimmerman, 1960). A study utilizing spring born gilts under different management regimes (3 levels of protein, 2 levels of feeding and pasture vs drylot) found Chester White gilts to be significantly older at puberty than Poland China gilts only when gilts were fed on pasture and high protein groups. No differences were noted for weight at puberty except in the drylot comparisons, where Chester Whites were significantly heavier (40 lbs) than Poland China gilts (Robertson et al., 1951b).

A comparison among five inbred lines (3 inbred Chester Whites, 1 Yorkshire and 1 Yorkshire-Chester White line) found a significant line by year interaction indicating that the environments in different years affected lines differently (Warnick et al., 1951).

The effect of crossing lines or breeds has consistently resulted in a decreased mean age at puberty. Linecrossed gilts were 34.4 days younger at puberty than inbred lines (227 vs 193.4 days) (Foote et al., 1956). Two-breed cross gilts involving Duroc, Yorkshire, and Poland China breeds attained puberty an average of 27 days earlier than the respective purebreds. The largest advantage was when Yorkshires were mated with Durocs or Poland Chinas (37 and 32 days, respectively, as compared to the Poland China-Duroc advantage of 12 days (Foote et al., 1956). Comparisons utilizing Chester Whites and Poland Chinas Zimmerman et al., 1960) and Yorkshires and Poland Chinas (Clark, 1970) found crossbred gilts reached puberty 21.7 and 14 days earlier than the average of their purebred parents, respectively. However, only a 4.3 day advantage ($P < .05$) of crossbreds was observed in a study involving Yorkshires and Durocs. In addition, the Duroc-Yorkshire crossbreds were significantly heavier at puberty (247.5 vs 256.7 lbs) than purebreds (Short, 1963). Purebreds were also 30 days older at breeding as compared to crosses, suggesting crossbreds may have been younger at puberty (Squiers et al., 1952).

Age at puberty is negatively associated with growth rate (Robertson et al., 1951a; Warnick et al., 1951; Self et al., 1955; Foote et al., 1956; Haines et al., 1959; Zimmerman et al., 1960; Reutzel and Sumption, 1968; Synenki, 1972; Revelle and Robison, 1973; Young et al., 1978). However the faster growth rate exhibited by crossbreds could not account for the earlier age at puberty (Foote et al., 1956) and age at breeding (Squiers et al., 1952) exhibited by crossbreds.

The heterotic effect upon pubertal characteristics has also been observed in other species. Crossbred beef heifers were found to be significantly lighter and younger at puberty (Kaltenbach and Wiltbank, 1963; Wiltbank et al., 1966). Laster et al. (1976) also found crossbred heifers to be younger at puberty, however no differences between purebred and crossbreds were observed for weight at puberty. Whereas, Gregory et al. (1978) found crossbred heifers to be heavier and younger at puberty. In sheep, the heterosis advantage for the percent of ewe lambs reaching puberty was small, however the crossbred advantage appeared larger for specific crosses (Dickerson and Laster, 1975). In mice, line crosses were both lighter and younger at first estrus, however a comparison among two control lines indicated no heterosis effect upon weight at first estrus (Bakker et al., 1977).

Maternal effects in swine account for a significant portion of the variation for most traits, including those that are manifested late in life, such as 140 day weight, carcass backfat, ovulation rate and litter size farrowed. In addition, significant maternal differences have been found between several breeds for various traits (Robison, 1972). Gilts raised in litters larger than twelve were increasingly older at puberty than gilts from smaller litters (Revelle and Robison, 1972), which suggest possible post-natal maternal effects. However, no indications of an effect due to post-natal litter size was observed for age at puberty in gilts by Young et al. (1978). Therefore the effects of postnal litter size on age at puberty is still unclear. Indications of maternal genetic effects have been suggested for age at breeding and age at puberty as evidence by larger components of variance for dams than that of sires of families (Reddy et al., 1958 and Legault, 1973, respectively). Reutzel and Sumption (1968) also suggested possible maternal genetic effects, as indicated by a larger heritability estimate from regression of offspring on dam than from paternal half-sibs.

Investigations of maternal differences between breeds or lines for pubertal characteristics are limited. A comparison of Poland-Yorkshire reciprocals (Clark et al., 1970) and Yorkshire-Duroc reciprocals (Short, 1963) indicated no maternal differences between these breeds for age at puberty. However, a comparison of Yorkshire-Duroc reciprocals by Foote et al. (1956) found Duroc sired gilts to reach puberty significantly earlier than Yorkshire sired gilts (200.4 and 231.8 days) which suggest possible maternal differences between these breeds. In cattle significant differences between reciprocals crosses have been found for age at puberty and weight at puberty (Gregory et al., 1978). However, Wiltbank et al. (1969) found no significant differences among reciprocal crosses for either age or weight at puberty. In mice, reciprocal differences between two lines of mice have been found for age at first estrus, however no differences were noted in weight at first estrus (Bakker et al., 1977).

Summary Review of the Literature

The heritability estimates of individual pig preweaning growth traits are low and heritability estimates of postweaning growth are moderate to high. The heritability of backfat measured on the live pig is moderate to highly heritable. Age at puberty and weight at puberty heritability estimates suggest that these traits are moderately heritable.

Genetic and phentypic correlations among growth parameters generally indicate that animals heavier or faster growing at a particular age or period tend to be genetically and phenotypically heavier and faster growing at another given age or period.

Genetic and phenotypic correlations between growth rate and live backfat are generally low, except for a moderate negative genetic correlation between birth weight and backfat which suggests selection for decreased backfat would tend to increase birth weights.

The genetic and phenotypic correlations of age at puberty with growth rate were low to moderate; with the largest correlations with age at puberty existing between growth measured as postweaning daily gain. Both genetic and phenotypic correlations suggest that gilts superior in growth rate would tend to be younger at puberty.

The genetic and phenotypic correlations between weight at puberty and growth rate indicate that selection for growth rate would tend to increase the weight at which gilts attain puberty. The magnitude of the correlation increased with the age at which the measurement of growth is taken.

Live backfat thickness is lowly correlated genetically and phenotypically with both age and weight at puberty, suggesting little if any relationship between pubertal characteristics and live backfat.

The correlations between age at puberty and weight at puberty are moderate to high both genetically and phenotypically indicating that genes which influence weight at puberty may also influence age at puberty. These results suggest that some improvement could be made through selection for age at puberty; and that the age at which gilts reach puberty is favorably related to growth rate and uncorrelated with backfat.

Several factors influence age and weight at puberty and interactions between these factors exist. The effects of season is generally considered to be important, however, the results are not consistent. This may be partially due to the interaction with other factors such as breed, boar exposure and housing which have all been indicated as possible factors influencing seasonal effects. Exposing gilts to pubertal boars generally reduces the age and weight at puberty, however, this effect depends upon the age of the gilts. It has been suggested that exposure to boars too early may even have a delaying effect, as compared to exposure of gilts at a later age. Total confinement delays age at puberty, however, this may be related more to photoperiod and not to crowding.

Non-additive gene action plays an important role in influencing the age at which gilts reach puberty; as evidenced by that fact that crossbred gilts attain puberty at a younger age than their respective parents. In addition, genetic differences for pubertal characteristics have been noted in several species. Maternal genetic effects may also influence age at puberty.

There are few investigations concerning age at puberty and related characteristics in which breed differences have been evaluated in swine; consequently, this study may provide some information to help characterize possible differences and estimate the magnitude of heterosis.

CHAPTER III

MATERIAL AND METHODS

Experimental Design

Gilts produced in a four breed diallel mating system involving Duroc, Yorkshire, Spot and Landrace breeds were born during four consecutive (fall and spring) farrowing seasons beginning in the fall of 1976. Each season, boars were mated at random to at least one female of each breed group (Table XXI). A total of 819 gilts were available, however only 737 gilts had complete records (Table XXII). Age and weight at puberty (first estrus) were not obtained on all gilts since estrus detection was discontinued at the end of each season when the youngest gilt was at least 219 days of age.

In the spring of 1976, 25 gilts and four boars of Landrace and Spot breeds were purchased from breeders to establish herds in Stillwater. Landrace gilts, primarily American Landrace, were purchased from two breeders. Two Canadian and two Swedish Landrace sires were purchased from four different sources. Spot boars and gilts came from nine different breeders. A broad genetic base of the Duroc and Yorkshire breeds had been maintained for several years in Stillwater, primarily by purchasing boars from performance testing stations throughout the United States. In order to sample and maintain a broad genetic base in all four breeds, one or more boars of each breed were replaced each

TABLE XXI

NUMBER OF LITTERS OF EACH BREED TYPE PRODUCED EACH SEASON

Breed of Sire	Number of Sires	Breed of Dam			
		D	Y	L	S
Duroc (D)	4	6	4	4	4
Yorkshire (Y)	4	4	6	4	4
Landrace (L)	4	4	4	6	4
Spot (S)	4	4	4	4	6

TABLE XXII

NUMBER OF GILTS PRODUCED OF EACH BREED TYPE[a]

Breed of Sire	Breed of Dam			
	D	Y	L	S
Duroc (D)	62 (19)[b]	45 (4)	60 (6)	48 (0)
Yorkshire (Y)	52 (5)	42 (8)	53 (7)	47 (4)
Landrace (L)	48 (3)	44 (5)	59 (5)	45 (2)
Spot (S)	51 (0)	58 (7)	55 (4)	50 (3)

[a] Total number of gilts produced during Fall 1976, Spring 1977, Fall, 1977 and Spring, 1978 farrowing seasons.

[b] Number of gilts which were not observed in estrus (each season, the youngest gilts were at least 219 days of age when estrus detection was terminated).

season. Replacement gilts were selected within herds, based primarily upon an index of growth and backfat (Appendix, Table XXXVIII). The total number of sires and dams representing each breed group is presented in Table XXIII.

TABLE XXIII

THE NUMBER OF SIRES AND DAMS UTILIZED IN EACH BREED[a]

Breed	Sires	Dams
Duroc	9	31 (1)
Yorkshire	7	37 (2)
Landrace	8 (1)[b]	33
Spot	9	30

[a] Total number of sires and dam utilized to produce gilts in Fall 1976, Spring 1977, Fall 1977 and Spring 1978 farrowing seasons.

[b] The number of sires and dams which had offspring which were never detected in estrus.

Husbandry

Females were hand-mated during an eight week breeding season and fed 1.8 to 2.2 kg of a 15 percent protein corn or milo based diet in pastures. Spring litters were farrowed during March and April and fall litters were farrowed during September and October. Sows were farrowed in a central confinement building and were moved at one to two weeks after farrowing, to either pasture lots with three to four litters per lot or to an open-front confinement building with one litter per pen. Creep was made available at three weeks of age. At six weeks of age, litters were weaned and only the two heaviest males were not castrated. Then at approximately eight weeks of age, pigs were allotted to pens for gain test. All of the boars were fed in open-front confinement pens with 10 boars per pen. Gilts were randomly allotted within litter to be fed in either the confinement building (10 gilts per pen) or in pasture lots along with barrows. Confinement pens of gilts and boars were allotted such that all gilts had exposure (at least one adjacent pen) to boars of a similar age in all seasons except the fall of 1976 when only half of the pens were adjacent to boars. All gilts were self-fed at 14% protein corn or milo based diet during the test period.

Gilts were weighed weekly and removed from the gain test as they reached 90.7 kg. After being removed from gain test, gilts were probed for backfat, placed together in a pasture lot and limit fed 1.8 to 2.2 kg of a 15 percent protein diet. In pasture lots, estrus detection was started on a daily basis by placing "teaser" boars with gilts. The maximum number of gilts per lot was held to about 30 head and "teaser" boars were kept in the pens 15 to 30 minutes so as to provide uniform stimulation. The "teaser" boars utilized for estrus detection were generally older boars during the first couple of weeks of the teasing period. However, as littermate boars of the gilts (which were taken off the gain test at 100 kg) began to express libido, these were utilized for detection purposes. In all cases boars were replaced whenever a boar became uninterested in seeking out estrus females. Eight to 10 boars were kept per pasture lot, except for mature boars which were generally penned individually. The placement of the gilts and boar lots were such that a "lane" of about 25 feet was the distance that separated them. Therefore some degree of visual, auditory and olfactory stimulation was available continuously.

Data Collection

Individual pig birth weights were recorded within 12 hours of farrowing. Weaning weights were taken at approximately 42 days of age. The actual age off test was adjusted to 90.7 kg live weight basis. A list of correction factors utilized to adjust raw data is presented in Appendix Table XXXVIII (Olson et al., 1977). Backfat was measured approximately 4 cm from the midline (Duncan Model 5C Lean-Meter). An average of measurements taken near the first rib, last rib and last lumbar vertebrae was used in the analyses. Average daily gain was measured as the actual rate of gain utilizing unadjusted on test and off test dates and weight.

Since gilts were taken off test on a constant weight basis, some gilts may have initiated estrous cycles before estrus detection was begun. Therefore if a particular breed group started estrous cycles before reaching 90.7 kg, this group would be expected to be detected in estrus sooner after detection had begun. Thus to investigate differences in response, the number of days a gilt was exposed to a teaser boar was recorded. In addition the average daily gain was measured over this same period. Age and weight at puberty was measured as the actual age and weight when gilts attained first estrus, as indicated by a standing response to a teaser boar. Any gilts which displayed obvious signs of disease, lameness or died before reaching 219 days of age were omitted from the analysis.

Statistical Analysis

Heritability and Correlation Estimates

An objective of this study was to estimate the heritability for pubertal traits and genetic and phenotypic correlations of pubertal traits with growth characteristics. Variance and covariance components were obtained for the following individual pig traits: individual pig birth weight, 42-day weaning weight, postweaning daily gain, age at 90.7 kg, live backfat at 90.7 kg, age at first estrus and weight at first estrus.

