The Genetic Foundation of Fitness and Reproduction Traits in Australian Pig Populations

I. Genetic parameters for weaning to conception interval, farrowing interval and stayability

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1. Introduction

As the optimal fat levels for market pigs are reached the relative importance of reproductive efficiency in pigs will increase. WEBB (1991) stated that"... the limiting factor (of production) will be litter size born alive. This new breeding objective must be achieved without any penalties in birthweight, farrowing interval or sow longevity."

In Australia, the high rate of breeding sow turnover tends to be overlooked by piggery managers. The average number of parities in Australian pig herds is 2.4 (ANON., 1994), which is less than the average in other countries. Economic simulations indicate that an increase in sow removal due to death or unplanned culling (termed sow wastage) may significantly depress profitability. The simulation results of DIJKHUIZEN *et al.* (1989) and DE VRIES (1989) show an economic benefit for improving the average longevity from fourth to fifth parity of approximately $50 per sow/year. AUSPIG simulations indicate that it could cost a 100 sow piggery up to $52 per sow/year if removal rates increased from 55 to 65% (POINTON *et al.* 1995).

According to a survey of Australian pig producers six specific reasons were listed for removal of females from the breeding herd. These included reproductive failure (33%), lameness (15%), death/destroyed (16%), other health problems (8%), rearing ability (4%) and age/litter size (19%) (PATERSON, 1995). Important reproductive failures were returns or delayed or no oestrus after weaning, which are mainly problems for sows after their first litter, and to a lesser extent second litter sows. However, it is common practice to cull sows after one or more returns following infertile matings, or to induce oestrus with exogenous hormones when sows do not show an oestrus within two to three weeks after weaning. Thus, it is desirable to reduce the number of reproductive failures because of animal health and welfare considerations, improving longevity and reducing the number of non productive days of sows.

Environmental factors such as poor care at farrowing, poor housing, fighting of group penned sows post mating and nutritional deficiencies during lactation are probably the main causes for high mortality rates in sows. These factors may also be responsible for many disposals classified under lameness and reproductive failure. Whereas at least some of the environmental factors affecting longevity of sows were reported in literature (e.g. GAUTHIER *et al.* 1992, GUEBLEZ *et al.* 1985), almost no information could be found about the genetic foundation of longevity.

The aim of the present paper was to investigate the genetic foundation of weaning to conception interval, farrowing interval and longevity. In a second paper (THOLEN *et al.* 1995), the correlations between these traits and other reproductive and performance traits used in Australian pig selection schemes are presented.

2. Material

The data used in this study included reproductive data of sows from two Australian piggeries. The first herd (Herd A) was established in 1981. The original purchased breeding stock comprised the breeds Large White (LW), Landrace (LR) and their crosses (LW*LR), allocated to five different lines on entry to the herd. On the female side, these lines were kept separate and boars selected from one line were placed into the next to reduce the likelihood of inbreeding. The result was a synthetic line that combined genes of the breeds LW and LR. Overall, data from 3942 sows recorded from 1983 through to 1995 were used in the present analysis. The data set of the second herd (Herd B) included data from 3776 LW and 2274 LR sows, which were performance tested in the years 1991 to 1995. Sows were housed in two separate units. 60.5, 64.0 and 74.3% of the first, second and third LW - litters were crossbred (LR service sire). The crossbred (LW service sire) proportions of the LR litters were 53.8, 56.0 and 70.5%, respectively.

From both data sets the interval between weaning and conception in the first, second and third reproductive cycles ($WCI_{12,23,34}$), the interval between the first and second, second and third, and third and fourth farrowing ($FI_{12,23,34}$), and age at first farrowing (FA) were considered. In addition, fitness was defined by stayability of the sow. In pig breeding the ability of a sow to remain in the herd after a certain parity seems to be a reasonable measurement of longevity (true stayability). In addition, the ability of a sow to avoid culling due to reasons other than productivity, such as reproductive failure, lameness or other health problems is of particular interest (functional stayability). In our study we defined true and functional stayability as follows:

True stayability of the sow from the first to the second, first to third and first to fourth parity ($STAY_{12,13,14}$).

$STAY_{1i}$ was defined as the probability of surviving in the herd from parity one to parity i, where i can take values of 2, 3 or 4. $STAY_{1i}$ was an all-or-none trait scored as 0% or 100%. A sow was assumed to have had the opportunity to express true stayability from the first to i^{th} parity, if she had an information in the previous parity (i-1) and her last known date plus 150 days was before the last known date in the data set (March, 1995).

