Improvement of sow longevity through identification of early lifetime performance indicators, including the assessment of gonadotropin response as a suitable selection tool for replacement gilts

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Executive Summary

High sow turn over or replacement rate is an ongoing issue in the Australian pig industry. High sow turnover within a herd leads to a reduction in sow lifetime performance (calculated as the number of pigs produced per female per day of herd life), especially if replacement rates for early parity sows are high. High sow turnover rates result in a higher proportion of younger sows in the herd, in particular gilts, leading to increases in HFC (feed consumed per unit carcass weight produced) due to a greater proportion of gilt progeny within the herd (Smits, 2011). Over the past decade there has been considerable research into this topic, however, little improvement has been made.

In 2013 the sow replacement rate was 56.1%, with the average parity at which a sow was culled sitting at 4.1 (Australian Pork Limited). A sow needs to at least reach her third or even her fourth parity before she begins to recover her own cost (Rodriguez-Zas et al. 2003; Levis, 2005). Therefore, her removal from the herd prior to parities 3-4 results in financial loss for the producer. There are a number of key reasons for premature sow turnover, with poor reproductive performance during the early parities a major cause of removal. In a review of the major causes for sow removal within a large commercial Australian farm, Hughes et al. (2010) found the single largest cause for culling was poor fertility, particularly in early parity sows. Interestingly, gilt culls accounted for 42.5 % of the fertility culls, with the majority of these (42%) failing to exhibit signs of pubertal oestrus in the required timeframe.

Focussing on the development of the replacement gilt from birth up until the time of selection, with particular focus on early-in-life parameters such as pre-weaning growth and development, rather than just weight for age and conformation at the time of selection into the breeding herd could be one way to improve the selection process in order to select replacement gilts with improved longevity and lifetime performance. Also, it has been well documented that gilts that show early puberty have improved longevity and greater lifetime performance (Koketsu et al. 1999; Patterson et al. 2010). Flowers (2014) suggested that show early puberty have an increased longevity because they are more sensitive to oestrogens (i.e. their reproductive system can function normally with less oestrogen). Therefore, giving gilts a low dose of gonadotropins (200IU of PG600 – one third of a normal dose used to induce oestrus and ovulation) may be a feasible and practical way to test a gilt's response to gonadotropic hormones without inducing ovulation and therefore aid in the selection of superior replacement multiplier gilts.

Higher pre-weaning gain (rather than heavier birth weight) had the most consistent outcome for improving the probability of gilt selection and subsequent reproductive success. Females with a pre-weaning average daily gain of <125 g had a reduced probability of being selected or of being mated (displaying oestrus) or farrowing if they were selected. In addition to an increased pre-weaning gain, increasing weaning age linearly improved the probability of a gilt being selected. At selection, a higher P2 backfat linearly increased the likelihood of the selected gilt being mated and farrowing. Whereas, for selection weight, only the lightest 20% of the selected gilts (<92 kg) had a lower mating and farrowing outcome. Increasing P2 backfat was related to an improvement in farrowing success at parity 1 from 62 to 84% (from the lowest average P2 backfat of 10.8 mm to the highest average P2 backfat 22.2 mm, respectively). Even the average mid-population P2 backfat of 15.1 mm at selection substantially reduced farrowing outcomes compared to the average fattest P2 backfat of 22.2 mm (73% vs 84%, respectively). In terms of longevity, a linear relationship could be seen between selection P2

backfat and survival to parity 2 with the percentage of sows being culled by parity 2 decreasing 59% to 35% between the leanest and fattest average P2 backfat levels.

Season of birth and farm-specific management practices had a significant impact on gilt selection, gilt mating, sow longevity and lifetime performance. More than 90% of the variation which could be explained by known factors for outcomes or lifetime performance measures were attributable to the season of birth and site the gilt was managed at after selection. Therefore, characteristics of individual gilts recorded early in life or at selection had relatively little impact on outcomes.

Physiological response to a low dose of gonadotropin at approximately day 140 of age was not associated with improved longevity or reproductive performance. There seemed to be an advantage of being heavier at a younger age in terms of showing a physical response, however this did not equate to superior longevity or reproductive performance to parity 3.

Overall, early-in-life parameters were not strong predictors of subsequent reproductive performance and longevity after selection. Whereas, characteristics recorded at selection, such as P2 backfat, were better indicators of subsequent performance and longevity. However, management factors after selection had the greatest effect on performance and longevity, despite the common rearing environment of gilts before selection.

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1. Background to the Research

1.1 Early lifetime performance indicators

Sow lifetime performance and herd feed conversion ratio are two of the most important economic factors affecting the profitability of pork production worldwide. High sow turnover or replacement rate within a herd leads to a reduction in sow lifetime performance (calculated as the number of pigs produced per female per day of herd life), especially if replacement rates for early parity sows are high. High sow turnover rates result in a higher proportion of younger sows in the herd, and in particular gilts, leading to increases in HFC (feed consumed per unit carcass weight produced) due to a greater proportion of gilt progeny within the herd (Smits, 2011). Compared to the progeny of multiparous sows, the progeny of gilts are lighter at birth and at weaning (Hendrix et al. 1978, Gatford et al. 2010, Craig et al. 2017), gain weight more slowly through to sale and are more susceptible to disease (Holyoake, 2006, Miller, 2008). All of these factors have a substantial impact on progeny feed efficiency and therefore negatively impact on overall HFC (Smits, 2011).

There has been little improvement over the last decade in the amount of sow turn-over despite considerable efforts to research the topic (Fig i). An APL (Australian Pork Limited) study conducted in 2003, identified that sows that were culled or died from a commercial breeding herd were lighter and leaner than the cohort of sows that remained productive. Improving sow body condition and feeding to maintain tissue protein and fat reserves was identified as necessary for lifetime reproductive performance improvements and lower sow replacement rates. The Pork CRC funded a large project in 2008 as 2D-104. As part of this project, increasing gilt protein reserves through her first gestation and lactation was examined. Although there was an increase in live weight without an increase in measured P2 backfat through dietary treatment, there was no benefit to lifetime number of litters or live born (Smits et al, 2009a). The authors, however, identified that gilt and sow weight affected lifetime performance, with animals that were above a recommended gilt mating weight of 135 kg exiting the herd early. In a further study (Smits et al. 2009b), it was found that sows with low fat reserves after parity 1 mating (<40 kg body fat) had a lower lifetime live born and longevity.