Henderson's Method 3 (1953), often called the fitting constants method, was utilized to obtain unbiased estimates of the variance and covariance components. Henderson's Method 3 utilizes reductions due to fitting different models equated to their expected values under the full model. The models utilized in this analysis were:

$$Y = \underset{\sim}{X}\underset{\sim}{\beta} + \underset{\sim}{Z}_1\underset{\sim}{s} + \underset{\sim}{Z}_2\underset{\sim}{d} + \underset{\sim}{e} \qquad (1)$$

$$Y = \underset{\sim}{X}\underset{\sim}{\beta} + \underset{\sim}{Z}_1\underset{\sim}{s} + \underset{\sim}{e} \qquad (2)$$

$$Y = \underset{\sim}{X}\underset{\sim}{\beta} + \underset{\sim}{Z}_2\underset{\sim}{d} + \underset{\sim}{e}$$

where

$\underset{\sim}{Y}$ is a vector of observations;

$\underset{\sim}{X}$ is a known design matrix;

$\underset{\sim}{\beta}$ is a vector of breed of sire effects, breed of dam effects, season effects, year effects, management effects, breed of sire x breed of dam effects, breed of sire x year effects, breed of sire by management effects, breed of dam x year effects, breed of dam x management effects, year x season effects, management x season effects, breed of sire x breed of dam x season effects, breed of sire x breed of dam x management effects and breed of sire x breed of dam x year effects (Table XXIV) and a common constant u;

$\underset{\sim}{Z}_1$ is a known design matrix for sires;

$\underset{\sim}{s}$ is a vector of one-half the additive genetic effects of the sires having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\underset{\sim}{G}_1$;

$\underset{\sim}{Z}_2$ is a known design matrix of dams;

$\underset{\sim}{d}$ is a vector of one-half the additive genetic effects and any maternal effects of the dams having a multivariate distribution with mean zero and a nonsingular variance-covariance matrix $\underset{\sim}{G}_2$;

$\underset{\sim}{e}$ is a vector of residual effects including environmental and other genetic effects having a multivariate distribution with mean zero and variance-covariance matrix $\underset{\sim}{R}$; and $\underset{\sim}{s}$, $\underset{\sim}{d}$ and $\underset{\sim}{e}$ are mutually uncorrelated.

It was assumed that $\underset{\sim}{R} = \underset{\sim}{I}\ \sigma_e^2$, where I is an identity matrix with order equal to the number of records, which implies that the elements of $\underset{\sim}{e}$ are uncorrelated and that all records have common variance, σ_e^2. The variance-covariance matrix $\underset{\sim}{G}_1$ was assumed to be $\underset{\sim}{I}\ \sigma_s^2$, where $\underset{\sim}{I}$ is an identity matrix with order equal to the number of sires and σ_s^2 is equal to one-fourth the additive genetic variance. The variance-covariance matrix $\underset{\sim}{G}_2$ was assumed to be $\underset{\sim}{I}\ \sigma_d^2$, where $\underset{\sim}{I}$ is an identity matrix with order equal to the number of dams and σ_d^2 is equal to one-fourth the additive genetic variance plus any material variation.

TABLE XXIV

LIST OF FIXED FACTORS STUDIED

Management:

Confinement - gilts raised in confinement pens next to boars of a similar age.

Pasture - gilts raised on pasture mixed with barrows of a similar age.

Year:

Year 1 - Fall 1976 and Spring 1977 farrowing seasons

Year 2 - Fall 1977 and Spring 1978 farrowing seasons

Season:

Fall - gilts born during months of September and October

Spring - gilts born during months of March and April

Breed of Sire:	Breed of Dam:
Duroc	Duroc
Landrace	Landrace
Yorkshire	Yorkshire
Spot	Spot

Variances and covariances were estimated for sires by equating the differences in reductions from model (1) and (2) to their expectations, while those for dams were found utilizing the differences in reductions from Model (1) and (3).

For the trait concerning the percentage of gilts expressing estrus the variance components were obtained using the same method and models. However for this trait all gilts were utilized and therefore an additional sire and three more dams were involved. Since this trait involved discrete classification of the data the heritability estimates based upon half-sib relationships were transformed by multiplying the estimates obtained by,

$$\frac{p\ (1-p)}{Z^2}$$

where: Z is the ordinate of the normal distribution at the threshold point corresponding to a fraction p of the population having the character of interest.

This method was utilized by Lush et al. (1948) and is based upon the theory that there is an underlying normal distribution of genetic and environmental values. This method attempts to free the estimates from its relationship with p, the proportion with the observed characteristic. Van Vleck (1972) tested the theory of the transformation and suggested this method would only slightly overestimate the heritability on the normal scale if the estimate was based upon half-sibs and p was between .25 and .75.

Heritability estimates were obtained by:

$$\hat{h}_X^2 = \frac{4\ \hat{\sigma}_S^2}{\hat{\sigma}_S^2 + \hat{\sigma}_D^2 + \hat{\sigma}_e^2} \qquad \text{(sire);}$$

$$\hat{h}^2_x = \frac{4\ \hat{\sigma}^2_d}{\hat{\sigma}^2_s + \hat{\sigma}^2_d + \hat{\sigma}^2_e} \qquad \text{(dam);}$$

$$\hat{h}^2_x = \frac{2(\hat{\sigma}^2_d + \hat{\sigma}^2_s)}{\hat{\sigma}^2_s + \hat{\sigma}^2_d + \hat{\sigma}^2_e} \qquad \text{(sire + dam);}$$

where

$\hat{h}^2_x$ = heritability estimate of the trait x

$\hat{\sigma}^2_s$ = estimated sire component of variance for trait x

$\hat{\sigma}^2_d$ = estimated dam component of variance for trait x

$\hat{\sigma}^2_e$ = estimated environmental component of variance for trait x

Approximate standard deviations of the heritability estimates were obtained using an approximate formula (Swiger et al., 1964).

Genetic correlations were calculated from sire and sire + dam variance and covariance components. These genetic correlations were calculated by:

$$\hat{r}_g = \frac{\hat{\sigma}_{s_x s_y}}{\sqrt{\hat{\sigma}^2_{s_x} \cdot \hat{\sigma}_{s_y}}} \qquad \text{(sire);}$$

$$\hat{r}_g = \frac{\hat{\sigma}_{s_x s_y} + \hat{\sigma}_{d_x d_y}}{\sqrt{\hat{\sigma}^2_{s_x} \cdot \hat{\sigma}^2_{s_y} + \hat{\sigma}^2_{d_x} \cdot \hat{\sigma}^2_{d_y}}} \qquad \text{(sire + dam);}$$

$\hat{r}_g$ = estimated genetic correlation coefficient

$\hat{\sigma}_{s_x s_y}$ = estimated covariance of trait x and y for sires

$\hat{\sigma}_{d_x d_y}$ = estimated covariance of trait x and y for dams

$\hat{\sigma}_{s_x}$ and $\hat{\sigma}^2_{s_y}$ = estimated sire components of variance for trait x and y, respectively

$\hat{\sigma}^2_{d_x}$ and $\hat{\sigma}^2_{d_y}$ = estimated dam components of variance for trait x and y, respectively

Phenotypic correlation utilizing the sum of the variance and covariance components were calculated by:

$$\hat{r}_p = \frac{\hat{\sigma}_{d_x d_y} + \hat{\sigma}_{s_x s_y} + \hat{\sigma}_{e_x e_y}}{\sqrt{\left(\hat{\sigma}^2_{d_x} + \hat{\sigma}^2_{s_x} + \hat{\sigma}^2_{e_x}\right)\left(\hat{\sigma}^2_{d_y} + \hat{\sigma}^2_{s_y} + \hat{\sigma}^2_{e_y}\right)}} = \frac{\hat{\sigma}_{p_x p_y}}{\sqrt{\hat{\sigma}^2_{p_x} \cdot \hat{\sigma}^2_{p_y}}}$$

where

$\hat{r}_p$ = the estimated phenotypic correlation coefficient

$\hat{\sigma}_{e_x e_y}$ = estimated environmental covariance for trait x and y

$\hat{\sigma}^2_{e_x}$ and $\hat{\sigma}^2_{e_y}$ = estimated environmental variance for trait x and y, respectively

$\hat{\sigma}_{p_x p_y}$ = the sum of the sire, dam and environmental covariance components for trait x and y

$\hat{\sigma}^2_{p_x}$ and $\hat{\sigma}^2_{p_y}$ = the sum of the sire, dam and environmental variance components for trait x and y, respectively

Fixed Factors

The following linear model was assumed for age at puberty, weight at puberty and the percentage of gilts expressing puberty by 219 days of age:

$$\underset{\sim}{y} = \underset{\sim}{X}\underset{\sim}{\beta} + \underset{\sim}{Z}_1\underset{\sim}{s} + \underset{\sim}{Z}_2\underset{\sim}{d} + \underset{\sim}{e}$$

where,

$\underset{\sim}{y}$ is an observation vector;

$\underset{\sim}{X}$ is a known design matrix of fixed effects;

$\underset{\sim}{\beta}$ is an unknown vector of fixed effects (all levels of breed of sire, breed of dam, season, year, management, year x season, management x breed of sire, management x breed of dam, year x breed of sire, year x breed of dam, breed of sire x breed of dam x season, breed of sire x breed of dam x management, breed of sire x breed of dam x year and a common constant u);

$\underset{\sim}{Z}_1$ is a known design matrix for sires;

$\underset{\sim}{Z}_2$ is a known design matrix for dams;

$\underset{\sim}{s}$ is a random vector of one-half the additive genetic effect of the sires having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\underset{\sim}{G}_1$;

$\underset{\sim}{d}$ is a random vector of one-half the additive genetic effects plus any maternal effect of the dams having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\underset{\sim}{G}_2$;

$\underset{\sim}{e}$ is a random vector of residual effects including environmental and other genetic effects having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\underset{\sim}{R}$; and $\underset{\sim}{s}$, $\underset{\sim}{d}$, and $\underset{\sim}{e}$ are mutually uncorrelated.

For the class of linear models assumed, the solutions of the equations:

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}Z_1 & X'R^{-1}Z_2 \\ Z_1'R^{-1}X & Z_1'R^{-1}Z_1 + G_1^{-1} & Z_1'R^{-1}Z_2 \\ Z_2'R^{-1}X & Z_2'R^{-1}Z_1 & Z_2'R^{-1}Z_2 + G_2^{-1} \end{bmatrix} \begin{bmatrix} \hat{\beta} \\ s \\ d \end{bmatrix} \quad \begin{bmatrix} X'R^{-1}y \\ Z_1'R^{-1}y \\ Z_2R^{-1}y \end{bmatrix}$$

namely $\hat{\beta}$ are best linear unbiased estimates (BLUE) of functions of the fixed effects (Henderson et al., 1959; Henderson, 1973) and $\hat{s}$ and $\hat{d}$ are best linear unbiased predictors (BLUP) of the random effects (Henderson, 1963, 1973) fo sire and dam, respectively.

It was assumed that the variance-covariance matrix $R = I\sigma_e^2$ where I is an identity matrix with order equal to the number of records, which implies that the elements of e are uncorrelated and that all records have a common variance, σ_e^2. The variance-covariance matrix G_1 was assumed to be $I\sigma_s^2$, where I is an identity matrix with order equal to the number of sires and σ_s^2 is equal to one-fourth the additive genetic variance. The variance-covariance matrix G_2 was assumed to be $I\sigma_d^2$ where I is an identity matrix with order equal to the number of dams and σ_d^2 is equal to one-fourth the additive genetic variance plus any maternal variation.

These assumptions allow the equations to be simplified to:

$$\begin{bmatrix} X'X & X'Z_1 & X'Z_2 \\ Z_1'X & Z_1'Z_1 + I\dfrac{\sigma_e^2}{\sigma_s^2} & Z_1'Z_2 \\ Z_2'X & Z_2'Z_1 & Z_2'Z_2 + I\dfrac{\sigma_e^2}{\sigma_d^2} \end{bmatrix} \begin{bmatrix} \hat{\beta} \\ \hat{s} \\ d \end{bmatrix} = \begin{bmatrix} X'y \\ Z_1'y \\ Z_2'y \end{bmatrix}$$

where knowledge of $\dfrac{\sigma_e^2}{\sigma_d^2}$ and $\dfrac{\sigma_e^2}{\sigma_s^2}$ are required. Although these parameters are never really known, estimates of these ratios can be obtained from either variance components or heritability estimates reported in the literature. Few and in some cases no estimates were available for these traits in swine. Since both maternal and paternal half-sib heritability estimates were available from the analysis of these data, our estimates were used to obtain the proper ratios to be added to the diagonal of the sire and dam equations. Estimates of the ratios can be estimated by direct substition of the variance components or by utilizing the equations.

$$\frac{\hat{\sigma}^2_e}{\hat{\sigma}_s} = \frac{4 - \hat{h}^2_d - \hat{h}^2_s}{\hat{h}^2_s}$$

and

$$\frac{\hat{\sigma}^2_e}{\hat{\sigma}^2_d} = \frac{4 - \hat{h}^2_d - \hat{d}^2_s}{\hat{h}^2_d}$$

where:

$\hat{h}^2_s$ = paternal half-sib estimate of heritability

$\hat{h}^2_d$ = maternal half-sib estimate of heritability

In order to obtain a non-singular matrix, the last equation within each fixed class was set to zero. In obtaining a direct inverse the dam equations were absorbed to save computer time.

The effectiveness of adding one fixed effect to the model over and above having the remaining fixed effects in it was tested by differences in reductions due to fitting different models. Differences among means were tested utilizing Tukey's w-procedure. This procedure is also called the honestly significant difference (HSD) procedure (Steel and Torrie, 1960).

CHAPTER IV

RESULTS AND DISCUSSION

Heritabilities and Correlation Estimates

Heritabilities

Heritability estimates for birth weight (BW), weaning weight (WW), postweaning daily gain (ADG), adjusted live backfat (BF), age at 90.7 kg (AGE), age at puberty (AGEPUB) and weight at puberty (WTPUB) were calculated from sire and or dam components of variance (Table XXV).

The expectations of the covariances between maternal and paternal half-sibs when direct and maternal affects are considered are:

$$\text{COV(PHS)} = 1/4\ \sigma^2_{G_O}$$

$$\text{COV(MHS)} = 1/4\ \sigma^2_{G_O} + \sigma_{G_O G_M} + \sigma^2_{G_M} + \sigma^2_{D_M} + \sigma^2_{E_M}$$

where:

COV(PHS) = the covariance between paternal half-sibs.

COV(MHS) = the covariance between maternal half-sibs.

$\sigma^2_{G_O}$ = variance from average direct effect of genes.

$\sigma^2_{G_M}$ = variance in maternal influence from average gene effects.

$\sigma^2_{D_M}$ = variance in maternal influences due to dominance deviations.

TABLE XXV

COMPONENTS OF VARIANCE AND HERTABILITY ESTIMATES

	Components of Variance			Heritabilities		
Trait	Sire	Dam	Residual	Sire	Dam	[Sire + Dam]
BW	.0339	.0071	.0478	1.53 ± .26	.32 ± .12	.92 ± .15
WW	2.2328	1.4933	3.7438	1.2 ± .24	.80 ± .15	1.00 ± .14
ADG	.0012	.0010	.0049	.69 ± .18	.54 ± .14	.61 ± .11
AGE	42.0852	54.8175	181.5469	.60 ± .17	.79 ± .15	.70 ± .11
BF	.0150	.0163	.0876	.51 ± .15	.55 ± .14	.53 ± .10
AGEPUB	22.3010	47.55920	403.5002	.19 ± .09	.40 ± .13	.30 ± .08
WTPUB	8.6878	6.4880	83.1203	.35 ± .12	.26 ± .12	.31 ± .09

$\sigma^2_{E_M}$ = variance from environment that is alike for fall sibs but differs randomly between families from different dams.