Functional stayability ($STAYc_{13,14}$) was defined as the true stayability corrected for the average NBA calculated from the first to last recorded litter (NL).

If $STAY_{1i}$ was equal 100%, the last litter was litter i; if $STAY_{1i}$ was equal 0%, then the last litter was the last litter before culling. NL was grouped into four classes from '< 7 NBA' to '> 10 NBA'. Before grouping, NBA were preadjusted for parity and year*season effects. Functional stayability was not calculated for $STAY_{12}$. It is common practice for first parity sows to be given a chance to produce a second litter. Thus, it was assumed that no planned selection for NBA took place between the first and second parity.

3. Data Characteristics

Only sows that had at least first parity information were considered for analysis. Additionally, sows that did not complete a reproduction cycle due to abortion were excluded. Records were excluded if one of the traits exceeded realistic biological limits. The acceptable trait ranges were: WCI 1 to 60 days, FI 130 - 300 days and FA 220-450 days. The number of records and standard deviations for the analysed traits in Herds A and B are presented in Table 1.

Table 1: Number of records (N), and. standard deviations (SD) for the analysed traits

		Herd A		**Herd B**	
Trait [units]	**Parity**	**N**	**SD**	**N**	**SD**
WCI [days]	1	3164	13.11	481	9.29
	2	2356	12.40	388	8.45
	3	1629	12.53	-	-
FI [days]	1	3165	14.11	4183	9.66
	2	2348	13.64	2871	9.16
	3	1634	13.72	1130	8.28
Lactation	1	3943	3.83	481	3.58
length [days]	2	3212	4.20	388	4.18
	3	2441	7.22	-	-
No. of	1	3942	1.58	6050	1.81
weaned	2	3076	1.67	4196	1.60
piglets	3	2309	1.70	3025	1.63
FA [days]	1	3943	26.68	6050	21.68

Differences between farms in their management strategies largely explained differences between herd means which are not presented to maintain confidentiality.

The coefficient of variation for the weaning to conception interval in all parities exceeded 100%, which indicated that the distribution of WCI was far from normal. WCI had a highly left skewed distribution with two peaks. The first dominant peak was around the 5th day after weaning. The second, smaller peak at day 26 after weaning mostly included sows that had either a silent first oestrus or returned after an infertile first mating.

The opportunity to express $STAY_{12,13,14}$ (uncensored sows) are presented in Table 2. 3942 and 6050 sows with records in Herds A or B respectively were included in the analysis of reproduction and production traits. Relative to this number in Herd A, 4.7, 8.0 and 9.6% of the sows did not have the opportunity to express $STAY_{12}$, $STAY_{13}$ and $STAY_{14}$ (censored sows). The corresponding proportions in Herd B were 10.7, 20.9 and 34.4%. Differences in culling rates between the herds could be explained by different selection strategies and/or by a different health status of the sow herd. Specific information about the disposal reasons of the sows was not available.

Table 2: Number of uncensored sows (N = 100%) with a stay ability of 100% at the second, third or fourth parity

Parity	Herd A N	Herd B N
1 - 2	3757	5402
1 - 3	3627	4784
1 - 4	3563	3970

4. Statistical methods

PROC GLM (SAS 1993) was used to verify the significance of possible systematic effects found in literature and available in the data sets of the two herds for each trait. Since the distribution of WCI was skewed, the data were first log transformed to obtain a more symmetrical distribution. The mixed models used to estimate the fixed and random effects were also run with the non-log-transformed WCI to present the GLS means of the WCI in days. For each trait the fixed effects finally included into the model of analysis and the proportion of variation explained by the fixed effects part of the model (R^2) are presented in Table 3.

Table 3: Fixed effects (and R^2 resulting from the fixed model analysis) included in the model of analysis for each trait recorded in Herds A and B

		Fixed effects[b]							R^2 [%], Parity:		
Traits	**Herd**	UN	BS	FA	Y*S	LA	NA	NL	1	2	3
WCI	A			1	123	123	1		4.7	5.9	8.9
	B		2		12	12	1		9.9	17.5	-
FI	A			1	123	123	1		6.7	6.1	6.7
	B	123[a]	123		123		123		4.6	6.2	7.0
STAY	A			234	234				6.8	9.0	7.9
	B		234	234	234				4.6	7.5	16.5
STAYc	A			34	34			34		12.1	11.7
	B		34	34	34			34	-	8.8	17.5

[a] Factor used for analysing trait recorded in the first, second and third parity or factor used for analysing STAY and STAYc from first to second, third or fourth parity

[b] Fixed effects included into the model of analysis:

UN: Farrowing unit of the dam (class: 2 levels in Herd B only)
BS: Breed of the sow (class: 2 levels; LW; LR in Herd B only)
FA: Age of the dam at the first parity (linear covariable)
Y*S: Year*season (class: 46 levels in Herd A, 20 levels in Herd B)
LA: Length of Lactation for the first, second or third litter (class with 5 levels: < 20; 21 - 23; 24-26; 27-30; >30 days)
NA: Number of piglets nursed (class with 6 levels: < 6; 7; 8-; 9; 10; > 10 piglets)
NL: Average Number of piglets (linear covariable)

The effect of mating type (natural or artificial) was not included in the models for Herd A as less than 2% of the sows were artificially inseminated (AI). The proportions of AI matings in Herd B were 19.2, 24.3 and 26.6% of the first three litters. However, mating type was not a significant effect ($p > 0.05$) for any of the traits analysed in this herd. In Herd B information about the breed of the sow (BS) and the breed of the service sire (BSS) was available. However, the factors BSS and BS*BSS were not significant for any trait and consequently not included into the model of analysis. Season was defined as a 3-month class (class 1: Jan.-Mar.; 2: Apr.-Jun.; 3: Jul.-Sept.; 4: Oct.-Dec.). Year*season effects were assigned on the basis of date of birth (STAY) or date of farrowing (WCI, FI).

Estimates of linear contrasts for fixed effects were obtained using generalised least squares. The unknown dispersion parameters were replaced by the REML (Restricted Maximum Likelihood) estimates. Students t-test was used to test the contrast deviation from 0 ($p < 0.05$).

Genetic and environmental parameters were estimated using REML analysis based on an animal model. Traits recorded in each parity were treated as separate traits of the sow. A bi-variate trait model was used to estimate the correlations between traits. Possible different design matrices for different traits and/or missing values for traits were taken into account. The mixed model utilised for all traits was: $\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e}$, where $\mathbf{y}$ is the vector of observations; $\mathbf{X}$, $\mathbf{Z}$ are known incidence matrices; b is a vector of the fixed effects, listed in Table 2; $\mathbf{a}$ is the vector of random additive genetic effects and $\mathbf{e}$ is the vector of the residuals. The variance of y was: $\mathbf{V(y)} = \mathbf{ZGZ'} + \mathbf{E}$ where $\mathbf{G}$ was the direct product between the relationship matrix and the matrix of genetic (co) variances. $\mathbf{E}$ was the product of the identity matrix and the matrix of error (co-) variances.

Computation of the multi-variate models were carried out with the derivative free approach program VCE (GROENEVELD, 1994). Iteration stopped when the variance of the likelihood function values was less than 10^{-8}. Approximate standard errors of estimates of dispersion parameters were obtained using a quadratic approximation of Fisher's information matrix (SMITH and GRASER, 1986). These calculations were performed by means of a uni-variate (single trait) model, using the program DFREML (MEYER, 1991).

5. Results and discussion

5.1 Estimates of fixed effects

Fixed effects for weaning to conception interval and farrowing interval

Lactation length had a significant influence on the weaning to conception interval in Herd A. Linear contrasts between different class levels of lactation length are presented in Table 4. The optimal lactation length with respect to the farrowing or weaning to conception interval was between 21 and 23 days in our study. Away from this optimum, a lactation length of more than 29 or less than 20 days led to an increase of the weaning to conception interval after the first farrowing by two or three days respectively. Older sows showed a significantly prolonged weaning to conception interval when the lactation length was shorter than 20 days relative to the optimum. A long lactation may be harmful when feed intake during lactation is insufficient. Severe body weight losses will then be closely associated with lactation length. On the other hand, weaning shortly after farrowing also causes considerable stress (SCOTT, 1995).

Table 4: Effects of lactation length on the weaning to conception interval (Herd A and B) and farrowing interval (Herd A).

	Parity	Lactation length [days] <20*	21-23	24-26	27-29	>29
Herd A				0		
WCI	1-2	1.37(0.91)	-0.77 (0.64)	0	0.21 (0.67)	2.48 (0.80)
	2-3	4.76 (1.15)	-0.46 (0.90)	0	-0.15 (0.90)	-1.29 (1.16)
	3-4	5.53 (1.54)	-2.86 (1.26)		2.37 (1.32)	0.98 (1.31)
FI	1-2	0.81 (0.98)	-1.07 (0.69)	0	0.04 (0.71)	2.25 (0.84)
	2-3	4.57 (1.26)	-1.00 (1.00)	0	0.17 (1.00)	-0.72 (1.25)
	3-4	5.23 (1.71)	-2.04 (1.40)	0	1.70 (1.46)	1.89 (1.73)
Herd B						
WCI	1-2	0.67 (1.83)	0.06 (1.07)	0	0.03 (1.11)	0.58 (1.71)
	2-3	0.90 (1.94)	1.98 (1.02)	0	0.90 (1.18)	-2.12 (1.74)