In 2013 the sow replacement rate was 54.8%, with the average parity at which a sow was culled sitting at 4.1 (Australian Pork Limited). This means that many sows are being culled from the herd before they reach can reach peak reproductive performance. A sow needs to at least reach her third or even her fourth parity before she begins to recover her own cost (Rodriguez-Zas et al. 2003; Levis, 2005). Therefore, her removal from the herd prior to parities 3-4 results in financial loss for the producer. There are a number of key reasons for premature sow turnover, with poor reproductive performance during the early parities a major cause of removal. In a review of the major causes for sow removal within a large commercial Australian farm, Hughes et al. (2010) found the single largest cause for culling was poor fertility, particularly in early parity sows. Interestingly, gilt culls accounted for 42.5 % of the fertility culls, with the majority of these (42%) failing to exhibit signs of pubertal oestrus in the required timeframe.

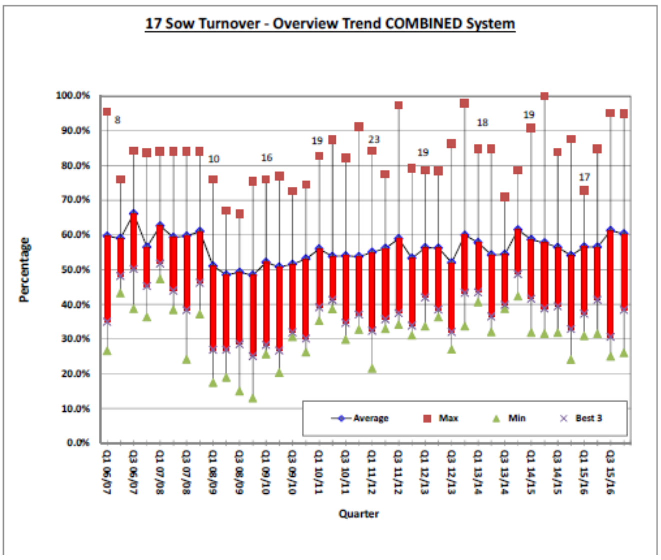

Figure i. Historical sow turnover figures since 2006/07 (Pork CRC Benchmark report, 2017)

Most research and on farm selection criteria for replacement gilts focuses on the gilt at or just prior to selection. Commercial multiplier gilts are typically assessed on phenotypic traits such as weight and physical conformation and to a lesser extent body fat or condition score. A recent study conducted in the USA by Knauer (2016) has suggested that lifetime performance characteristics of the replacement gilt should be the focus, rather than an assessment at one specific time point in her life (just prior to selection). Knauer (2016) looked at the effect of pre-weaning factors, such as birth weight, pre-weaning gain or weaning weight on sow lifetime productivity. Flowers (2009) has shown that gilts raised in litters of 7 or less show puberty earlier, have a higher ovulation rate and increased embryo survival compared to gilts raised in litters of 10 or more, reaffirming the hypothesis that factors that affect early life development may have significant effects on future reproduction. Further work, especially with Australian herds, on early life performance indicators, the relationships between multiple indicators as well as any risk factors that may impact on sow longevity is clearly warranted.

Therefore, by focussing on the development of the replacement gilt from birth up until the time of selection, with particular focus on pre-weaning growth and development, it is hypothesised that risk factors associated with poor sow longevity can be identified and interventions sought that can help reduce the effects of these factors.

1.2 Gonadotropin response as a selection tool

If a large proportion of replacement gilts fail to exhibit oestrus as identified by Hughes and Smits (2010), a selection tool that may help to identify gilts that have a higher probability of reproductive success is clearly warranted. Current selection criteria, particularly for multiplier replacement gilts, is primarily based on physical attributes at the time of selection (e.g. live weight, number of teats, conformation) which occurs when a gilt is approximately 23 weeks of age. However, the average mating age is approximately 30-34 weeks of age, after which a gilt will be deemed anoestrus and culled if she has not yet displayed oestrus or been mated. By the time a gilt has reached 34 weeks of age she will usually be too heavy and/or fat to be marketed as a prime animal, and therefore return on the carcass is less than optimal, especially when the extra costs incurred resulting from increased non-productive days are taken into consideration (Levis, 2005).

It has been well documented that gilts that show early puberty have improved longevity and greater lifetime performance (Koketsu et al. 1999; Patterson et al. 2010). Flowers (2009) proposed that boar exposure at approximately 20 weeks of age may allow the identification of gilts that display early puberty and could be potentially used to select replacement gilts. However, boar exposure can be logistically difficult and labour intensive, particularly during seasonal infertility periods when it's recommended to stimulate gilts twice a day (Hughes, 1994). Boar exposure stimulates the secretion of gonadotropic hormones that stimulate oestrogen production by the ovaries. As the level of oestrogen increases, classic sexual behaviours associated with oestrus i.e. reddening/enlargement of the vulva and the standing reflex are exhibited and eventually ovulation occurs. Flowers (2014) suggested that gilts that show early puberty have an increased longevity because they are more sensitive to oestrogens (i.e. their reproductive system can function normally with less oestrogen). Therefore, rather than using boar exposure, giving gilts a low dose of gonadotropins (200IU of PG600 – one third of a normal dose used to induce oestrus and ovulation) may be a feasible and practical way to test a gilt's response to gonadotropic hormones without inducing ovulation. PG600 is normally used in commercial pig production to induce pubertal oestrus in gilts. Essentially, PG600 mimics the actions of follicle stimulating hormone and luteinising hormone causing follicle growth and ovulation. Flowers (2014) found that a low dose of gonadotropins at 140 days of age evoked a physical response (in terms of vulva swelling and redness) comparable to that of using boar exposure. Also, the authors observed that gilts that responded within 10 days of the injection with clear swelling and reddening of the vulva were more likely to respond to the induction of a natural pubertal oestrus later on. Obviously, only using one third of a dose of PG600 is more cost effective per gilt than using a full dose and, because the intention is not to cause ovulation, as gilts will not be mated immediately on the induced oestrus.

Therefore, the hypothesis for this part of the study was that gilts that show a physical response (i.e. reddening and swelling of the vulva) within 7 days of a low dose of PG600 will be more likely to have a successful first mating and therefore have increased longevity in the breeding herd, compared to gilts that do not show a response.

2. Objectives of the Research Project

1. To reduce annual sow replacement rates in commercial multiplier herds from 60 to 40% by focussing on a novel selection index for replacement gilts.

2. To develop specific targets for early lifetime performance parameters that reduce early sow turnover due to poor reproductive performance.

3. To assess the use of gonadotropins at selection as a means of identifying gilts that are less likely to successfully enter and stay in the sow herd.