$\sigma_{G_O G_M}$ = covariance between direct and maternal average gene effects (Willham, 1972).

Thus if maternal effects are important, the paternal half-sib estimate would be a better estimate of the variance due to direct gene effects. If maternal half-sib heritability estimates are significantly larger than paternal half-sib heritability estimates, it would suggest important maternal influences. However, in these data the estimated standard errors are rather large, thus differences between maternal and paternal half-sib heritability estimates could also be due to chance.

The paternal half-sib heritability estimate for age at puberty was .19. While this is generally not considered a high heritability, it does suggest that improvement can be made through selection. This estimate is lower than the weight average (.34) of estimates in swine found in the literature.

Estimates in other species also suggest that the heritability of age at puberty is low to moderate. From a bi-directional selection for age at puberty in rats, a realized heritability estimate of .17 was obtained (Warren and Bogart, 1952). A weighted average of two estimates in mice was .31 (Crane et al., 1972; Eisen, 1973) and in beef cattle a weighted average of heritability estimates was .28 (Arije and Wiltbank, 1971; Smith et al., 1976).

The maternal half-sib heritability estimate for age at puberty was considerably larger than the paternal half-sib estimate (.40 vs. .19).

A possible explanation for this, other than chance, would be the existence of maternal genetic effects and covariance between the direct genetic and maternal genetic effects. This suggestion of maternal genetic effects upon age at puberty would agree with Reutzel and Sumption (1968) who reported a paternal half-sib estimate and offspring on dam regression estimate of -.20 and .49, respectively; and Reddy et al. (1958) and Legault (1973) found variance components of the dams to be larger as compared to variance components of sires for age at puberty and age at breeding, respectively. Also 49.0 and 53.5 percent of full sisters have been reported to reach puberty within a period of five days (Dyck, 1971; Burger, 1952, respectively).

Since the maternal half-sib heritability estimate for weight at puberty (.26) was lower than the paternal half-sib estimate (.35) these data do not suggest any maternal genetic effects and thus the difference may be due to chance. However Reutzel and Sumption (1968) found estimates based on regression of offspring on dam considerably larger than those based upon paternal half-sib estimates, suggesting that weight at puberty may also be maternally influenced. The estimates from these data are in remarkable agreement with the weighted average (.32) of estimates in swine which were found in the literature. These estimates suggest that weight at puberty is moderately heritable.

In mice, a weighted average of two heritability estimates for weight at puberty was .34 (Crane et al., 1972; Eisen, 1973), which is similar to those estimated in swine. Estimates in beef cattle, however were larger with 1.09 and .44 reported by Arije and Wiltbank (1971); Smith et al. (1976), respectively.

The paternal half-sib heritability estimate of the percent of gilts detected in estrus (binomially distributed trait) was .54 (Table XXVI). After transformation to a normal scale, as suggested by Lush et al. (1948) the estimate was 1.10. This transformation only slightly overestimates the heritability on a normal scale provided the proportion of the population having the characteristic of interest in between .25 and .75 (Van Vleck, 1972).

TABLE XXVI

COMPONENTS OF VARIANCE AND HERITABILITY ESTIMATES FOR THE PERCENTAGE OF GILTS DETECTED IN ESTRUS BY 219 DAYS OF AGE

Components of Variance			Heritability			
Sire	Dam	Residual	Sire	Sire[a]	½[Sire + Dam]	½[Sire + Dam][a]
.0219	.0169	.1237	.54	1.10	.48	.97

[a] Adjusted to a normal basis according to Lush et al. (1948).

The Proportion of gilts exhibiting estrus prior to 219 days of age was .80; consequently, the heritability estimate of 1.10 might be biased upward. These data thus suggest that the heritability of the percentage of gilts detected in estrus by 219 days of age is high. No other estimate was found in the literature for comparison. However, Milagres et al. (1979) also found a relatively high heritability estimate (.64) for cow fertility; measured as the ability of heifers to produce at least one calf after being exposed for two breeding seasons.

Correlations

The genetic and phenotypic correlation estimates between all traits (Table XXVII) were calculated from the components of variance (Table XXV) and covariance (Appendix Table XXXIX).

The genetic correlations of age at puberty with birth weight, weaning weight, postweaning daily gain and age at 90.7 kg followed a general pattern of increase in magnitude (r_g = -.07, -.25, -.38 and .56, respectively). Thus these data indicate that gilts genetically superior for growth rate tend to be genetically younger at puberty.

These estimates are similar to those of Young et al. (1978) who also indicated a favorable genetic relationship of birth weight, weaning weight and postweaning daily gain (r_g = -.14, -.04 and -.33, respectively) with age at puberty. However, these results disagree with between line correlation estimates which suggest that lines having the heaviest average 154 day weight tended to be the slowest to reach puberty, suggesting that the same genes that act to bring about rapid growth tend to retard sexual maturation (Warnick et al., 1951; Phillips and Zeller, 1943). However, unless lines have been selected under similar environments and for similar objectives these correlations may not reflect accurate inferences regarding genetic correlations.

Although Reutzel and Sumption (1968) did not obtain a genetic correlation estimate, due to a negative estimate of the sire variance for age at puberty, they obtained a positive genetic covariance between postweaning daily gain and age at puberty, thus possibly suggesting that genes which increase growth rate would tend to increase the age

TABLE XXVII

GENETIC AND PHENOTYPIC CORRELATIONS AMONG PUBERTAL AND GROWTH CHARACTERISTICS[a]

Trait	AGEPUB	WTPUB	BW	WW	ADG	AGE	BF
AGEPUB		.54	-.09	-.19	-.34	.38	.01
WTPUB	-.03[b]						
	.17[c]		.24	.29	.34	-.38	.01
BW	-.07	.46					
	-.14	.50		.51	.29	-.42	-.03
WW	-.25	.69	.54				
	-.32	.65	.61		.31	-.58	-.04
ADG	-.38	.81	.50	.49			
	-.47	.63	.48	.47		-.83	.05
AGE	.56	-.70	-.61	-.88	-.73		
	.57	-.62	-.63	-.84	-.74		.01
BF	.27	.28	.19	-.01	.16	.00	
	.23	.43	.45	.01	-.03	.13	

[a] Phenotypic correlations above the diagonal and genetic correlations below the diagram.

[b] Based on sire variances.

[c] Based upon sire and dam variances.

at which gilts reach puberty.

Genetic correlations between age at puberty and weaning weight in mice and cattle suggest a moderate favorable relationship between growth and the onset of puberty (Eisen, 1973; Smith et al., 1976).

The phenotypic correlations of age at puberty with birth weight, weaning weight, postweaning daily gain and age at 90.7 kg (r_p = -.09, -.19, -.34 and .38, respectively) generally showed an increase with the age at which growth was measured. These phenotypic correlation estimates with birth weight and weaning weight were in agreement with the weighted averages found in the literature (r_p = -.01 and -.12, respectively), however the phenotypic correlation between postweaning daily gain and age at puberty was higher than the weighted average of estimates (-.17) found in the literature. However, since gilts in the investigation which grew faster, were exposed to boars at a younger age, they were given the opportunity to be detected in estrus at a younger age. Therefore, this might be a possible explanation for the higher correlation observed in these data. However, this estimate is similar to many of those reported between 154 day weight and age at puberty (Warnick et al., 1951; Self et al., 1955; Robertson et al., 1951a; Robertson et al., 1951b; Foote et al., 1956). Thus these estimates suggest that faster growing gilts would tend to exhibit first estrus at a younger age.

The genetic correlation between age at puberty and backfat was low and positive (.27) suggesting that selection for reduced backfat would cause a slight reduction in age at puberty. This is higher than the genetic correlation estimate of .00 found by Young et al. (1978).

The phenotypic correlation between age at puberty and backfat was .01 which is in close agreement with the weighted average (.07) of estimates found in the literature. Thus there appears to be little if any phenotypic relationship between age at puberty and backfat.

The genetic correlations between weight at puberty and growth traits was consistently higher than those with age at puberty, suggesting weight at puberty is more closely related to growth than age at puberty. The genetic correlations of weight at puberty with birth weight, weaning weight, postweaning daily gain and age at 90.7 kg (r_g = .46, .69, .81 and -.70, respectively) followed the increase pattern, with a moderate genetic correlation between birth weight and relatively high correlations with weaning weight, postweaning daily gain and age at 90.7 kg.

The genetic correlation estimate between weight at puberty and birth weight is considerably higher than the .04 reported by Young et al. (1978). The estimate in beef cattle (.41) was similar to that observed in these data (Smith et al., 1976).

A comparison of the genetic correlation estimates of weight at puberty with weaning weight and postweaning daily gain found these estimates (r_g = .69 and .81, respectively) to be intermediate between those of Young et al. (1978) (r_g = .01 and .19, respectively) and Reutzel and Sumption (1968) (r_g = .70 and 1.01, respectively). However, estimates in both studies showed a similar trend as was seen in these data, with the strongest correlation existing with growth measured later in life.

Estimates in beef cattle and mice also suggested a positive genetic relationship between increased growth rate and weight at puberty (Smith et al., 1976; Eisen, 1973).

Estimates of the phenotypic correlations of weight at puberty with birth weight, weaning weight, postweaning daily gain and age at 90.7 kg (r_p = .24, .29, .34 and -.38, respectively) were low to moderate with the strongest correlation existing between growth rate measured later in life. These correlations agree quite well with the weighted average (r_p = .27, .28 and .39 with birth weight, weaning weight and postweaning daily gain, respectively) of estimates found in the literature (Reutzel and Sumption, 1968; Young et al., 1978).

The genetic correlation between weight at puberty and backfat was .28. This disagrees with a weighted average (-.22 of estimates found in the literature, which suggest a low negative relationship (Reutzel and Sumption, 1968; Young et al., 1978). However, the magnitude of all estimates are low to moderate.

The phenotypic correlation between weight at puberty and backfat was.01. Thus these data suggest that there is no phenotypic association between weight at puberty and backfat, however the weighted average of estimates found in the literature of -.12 suggest that the fatter gilts would tend to be slightly heavier at puberty (Reutzel and Sumption, 1968; Young et al., 1978).

The genetic correlation between age at puberty and weight at puberty was -.03 utilizing sire components, suggesting little or no genetic relationship between age and weight at puberty. This disagrees with Young et al. (1978) who estimated the correlation to be .90. This estimate also disagrees with a weighted average of .49 found in beef cattle (Arije and Wiltbank, 1971; Smith et al., 1976).

The phenotypic correlation between the age and weight at which gilts reached puberty was .54, which is in close agreement with the weighted average of .65, calculated from estimates found in the literature.

Fixed Effects

Environmental Factors

Year by season interaction explained a significant amount of variation in age and weight at puberty (Table XXVIII). In addition, management by season interaction and management accounted for a significant amount of variation in weight at puberty and age at puberty, respectively.

In year 1, spring born gilts were 6.4 days younger, while in year 2 spring born gilts were 15.3 days younger (Table XXIX). Spring born gilts have been found to be younger at puberty than fall born, when raised in non-confinement (Christenson, 1979). However, fall born gilts have been found to reach puberty at an earlier age than spring born (Robertson et al., 1951a; Warnick et al., 1951; Scanlon and Krishnamurphy, 1974; Wiggins et al., 1950). The conflicting findings suggests that other underlying factors may influence seasonal differences.

In this study, spring born gilts grew faster than fall born gilts (as indicated by the age when gilts were removed from gain test, Appendix, Table XXXX). Consequently, spring born gilts were exposed to boars at an earlier age and thus were given the opportunity to be detected in estrus at an earlier age. Hughes and Cole (1976) indicated that delaying the introduction of a boar after Landrace-Large White

TABLE XXVII

MEAN SQUARES AND TEST OF SIGNIFICANCE FOR FIXED EFFECTS FOR AGE AND WEIGHT AT PUBERTY

Source	d.f.	Trait	
		Age at Puberty	Weight at Puberty
Breed of Sire (BOS)	3	218.28	287.28*
Breed of Dam (BOD)	3	1,356.52*	69.78
Season (SEA)	1	14,950.40**	161.78
Management (MGT)	1	4,809.22*	764.03**
Year (YR)	1	58.20	1,443.86**
YR x SEA	1	2,616.15*	1,290.72**
MGT x SEA	1	266.51	473.72*
MGT x BOS	3	850.56	105.32
MGT x BOD	3	342.47	108.56
YR x BOS	3	270.69	145.88
YR x BOD	3	512.22	136.53
BOS x BOD	9	1,773.27**	204.37*
BOS x BOD x MGT	9	556.47	75.40
BOS x BOD x YR	9	368.93	115.28
BOX x BOD x SEA	9	327.89	49.89
Error	677	395.47	84.05

*P<.05

**P<.01

TABLE XXIX

ADJUSTED YEAR-SEASON SUBCLASS MEANS FOR PUBERTAL CHARACTERISTICS PRESENTED AS DEVIATIONS FROM YEAR 2 SPRING SUBCLASS[c]

	Age at Puberty (Days)		Weight at Puberty (kg)	
	Fall	Spring	Fall	Spring
Year 1	11.7	5.3	3.1	6.8
Year 2	15.3	0[a]	2.6	0[b]

[a] Adjusted mean of 183.3 days.

[b] Adjusted mean of 90.6 kg.

[c] Refers to the season or year of birth.

gilts were 160 days of age was unnecessary since the reproductive mechanisms seemed sufficiently developed to respond to male stimulation. Therefore, since the mean age at which gilts were exposed to boars was 167 days these gilts would be expected to respond to boar exposure. Hence, seasonal differences may be confounded with the age at which gilts were exposed to boars. However, spring born gilts reached puberty earlier than fall born even when gilts were exposed to boars at a mean age of 4.8 months (Christenson, 1979). Twice as many of the gilts which were not detected in estrus in this study (each season, estrus detection was discontinued when the youngest gilts was 219 days old) occurred in spring born gilts as compared to fall born gilts (5.9 vs. 11.9 percent). Thus, results from this study are similar to those of Christenson (1979) in which spring born gilts attained puberty earlier, resulting in a lower mean age at puberty for spring born gilts, but a reduced percentage exhibited regular estrous cycles. Assuming that all gilts would eventually exhibit first estrus and be detected, the mean age at puberty may have been more similar for spring and fall born gilts. These results indicate spring born gilts may begin exhibiting first estrus earlier.