* linear contrasts between the median 'lactation length' class (24-26) and other classes, along with the corresponding standard error (in brackets)

The effect of **number of piglets nursed** on WCI or FI is shown in Table 5. Increasing the number of piglets nursed by first parity sows prolonged the farrowing interval and weaning to conception interval almost linearly for both herds. However, first parity sows suckling 7 or 8 piglets were not significantly advantaged with regard to WCI and FI relative to sows suckling 9 piglets. The difference between the classes '<7 piglets' and '>10 piglets' nursed was up to four days in both herds. In later parities the effect of number of piglets nursed was not significant in Herd A, whereas in Herd B WCI and FI were on average 2.5 days longer when second or third parity sows had to nurse more than nine piglets.

Table 5: Effects of the number of piglets nursed on the weaning to conception interval and farrowing interval.

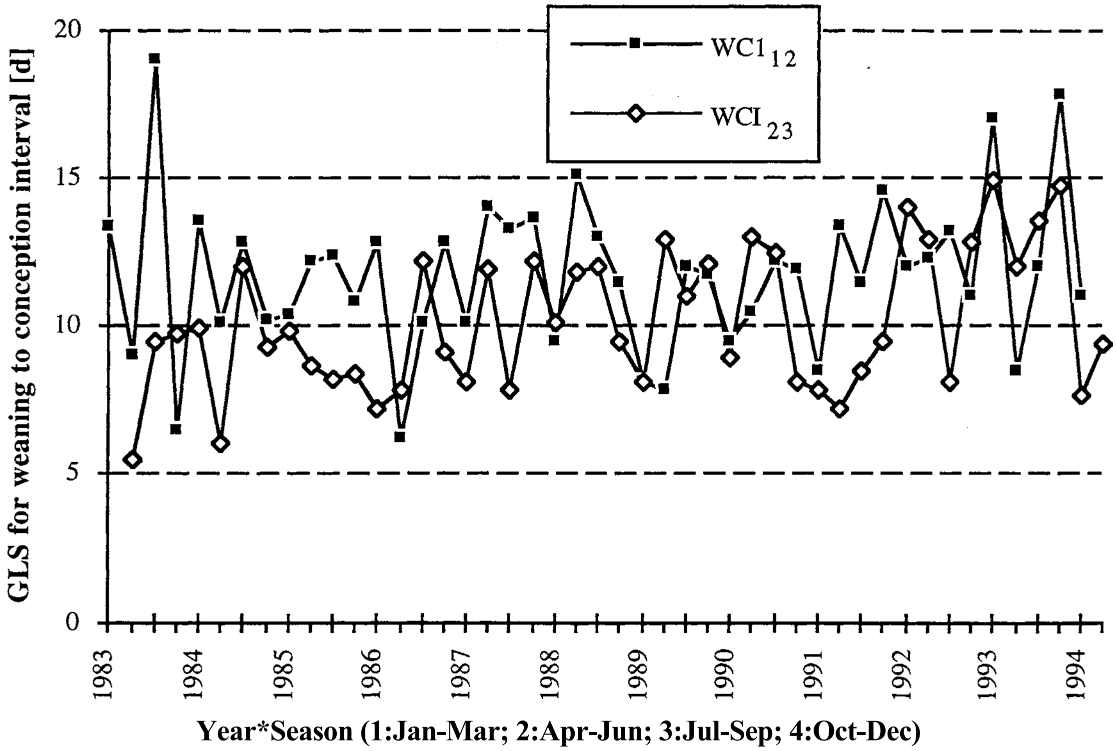
		Number of pigs nursed					
	Parity	<7*	7	8	9	10	>10
Herd A							
WCI	1 -2	-2.18 (0.78)	-0.16 (0.77)	-1.02 (0.65)	0	0.58 (0.72)	1.45 (1.25)
FI	1 -2	-2.83 (0.82)	-0.24 (0.81)	-0.57 (0.69)	0	0.93 (0.77)	2.00 (1.31)
Herd B							
WCI	1 -2	-1.97 (1.91)	-0.43 (1.85)	-0.87 (1.34)	0	1.97 (1.15)	2.24 (1.41)
FI	1 -2	-1.62 (0.66)	-1.02 (0.67)	-1.21 (0.54)	0	1.94 (0.42)	2.07 (0.58)
	2-3	0.37 (0.97)	-0.47 (0.79)	-0.63 (0.60)	0	3.29 (0.45)	2.56 (0.73)
	3-4	-0.04 (1.18)	-1.42 (1.10)	0.80 (0.72)	0	2.72 (0.58)	1.64 (1.10)