3. Research Methodology - Early lifetime performance indicators

3.1 Animals

All animal procedures were conducted with prior institutional ethical approval under the requirements of the NSW Prevention of Cruelty to Animals Act 1985, in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organisation/Australian Animal Commission *Code of Practice for the Care and Use of Animals for Scientific Purposes.*

From January 2014 until March 2015 individual birth weights (N=30,652) and day 21 weights were recorded on multiplier gilts (F1: Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) born at the genetic supply unit of a large commercial pig producer located in southern New South Wales, Australia. At this facility, approximately 90% of weaned gilts were housed for rearing as potential replacement females (N=22,116). As a matter of routine recording, the breed, parity and gestation length of their dams as well the number of total piglets born in that litter were recorded for each individual gilt through historical data capture. The date of birth was also recorded as a means of discerning if seasonal effects had any implications on the traits measured. Post-weaning weights and gain were recorded on a subset of gilts approximately two weeks (mean age: 46 days) after weaning at an average age of 29 days.

At approximately 160-170 days of age, all gilts were evaluated at the genetics multiplier supply farm and around 40% of the weaned F1 gilts were selected to enter the breeding herd as replacement animals. Selection criteria at this time point included live weight (gilts must have been heavier than 70 kg at selection to be used for breeding); body, vulva and udder conformation; teat number; and absence of physical defects such as hernias or lameness. Live weight at selection was recorded for all selected F1 gilts, while P2 backfat depth was recorded on approximately half of these F1 gilts. Gilts excess to internal gilt supply needs were sold and were excluded from the dataset.

All selected gilts were managed under commercial conditions at the Corowa site. Once selected, gilts were kept for approximately five weeks at the multiplier farm, after which they were transported to the mating shed of one of the five individual farms for boar exposure and oestrus detection from this period onwards (approximately 190 days age, depending on farm). Gilts were then brought to the designated mating area (DMA) at least once daily and exposed to a number of 'teaser' boars to stimulate puberty. Gilts were mated (by artificial insemination with 2.3×10^9 sperm cells) at their first or second observed oestrus depending on the farm, time of year, and management recommendation indicated by the estimated weight at each observed oestrus (measured by the Allometric Growth Tape for Gilts; SRDP, University of Alberta, Canada). The growth tape approximates the live weight of the animal at oestrus according to the circumference of the girth of the animal at the level of the shoulder, and recommends mating or measuring again at the next observed oestrus (101-135 kg), mating at the observed oestrus (136-150 kg), or not mating (<100 kg or >150 kg) based on this approximation. The age and estimated weight of the gilt at her first mating as well as the number of days from selection to mating was recorded. After mating, all gilts were housed for the duration of their gestation in group pens with various group sizes and feeding systems depending on farm (space allowance approximately 1.8 m^2 per sow).

The feeding regime varied throughout the gilts' lifetime. Gilts were given *ad libitum* access to a number of commercial weaner and grower diets from weaning until 18 weeks of age. From 19 weeks of age, gilts were fed a specific gilt developer diet *ad libitum* until entry into the breeding herd at approximately

28 weeks of age. Once transferred to the breeding site gilts were fed a commercial lactation diet *ad libitum* (where possible – this was somewhat restricted at sites where training in the use of electronic sow feeders takes place) up until they were mated. In gestation, gilts and sows were restrict-fed approximately 2.3 to 2.5 kg per day of a commercial gestation diet up until farrowing. Access to feed was *ad libitum* during lactation, except in the first 4 days after farrowing where they were fed on a step-up program. All sites had identical diet specifications and feeding curves throughout the different stages of the reproductive cycle. However the mode of delivery of the gestation diet varied between sites, with some sites using electronic sow feeder systems and others floor fed systems; either open floor or with shoulder bays. Pregnancy and farrowing outcomes were recorded for each successive mating up until the end of the recording period (November 2016). If a sow was removed from the herd prior to the end of the recording period, the reason for and age of the gilt/sow at removal was recorded. Removals were categorised as being either for reproductive, management or health reasons.

3.2 Traits evaluated and analyses of data

Selection outcomes were established for gilts which were known to be weaned (N=22,116). Subsequent outcomes were established only for selected gilts (N=8,893), which were tagged and transferred to commercial farms at the Corowa site. Outcomes for selected gilts included whether they were selected or not (SEL01); mated or not (MATE01); farrowed at least once or not (FARR01); and were culled without farrowing (CULLP0), after their first (CULLP1), second farrowing (CULLP2) or third farrowing (CULLP3). The trait FARR01 is for any farrowing as a parity 1, including farrowings from a return mating. These traits were considered for analyses within two subsets of data: 1) all selected gilts, and 2) gilts which were mated at least once, and therefore could be considered to have entered the breeding herd (Table 1). The SEL01 outcome was determined on all records that were weaned. The other outcomes in Table 1 were recorded on the records of selected gilts only. Outcome traits all took values of 0 or 1.

Factors associated with the binary outcomes for individual gilts were subsequently investigated using stepwise logistic regression, using the procedure PROC LOGISTIC (SAS, Cary, NC). Early in life factors investigated included litter size of origin, individual birth weight, 21 day-weight (or pre-weaning gain), post-weaning weight (or post-weaning gain), each represented as ranking via deciles and treated as class effects for analyses. Early in life factors could be considered for their associations with all later outcome traits. Later in life traits included weight or P2 backfat at selection, or gilt mating weight, also represented as ranking in deciles. These factors could only be examined for their associations with traits recorded after selection, or after mating, in the case of gilt mating weights. Relevant factors were submitted as possible explanatory variables for each outcome trait, were included in the model in a step-wise fashion if significant at $P<0.05$, and only those remaining significant at $P<0.05$ were retained in the final models. Other significant factors affecting outcomes for sows, such as season of birth and breeding site, were accommodated simultaneously within the logistic regression analyses.

Table 1. Descriptions for traits or explanatory variables along with their abbreviations.

Trait	Abbreviation
Birth litter size (pigs/litter)	DamTB
Gestation length of birth litter (days)	DamGL
Birth weight (kg)	BWT
Pre-weaning gain to 21 days (kg)	PREGN
Weight at 21 days (kg)	WT21
Weaning age (days)	WAGE
Post-weaning age (days)	PWAGE
Post-weaning weight (kg) at 46 days of age	POSTWT
Post-weaning gain (kg) 21 d to 46 days of age	POSTGN
Selection age (days)	SELAGE
Selection weight (kg)	SELWT
Selection P2 (mm)	SELP2
Mating weight (kg)	MWT
Selected or not (values are 1 or 0)	SEL01
Mated or not (values are 1 or 0)	MATE01
Farrowed or not (values are 1 or 0)	FARR01
Culled by parity 0* (values are 1 or 0) as an un-farrowed gilt	CULLP0
Culled by parity 1* (values are 1 or 0)	CULLP1
Culled by parity 2* (values are 1 or 0)	CULLP2
Culled by parity 3* (values are 1 or 0)	CULLP3

*of selected gilts

3.2.1 Characterisation of deciles

F1 gilts were ranked using explanatory variables (e.g. birth weights) into 10 approximately equal sized groups representing deciles to investigate the association between early in life traits and later reproductive outcomes. However, variables with clustered or categorical values (e.g. weaning age or P2 backfat) were less likely to enable even distribution of sows across "decile" groups. Females without a record for explanatory variables were allocated to a separate (unrecorded) class level. Assignment to a decile (D) was performed either across time (DT), or within birth year-quarter (DBYQ). Correlations (r) between the alternative methods for ranking (DT vs DBYQ) into deciles exceeded 0.95 for all traits except weaning age and P2 backfat depth at selection (r: ~0.85) (Table 2). This is because weaning age and P2 backfat depth at selection vary more over time than other early in life characteristics. Correlations between trait deciles for DBYQ are also shown in Table 2.