No difference was found between mean age at puberty of fall and spring born gilts when utilizing teaser boars (Marvogenis and Robison, 1976). In addition they observed a bimodal distribution for expression of puberty in spring born gilts as compared to a more normal distribution for fall born gilts. A difference in the distribution for age at puberty in spring and fall born gilts may explain why spring born gilts had a lower mean age at puberty but a higher percentage of gilts which were never detected in estrus.

The major difference between years other than environmental differences associated with the two years were herd managers and methods of estrus detection. In year 1, estrus was detected once daily as compared to twice daily during year 2. Since frequency of estrus detection is confounded with year no conclusion can be drawn regarding once or twice daily boar exposure. However, a higher degree of response was observed when gilts were allowed contact continuously for 16 days as compared to gilts penned adjacent to boars continuously but not allowed any physical contact with boars (Schieman et al., 1976). Thus increased stimulation by boars may result in an increased response. If this similar phenomenon occurred with once a day versus twice a day exposure in the experiment, this would suggest that twice a day exposure to boars would be beneficial with spring born gilts but not in fall born gilts. This type of response would be similar to that found by Marvogenis and Robison (1976) in which boar exposure decreased the mean age at puberty in spring born gilts but not in fall born gilts.

Spring born gilts were heavier at puberty than fall born gilts in year 1 (3.7 kg), but lighter at puberty in year 2 (2.6 kg; Table XXIX). These results may be due to the environmental differences between years; however I feel these results could be due to the magnitude of the seasonal effects for age at puberty in the two years.

In year 1 spring born gilts were only 6.4 days younger at puberty, which is similar to the magnitude of difference in age when gilts were exposed to boars (Appendix, Table XXXX). However, since spring born gilts grew faster and had a similar number of days of boar exposure until first estrus, they were heavier at puberty. On the other hand, in year 2 the advantage of spring born gilts for mean age at puberty of 15.4 days was considerably larger than the advantage for the mean age when gilts were exposed to boars (Appendix, Table XXXX). Thus, the mean days of boar exposure until first estrus was considerably less (Appendix, Table XXXX), suggesting a stimulatory effect in year 2. Whenever gilts at similar weights are stimulated by exogenous factors, reduction in age at puberty is associated with lower weights at puberty (Brooks and Cole, 1970; Hughes and Cole, 1976; Hughes and Cole, 1978 and Marvogenis and Robison, 1976). Therefore, the decrease in mean weight at puberty in year 2 might be expected.

Gilts reared in confinement penned next to boars of a similar age were 5.5 days younger at puberty than gilts reared on pasture with barrows of a similar age (Table XXX). This difference may be partially due to the fact that gilts in confinement grew faster and were therefore removed from gain test 5.7 days earlier (Appendix, Table XXXXI). Thus confinement gilts were exposed to boars at an earlier age and were given the opportunity to be detected in estrus at an earlier age.

TABLE XXX

ADJUSTED CONFINEMENT VS PASTURE MEANS FOR AGE AT PUBERTY PRESENTED AS A DEVIATION FROM CONFINEMENT GROUP

	Confinement	Pasture
Age at Puberty (Days)	0[a]	5.5

[a] Adjusted mean of 188.6 days.

Negative phenotypic correlations have been reported between growth rate and age at puberty in swine (Robertson et al. 1951; Self et al., 1955; Foote et al., 1956; Reutzel and Sumption, 1968; Revelle and Robison, 1973; Cunningham et al., 1974; Young et al., 1978) which might suggest that one reason confinement gilts were younger at puberty was due to the increased growth rate. As to whether gilts penned next to boars or mixed with barrows had only influence upon age at puberty is difficult to evaluate since these differences are confounded with the confinement regime. Information is lacking on the influence of rearing gilts next to boars or mixed with barrows, however it has generally been shown that when prepuberal gilts are exposed to mature boars the mean age at puberty will be reduced (Brooks and Cole, 1970; Hughes and Cole, 1976; Mavrogenis and Robison, 1976; Thompson and Savage, 1978). However, it has been shown that gilts exposed to boars at too early an age may actually delay the onset of puberty as compared to boar exposure at a later age (Zimmerman, 1969). Also little difference was found for age at puberty in gilts exposed to either boar or barrow exposure (Kinsey et al., 1976).

Movement or transportation of gilts to a new environment has also been suggested to trigger the onset of puberty (Zimmerman et al., 1974; Kinsey et al., 1976; Schiemann et al., 1976; Zimmerman et al., 1976). Since gilts in this study were placed on pasture after removal from gain test, confinement gilts were exposed to a more diverse environment than gilts reared on pasture; thus this might also contribute to the observed differences.

A significant management by season interaction observed for weight at puberty indicated weight at puberty was similar for fall born gilts irregardless of management, however spring born gilts reared in confinement were 3.9 kg lighter at puberty than pasture reared (Table XXXI). Generally spring born gilts grew faster than fall born gilts and confinement gilts grew faster than pasture gilts as indicated by the age when gilts were removed from gain test (Appendix, Table XXXXII), thus spring born gilts reared in confinement might be expected to be heavier at puberty, however this was not the case. Since the mean days of boar exposure was the same for these management-season subclasses they had an equal opportunity to gain weight (Appendix, Table XXXXII). Therefore these data suggest that gilts reared in confinement and being exposed boars in the fall (spring born) may be undergoing some type of environmental stress sufficient enough to decrease weight at puberty. This is supported by the lower average daily gain measured from the time gilts were removed from gain test until they reached first estrus (Appendix, Table Table XXXXII).

TABLE XXXI

ADJUSTED MANAGEMENT[b]-SEASON[c] SUBCLASS MEANS FOR WEIGHT AT PUBERTY PRESENTED AS DEVIATIONS FROM SPRING CONFINEMENT SUBCLASS

	Confinement	Pasture
Fall	1.1	1.6
Spring	0[a]	3.9

[a] Adjusted mean of 90.1 kg.

[b] Refers to the management in which gilts were reared.

[c] Refers to the season of birth.

Genetic Differences

The primary interest of this study was to evaluate purebred performance and the combining ability of Yorkshire, Landrace, Spot and Duroc breeds for pubertal characteristics. The mating system utilized allows for the estimation of the performance of individual breed combinations as well as the importance of additive and non-additive gene action.

The breed of sire by breed of dam interaction explained a significant amount of variation in both age and weight at puberty (Table XXVIII). The failure of the average of reciprocal crosses to be equal to the average of their respective purebred parents is defined as heterosis and is evidence of non-additive type gene action (Willham, 1970). Since reciprocal crosses produced would be expected to contain similar gene combinations; any differences between reciprocals would be expected to be due to maternal genetic differences or an interaction between the maternal genetic effect and the direct genetic effect.

To investigate any possible heterotic effect upon pubertal characteristics contrasts were made between the mean of the reciprocal crosses and the mean of their respective purebred parents. In addition, contrasts were made between reciprocal crosses as an indication of possible maternal differences among breeds.

A comparison among reciprocals for pubertal characteristics (Table XXXII) indicates no significant differences among any of the reciprocals for either weight at puberty or age at puberty ($P>.05$). However, the largest difference for age at puberty (12.6 days) between reciprocals was exhibited by the Landrace-Yorkshire reciprocals. Crosses involving Landrace dams tended to be the youngest at puberty, while crosses involving Yorkshire dams tended to be older (Table XXXXIV). Thus differences among the Landrace-Yorkshire reciprocals might be expected to be the largest.

TABLE XXXII

RECIPROCAL COMPARISONS OF CROSSBRED GILTS FOR PUBERTAL TRAITS

	Age at Puberty (Days)		Weight at Puberty (kg)	
Contrast[a]	Difference	$S_{\bar{d}}$[b]	Difference	$S_{\bar{d}}$[b]
DS - SD	4.7	5.5	1.9	2.7
DY - YD	3.1	5.9	3.7	2.8
DL - LD	4.0	5.8	3.8	2.8
SY - YS	-.2	5.6	-2.6	2.7
SL - LS	-2.2	5.8	2.7	2.8
YL - LY	-12.6	6.1	2.3	3.0

[a] D = Duroc, L = Landrace, S = Spot and Y = Yorkshire; breed of sire listed first.

[b] Standard error of the difference between means.

Investigations of reciprocal differences in swine for pubertal characteristics is limited. Foote et al. (1956) found a significant difference among Duroc-Yorkshire reciprocals for age at puberty. However, no significant difference for age at puberty was found between

Yorkshire-Poland China reciprocals and Yorkshire-Duroc reciprocals (Clark et al., 1970; Short, 1963, respectively).

Crossbred gilts were 7.9 days younger at puberty than purebred gilts (Table XXXIII). However, since estrus detection was begun when gilts attained a constant weight and was discontinued when the youngest gilts was 219 days of age certain biases may exist. Crossbred gilts grew faster and thus were exposed to boars at an earlier age (Appendix, Table XXXXV). Consequently crossbred gilts were given the opportunity to be detected in estrus at a younger age. In addition, of those gilts which were never detected in estrus at the end of each season, a much larger percent were purebreds (Table XXII, Chapter III). Thus assuming that many of these gilts would eventually exhibit estrus the heterotic advantage for age at puberty may be biased downwards.

Specific comparisons among breed crosses for age at puberty found a heterotic advantage among all crosses except the Duroc-Yorkshire and Landrace-Yorkshire (Table XXXIII). However, since purebred Durocs had a much lower percentage of gilts detected in estrus than any other breed group (Table XXII, Chapter III), contrasts involving Durocs may be expected to be biased downward. Thus even though only a 1.1 day advantage was found for the Duroc-Yorkshire crosses this difference may be biased downwards. A significant 4.3 day and 37.0 advantage for Duroc-Yorkshire crosses compared to purebreds was found for age at puberty (Short, 1963; Foote et al., 1956, respectively).

A comparison of the mean of the Yorkshire-Landrace crosses with their respective purebreds found little advantage for age at puberty (.7 days), however, the crossbreds were significantly heavier at puberty (4.5 kg). This is due to the fact that the Landrace sired cross was

TABLE XXXIII

INDIVIDUAL HETEROSIS OF CROSSBRED GILTS FOR PUBERTAL TRAITS

	Age at Puberty (Days)		Weight at Puberty (kg)	
Contrast[a]	Difference	$S_{\bar{d}}$[c]	Difference	$S_{\bar{d}}$
½[(DS + SD) - (DD + SS)]	-12.8**	3.4	1.6	1.5
½[(DY + YD) - (DD + YY)]	-1.1	4.7	3.9	2.1
½[(DL + LD) - (DD + LL)]	-14.3**	3.3	-2.2	1.5
½[(SY + YS) - (SS + YY)]	-11.5*	4.8	2.2	2.2
½[(SL + LS) - (SS + LL)]	-9.0**	3.3	.4	1.5
½[(YL + LY) - (YY + LL)]	-.7	3.6	4.5*	1.6
Crossbred-Purebred[b]	-7.9**	2.0	1.2	.9

[a] D = Duroc, L = Landrace, S = Spot and Y = Yorkshire; breed of sire listed first.

[b] Mean of crossbreds minus mean of purebreds.

[c] Standard error of the difference between means.

*P<.05; **P<.01.

older and heavier at puberty than either of their purebred parents (Appendix, Tables XXXXIII and XXXXIV). These data indicate little heterosis for age at puberty between these two breeds, however since the crossbreds continued to grow faster, they were significantly heavier at puberty ($P<.05$).

Significant heterosis occurred for age at puberty for all crosses involving Spot breeding (9.0, 11.5 and 12.8 day advantage was found for Spot crosses involving Landrace, Yorkshire, and Durocs, respectively). The largest heterosis advantage for age at puberty of 14.3 days was for the Duroc-Landrace cross, however due to the fact that many purebred Durocs were not detected in estrus this difference may be biased downward.

Few investigations have been made utilizing the same breed combinations which were utilized in this study, however generally the heterosis advantage observed by other investigations have been larger. Results from a comparison of crossbred and purebreds of Duroc, Yorkshire and Poland China found crossbreds reached puberty 27 days earlier than their respective purebreds with a 37 day advantage for the Duroc-Yorkshire cross (Foote et al., 1956). While comparisons utilizing Chester Whites and Poland Chinas (Zimmerman et al., 1960) and Yorkshire and Poland Chinas (Clark, 1970) found crossbred gilts reached puberty 21.7 and 14 days earlier than their respective purebred parents. However, only a 4.3 advantage of crossbreds was observed in a study involving Yorkshire and Durocs (Short, 1963).

The only comparison between purebreds and crossbreds for weight at puberty in swine found in literature reported Duroc-Yorkshire crossbreds to be 4.2 kg heavier ($P<.05$) at puberty than their respective purebreds (Short, 1963), which is similar to the advantage of 3.9 kg found for the Duroc-Yorkshire crosses in this study, however this difference was not significant (P>.05). Generally crossbreds in this study were only slightly heavier than the average of their purebred parents (1.2 kg), with the exception of the Duroc-Landrace which was 2.2 kg lighter and the Yorkshire-Landrace which was 4.5 kg heavier. Thus these results suggest little if any heterosis for weight at puberty. Results in beef cattle for the heterotic effect are generally inconsistent (Kaltenbach and Wiltbank, 1963; Laster et al., 1976; Gregory et al., 1978), and no general statement concerning the effects of crossbreeding can be made.

Since there were no significant differences among reciprocal cross gilts for age and weight at puberty, they were pooled and comparisons were made between all breed groups (Table XXXIV). Crossbred gilts tended to be younger at puberty than purebreds with the exception of Yorkshire-Landrace and Yorkshire-Duroc crosses which were both older at puberty than purebred Spot and Landrace gilts. The oldest gilts at puberty were the Duroc and Yorkshire purebreds, while the youngest breed groups were the Duroc-Landrace, Duroc-Spot and the Spot-Landrace crossbreds. The Spot-Yorkshires were intermediate. Significant differences were found only between the extremes. The Duroc-Landrace were 17.7, 13.8 and 13.2 days younger at puberty than the Duroc, Duroc-Yorkshire and Yorkshire-Landrace, respectively; the Duroc-Spot 16.3 and 12.4 days younger than Duroc and Duroc-Yorkshire, respectively and the Spot-Landrace 15.8 days younger than the purebred Duroc.