* linear contrasts between the median 'piglets nursed' class (9) and other classes, along with the corresponding standard error (in brackets)

In Herd B, relative to the reduced amount of available information for WCI, all FI could be calculated. However, the statistical analysis of FI in this data subset was of limited value because lactation length was only available for a small number of sows. Therefore this effect could not be included into the model. Nevertheless, similar to the WCI, the FI of sows nursing more than nine piglets in the first litter was significantly increased by approximately four days relative to sows which have raised less than seven piglets (Table 4). In contrast to Herd A, these deviations could also be observed in the subsequent farrowing intervals. Greater stress during lactation may be responsible for the increase in the length of the weaning to conception interval for sows nursing large litters (SMIDT *et al.* 1965).

Seasonal effects on WCI in Herd A after the first and second farrowings are presented in Figure 1. The expected cyclic seasonal pattern with a high WCI during the warm summer months (season class 1) and a low WCI (season class 3) during the winter months could only be seen in certain years.

Figure 1. Effect of 'year*season' on 'weaning to conception interval' after the first and second farrowing is standardised to the mean value



In Australia, high temperature is the most important factor which contributes to seasonal patterns in fertility (HENNESSY and WILLIAMSON, 1984). The distinct GLS estimates for the year*season effects on the weaning to conception interval in the years 1993 and 1994 were probably caused by high temperatures during the summer months. However, TEN NAPEL *et al.* (1995a) pointed out that seasonal infertility is not common in all herds, and management factors can overcome it to some extent, as in the experiment of COX *et al.* (1983). In this study, supplementing 10% fat to lactational diets diminished the increase in average weaning to oestrus interval during the summer.

In Herd A, there was a significant increase in WCI_{12} and FI_{12} with **age at farrowing** of 0.027 days (SE 0.009) and 0.026 days (SE 0.010) respectively, per day increase in age at first farrowing. Age at first farrowing was not a significant factor influencing WCI and FI in Herd B. The influence of the **breed of the sow** (LW, LR) on WCI in Herd B was significant for first parity sows. LW sows had a longer WCIi2 of 4.8 (SE 1.92) days. The superiority of LR for FI was apparent in all three analysed parities. The results of the linear contrast LR versus LW were -2.59 (SE 0.86), -0.48 (SE 0.80) and -3.25 (SE 1.46) days in parities one to three respectively.

Stayability of sows from the first to fourth parities

Research studies of sow longevity are few because of the significant amount of time committed to obtain results. In addition, it is difficult to control all factors which may influence longevity, making it difficult to establish the relative importance of individual factors. In this respect, retrospective studies of sow longevity from field data are useful. However, care is required in interpretation of results obtained this way as significant management differences may exist between individual farms which may not be accounted for in the analysis of data.

In this study, **age at first farrowing** was one effect that could be included in the analysis of stayability of a sow from the first to later parities. For both herds the estimated regression coefficients showed a minor but significant increase in the probability of sows being culled in later parities with increasing age at first farrowing. Regression coefficients ranged from 0.07 to 0.15% per additional day of age, although trends with increasing parity differed between herds (Table 6).

Table 6: Regression of age at first farrowing [days] on stayability (with standard error SE) recorded at the second, third or fourth parity

		Herd A		Herd B	
Trait	Parity	b	SE	b	SE
STAY [%]	1-2	-0.073	0.020	-0.116	0.025
STAY [%]	1-3	-0.082	0.031	-0.122	0.081
STAY [%]	1-4	-0.152	0.033	-0.074	0.035

An increase in longevity with increased age of gilts at first parity was found by ZIKOVIC *et al.* (1986). In their study sow culling in the first three parities decreased linearly from 57.7 to 34.0% as age at first conception increased from less than 200 to greater than 300 days. In contrast, NOGUERA and GUEBLES (1984) reported a linear decrease in longevity as age at first farrowing increased. They estimated the following regression equation: parity attained = 5.89 - 0.006 * age. Conflicting results for longevity between studies are most likely the result of differing managerial and environmental factors (e.g. culling criteria or lactational feeding). In addition, growth of gilts during rearing may not have been equal in each trial. In some herds younger gilts may have accumulated sufficient body reserves to remain in the breeding herds as long as older gilts.