Table 2. Correlations between ranking for decile across or within birth-year month (on diagonal in bold), along with the correlation between decile rank (ranked within BYQ) across traits (off-diagonals, plain text).

	DamTB	DamGL	BWT	PREGN	WT21	WAGE	POSTWT	POSTGN	SELWT	SELP2	MWT
DamTB	**1.0**	-0.09	-0.22	-0.03	-0.07	0.07	-0.04	-0.03	-0.06	-0.01ns	-0.01ns
DamGL		**1.0**	0.12	0.03	0.05	-0.37	-0.02	-0.08	-0.01ns	-0.00ns	-0.01ns
BWT			**0.99**	0.29	0.45	-0.03	0.36	0.21	0.24	0.02ns	0.12
PREGN				**0.97**	0.97	0.04	0.53	0.08	0.23	0.03ns	0.08
WT21					**0.97**	0.03	0.57	0.12	0.27	0.02ns	0.10
WAGE						**0.85**	0.42	0.56	0.12	-0.03ns	0.02ns
POSTWT							**0.97**	0.85	0.47	0.07	0.16
POSTGN								**0.97**	0.41	0.10	0.16
SELWT									**0.96**	0.40	0.28
SELP2										**0.85**	0.18

Deciles formed across time allow discreet within decile variable ranges to be identified, whereas deciles assigned within birth year-quarter resulted in some overlap of ranges for adjacent classes, but better describes relative ranking within groups of contemporaries which will be exposed to selection, mating and culling decisions at the same time. Therefore, results presented hereafter are based on ranking variables by DBYQ. For reference, the means and standard deviations (SDs) for each early-in-life trait ranked into deciles by DBYQ are shown in Table 3, along with the percent of gilts from each decile which were subsequently selected, mated and farrowed at least once. Similarly, ranking for traits recorded at selection or after are shown in Table 4.

Table 3. Means (standard deviations) of deciles (lowest to highest) for early-in-life traits for all gilts, along with the percent of gilts from each decile which were subsequently selected, mated and farrowed at least once (N=22,116).

Trait	Decile[1]	1	2	3	4	5	6	7	8	9	10
DamTB	recorded	6.81(1.34)	9.6(0.49)	11.0 (0)	12.0 (0)	13.0 (0)	na	14.0(0)	15.0(0)	16.0(0)	17.8(1.05)
	Selected %	41	44	42	42	40	na	39	40	38	39
	Mated, %	35	38	35	36	34	na	31	34	33	33
	Farrowed, %	30	34	32	32	30	na	31	31	30	30
BWT, kg	weighed	1.02(0.11)	1.22(0.04)	1.32(0.04)	1.42(0.04)	1.50(0.04)	1.59(0.04)	1.68(0.04)	1.79(0.05)	1.92(0.05)	2.17(0.17)
	Selected %	25	33	37	41	41	44	44	46	46	45
	Mated, %	21	29	32	35	36	37	38	39	40	38
	Farrowed, %	19	26	29	31	32	34	34	35	36	34
PREGN, kg	weighed	1.64(0.51)	2.61(0.32)	3.21(0.33)	3.70(0.34)	4.13(0.35)	4.55(0.36)	4.98(0.36)	5.43(0.37)	6.00(0.38)	7.02(0.67)
	Selected %	10	26	36	42	45	47	49	50	50	48
	Mated, %	8	20	31	35	39	41	42	44	43	42
	Farrowed, %	7	18	27	32	35	37	39	40	39	37
WT21, kg	weighed	3.00(0.53)	4.03(0.28)	4.69(0.31)	5.21(0.33)	5.67(0.36)	6.15(0.36)	6.59(0.37)	7.08(0.40)	7.72(0.40)	8.83(0.72)
	Selected %	8	25	37	42	44	49	49	49	50	49
	Mated, %	7	19	31	37	38	42	42	43	44	42
	Farrowed, %	6	17	28	34	34	38	38	39	30	37
WAGE, d	weighed	23.9(1.82)	25.5(1.37)	26.4(1.45)	27.1(1.60)	27.5(1.75)	29.0(2.13)	30.0(2.59)	29.2(1.83)	32.6(1.92)	33.0(2.82)
	Selected %	33	38	39	43	38	41	44	40	46	44
	Mated, %	27	32	33	37	32	36	38	33	40	38
	Farrowed, %	24	28	30	33	29	32	35	31	36	35
POSTWT, kg	weighed	7.17(1.16)	8.95(0.70)	9.88(0.67)	10.7(0.71)	11.5(0.76)	12.3(0.78)	13.0(0.85)	14.1(0.83)	15.3(0.86)	17.6(1.51)
46d of age	Selected %	34	49	52	57	55	56	59	57	59	58
	Mated, %	28	40	43	48	47	50	51	53	54	53
	Farrowed, %	25	37	39	43	42	47	47	48	50	49
POSTGN, kg	weighed	1.73(1.20)	3.32(0.64)	4.10(0.64)	4.80(0.59)	5.40(0.61)	5.98(0.61)	6.66(0.59)	7.39(0.60)	8.40(0.61)	10.3(1.23)
21d-46d of age	Selected %	37	52	52	56	51	57	55	57	60	58
	Mated, %	30	44	42	48	44	49	47	51	55	53
	Farrowed, %	29	39	38	44	42	45	43	47	50	50

[1]The number of observations in each decile (D) ranged from 989(D1)-3288 (D7) for DamTB; 2151-2350 for BWT, 2189-2200 for PRE; 1970-2404 for WT21; 1745-2562 for WAGE; 503-566 for POSTWT; and 506-554 for POSTGN.