Part of these differences in age at puberty could be attributed to differences in growth rate, since faster growing gilts would be exposed

TABLE XXXIV

ADJUSTED BREED GROUP MEANS PRESENTED AS A DEVIATION FROM THE YORKSHIRE PUREBRED[1]

Breed Group[2]	Age at Puberty (Days)	Weight at Puberty (kg)
Duroc	2.3 ± 4.1[d]	6.6 ± 2.0[ab]
Spot	-4.6 ± 3.9[abcd]	2.2 ± 1.9[ab]
Yorkshire	0.0 ± 4.6[abcd]	0.0 ± 2.2[a]
Landrace	-4.4 ± 3.9[abcd]	-1.2 ± 1.9[a]
D.S[3]	-14.0 ± 2.8[ac]	2.8 ± 1.3[ab]
D.Y	-1.6 ± 2.9[bd]	7.3 ± 1.4[b]
D.L	-15.4 ± 2.8[a]	.6 ± 1.4[a]
S.Y	-9.8 ± 2.8[abcd]	3.2 ± 1.4[ab]
S.L	-13.5 ± 2.9[ab]	.9 ± 1.4[a]
Y.L	-2.2 ± 3.0[bcd]	3.9 ± 1.5[ab]

[1] Yorkshire purebred adjusted means = 198.9 (days) and 90.9 (kg).

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

[3] Reciprocals combined (D.S = DxS and SxD).

[a,b,c,] Means in the same column that do not share at least one superscript are significantly different ($P<.05$).

to boars at a younger age, and had the opportunity to be detected in estrus at a younger age. However, in these data there is no consistent trend for the fastest growing breed groups to be the youngest at puberty, with the exception that crossbred gilts tend to be faster growing and younger at puberty than purebred gilts. In addition, since gilts were removed from gain test at approximately 90.7 kg some of the gilts may have expressed first estrus prior to being removed from gain test. As an indication that certain breed groups may have had fewer gilts which expressed estrus prior to being removed from gain test and or a different response to boar exposure can be seen in Appendix Table XXXXV. Duroc, Yorkshire, Duroc-Yorkshire and Yorkshire-Landrace crosses responded slower than all other breed groups suggesting that these gilts may not have been as mature when exposed to boars as compared to all other breed groups. The mean number of days of boar exposure until first estrus is lower for gilts closer to puberty (Hughes and Cole, 1976).

A comparison of the breed groups for weight at puberty found Duroc-Yorkshire and Duroc gilts to be the heaviest at puberty. Significant differences were found between the breed groups with the Duroc-Yorkshires 8.5, 7.3, 6.7 and 6.4 kg heavier than Landrace, Yorkshire, Duroc-Landrace and Spot-Landrace, respectively.

Since all gilts were removed from gain test at similar weights, the weight at which gilts reached puberty is a function of the growth rate and the number of days the gilts were exposed to boars before they exhibited first estrus. However, gilts generally lost weight during the first two weeks after they were removed from gain test and feed intake was limited, therefore differences in growth rate would be expected to be minimal; hence, the differences in weight at puberty should be closely related to the mean number of days that a breed group was exposed to boars before the onset of first estrus. Duroc-Yorkshire, Duroc, Yorkshire-Landrace and Yorkshire were exposed to boars the longest before exhibiting first estrus (Appendix, Table XXXXV). Upon comparison, these breed groups were also the heaviest at puberty with the exception of the Yorkshire. However, the purebred Yorkshire had the slowest growth rate (age at which gilts were removed from gain test) (Appendix, Table XXXXV).

There are very few reports concerning difference among these breeds and their crosses. A comparison involving Yorkshire, Duroc, Landrace, Hampshire and Large White purebred gilts found Landrace to be the youngest at puberty with Duroc and Yorkshire the oldest (Christenson and Young, 1978). This agrees with the ranking of the mean ages of puberty of these purebreds in this investigation. In addition, Duroc and Yorkshire purebreds were the oldest at puberty when compared with all possible purebred and two-breed cross gilts involving Duroc, Yorkshire, and Poland Chinas (Foote et al., 1956). No comparisons were found utilizing Spots, however since Poland Chinas were utilized as a foundation breed during their development these breeds might be expected to be similar. Poland China gilts mature earlier than Yorkshires (Clark et al., 1970 and Foote et al., 1956) and Durocs (Foote et al., 1956). Thus if Spots and Poland Chinas are genetically similar with regard to pubertal characteristics the results in the literature would be in agreement, since purebred Spots were younger at puberty than either Duroc or Yorkshire purebred.

Previous investigations in the literature comparing similar two-bred crosses were limited to the two-bred crosses involving Duroc, Landrace and Yorkshire. Duroc-Yorkshire and Yorkshire-Landrace had similar ages at puberty (200 and 202 days, respectively) with the Landrace-Duroc being 16 and 18 days older at puberty than either the Duroc-Yorkshires and Yorkshire-Landrace, respectively (Holtman et al., 1975). Differences between Duroc-Yorkshire and Yorkshire-Landrace cross gilts inthis study were also small (.6 days), however the Duroc-Landrace was 13.2 and 13.8 days younger at puberty than the Duroc-Yorkshire and Yorkshire-Landrace, respectively. These results are in disagreement with regard to Yorkshire crosses. In this study Yorkshire crosses tended to be older at puberty, where as Holtman et al. (1975) found the Yorkshire crosses to be among the youngest breed groups at puberty.

Results comparing all possible two-breed crosses involving Poland China, Duroc and Yorkshire indicated Poland China crosses reached puberty earlier than the Duroc-Yorkshire cross (Foote et al., 1956). Results of this study indicate Spot-Duroc and Spot-Yorkshire crosses are younger at puberty than the Duroc-Yorkshire, thus these results could be considered in agreement with Foote et al. (1956) if Poland China and Spot breeds are genetically similar with regard to pubertal characteristics.

The only investigation found in the literature which compared similar breeds for weight at puberty indicated no differences between Yorkshire, Landrace, Lacombe, Hampshire, Duroc and Large Black purebreds (Fahmy et al., 1971). Although no significant differences between the purebreds were found in this study the ranking of the Duroc, Yorkshire and Landrace were similar. The Duroc gilts being the heaviest, Landrace the lightest and Yorkshires intermediate.

Evidence of differences among swine breeds for weight at puberty is limited, however breed differences have been found between Chester Whites and Poland Chinas (Robertson et al., 1951a and Robertson et al., 1951b). In addition breed differences have been noted in other species, with regard to weight at puberty (Swiestra et al., 1977; Laster et al., 1976; Hafez, 1953).

Percent Gilts Detected in Estrus

All gilts were removed from gain test prior to 219 days of age and thus were given the opportunity to be detected in estrus prior to reaching 219 days of age; hence the percentage of gilts detected in estrus should not be affected by the fact that estrus detection was begun earlier for certain groups.

The three-way interaction between breed of sire, breed of dam and season explained a significant amount of variation in percent gilts detected in estrous (Table XXXV). This interaction suggest that breed groups were affected differently by the season of birth, suggesting a genotype by environment interaction. A season by breed interaction in swine has been reported previously for age at puberty utilizing Poland China and Chester White gilts (Zimmerman et al., 1960).

Reciprocal crossbreed gilts were generally quite similar for the percentage of gilts detected in estrus and upon comparison, no significant differences were found, therefore reciprocals were combined and a comparison of breed groups was made within season.

The adjusted means are presented as a deviation from the spring born purebred Yorkshire subclass (Table XXXVI). The percentage of gilts detected in estrus was similar for all breeds for spring born gilts,

TABLE XXXV

MEAN SQUARES AND TEST OF SIGNIFICANCE FOR THE PERCENTAGE OF GILTS DETECTED IN ESTRUS BY 219 DAYS OF AGE

Source	d.f.	Mean Squares
Breed of Sire (BOS)	3	.0763
Breed of Dam (BOD)	3	.3674*
Season (SEA)	1	.0204
Management (MGT)	1	.0472
Year (YR)	1	.0133
YR x SEA	1	.0845
MGT x SEA	1	.2869
MGT x BOS	3	.0723
MGT x BOD	3	.0361
YR x BOS	3	.2880
YR x BOD	3	.0264
BOS x BOD	9	.2773*
BOS x BOD x MGT	9	.0869
BOS x BOD x YR	9	.0756
BOS x BOD x SEA	9	.2391*
Error	759	.1166

TABLE XXXVI

ADJUSTED MEANS AND STANDARD ERRORS FOR THE PERCENTAGE OF GILTS DETECTED IN ESTRUS PRESENTED AS A DEVIATION FROM THE SPRING BORN YORKSHIRE PUREBRED[1]

Breed Group	Spring Born	Fall Born	Difference [Spring-Fall]
Duroc	5.0 ± 11.9^{a}	-7.8 ± 12.3^{b}	12.8
Spot	27.7 ± 12.3^{a}	45.5 ± 13.7^{ac}	-17.8
Yorkshire	0.0 ± 14.4^{a}	6.9 ± 14.9^{ab}	- 6.9
Landrace	12.8 ± 11.7^{a}	14.4 ± 11.7^{ab}	- 1.7
D.S[2]	36.6 ± 9.4^{a}	27.5 ± 9.5^{ab}	9.1
D.Y	20.5 ± 9.6^{a}	2.8 ± 9.6^{bc}	17.7
D.L	25.5 ± 8.6^{a}	27.1 ± 8.8^{ab}	- 1.6
S.Y	16.2 ± 9.5^{a}	44.0 ± 9.6^{a}	-27.8*
S.L	29.7 ± 8.6^{a}	31.4 ± 8.8^{ab}	- 1.6
Y.L	9.5 ± 8.8^{a}	11.1 ± 9.2^{bc}	- 1.6

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[1] Adjusted mean = 64.2 percent.

[2] Reciprocals combined (D.S = DxS and SxDO.

[abc] Means in the same column that do not share at least one superscript are significantly different (P<.05).

[*] P<.05.

however there were significant differences ($P<.05$) among fall born gilts. Fifty-three percent more Spot gilts born in the fall exhibited estrus than Duroc purebreds, while Spot-Yorkshires exhibited 41.2 and 32.9 percent more gilts in estrus than the Duroc-Yorkshire and Yorkshire-Landrace, respectively.

The rankings of the breed for the percentage of gilts in estrus were generally similar, within season, with Duroc-Spot, Duroc-Landrace, Spot-Landrace and Spot purebreds exhibiting the highest percentage of gilts detected in estrus and Duroc, Yorkshire, Yorkshire-Landrace and Duroc-Yorkshire the lowest. However, significantly fewer Spot-Yorkshire gilts (27.8 percent) were detected in estrus when born in the spring than in the fall, thus their rank changed considerably between seasons.

Christenson and Young (1978) utilizing spring born gilts, found the percentage of gilts exhibiting estrus at 180 days of age the highest for Landrace followed by Yorkshire and Duroc, respectively. By 8.5 months of age the differences had become smaller, however Landrace gilts continued to exhibit a higher percentage of regular estrous cycles, 7 and 22 percent more than Yorkshires and Durocs, respectively. A comparison of the spring born purebreds gilts in this study was similar, with Landrace exhibiting 15.5 and 22.2 percent more gilts detected in estrus and Yorkshire and Duroc gilts, respectively.

A higher percentage of crossbreds were consistently detected in estrus as compared to the average of their respective parent breeds (Table XXXVII). Although the magnitude of heterosis varied considerably between seasons, heterosis did not significantly differ between seasons for any breed group. A comparison of crossbreds versus purebreds found

9.3 and 11.6 percent more of the crossbreds exhibited estrus in fall and spring born gilts, respectively, as compared to purebred gilts.

TABLE XXXVII

INDIVIDUAL HETEROSIS FOR THE PERCENTAGE OF GILTS DETECTED IN ESTRUS

Contrast[a]	Fall Born	Spring Born	Difference [Fall-Spring]
½[(DS + SD)-(DD + SS)]	8.6	20.2*	-11.5
½[(DY + YD)-(DD + YY)]	3.3	18.0*	-14.6
½[(DL + LD)-(DD + LL)]	23.8*	16.6*	7.2
½[(SY + YS)-(SS + YY)]	17.8*	2.3	15.4
½[(SL + LS)-(SS + LL)]	1.5	9.5	-8.0
½[(YL + LY)-(YY + LL)]	.5	3.1	-2.6
Crossbred-Purebred[b]	9.3	11.6*	-2.3

[a] D = Duroc, L = Landrace, S = Spot and Y = Yorkshire; breed of sire listed first.

[b] Mean of crossbreds minus mean of purebreds.

[c] $P<.05$.

CHAPTER V

SUMMARY

Data were collected from 819 purebred and crossbred gilts of Duroc, Yorkshire, Landrace and Spot breeding farrowed during four consecutive fall and spring farrowing seasons (Fall 1976 - Spring 1978). Gilts were produced by randomly mating boars of each breed to at least one female of each of the four breeds.

Litters were farrowed in confinement and weaned at six weeks of age. At eight weeks of age, gilts were randomly allotted within litter to be fed in confinement pens adjacent to boars or on pasture with barrows. As gilts reached approximately 90.7 kg they were removed from gain test, probed for backfat and placed in pasture lots. Estrus detection was then begun with the aid of a teaser boar. Teaser boars were placed with gilts for 15-30 minutes at least once daily. Upon exhibiting first estrus gilts were removed from lots and age and weight at puberty recorded. For this study puberty was defined as the first estrus which was indicated as a standing response to a teaser boar.

Heritability estimates for age at puberty were low to moderate (.19 and .40, based upon paternal half-sib and maternal half-sib estimates, respectively). Since the maternal half-sib estimate was considerably larger, important maternal genetic factors may affect age at puberty. The maternal and paternal half-sib estimates for weight at puberty were both moderate (.35 and .26, respectively) which suggest weight at puberty is moderately heritable. Therefore these traits could be modified through selection.

The genetic correlation between age at puberty and weight at puberty was low -.03 suggesting little if any genetic relationship between these two pubertal characteristics. The phenotypic correlation estimate between these traits was moderate and postive (.54) suggesting gilts older at puberty also tend to be heavier at puberty.

Both the phenotypic and the genetic correlations between age at puberty and measurements of growth were favorable, with the largest correlations existing with adjusted age to reach a constant weight (.38 and .56, for the phenotypic and genetic correlations, respectively). The genetic and phenotypic correlations between age at puberty and backfat were .27 and .01, respectively. The genetic correlations between weight at puberty and measurements of growth rate were moderate to high suggesting that the genes which affect increased growth rate may tend to increase the weight at which gilts reach puberty. The largest genetic correlation (.81) was between weight at puberty and postweaning average daily gain. The phenotypic correlation between weight at puberty and growth rate were similar in direction as the genetic correlations, however they were lower in magnitude with the largest phenotypic correlation between weight at puberty and adjusted age at 90.7 kg. The genetic correlation between weight at puberty and backfat was .28 and the phenotypic correlation was .01.

The heritability of the binomially distributed trait, percentage of gilts detected in estrus before 219 days of age, was .54. This heritability estimate was increased to 1.10 when the estimate was transformed to a normal basis. However since a large proportion of gilts had been detected in estrus by 219 days of age this transformation is biased upwards.