Most of the variation in stayability traits was explained by **year*season** effects, which were based on sow birthdates. Specific environmental conditions such as high temperatures and differences in health status of the herd certainly influence the stayability of a sow in subsequent parities. As a result, a high variation and range in the different GLS levels of the factor year*season was found in both herds.

DARGON and AUMAITRE (1978) showed that the percentage of culling for breeding failure was higher for sows weaned during the summer time (around 35% during June, July and August) and lower in sows weaned in January (27.2%) in the Netherlands. However, neither the percentage of sows culled due to old age nor that of sows which died on the farm varied according to month of the year. In particular because of the high temperatures during the summer time, it can be assumed that the seasonal differences in Australia are more distinct than in Netherlands. However, it should be pointed out that the applied year*season factor used in our study was probably only an approximate method to correct stayability for systematic climatic or management effects.

In Herd B, the probability of being culled after the first, second or third litter was decreased by 3.0 (SE 1.6), 5.5 (SE 2.1) and 6.0 (SE 2.0)% respectively in **LR** sows relative to **LW** sows. It was not possible to determine whether planned selection or a higher susceptibility of LW sows to health problems were responsible for this apparent breed difference.

In order to correct for the possible effects of planned selection on NBA, $STAY_{13}$ and $STAY_{14}$ were analysed with the **average NBA (NL)**, calculated from all previous litters, and included as a class effect in the model. No correction for planned selection was performed for $STAY_{12}$ because it is common practice to give every first parity sow a chance to produce a second litter. The introduction of the factor NL improved the fixed model R^2 by 3.5% on average in Herd A and 1.2% in Herd B (Table 3). In Herd A, the GLS means for the factor NL (Table 7) showed the expected increase of the probability of being culled as NL declined. However, for Herd B it appeared that the fitted correction factor for planned selection did not reflect the true selection process. This can be concluded from the poor increase in R^2 after fitting NL into the models for analysing $STAY_{13}$ and $STAY_{14}$. Additionally, including NL in the model of analysis led to an unexplainable advantage from a selection viewpoint in $STAY_{14}$ of sows with the lowest NL. Relative to Herd A, where the analysed data set included 12 years of performance recording, the analysed period of time in Herd B was considerably shorter (four years) and a higher proportion of the sows did not have the opportunity to express $STAY_{13; 14}$. The reasons given might serve as an explanation for the poor behaviour of the applied correction procedure for the $STAY_{13}$ and $STAY_{14}$ in Herd B.

Table 7: Effect of average NBA from first to last recorded parity on STAY [%]

		Average number of piglets from first to last recorded parity			
	Parity	<6*	6-8	8-10	>10
Herd A					
STAY	1-3	-36.9 (3.8)	-9.6 (2.4)	0.9 (1.8)	0
	1-4	-40.1 (4.1)	-25.0 (2.8)	0.9 (1.8)	0
Herd B					
STAY	1-3	-27.3 (4.2)	-0.3 (2.4)	7.8 (1.5)	0
	1-4	11.1 (3.2)	-13.8 (2.5)	2.6 (1.6)	0

* linear contrasts between the highest 'average number of piglets born' (<10) and other classes, along with the corresponding standard error (in brackets)

5.2 Estimates of heritability

Estimates of trait heritabilities along with their standard errors and additive genetic variances are presented in Table 8. For the traits **FI and WCI**, heritability estimates differed significantly between the first and later parities. On average, heritabilities for FI and WCI in the first parity were 0.09 respectively, whereas estimates from later parities were not significantly different from zero.

Table 8: Heritabilities (h^2) with standard error (SE) and genetic variance (σ^2_g) of interval reproduction traits and stayability

		Herd A			Herd B		
Trait	Parity	h^2	SE	σ^2_g	h^2	SE	σ^2_g
WCI	1-2	.10	.03	17.48	.08	.07	6.45
	2-3	.01	.03	1.25	.00	-	0.71
	3-4	.03	.05	4.48	-	-	-
FI	1-2	.09	.03	16.66	.00	-	1.82
	2-3	.03	.04	5.92	.02	.03	1.20
	3-4	.03	.04	4.30	.00	-	0.63
STAY	1-2	.05	.03	0.0060	.02	.02	0.0034
	1-3	.08	.03	0.0165	.06	.02	0.0142
	1-4	.08	.03	0.0181	.09	.02	0.0160
STAYc	1-3	.09	.03	0.0201	.07	.02	0.0146
	1-4	.06	.02	0.0241	.09	.02	0.0168