Table 4. Means (standard deviations) of deciles for traits recorded at selection or mating for selected gilts (N=8,893), along with the percent of gilts from each decile which were subsequently mated and farrowed at least once

Trait	Decile[1]	1	2	3	4	5	6	7	8	9	10
SELWT	weighed	84.7 (4.5)	91.7(3.7)	95.7(3.62)	98.4(3.24)	102(3.29)	105(3.62)	108(3.27)	112(3.38)	117(3.57)	125(5.90)
	Mated, %	77	81	85	84	85	88	89	87	89	89
	Farrowed, %	70	72	77	75	77	80	78	79	79	77
SELP2	Weighed	10.8(1.23)	12.3(0.88)	13.4(0.83)	14.1(0.91)	15.1(0.82)	15.4(0.53)	16.6(0.49)	17.5(0.62)	19.0(0.71)	22.2(2.44)
	Mated, %	71	78	80	84	86	87	88	90	90	93
	Farrowed, %	62	70	72	78	73	72	76	82	78	84
MWT	weighed	118(5.8)	128(3.1)	133(2.3)	137 (1.2)	140 (1.3)	143(1.6)	147 (1.4)	151 (1.2)	156 (2.1)	166(5.4)
	Farrowed, %	91	90	91	90	89	90	90	90	91	91

[1]The number of observations in each decile ranged from 663-822 for SELWT; 268-440 for SELP2; and 616 to 783 for MWT.

4. Research Methodology - Gonadotropin response as a selection tool

4.1 Animals

All animal procedures were conducted with prior institutional ethical approval under the requirements of the NSW Prevention of Cruelty to Animals Act 1985, in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organisation/Australian Animal Commission *Code of Practice for the Care and Use of Animals for Scientific Purposes.*

At 144 ± 0.15 days of age, 563 F1 gilts (Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) were injected with a low dose (200 i.u.) of PG600® (400 IU of PMSG and 200 IU of hCG; Intervet, Holland). Only gilts that were showing no physical signs of cyclicity and had a high likelihood of being selected into the breeding herd were injected. Visual evaluations of the external genitalia of all gilts were undertaken once daily for 7 days following injection. Scoring of the external genitalia was done in accordance with that described in the study of Flowers (2014). The criteria used for scoring was as follows: 0 = no swelling and pale vulva; 1 = medium swelling and pink vulva; and 2 = large swollen and red vulva.
As these animals were also part of the larger project looking at early lifetime performance indicators details of gilt/sow management and measurements taken are outlined in section 3.1.

4.2 Statistical analyses

Continuous variables were analysed using GLM univariate analysis (SPSS, v. 24.0, IBM, USA). Binomial variables were analysed using chi square (χ^2). Values of $P < 0.05$ were considered significant and values of $P < 0.10$ were considered a trend.

Gilts that received a vulva response score of 0 within 7 days of PG600 at 20 weeks of age were considered Non-Responders (n=244) whilst gilts that received either a score of 1 (n=217) or 2 (n=102) were considered Responders for analysis.

5. Results – Early lifetime performance indicators

5.1 Raw data characteristics

There were 22,116 gilts weaned across 4231 litters (3348 dams) recorded in this project. The distribution of litters represented by dam parity group (PGRP) were: parity 1: 27.2%; parity 2: 23.2%, parities 3-5: 38.4% and parities 5+: 11.2%. However, the distribution of selected gilts by dam parity group was: parity 1: 18.6%; parity 2: 22.6%; parities 3-5: 47.4% and parities 5+: 11%. Therefore, selected gilts at birth were proportionally under-represented from gilt litters (first parity litters), and over-represented from later parity litters, at a level (~32%) higher than the discrepancy in born alive litter sizes (~9%) between these age groups. Part of the reduced representation of gilts from gilt litters arises from increased mortality of gilt progeny, as well as a higher percentage of gilts which do not meet the minimum weight criterion at selection. Dam parity and weaned litter size were not known by staff at the time of selection; therefore no allowances are made for smaller gilts resulting from parity 1 litters or larger weaned litters.

Raw data characteristics for commercial F1 gilts are shown in Table 5, along with the trait abbreviations which will be used hereafter. Based on mean values (Table 5), gilts grew at around 223g/day between birth and 21 days of age, 237 g/day between 21 to 46 days of age, or 612 g/day from birth to the point of selection. Of 22116 gilts weaned, 8893 (40.2%) were selected, 7608 (34%) were mated, and 6869 (31%) farrowed at least once. Of the selected gilts, the cumulative culls were 20.6% culled as gilts (P0, unmated); 34.8% were culled before P1 (selection to gilt farrowing); 43.1% were culled before parity 2 (selection to second litter farrowing); and 49% were culled before or within parity 3 (selection to fourth litter farrowing). Therefore, losses of selected gilts and un-censored gilts (un-selected gilts with an unknown reason) were largest from selection to herd entry (20.6%), decreasing to 14.2%, 8.3% and 5.9% between subsequent parities. Taking into account whether gilts were initially mated, or whether culling was due to "management culls" (~1% of culling decisions) rather than a deficiency of the individual sow, losses from mating to farrowing reduced to 7.8%, or from mating to culling in parity 1 (24.1%), parity 2 (33.7%) and parity 3 (40.5%). Thus, the breakdown of early losses (e.g. before P4) follows the pattern of: unmated gilts 12.8%, mated gilts which did not farrow (7.2%), sows culled in P1 (15.0%), sows culled in P2 (8.9%) and sows culled in P3 (6.3%).

Table 5. Raw data characteristics for F1 gilts

Trait	N records	Mean(SD)	Range
Birth litter size	10463	13.5 (2.87)	1-23
Birth weight (kg)	10477	1.61 (0.32)	0.58-3.0
Pre-weaning gain to 21 days (kg)	10423	4.69 (1.41)	-0.3 to 10.9
Weight at 21 days (kg)	10425	6.29 (1.51)	1.20-12.5
Weaning age (days)	10465	28.7 (3.40)	19-38
Post-weaning age (days)	3288	46.1 (3.66)	35-59
Post-weaning weight (kg)	3288	12.3 (2.99)	2.80-22.7
Post-weaning gain (kg)	3216	5.95 (2.46)	-3.7 to 14.8
Selection age (days)	8962	170 (4.23)	146-195
Selection weight (kg)	7446	104 (12.1)	67-151
Selection P2 (mm)	3399	15.7 (3.27)	5-37
Mating weight (kg)	7056	142 (13.5)	90-195
Selected or not	10480	84.9	0/1
Mated or not	10480	72.6	0/1
Farrowed or not	10480	65.6	0/1
Culled without farrowing*	8893	20.6	0/1
Culled by parity 1*	8893	34.8	0/1
Culled by parity 2*	8893	43.1	0/1
Culled by parity 3*	8893	49.0	0/1

*of selected gilts, including "management" culls

5.2 Correlations between deciles for explanatory variables

In addition to demonstrating the association between deciles assigned over time vs within contemporaries, the associations between early-in-life traits and traits at selection or mating are also illustrated by the correlations between deciles (refer Table 2). Gain traits were highly correlated with end weights at 21 days (r: 0.97) or post-weaning (r: 0.85), showing that weight provides similar ranking to gain recorded up to each end point. However, individual ranking for pre- and post-weaning gains were poorly correlated with each other (r: 0.08), whereas ranking on absolute values for pre- and post-weaning weights were moderately correlated (r: 0.57). Gain traits have higher coefficients of variation than weight traits, contributing to lower correlations between different periods of gain. In addition, gain while suckling is influenced by maternal effects, whereas gain after weaning reflects individual adaption to weaning, and these sources of variation for gain are relatively independent.