A season of birth by year interaction existed for age at puberty. In year 1, spring born gilts were 6.4 days younger, while in year 2 spring born gilts were 15.3 days younger. Thus suggesting spring born gilts reach puberty at a younger age. Part of these differences may be due to the fact that spring born gilts grew faster than fall born gilts and thus estrus detection and boar exposure was begun at an earlier age for spring born gilts.

There was a significant year by season interaction for age at puberty. Spring born gilts were 3.7 kg heavier in year 1 and 2.6 kg lighter in year 2. Spring born gilts grew faster and thus might be expected to beheavier at puberty. The reduction in weight at puberty in year 2 may be related to the fact that spring born gilts were considerably younger at puberty than fall born gilts in year 2.

Gilts reared in confinement next to boars of a similar age were significantly younger than those reared in pasture lots with litter mate barrows (5.5 days). However part of this difference found may be due to the fact that gilts reared in the open-fronted confinement pens were removed from test at a younger age than pasture fed gilts and thus exposed to boars for estrus detection at an earlier age.

There was a significant management by season interaction for weight at puberty. Management did not influence weight at puberty in fall born gilts, however spring born confinement gilts were 3.9 kg lighter than pasture gilts. Since all gilts were placed in pasture lots after removal from gain test, the change in environment would tend to be more diverse for the gilts reared in confinement. Thus these data suggest that confinement gilts being removed from gain test in the fall (spring born) were stressed, sufficiently to cause a reduction in weight at puberty.

The interaction between breed of sire and breed of dam explained a significant amount of variation for both age and weight at puberty. A comparison among reciprocal crosses indicated no significant differences, suggesting no maternal genetic differences between these breeds. However a large difference was found between Landrace-Yorkshire reciprocals for age at puberty, with gilts from Yorkshire dams 12.6 days older than gilts from Landrace dams.

Significant heterosis estimates for age at puberty exist for all Spot crosses (12.8, 11.5 and 9.0 days for crosses involving Duroc, Yorkshire and Landrace, respectively). There is little heterotic advantage for Duroc-Yorkshire and Yorkshire-Landrace crosses (1.7 and .7 days, respectively). The largest heterotic effect is for the Duroc-Landrace (15.4 days).

Generally crossbreds were slightly heavier at puberty, however significant heterosis occurred in the Landrace-Yorkshire cross (4.5 kg). This was primarily due to the fact that the Landrace sired cross was heavier and older at puberty than either of their respective purebred parents.

Reciprocal crosses were combined and a comparison was made between all breed types since no reciprocal differences were found for either age or weight at puberty. Crossbreds were younger at puberty than the purebreds, with the exception of the Duroc-Yorkshires and Landrace-Yorkshire which were older than both the Landrace and Spot at puberty. The oldest breed groups at puberty were the Duroc and Yorkshire, while the youngest were the Duroc-Landrace and Duroc-Spot. Significant differences between breed groups were only found among extremes. Few differences were found among breed groups for weight at puberty, however, the Duroc-Yorkshire was significantly heavier than the Landrace, Yorkshire, Spot-Landrace and Duroc-Landrace.

The breed of sire by breed of dam by season influenced the percent of gilts cycling by 219 days of age indicating a genetype by environment interaction. No significant differences existed among reciprocals within season, therefore reciprocals were combined. A comparison among breed groups within season indicates significant differences between breed groups born in the fall, but not in spring born gilts. The ranking of the breeds was generally the same within season, with Duroc-Spot, Spot-Landrace, Duroc-Landrace and Spots having a higher percentage of gilts exhibiting estrus and Yorkshire, Duroc and Yorkshire-Landrace the lowest. The only exception was the Spot-Yorkshire which was significantly affected by season of birth, with a higher percentage exhibited in fall than spring born gilts.

A higher percentage of crossbred gilts exhibited estrus, however the magnitude of heterosis did not differ significantly between seasons for any breed groups. Crossbred gilts exhibited 9.3 and 11.6 percent more gilts in estrus than purebreds, by 219 days of age, in fall and spring born gilts, respectively.

These data indicate that breed of sire and breed of dam account for a significant amount of variation in the age and weight at which gilts attain puberty. In addition, these data suggest that specific combining is also important and thus generalization should not be made across breed groups when referring to their two-breed crosses.

Based upon the heritability and heterosis estimates it appears that both additive and non-additive gene effects are important factors affecting the age when gilts reach puberty. Heritability estimates also suggest that age at puberty could be reduced through selection. However, these data also indicate that continued selection pressure for growth rate would result in a decrease in age at puberty.

LITERATURE CITED

Arganosa, V. G. 1968. The influence of genetic factors on pork quality. Phd. thesis, Oklahoma State University, Stillwater.

Arganosa, V. G., F. F. Penalba, P. F. Alcantara. 1974/75. Genetic and phenotypic parameters of traits associated with sow productivity. Phillippine Agriculturists 58 (7/8) 299-307. (Anim. Breed. Abstr. 45:241).

Arije, G. F. and J. N. Wiltbank. 1971. Age and weight at puberty in Hereford heifers. J. Anim. Sci. 33:401.

Baker, M. L., L. N. Hazel and C. F. Reinmiller. 1943. The relative importance of heredity and environment in the growth of pigs at different ages. J. Anim. Sci. 2:3.

Bakker, H., J. Nagai and E. J. Eisen. 1977. Genetic differences in age and weight at sexual maturation in female mice selected for rapid growth rate. J. Anim. Sci. 44:203.

Berruecos, J. M., E. U. Dillard and O. W. Robison. 1970. Selection for low backfat thickness in swine. J. Anim. Sci. 30:844.

Biedermann, G., J. Kripple, O. A. Summer and F. Tschirch. 1971. Investigations on heritability of important production characters in the German Landrace. Bayer. Landw. Fb., 48:781-836. (Anim. Breed. Abstr. 40:329).

Biswas, D. K., P. V. Hurt, A. B. Chapman, N. L. First and H. L. Self. 1966. Feed efficiency and carcass desirability in swine. J. Anim. Sci. 25:342.

Blunn, C. T. and M. L. Baker. 1947. The relation between average daily gain and some carcass measurements. J. Anim. Sci. 6:424.

Blunn, C. T., E. J. Warnick and J. R. Wiley. 1954. Interrelationships of swine weights at three ages. J. Anim. Sci. 13:383.

Broderick, T. 1960. Genetic aspects of pedigree Irish Large White pigs. J. Dep. Agric. 56:14-55. (Anim. Breed. Abstr. 29:77).

Brooks, P. H. and D. J. Cole. 1970. The effect of the presence of a boar on the attainment of puberty in gilts. J. Reprod. Fert. 23:435.

Burger, J. F. 1952. Sex physiology of pigs. Onderstepoort J. Vet. Res., Suppl. 2:218.

Bus'Ko, A. 1973. Heritability of various traits in pigs selected for fattening performance and carcass quality. Svinovodstvo No. 11, 34-35. (Anim. Breed. Abstr. 43:17).

Bywaters, J. H. 1937. The heritability and environmental portions of variance in weaning weight of Poland China swine. Genetics 22:457.

Christenson, R. K. 1979. Influence of confinement and season on age at first estrus and estrous activity of gilts. Proc. Amer. Soc. Anim. Sci. Midwestern Section Meeting, June 14-15, St. Louis, Mo. (Abstr.).

Christenson, R. K. and L. D. Young. 1978. Age at first estrus in five breeds of gilts reared in confinement. 70th Annual Meet. of ASAS July 9-13, Michigan State Univ., East Lansing Abstr. 341, p. 351.

Clark, J. R., N. L. First, A. B. Chapman and L. E. Casida. 1970. Age at puberty in 4 genetic groups of swine. J. Anim. Sci. 31:1032. (Abstr.).

Clarke, J. N., J. L. Adam and K. Hargreaves. 1975. Estimates of genetic variation and covariation from New Zealand national boar performance testing data. Proc. New Zealand Soc. Anim. Prod. 35, 151. (Anim. Breed. Abstr. 44:192).

Cockerham, C. C. 1952. Genetic covariation among characteristics of swine. J. Anim. Sci. 11:738. (Abstr.).

Comstock, R. E., L. M. Winters, P. S. Jordan and O. M. Kiser. 1942. Measure of growth rate for use in swine selection. J. Agr. Res. 65:379.

Cox, D. F. 1959. Components of genetic variance in swine as estimated from the regression of phenotypic variance on relationship within pens. J. Anim. Sci. 18:1464. (Abstr.).

Cox. D. F. 1964. Heritability of backfat thickness measured on the live pig at a constant age. J. Anim. Sci. 23:447.

Craig, J. V., H. W. Horton and S. W. Terrill. 1956. A genetic study of weight at five ages in Hampshire swine. J. Anim. Sci. 15:242.

Crane, D. S. D., A. C. Warnick, M. Koger and R. E. Rodriquez. 1972. Relation of age and weight at puberty to reproductive performance in two lines of mice selected for 42-day weight. J. Anim. Sci. 34:596.

Cunningham, P. J., C. H. Naber, D. R. Zimmerman and E. R. Peo Jr. 1974. Influence of nutritional regime on age at puberty in gilts. J. Anim. Sci. 39:63.

Dickerson, G. E. and J. C. Grimes. 1947. Effectiveness of selection for efficiency of gain in Duroc swine. J. Anim. Sci. 6:265.

Dickerson, G. E. and D. B. Laster. 1975. Breed, heterosis and environmental influences on growth and puberty in ewe lambs. J. Anim. Sci. 41:1.

Dickerson, G. E. 1947. Composition of hog carcasses as influenced by heritable differences in rate and economy of gain. Iowa Agr. Sta. Res. Bul. 354.

Dillard, E. U., O. W. Robison and J. E. Lagates. 1962. Selection for low backfat/weight ratio in swine. J. Anim. Sci. 21:971. (Abstr.).

Dufour, J. and C. Bernard. 1968. Effect of light on the development of market pigs and breeding gilts. Can. J. Anim. Sci. 48:425.

Dyck, G. W. 1971. Puberty, postweaning estrus and estrous cycle length in Yorkshire and Lacombe swine. Can. J. Anim. Sci. 51:135.

Edwards, R. L. and I. T. Omtvedt. 1971. Genetic analysis of a swine control population. II. Estimation of population parameters. J. Anim. Sci. 32:185.

Eisen, E. G. 1973. Genetic and phenotypic factors influencing sexual maturation of female mice. J. Anim. Sci. 37:1104.

El-Issawi, H. F. and W. E. Rempel. 1961. Heritability of growth rate in inbred swine based upon a crossbred foundation. J. Anim. Sci. 20:593.

Fahmy, M. H. and C. Bernard. 1970. Genotypic and phenotypic study of pre- and post-weaning weights and gains in swine. Can. J. Anim. Sci. 50:593.

Fahmy, M. H. and C. Bernard. 1972. Interrelations between some reproductive traits in swine. Can. J. Anim. Sci. 52:39.

Fahmy, M. H., C. S. Bernard and W. B. Holtman. 1971. Crossbreeding swine: Reproductive performance of 7 breeds of sows bred to produce crossbred progeny. Can. J. Anim. Sci. 51:361.

Flock, D. K. 1970. Genetic parameters of German Landrace pigs estimated from different relationships. J. Anim. Sci. 30:839.

Foote, W. C., D. P. Waldorf, A. B. Chapman, H. L. Self, R. H. Grummer and L. E. Casida. 1956. Age at puberty of gilts produced by different systems of mating. J. Anim. Sci. 15:959.

Ford, J. J. and H. S. Teague. 1978. Effect of floor space restriction on age at puberty in gilts and on performance of barrows and gilts. J. Anim. Sci. 47:828.

Fowler, S. H. and M. E. Ensminger. 1960. Interactions between genotype and plane of nutrition in selection for rate of gain in swine. J. Anim. Sci. 19:434.

Freedeen, H. T. 1953. Genetic aspects of canadian bacon production. Can. Dept. of Agr., Ottaw, Canada. Pub. 889.

Gajic, Z., A. Masic, M. Radic and V. Tatarski. 1976. The use of selection indices in estimating the breeding value of sows. Radovi poljoprivrednog Fakulteta Univerziteta u Sarajevu 24(27) 117-126. (Anim. Breed. Abstr. 45:116).

Gossett, J. W. and A. M. Sorenson, Jr. 1959. The effects of two levels of energy and seasons on reproductive phenomena of gilts. J. Anim. Sci. 18:40.

Gray, R. C., L. F. Tribble, B. N. Day and J. F. Lasley. 1964. Genetic aspects of backfat probes at different weights. J. Anim. Sci. 23:849. (Abstr.).

Gray, R. C., L. F. Tribble, B. N. Day and J. F. Lasley. 1965. Five generations of selection for thinner backfat. J. Anim. Sci. 24:848. (Abstr.).

Gray, R. C., L. F. Tribble, B. N. Day and J. F. Lasley. 1968. Results of five generations of selection for low backfat thickness in swine. J. Anim. Sci. 27:331.

Gregory, K. E., L. V. Cundiff, R. M. Koch, D. B. Laster and G. M. Smith. 1978. Heterosis and breed maternal and transmitted effects in beef cattle. II. Growth rate and puberty in females. J. Anim. Sci. 47:1031.

Hacker, R. R., G. J. King and W. H. Bearss. 1974. Effects of complete darkness on growth and reproduction in gilts. J. Anim. Sci. 39:155. (Abstr.).

Hafez, E. S. E. 1953. Puberty in farm animals. Emp. J. Exp. Agric. 21:217.

Haines, C. E., A. C. Warnick and H. D. Wallace. 1958. The effect of exogenous progesterone and level of feeding on prenatal survival in gilts. J. Anim. Sci. 17:879.

Haines, C. E., A. C. Warnick and H. D. Wallace. 1959. The effect of energy intake on reproductive phenomena in Duroc Jersey gilts. J. Anim. Sci. 18:347.

Henderson, C. R. 1953. Estimation of variance and covariance components. Biometrics 9:226.

Henderson, C. R., O. Kempthorne, S. R. Searle and C. M. von Krosigk. 1959. The estimation of environmental trends from records subject to culling. Biometrics 15:192.

Henderson, C. R. 1963. Selection index and expected advance. In W. D. Hanson and H. F. Robinson (Ed.) Statistical Genetics and Plant Breeding. Pub. 982, p. 141-163. National Academy of Science - National Research Council, Washington, D.C.

Henderson, C. R. 1973. Sire evaluation and genetic trends. Proc. of the Animal Breeding and Genetics Symposium in Honor of Dr. Jay L. Lush. ASAS-ADSA, p. 10.

Hetzer, H. D. and W. R. Harvey. 1967. Selection for high and low fatness in swine. J. Anim. Sci. 26:1244.