Heritability estimates found in literature for the weaning to oestrus interval were 0.25 (FAHMY *et al.* 1979), 0.22 and 0.12 in two breeds (PETROVICOVA *et al.* 1988) and 0.36 TEN NAPEL *et al.* (1995b). The estimate of heritability for weaning to conception interval following the first farrowing was lower for both herds than the values reported in literature. However, data used in most of the above mentioned studies were the result of planned experiments under the control of research institutes, whereas the data set used in our study was recorded under the production conditions of two Australian piggeries. Relative to controlled experimental conditions, our data was characterised by considerable variation in lactation length and no. of piglets weaned. In addition, differences in the accuracy of oestrus detection may have occurred. Moreover, the weaning to conception interval included a second or third cycle length when a sow returned after an infertile mating. These additional components probably decreased heritability estimates for the weaning to conception interval obtained from our data. A further possible reason for the low h^2 may lie with the failure to identify sows which were culled because of a long WCI. Data from both herds did not contain disposal codes relating to specific areas of reproductive failures, so these sows could not be identified.

Another explanation for different h^2 estimates of the WCI is given by TEN NAPEL *et al.* (1995a). He pointed out that the expression of genetic differences in the weaning to oestrus interval depends on the environmental, housing and feeding conditions of the sow. Both in an extremely favourable or unfavourable environment, no genetic variation will be observed, because in the one environment all animals will have a normal interval and in the other all animals will remain anoestrus. In intermediate environments some families may be more affected by stressors than others. This can be observed as genetic variation in the weaning to oestrus interval.

The low heritability for farrowing interval found in this study corresponded with the results of JOHANSSON and KENNEDY (1985) and RYDHMER *et al.* (1995), but was lower than the value of 0.2 reported by VANGEN (1986). Farrowing interval is a combination of several traits and management factors. Length of lactation, length of the weaning to oestrus interval, conception rate and gestation length constitute the farrowing interval. In Herd A, there was no difference in the heritability between weaning to conception and farrowing interval. Length of lactation was recorded for each sow in Herd A and could be included into the model. Moreover, it is well known that the variation in gestation length is low (MERCER and CRUMP, 1990). Hence, the similar heritability estimates between weaning to conception and farrowing interval could be expected. In contrast, the heritability estimate for farrowing interval in Herd B was not significantly different from zero. Considerable variation in lactation length, which could not be included into the model of analysis of FI, is probably responsible for this result.

The **heritability estimates for stayability** of a sow from first to second litter in both herds did not exceed 0.05. Slightly higher estimates were found for stayability from first to third or fourth parity. Only one estimate of heritability for longevity of sows was found in the literature. KRIETER (1995) estimated the heritability of longevity of sows (in terms of age) at 0.12 in a German pig breeding enterprise. After fitting NBA into the model of analysis, Krieter's estimate further dropped to 0.06. Except for the relatively low h^2 estimate for the stayability between first and second litter, the magnitude of h^2 estimates for stayability found in this study were similar to the results of KRIETER (1995). However, h^2 estimates in this study were not substantially affected by correcting for the effect of planned culling of sows with a low prolificacy. This could be explained by the poor behaviour of the applied correction procedure, particularly in Herd B. Such a result may also reflect higher rates of unplanned culling resulting in a decline in the efficiency of selection for NBA, or the absence of NBA as a selection criteria.

5.3 Estimates of phenotypic and genetic correlations

In the case of zero heritabilities of at least one trait, the genetic correlation estimated in the bi-variate REML analysis often became fixed to 1.0 or -1.0 and did not significantly differ from 0. Therefore, genetic correlations between WCI_{12}, FI_{12} and $STAY_{12,13,14}$ only are presented in Table 9.

The phenotypic correlations between WCI and FI measured at different parities were close to zero. Management factors in different reproductive cycles obviously influence this relationship to a high extent. Higher phenotypic correlations could be found between FI and WCI recorded in the same reproductive cycle, where part-whole relationships contribute to these higher estimates. The genetic correlation between WCI_{12} and FI_{12} in Herd A did not differ from unity. This result along with the similar h^2 estimates showed that WCI_{12} and FI_{12} in Herd A were essentially identical traits.

Strong negative genetic correlations were found between $STAY_{13,14}$ and WCI_{12}, whereas the phenotypic correlations were close to zero. It can be assumed that WCI_{12} plays a certain role in the selection decisions of the herd manager, which might affect the genetic correlation estimates between WCI and STAY. However, the magnitude of the genetic correlations between $STAY_{13,14}$ and WCI_{12} indicate that sows with a genetic disposition for a long WCI_{12} were more likely to be culled during the first four parities than sows with a disposition for a short WCI_{12}.