Correlations between deciles for early life and selection weight traits were relatively lower, ranging between 0.24 for BWT to 0.47 for POSTWT (Table 2), demonstrating the impact of individual variability in growth over time on later weights. That is, very early weights are only moderately associated, at best, with weights recorded at the time of selection for individual animals. At selection, the correlation between decile ranking for weight and P2 backfat was relatively high (r: 0.40), demonstrating the strong association between weight and fatness when these traits are recorded on young gilts at selection.

Despite the relatively short time interval between selection and mating, the correlation between rank for the weights recorded at these two time points was relatively low (r: 0.28), and the correlation between selection P2 backfat and mating weight was also reduced (r: 0.18; Table 2). Gilts in this study had very variable weight changes between selection and mating due to their transfer to multiple breeding sites, each site introducing variation via differences in gilt development and mating strategies. In addition, gilt weight at mating was based on gilt weight tapes (indirect weight assessment), whereas selection weights were obtained using weigh scales (direct weight data capture), which would also be expected to lower the correlation between these measurements because they are not recorded using the same methodology. Finally, the subsets of gilts with both records tended to decrease as measurements were temporally further apart, but these subsets were generally >3000 observations, with the exception of trait combinations involving P2 backfat at selection. Moreover, the animals in reduced subsets were generally a random representation of the population as a whole, and therefore the results should also represent associations which would be observed in the wider population.

5.3 Significant factors affecting outcomes for F1 multiplier gilts

Significant early-in-life factors affecting whether a gilt was selected, mated, farrowed, or was culled up to parity 1, 2 or 3 are summarised in Table 6. Early lifetime performance indicators had the maximum effect on the decision to select a gilt or not, in combination explaining up to 14.1% of the variation in selection outcomes (indicated by R^2 values). This is because early weights (BWT, WT21), WAGE and gain (PREGN, POSTGN) are positively correlated with later weights, which is a primary selection criterion for replacement gilts. Nevertheless, this R^2 value is relatively low, indicating that the early life performance indicators were not strong predictors for selection outcomes. For selected gilts, some early life performance indicators, such as pre- and post-weaning growth (PREGN and POSTGN), continued to act as significant predictors for MATE01 (max R^2 10.5%). However, post-weaning growth was only a significant predictor when selection characteristics (e.g. selection weight and P2) were not known. Moreover, after selection and if a mating was achieved, all model R^2 were very low (max 4.2%) for gilt outcomes, demonstrating that the variables considered were relatively poor predictors, either singly or in combination, of future performance outcomes for selected gilts after a first mating had been achieved. This pattern of results demonstrates that early-in-life characteristics are most important for whether a gilt is selected in the first instance, and successfully enters the breeding herd in the second instance, as indicated by a first mating.

Birth litter size (DamTB) and gestation length (Dam GL) were not significantly associated with any outcomes for gilts (Table 6). This was because birth litter size and gestation length did not affect whether gilts, of otherwise adequate weight at the time of selection, were likely to be excluded from selection for other reasons.

Birth year-month (BYM) significantly affected all outcomes for gilts, except for cull numbers at Parity 2 of the subset of gilts mated (Table 6). Birth year-month was the least significant for selection outcomes, as shown by the low partial R^2 value, because the number of selected gilts targeted per week is relatively constant. Farm site (FARM) where the gilts were sent from the multiplier significantly affected all reproductive outcomes from gilt mating onwards (Table 6). The breeder farm was a major factor which affected whether gilts were successfully mated and/or farrowed, and also when they were culled, even though all sites were owned by the same company. These sites differed in their management, layout, herd size, facility upgrades, and feeding systems, all of which will contribute to the success or otherwise of outcomes for selected gilts.

Dam parity group (i.e. gilt or sow litter at birth) of the selected gilt (PGRP) was a significant factor for MATE01, FAR01 and CULLP1 (Table 6). Selected gilts from gilt litters were more likely to record a failed mating than their contemporaries arising from sow litters, which affected their subsequent farrowing and culling outcome. When gilts originating from gilt litters were mated, there was no remaining effect of the 1st parity origin on farrowing or culling outcomes. This suggests that there may be a problem with the attainment of, or expression of, puberty and oestrus in progeny of gilt litters, even when differences in weight and fat depths at selection are also accommodated in the models for analysis.

Secondly, pre-weaning growth (PREGN) remained significant for FARR01 (Table 6), suggesting pre-weaning development was important to obtain successful matings, even when selection weight and P2 backfat were concurrently included in the models for analysis. In this sense, post-weaning growth (POSTGN) was relatively less significant because it was more highly correlated with weight at selection. Therefore, post-weaning growth was only a significant factor affecting outcomes when weight at selection was deliberately excluded from the models. Weight at selection captures variation in post-weaning growth. Accounting for pre-weaning growth did not eliminate the dam parity effect. Therefore, the dam parity effect of a breeder female being born to a gilt or older sow, cannot be fully explained by differences in the piglet development with respect to weight and body composition.

Finally, estimated weight at first mating (MWT) was always more important for outcomes in terms of early culling at parity 1 and 2 (CULLP1m; CULLP2m) than weight at selection (SELWT; Table 6). This was because the trajectory for changes in weight between selection and mating was quite diverse, both across gilts and across sites. Moreover, the estimated weight is used to make mating decisions (including not to mate).