Hetzer, H. O. and R. H. Miller. 1972. Rate of growth as influenced by selection for high and low fatness in swine. J. Anim. Sci. 35:730.

Holtman, W. B., M. H. Fahmy, T. M. MacIntryre and J. E. Moxley. 1975. Evaluation of female reproductive performance of 28 one-way crosses produced from eight breeds of swine. Anim. Prod. 21:199.

Homer, E. D., A. C. Ragsdale and C. S. Cheng. 1959. Effect of constant environmental temperatures 50 and 80°F., on appearance of puberty in beef calves. J. Anim. Sci. 18:1363.

Hughes, P. E. and D. J. Cole. 1976. Reproduction in the gilt: 2. Influence of gilt age at boar introduction on the attainment of puberty. Anim. Prod. 23:89.

Jensen, E. L., G. Smith, L. W. Baker and D. F. Fox. 1968. Quantative studies on blood groups and serum protein systems in pigs. II. Effects on production and reproduction. J. Anim. Sci. 27:856.

Jensen, A. H., J. T. Yen, M. M. Gehring, D. H. Baker, D. E. Becker and B. G. Harmon. 1970. Effects of space restriction and management on pre- and post-puberal response of female swine. J. Anim. Sci. 31:745.

Johansson, I. and N. Korkman. 1951. A study in variation in production traits of bacon pigs. Acta. Agr. Scand. 1:62.

Johar, K. S. and P. Saibaba. 1973. Heritability and variability in the birth weight of Middle White Yorkshire pigs. JNKVV Research Journal 7(4) 255-257. (Anim. Breed. Abstr. 43:291).

Jonsson, P. and J. W. B. King. 1962. Sources of variation in Danish Landrace pigs at progeny-testing stations. Acta. Agr. Scand. 12:68.

Kaltenbach, C. C. and J. N. Wiltbank. 1963. Heterotic effects on age and weight at puberty in beef heifers. J. Anim. Sci. 21:662. (Abstr.).

Kinsey, R. E., R. Carlson, C. Proud and D. R. Zimmerman. 1976. Influence of boar component stimuli on age at puberty in gilts. J. Anim. Sci. 43:1362.

Klusacek, J. 1972. Variance analysis of indices of fattening performance and carcass value in pigs. Zivocisna Vyroba 17(4) 307-314. (Anim. Breed. Abstr. 41:141).

Krider, J. L., B. W. Fairbanks, W. E. Carroll and E. Roberts. 1946. Effectiveness of selection for rapid and for slow growth rate in Hampshire swine. J. Anim. Sci. 5:3.

Kripple, J. H. Patz and D. Simon. 1965. Investigation of the inheritance of important production characters in German Improved Landrace pigs. Bayer. Landw. Jb., 42:917-940. (Anim. Breed. Abstr. 34:386).

Kupriyanova, E. and V. Leshchenya. 1975. Importance of live estimation of backfat thickness for selection. Svinovodstvo No. 10, 22-23. (Anim. Breed. Abstr. 44:548).

Laster, D. B., G. M. Smith and K. E. Gregory. 1976. Characterization of biological types of cattle. IV. Postweaning growth and puberty in heifers. J. Anim. Sci. 43:63.

Legault, C. 1970. Genetic parameters for the breeding performance of Large White sows. Journees de la recherche porcine in France, Paris, 1970. Paris: Institut Technique du porc. pp. 233-240. (Anim. Breed. Abstr. 39:548).

Legault, C. 1973. Genetic analysis of sexual precocity, ovulation and number of embryos in the sow: heritability, effect of heterosis. Journees de la recherche porcine en France p. 147.

Li, V. A., S. K. Kurmanbekov and P. A. Es'Kov. 1973. Heritability and repeatibility of selection traits in Kazah hybrid pigs. Sel' skokhozyaistvennaya Biologiya 8(2) 301-302. (Anim. Breed. Abstr. 42:26).

Locniskar, F. 1960. The part played by heredity in some fattening and carcass characteristics in the pig, and genetic correlations between them. SchrReihe Max-Planck-Inst. Tierz. Tierernahr, No. 9. (Anim. Breed. Abstr. 31:90).

Louca, A. and O. W. Robison. 1967. Components of variance and covariance in purebred and cro-sbred swine. J. Anim. Sci. 26:267.

Lush, J. L. 1936. Genetic aspects of the Danish systems of progeny-testing swine. Iowa Agr. Exp. Sta. Res. Bul. 204.

Lush, J. L. and C. C. Culbertson. 1931. The consequences of inbreeding Poland China hogs. Iowa Agr. Exp. Sta. Ann. Rot. p. 23.

Lush, J. L., H. O. Hetzer and C. C. Culbertson. 1934. Factors affecting birth weights of swine. Genetics 19:329.

Lush, J. L., W. F. Lamoreux and L. N. Hazel. 1948. The heritability of resistance to death in the fowl. Poultry Sci. 27:375.

Marquardt, O. W. 1974. Selection criteria for herdbook pig breeding in Lower saxony. Thesis, George-August-Universitat, Gottingen. (Anim. Breed. Abstr. 43:468).

Mavrogenis, A. P. and O. W. Robison. 1976. Factors affecting puberty in swine. J. Anim. Sci. 42:1251.

McClung, M. R. 1953. Heritability of productive characters in Duroc swine. PhD Thesis, Dept. Anim. Husb., Iowa State College, Ames, Iowa.

McPhee, C. P., P. J. Brennan and F. Duncalfe. 1979. Genetic and phenotypic parameters of Australian Large White and Landrace boars performance tested when offered food ad libitum. Anim. Prod. 28:79.

Menge, A. C., S. E. Mares, W. J. Tyler and L. E. Casida. 1960. Some factors affecting age at puberty and the first 90 days of lactation in Holstein heifers. J. Dairy Sci. 43:1099.

Mikami, H., K. Kai, I. Sato and T. Abe. 1974. The usefulness of ultrasonic measurements as an aid to selection for backfat thickness in swine. Japanese Journal of Zootechnical Science 45(7) 381-386. (Anim. Breed. Abstr. 43:16).

Milagres, J. C., E. U. Dillard and O. W. Robison. 1979. Heritability estimates for some measures of reproduction in Hereford heifers. J. Anim. Sci. 49:668.

Molenat, M. 1973. The heritability of performance in individually recorded Large White boars. Bulletin Technique d'Information. No. 280, 399-403. (Anim. Breed. Abstr. 44:24).

Monteiro, L. S. and D. S. Falconer. 1966. Compensatory growth and sexual maturity in mice. Anim. Prod. 8:179.

Moskal, V. 1975. Heritability of fattening performance of Czechoslvakian Improved White, Landrace and Pietrain pigs. Zivocisna Vyroba 20(7) 473-480. (Anim. Breed. Abstr. 44:241).

Moskal, V. 1976. Heritability of fattening performance and carcass characters in pigs and the effect of environmental factors. Scientia Agr. Bohemoslovaca 8(2) 125-136 (Anim. Breed. Abstr. 46:172).

Naveau, J. and J. Y. Fleho. 1977. Genetic parameters of on-farm testing of breeding pigs in 1976. Bulletin, Institut Technique de Porc 9(6) 39-45. (Anim. Breed. Abstr. 46:580).

Noland, P. R., C. J. Brown and W. Clifford. 1966. Heritability and genetic correlations among certain productivity traits in an inbred line of Poland China swine. Ark. Exp. Sta. Bull. 706.

Nordskog, A. W., R. E. Comstock and L. M. Winters. 1944. Hereditary and environmental factors effecting growth rate in swine. J. Anim. Sci. 3:257.

Nowicki, B. 1960. The inheritance of some useful characters in pigs. Postepy Nauk roln., 7:91-99. (Anim. Breed. Abstr. 29:458).

Ntunde, B. N., R. R. Hacker and G. J. King. 1979. Influence of photoperiod on growth, puberty and plasma LH levels in gilts. J. Anim. Sci. 48:1401.

O'Bannon, R. H., H. D. Wallace, A. C. Warnick and G. E. Combs. 1966. Influence of energy intake on reproductive performance of gilts. J. Anim. Sci. 25:706.

Olson, L. W., W. T. Ahlschwede and T. E. Socha. 1977. Adjustment factors for age and backfat at market weight in swine. 69th Annual Meet. of ASAS, July 23-27, Univ. of Wisc.

Omtvedt, I. T., D. F. Stephans, D. R. Rule and W. E. Sharp. 1967. Relationship between growth rate, probe backfat thickness and carcass traits in swine. Okla. Agr. Exp. Sta. MP-79:26.

Omtvedt, I. T., J. A. Whatley, Jr. and R. L. Willham. 1966. Some production factors associated with weaning records in swine. J. Anim. Sci. 25:372.

Pavlik, J., J. Fiedler and R. Siler. 1971. Genetic parameters of fattening ability and carcass characteristics of Large Black and Landrace pigs. Zivoc. Vyroba, 16:29-35. (Anim. Breed. Abstr. 40: 120).

Phillips, R. W. and J. H. Zeller. 1943. Sexual development in small and large types of swine. The Anat. Rec. 85:387.

Pochernyayer, F., N. A. Nozdrina and T. O. Pashchenko. 1974. Results of selection for early maturity in a herd. Svinarstvo No. 20, 3-9, 1 (Anim. Breed. Abstr. 44:315).

Popescu-Vifor, S. 1974. Genetic and environmental paramenters in swine. In 1st World Congress on Genetics applied to Livestock Production, 7-11 October 1974 3. Contributed papers. (Anim. Breed. Abstr. 43:140).

Pumfrey, R. A., P. J. Cunningham and D. R. Zimmerman. 1975. Heritabilities of swine reproduction and performance traits. J. Anim. Sci. 41:256. (abstr.).

Quijandria, B. and E. Montalvan. 1971. Genetic and environmental effects on piglet number and weight. III. Reun. lat-am. Prod. anim., Bogata, 150. (Anim. Breed. Abstr. 40:534).

Rahnfield, G. W. 1973. Mass selection for postweaning growth in swine. III. Correlated response in weaning weight and feed efficiency to recurrent selection for postweaning average daily gain in swine. Can. J. Anim. Sci. 537:173.

Rahnefield, G. W. and I. Garnett. 1976. Mass selection for growth in swine. IV. Selection response and control population stability. Can. J. Anim. Sci. 56:783.

Rampacek, G. B., A. R. Kraeling. 1978. Delayed puberty in gilts in a total confinement system. 70th Annual Meet. of ASAS, July 9-13, Michigan State Univ. East Lansing, p. 384.

Reddy, V. B. and J. F. Lasley. 1956. Heritability of differences in two economically important traits in swine. J. Anim. Sci. 15: 1218. (Abstr.).

Reddy, V. B., J. F. Lasley and D. T. Mayer. 1958. Genetic aspects of reproduction in swine. Mo. Agr. Exp. Sta. Res. Bull. 666.

Reddy, V. B., J. F. Lasley and L. F. Tribble. 1959. Heritabilities and heterosis of some economic traits in swine. Mo. Agr. Exp. Sta. Res. Bul. 689.

Reutzel, L. F. and L. J. Sumption. 1968. Genetic and phenotypic relationships involving age at puberty and growth rate of gilts. J. Anim. Sci. 27:27.

Revelle, T. J., O. W. Robison. 1973. An explanation for the low heritability of litter size in swine. J. Anim. Sci. 37:668.

Robertson, G. L., R. H. Grummer, L. E. Casida and A. B. Chapman. 1951a. Age at puberty and related phenomena in outbred Chester White and Poland China gilts. J. Anim. Sci. 10:647.

Robertson, G. L., L. E. Casida, R. H. Grummer and A. B. Chapman. 1951b. Some feeding and management factors affecting age at puberty and related phenomena in Chester White and Poland China gilts. J. Anim. Sci. 10:841.

Robison, O. W. 1972. Role of maternal effects in animal breeding: V. Maternal effects in swine. J. Anim. Sci. 35:1303.

Robison, O. W. and J. M. Berruecos. 1973a. Feed efficiency in swine. I. A comparison of measurement periods and methods of expressing feed efficiency. J. Anim. Sci. 37:643.

Robison, O. W. and J. M. Berruecos. 1973b. Feed efficiency in swine. II. Prediction of efficiency and genetic correlations with carcass traits. J. Anim. Sci. 37:650.

Roy, G. L., W. J. Boylan and M. E. Seale. 1968. Estimates of genetic correlations among certain carcass and performance traits in swine. Can. J. Anim. Sci. 48:1.

Scanlon, P. F. and S. Krishnamurphy. 1974. Puberty attainment in slaughter-weight gilts in relation to month examined. J. Anim. Sci. 39:160. (Abstr.).

Schiemann, C. A., D. C. England and W. H. Kennick. 1976. Initating estrus in prepubertal confinement gilts. J. Anim. Sci. 43: 210. (Abstr.).

Self, H. L., R. H. Grummer and L. E. Casida. 1955. The effects of various sequences of full and limited feeding on the reproductive pehnomena in Chester White and Poland China gilts. J. Anim. Sci. 14:573.

Short, R. E. 1963. Influence of heterosis and plane of nutrition on reproductive pehnomena in gilts. M. S. Thesis, Univ. of Nebraska, Lincoln, Nebr.

Sidor, V. and J. Mojto. 1971. Phenotypic and genetic correlations and heritability of fattening and carcass characters in Improved White pigs. Acta. zootech. Nitra. XXII:71. (Anim. Breed. Abstr. 40:543).

Siers, D. G. 1975a. Live and carcass traits in individually fed Yorkshire boars, barrows and gilts. J. Anim. Sci. 41:522.

Siers, D. G. 1975b. Chromic oxide determined digestion coefficients and their relationships to rate of gain and feed efficiency in individually fed Yorkshire boars, barrows and gilts. J. Anim. Sci. 41:1266.

Siers, D. G. and G. M. Thompson. 1972. Heritabilities and genetic correlations of carcass and growth traits. J. Anim. Sci. 35:311.

Singh, R., V. K. Taneja and P. N. Blat. 1972. Inheritance of age at sexual maturity and part egg production in a White Leghorn population. Indian Journal of Anim. Prod. 2(4):37-40. (Anim. Breed. Abstr. 43:314).

Smith, C., J. W. B. King and N. Gilbert. 1962. Genetic parameters of British Landrace pigs. Anim. Prod. 4:128.

Smith, C. and G. J. S. Ross. 1965. Genetic parameters of British Landrace pigs. Anim. Prod. 7:291.

Smith, G. M., H. H. Fitzaugh, Jr., L. V. Cundiff, T. C. Cartweight and K. E. Gregory. 1976. A genetic analysis of maturing pattern in straightbred and crossbred Hereford, Angus and Shorthorn cattle. J. Anim. Sci. 43:389.