Table 9: Multiple-trait estimates of phenotypic correlations (below diagonal) and genetic correlations (above diagonals) between reproductive interval measures and stayability

Trait			WCI	FI	STAY		
	Parity	Herd	1-2	1-2	1-2	1-3	1-4
WCI	1-2	A		.97	-.18	-.45	-.22
FI	1-2	A	.93		-.14	-.33	-.10
STAY	1-2	A	-	-		.83	.75
		B				.99	.99
	1-3	A	-.05	.06	.58		.99
		B			.68		.97
	1-4	A	-.05	.01	.39	.65	
		B			.30	.49	

6. Discussion of the applied statistical methods

In estimating parameters with VCE it is assumed that the data has a multivariate normal distribution. This assumption was certainly not fulfilled for the traits WCI and STAY. WCI had a left skewed distribution. A geometric or combined normal and exponential distribution as TEN NAPEL *et al.* (1995b) proposed should reflect the biological nature of the WCI more accurately. In order to achieve a normal distribution, FAHMY *et al.* (1985) proposed a logarithmic transformation of the WCI. However, a logarithmic transformation had in the present study only a minor influence on the magnitude of the h^2 for WCI and on correlations between WCI and other traits. In addition, TEN NAPEL (1995b) concluded from his simulation study that REML estimates will not be biased with exponentially distributed data.

The defined STAY can only take values of 0% or 100%. HOESCHELE *et al.* (1986) and HOESCHELE *et al.* (1995) showed how to predict fixed and random effects with binary and normally distributed traits by means of so called 'threshold models'. A number of authors, e.g. JANSEN (1992) have discussed maximum likelihood estimation for threshold models. Nevertheless, these methods are computationally handicapped by the need for high dimensional numerical integration. ENGEL *et al*. (1995) concluded, that a (generally accepted) maximum likelihood estimation for models with several variance components is practically impossible.

The presence of censored records is another problem in the analysis of survival traits. Statistical methods including censored records with their adequate weights have been developed in the area of medical statistics. DUCROCQ and SOERENSON (1994) showed the usefulness of those survival analysis techniques in animal breeding. However, methods and programs for the estimation of variance and covariance components in the case of a multitrait evaluation with censored records are currently not available.

7. Summary

Data sets from two Australian piggeries were used to estimate the genetic foundation of the weaning to conception interval (WCI) and farrowing interval (FI) in the first three reproductive cycles, as well as stay ability of sows from the first to fourth parities (STAY). The data was recorded during the years 1982 to 1995 (Herd A) and 1990 to 1995 (Herd B).

Of the fixed effects examined, lactation length (LA) had a significant effect on WCI recorded in both herds. Away from an optimum of 21 to 23 days, a LA of more than 29 or less than 20 days led to an increase in WCI after the first parity by two to three days. Older sows showed a prolonged WCI of up to 8 days when the LA was less than 20 days relative to the optimum. The effect of number of piglets nursed (NA) was significant for WCI after the first parity. The difference between NA classes containing < 7 piglets and > 10 piglets was approximately 4 days in both herds.

The influence of LA and NA on FI recorded in Herd A was similar to the results for WCI. In Herd B no information about LA was available. In contrast to the analysis of the WCI, the factor NA was significant for FI recorded in the second and third reproductive cycles of the sows in this herd.

Stayability of sows in both herds was mainly influenced by year * season effects (based on sow birthdate), and to a lesser extent by the age at first farrowing, in order to account for planned selection, STAY was corrected for the average number of piglets born in previous litters (NL). For Herd A this analysis showed the expected result of a higher probability of sows being culled which had a low NL. Presumably because of the short period of data recording, a reliable correction in Herd B was not possible.

Heritability estimates for WCI in Herds A and B were 0.10 (0.03) and 0.08 (0.07), and 0.09 (0.03) for FI in Herd A. Although low, these heritability estimates suggest that including WCI_{12} in the breeding objective of pigs could lead to a reduction of unproductive days. All other h^2 estimates for WCI and FI of older sows were not significantly different from zero. The h^2 for STAY from first to the second parity was below 0.05. Heritability estimates for STAY from first to third or fourth parity ranged from 0.06 (0.02) to 0.09 (0.02). The genetic correlation (r_g) between WCIi2 and all defined STAY were negative (r_g: -0.10 to -0.45). Hence, selecting for a short WCI could have favourable consequences for the longevity of sows.

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