Table 6. Significant factors affecting selection and reproductive outcomes for gilts, along with the full model R^2 (R^2), or the partial model R^2 (R^2_P) accounting for farm and/or birth year-month only (trait abbreviations are augmented to identify data subsets: s indicates the subset of selected gilts only, m represents the subset of mated gilts)

	SEL01	MATE01s	MATE01s	FAR01s	FAR01s	FAR01m	CULLP1s	CULLP1s	CULLP1m	CULLP2s	CULLP2s	CULLP2m
n	22116	8893	8893	8893	8893	7608	8893	8893	7608	8893	8893	7608
%*	40.2	85.9	86.0	77.6	77.6	90.3	35.0	35.0	24.4	43.3	43.3	34.1
R^2	14.1	9.2	10.5	5.3	6.1	4.2	3.4	4.6	3.3	1.8	2.6	2.0
R^2_P	1.9	7.5	7.5	4.1	4.1	4.2	2.9	2.9	1.2	1.8	1.8	1.2
BYM†	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ns
FARM‡	NA	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PGRP∫	ns	<0.0001	<0.0001	0.0108	0.0111	ns	0.0057	0.0109	ns	ns	ns	ns
DamTB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
DamGL	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
BWT	0.0062	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
WT21	<0.0001	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
WAGE	<0.0001	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PREGN	0.0014	0.0003	0.0026	<0.0001	<0.0001	ns	ns	ns	ns	ns	ns	ns
POSTGN	<0.0001	0.0230	ns	0.0339	ns	ns	0.0179	0.0495	ns	ns	ns	ns
SELWT	NA	NA	<0.0001	NA	0.0228	ns	NA	0.0168	ns	NA	ns	ns
SELP2	NA	NA	<0.0001	NA	<0.0001	ns	NA	<0.0001	0.0048	NA	<0.0001	0.0070
MWT	NA	NA	NA	NA	NA	ns	NA	NA	0.0440	NA	NA	0.0023

NA: not applicable; ns not significant. *Percentage of gilts mated, selected, farrowed & culled. †BYM: Birth Year-Month. ‡FARM: Breeder farm after selection. ∫PGRP: Parity Group of dam at selected gilt at birth, gilt litters or sows

5.3.1 Odds-ratios for significant effects

The significance, or otherwise, of variables for later outcomes is more clearly illustrated by considering the odds-ratio for individual class (decile) levels. The impact of early life variables for SEL01 is shown in Figure 1. The lowest decile of successfully weaned gilts for WAGE, BWT, WT21, PREGN or POSTGN were significantly less likely to be selected, with the largest impact occurring for low pre-weaning gain and weight at 21 days, where the probability of selection was generally <10% (see Table 3 for observed means by decile). The lowest 20% of females ranked for PREGN or WT21 were also compromised for SEL01, but to a lesser extent. Increasing WAGE and PREGN consistently improved the probability of a gilt being selected. However, there was no statistical advantage to being from deciles above the lowest 20% for BWT, WT21 or POSTGN for selection outcomes.

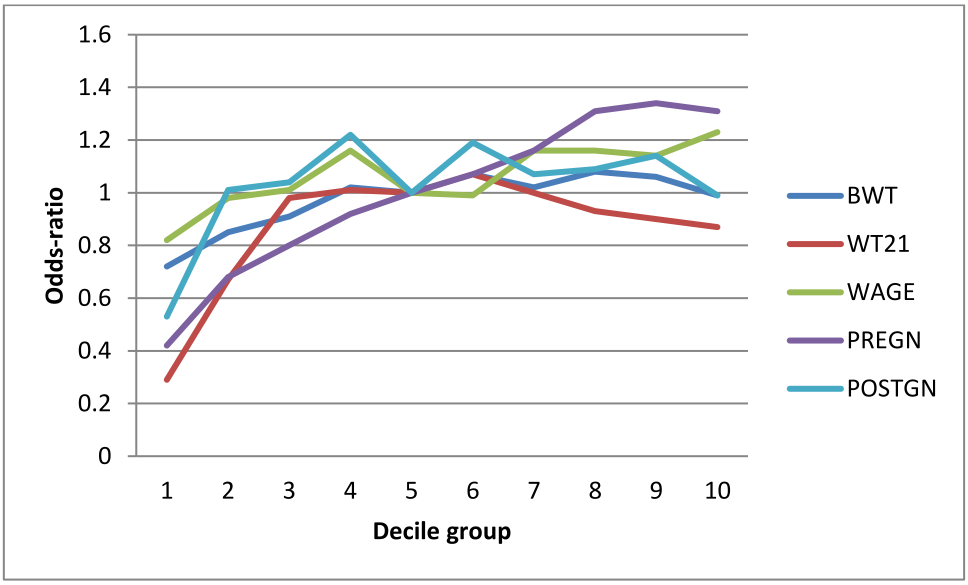

Figure 1. Odds-ratios for deciles of early weight and gain traits which are significantly (P<0.05) associated with the selection outcome (SEL01: selected or not) for weaned piglets. Decile 5 was denoted as the reference level, with odds-ratio equal to 1.

For selected gilts, pre-weaning gain remained significantly associated with gilts being mated and not culled before farrowing their first litter (Figure 2), even after weight and P2 backfat at selection were included in the model (see Table 6). Selected gilts in the lowest decile for pre-weaning gain had significantly reduced probabilities of being mated or farrowing (Table 6), based on the odds-ratios (Figure 2), while deciles higher than decile 1 for PREGN showed no clear advantage for mating and farrowing outcomes independent of their association with selection weight or P2 backfat.

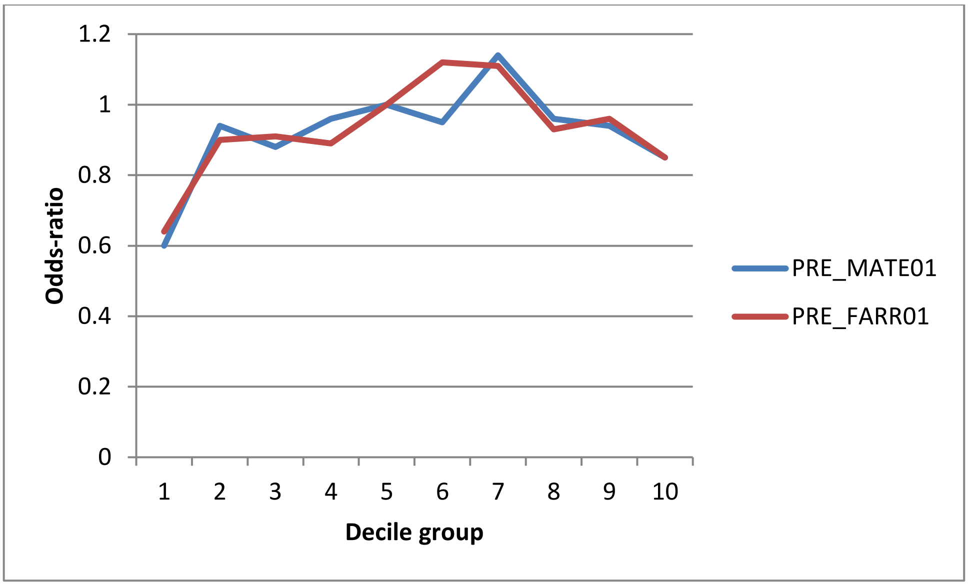

Figure 2. Odds-ratios for deciles of pre-weaning gain (PREGN) on mating (MATE01) and farrowing (FARR01) outcomes, when selection weight and P2 backfat are considered concurrently. Decile 5 was denoted as the reference level, with odds-ratio equal to 1.