Sorenson, A. M. Jr., W. B. Thomas and J. W. Gossett. 1961. A further study of the influence of level of energy and season on reproductive performance of gilts. J. Anim. Sci. 20:347.

Squiers, C. D., D. E. Dickerson and D. T. Mayer. 1952. Influence of inbreeding, age and growth rate of sows on sexual maturity, rate of ovulation, fertilization and embryonic survival. Mo. Agr. Exp. Sta. Bull. 494.

Stanislaw, C. M. 1966. A covariance analysis between purebred and crossbred populations of swine. PhD Thesis, Oklahoma State University, Stillwater.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., New York.

Stewart, T. S., C. R. Long and T. C. Cartwright. 1976. Heterosis and combining ability for female puberty characters. J. Anim. Sci. 43:22. (Abstr.).

Stockhauser, C. W. and W. J. Boylan. 1966. Heritability and genetic correlation estimates in a new breed of swine. Can. J. Anim. Sci. 46:211.

Sviben, M. 1965. Quantitive genetics and the estimation of heritabilities of economic characters in a pig population. Vet. Arh. 35:147-152. (Anim. Breed. Abstr. 34:232).

Sviben, M., A. Salehar, M. Herak, F. Cerne and Z. Vinorski. 1969. Effect of season of birth on age at the beginning of the first pregnancy in gilts. Stocarstvo 23:51-57. (Anim. Breed. Abstr. 37:658).

Swiestra, E. E., G. W. Rahnefield, R. L. Cliplef and J. H. Strain. 1977. Age and weight at puberty of crossbred heifers sired by Charolais, Limousine, and Simmental Bulls. Can. J. Anim. Sci. 57:697.

Swiger, L. A., W. R. Harvey, D. O. Everson and K. E. Gregory. 1964. The variance of interclass correlation involving groups with one observation. Biometrics 20:818.

Swiger, L. A., G. A. Isler and W. R. Harvey. 1979. Postweaning genetic parameters and indexes in swine. J. Anim. Sci. 48:1096.

Synenki, R. M., E. J. Eisen, G. Matrone and O. W. Robison. 1972. Thyroid activity in lines of mice selected for large and small body weight. Can. J. Genet. Cytol. 14:483.

Thompson, L. H. and J. S. Savage. 1978. Age at puberty and ovulation rate in gilts in confinement as influenced by exposure to a boar. J. Anim. Sci. 47:1141.

Upp, C. W. and R. B. Thompson. 1927. Influence of time of hatch on hatchibility of the eggs, rate of growth of the chicks and characteristics of the adult female. Okla. Agr. Exp. Sta. Circ. 67.

Vangelov, K. 1969. Heritability of some characters in Large White pigs. Zhivot. Nauk., 6:45-49 (Anim. Breed. Abstr. 38:464).

Van Vleck, H. D. 1972. Estimation of heritability of threshold characters. J. Dairy Sci. 55:218.

Vechionacce, H., O. Verde and B. Muller-Haye. 1976. Genetic and environmental effects on growth in piglets. Annales de Genetique et de Selection Animale 9(1) 87-103 (Anim. Breed. Abstr. 46:173).

Vogt, O. W., R. E. Comstock and W. E. Rempel. 1963. Genetic Correlations between some economically important traits in swine. J. Anim. Sci. 22:214.

Walters, J. R., M. K. Curran, P. A. Kentish. 1977. Genetic and phenotypic parameters in performance tested pigs. Anim. Prod. 25:225.

Ward, H. K., W. E. Rempel and F. D. Enfield. 1964. Genetic relationships of weaning weight with postweaning growth rate in swine. J. Anim. Sci. 23:651.

Warnick, A. C., E. L. Wiggins, L. E. Casida, R. V. Grummer and A. B. Chapman. 1951. Variation in puberty phenomena in inbred gilts. J. Anim. Sci. 10:479.

Warren, W. M. and G. E. Dickerson. 1952. Components of performance in selecting for heterosis in swine. Mo. Agr. Exp. Sta. Res. Bull. 511.

Warren, E. P. and R. Bogart. 1952. Effect of selection for age at time of puberty in rats on reproductive performance of the rat. Oregon Agr. Exp. Sta. Bull. 25.

Webb, A. J., J. W. B. King. 1976. Development of a synthetic pig sire line by selection and heritability estimates. Anim. Prod. 22:231.

Wiggins, E. L., L. E. Casida and R. H. Grummer. 1950. The effect of season of birth on sexual development of gilts. J. Anim. Sci. 9:277.

Wiggins, E. L., W. W. Miller III and H. B. Barker. 1970. Age at puberty in fall-born ewe lambs. J. Anim. Sci. 30:974.

Willham, R. L. 1972. The role of maternal effects in animal breeding. III. Biometrical aspects of maternal effects in animals. J. Anim. Sci. 35:1288.

Wiltbank, J. N., K. E. Gregory, L. A. Swiger, G. E. Ingalls, J. A. Rothlisberger and R. M. Koch. 1966. Effects of heterosis on age and weight at puberty in beef heifers. J. Anim. Sci. 25:744.

Wiltbank, J. N., C. W. Kasson and J. E. Ingalls. 1969. Puberty in crossbred and straight bred heifers on two levels of feed. J. Anim. Sci. 29:602.

Young, L. D., R. K. Johnson and I. T. Omtvedt. 1977. An analysis of the dependency structure between a gilts prebreeding and reproductive traits. I. Phenotypic and genetic correlations. J. Anim. Sci. 44:557.

Young, L. D., I. T. Omtvedt and R. K. Johnson. 1974. Relationships of various measures of performance with ovulation rate and number of embryos 30 days after breeding in gilts. J. Anim. Sci. 39:480.

Young, L. D., R. A. Pumfrey, P. J. Cunningham and D. R. Zimmerman. 1978. Heritabilities and genetic and phenotypic correlations for prebreeding traits and principal components. J. Anim. Sci. 46:937.

Zeek, C. 1968. Investigation of the production characters of Improved Landrace pigs in German testing stations. SchrReihe Max-Planck-Inst. Tierzucht, No. 37. (Anim. Breed. Abstr. 37:276).

Zimmerman, D. R., H. G. Spies, E. M. Riger, H. L. Self and L. E. Casida. 1960. Effect of restricted feeding, crossbreeding and season of birth on age at puberty in swine. J. Anim. Sci. 19:687.

Zimmerman, D. R., R. Carlson and L. Nippert. 1969. Age at puberty in gilts as affected by daily heat checks with a boar. J. Anim. Sci. 29:203 (Abstr.).

Zimmerman, D. R., R. Carlson and B. Lantz. 1974. The influence of exposure to the boar and movement on pubertal development in the gilts. J. Anim. Sci. 39:230.

Zimmerman, D. R., P. Bourn and D. Donovan. 1976. Effect of "Transport Phenomena" stimuli and boar exposure on puberty in gilts. J. Anim. Sci. 42:1362.

Zoeneller, K. O., J. F. Lasley, L. F. Tribble and B. N. Day. 1963. Selection for thinner backfat in swine. Mo. Agr. Exp. Sta. Res. Bull. 831.

APPENDIX

TABLE XXXVIII

INDEX AND ADJUSTMENT FACTORS FOR GILTS

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1. $I = 550 - 2\,[\text{Age (days)}] - 35.4\,[\text{BF(CM)}]$

   I = Index Value

   Age (days) = Adjusted age at 90.7 kg

   BF (cm) = Adjusted backfat at 90.7 kg

2. Age at 90.7 kg.

   $$\frac{90.7\text{ kg} - \text{wi}}{\dfrac{\text{wi}}{\text{age} - 31}} + \text{Age (days)} = \text{Adjusted age at 90.7 kg}$$

3. Probe backfat at 90.7 kg.

   $$\frac{\text{BFwi}}{\text{wi}} \times 90.7\text{ kg} = \text{Adjusted probe backfat (cm).}$$

   wi = Weight when probed (kg)

   BFwi = Probe backfat (cm) at weight wi

TABLE XXXIX

COVARIANCE COMPONENTS UTILIZED FOR CALCULATING CORRELATIONS

Trait	Age at Puberty (days)	Weight at Puberty (kg)	Birth Weight (kg)	Weaning Weight (kg)	Postweaning Daily Gain (kg)	Age at 90.7 kg (days)	Adjusted Backfat (cm)
Age at Puberty		111.6718[a]	-.3324	-6.2968	-.4393	90.9839	-.2623
Weight at Puberty	-.3937[b] 6.0442[c]		.3095	3.0673	.1732	-38.1814	.0056
Birth Weight	-.0609 -.1752	.2482 .1448		.1751	.0027	- .8345	-.0045
Weaning Weight	-1.7443 -3.3354	3.0315 1.8727	.1497 .0894		.0287	-105.0108	-.0445
Postweaning Daily Gain	- .0628 - .1207	.0826 .0305	.0032 .0012	.0255 .0166		- .8152	.0017
Age at 90.7 kg	17.1378 29.7654	-13.4259 -10.4936	-.7341 -.5224	-8.4830 -7.4664	-.1641 -.1764		-.1608
Adjusted Backfat	.1580 .1835	.1019 -.0025	.0042 -.0026	-.0022 .0056	.0007 -.0009	-.002 .224	

[a] Residual component of covariance

[b] Sire component of covariance.

[c] Dam component of covariance.

TABLE XXXX

RAW YEAR-SEASON SUBCLASS MEANS

Trait	Year[a] of Birth	Season of Birth	
		Fall	Spring
Age at Puberty (days)	Year 1	194.5	189.1
	Year 2	196.4	182.1
Weight at Puberty (kg)	Year 1	94.5	97.9
	Year 2	92.9	90.4
Days of Boar Exposure Until Puberty (days)	Year 1	22.8	25.1
	Year 2	25.5	19.8
Average Daily Gain (Post-test until puberty) (kg)	Year 1	-.031	.022
	Year 2	-.001	-.269
Age Off Gain Test (days)	Year 1	171.8	164.0
	Year 2	170.8	162.3

[a] Year 1 = Fall 1976 and Spring 1977, Year 2 = Fall 1977 and Spring 1978.

TABLE XXXXI

RAW SEASON SUBCLASS MEANS

Trait	Management Confinement	Pasture
Age at Puberty (days)	188.7	193.0
Weight at Puberty (kg)	93.3	95.2
Days of Boar Exposure Until Puberty (days)	24.1	22.8
Average Daily Gain (Post-test until Puberty) (kg)	-0.74	-.041
Age Off Gain Test (Days)	164.5	170.2

TABLE XXXXII

RAW MANAGEMENT-SEASON SUBCLASS MEANS

Trait	Season of Birth	Management	
		Confinement	Pasture
Age at Puberty (days)	Fall	192.4	198.5
	Spring	184.2	187.8
Weight at Puberty (kg)	Fall	93.6	94.0
	Spring	92.9	96.3
Days of Boar Exposure Until Puberty (days)	Fall	24.8	23.1
	Spring	23.3	22.5
Average Daily Gain (Post-test until Puberty) (kg)	Fall	.006	-.042
	Spring	-.172	-.040
Age Off Gain Test (days)	Fall	167.5	175.4
	Spring	160.9	165.3

TABLE XXXXIII

ADJUSTED BREED OF SIRE-BREED OF DAM SUBCLASS MEANS FOR AGE AT PUBERTY PRESENTED AS A DEVIATION FROM THE YORKSHIRE PUREBRED

	Breed of Dam			
Breed of Sire	Duroc	Spot	Yorkshire	Landrace
Duroc	2.3	-16.3	- .1	-13.4
Spot	-11.6	- 4.6	-9.9	-14.6
Yorkshire	- 3.2	- 9.7	0.0[a]	- 9.2
Landrace	-17.4	-12.4	3.4	- 4.4

[a] Adjusted mean for the Yorkshire purebred = 198.9 days

TABLE XXXXIV

ADJUSTED BREED OF SIRE-BREED OF DAM SUBCLASS MEANS FOR WEIGHT AT PUBERTY PRESENTED AS A DEVIATION FROM THE YORKSHIRE PUREBRED

	Breed of Dam			
Breed of Sire	Duroc	Spot	Yorkshire	Landrace
Duroc	6.6	3.8	9.1	2.4
Spot	1.9	2.2	1.9	2.2
Yorkshire	5.4	4.4	0.0[a]	5.0
Landrace	-1.4	-0.5	2.7	-1.3

[a] Adjusted means for the Yorkshire purebred = 90.9 kg.

TABLE XXXXV

RAW BREED OF SIRE-BREED OF DAM SUBCLASS MEANS

		Breed of Dam			
Trait	Breed of Sire	Duroc	Spot	Yorkshire	Landrace
Age at Puberty (days)	Duroc	200.5	185.0	200.6	186.2
	Spot	186.5	192.4	188.6	186.2
	Yorkshire	193.4	189.3	199.1	190.1
	Landrace	182.6	185.3	201.3	193.6
Weight at Puberty (kg)	Duroc	98.8	94.9	101.8	94.4
	Spot	93.8	93.1	93.4	93.7
	Yorkshire	96.5	95.1	90.8	95.6
	Landrace	90.2	91.4	94.3	90.9
Days of Boar Exposure Until Puberty	Duroc	31.0	19.4	32.9	22.7
	Spot	20.7	21.4	19.2	21.3
	Yorkshire	29.5	21.6	26.2	24.5
	Landrace	17.4	19.7	30.7	21.2
Average Daily Gain (Post-test until Puberty (kg)	Duroc	.175	-.115	.148	.006
	Spot	-.102	.052	-.145	.016
	Yorkshire	-.055	.067	-.080	.051
	Landrace	-.360	-.311	.067	-.263
Age Off Gain Test (days)	Duroc	169.4	165.6	167.7	163.5
	Spot	165.8	171.0	169.3	164.8
	Yorkshire	164.0	167.7	172.9	165.6
	Landrace	165.2	165.6	170.5	172.3

TABLE XXXXVI

RAW BREED OF SIRE-BREED OF DAM-SEASON SUBCLASS MEANS FOR THE PERCENTAGE OF GILTS DETECTED IN ESTRUS BY 219 DAYS OF AGE

		Breed of Dam			
Season	Breed of Sire	Duroc	Spot	Yorkshire	Landrace
Fall Born Gilts	Duroc	50.0	81.5	71.4	83.3
	Spot	100.0	94.4	96.7	87.5
	Yorkshire	66.7	95.5	68.4	77.8
	Landrace	80.0	100.0	76.9	75.0
Spring Born Gilts	Duroc	58.8	95.2	70.6	86.1
	Spot	96.6	81.3	64.3	91.3
	Yorkshire	78.6	80.0	65.2	76.9
	Landrace	100.0	83.3	61.1	80.6

VITA

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