In Figure 3, the association between SELWT or SELP2 for mating and farrowing outcomes is illustrated. As the decile for P2 backfat increased (range in average values between 11-22 mm approximately, see Table 4 for mean values) there was a consistent increase in the odds of gilts being mated or farrowing. In contrast, only ranking in the lowest two deciles for weight at selection (means 85 and 92kg, Table 4) was detrimental for mating and farrowing outcomes. Increasing P2 backfat at selection from the lowest to highest decile was associated with a change in observed farrowing success from 62 to 84% (Table 4). The leanest gilts at selection (mean 10.8 mm P2), had the lowest reproductive success.

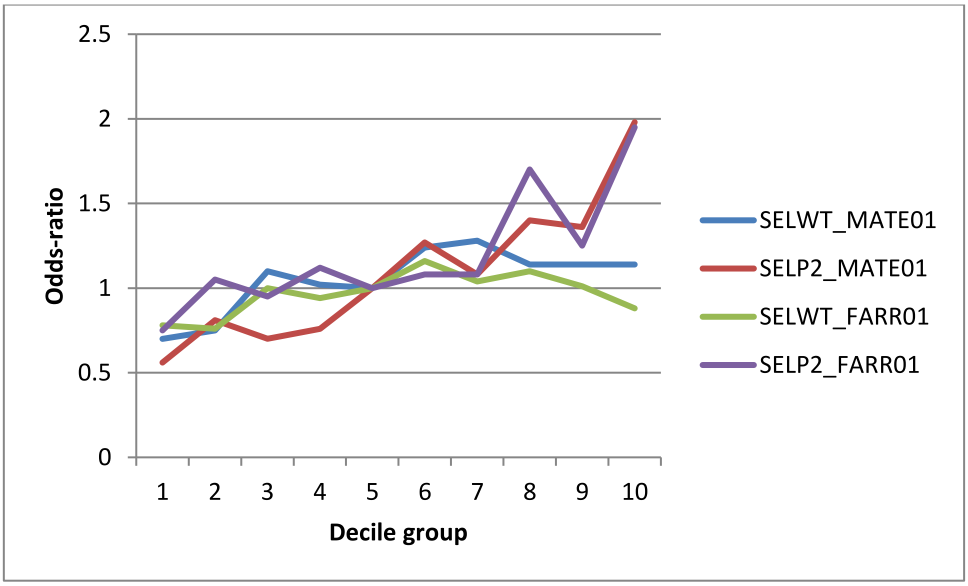

Figure 3. Odds-ratios for deciles of weight and P2 backfat at selection on mating (MATE01) and farrowing FARR01) outcomes. Decile 5 was denoted as the reference level, with odds-ratio equal to 1.

Similarly, the associations between post-weaning gain, selection weight or P2 backfat on culling patterns is illustrated by odds-ratios in Figure 4. The lowest decile for post weaning gain, selection weight or P2 backfat had a significantly increased probability of the selected gilt being culled in parity 1 compared to fatter gilts (Table 6). The corresponding observed culling rates for selected sows is shown in Table 7.

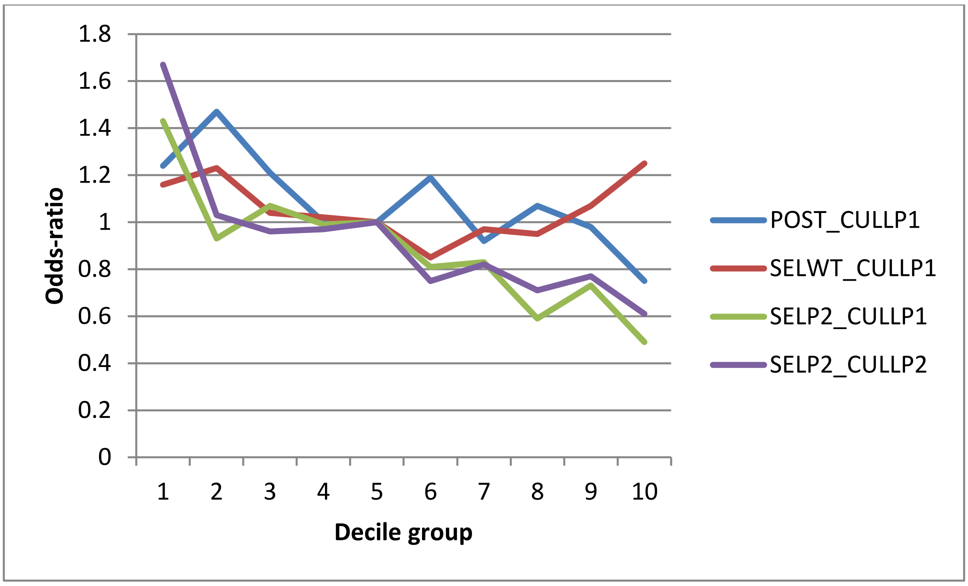

Figure 4. Odds-ratios for post weaning gain along with weight and P2 backfat at selection for culling within or before parity 1 (CULLP1) or parity 2 (CULLP2). Decile 5 was denoted as the reference level and was equal to 1.

Table 7. The number (N) and mean values (standard deviation) of selected gilts in each decile (ranked from lowest to highest) for post-weaning gain (POSTGN), selection weight (SELWT) or P2 backfat at selection (SELP2), along with the percentage from gilts selected of these sows culled in parity 0 (CULLP0), Parity1 (CULLP1) or Parity2 (CULLP2)

Trait	decile	1	2	3	4	5	6	7	8	9	10
POSTGN	N	192	274	271	309	260	304	284	300	318	302
	Mean	1.92(1.08)	3.27(0.67)	4.06(0.69)	4.84(0.59)	5.37(0.63)	5.97(0.63)	6.69(0.57)	7.36(0.61)	8.36(0.60)	10.3(1.15)
CulledP0, %		20	23	26	18	17	19	19	16	14	12
CulledP1, %		34	41	36	31	29	32	31	30	30	24
CulledP2, %		39	49	45	39	40	44	39	38	40	35
SELWT	N	749	721	746	729	812	659	711	766	766	718
	Mean	84.7(4.5)	91.7(3.7)	95.7(3.6)	98.3(3.2)	102(3.3)	105(3.6)	108(3.3)	112(3.4)	117(3.6)	125(5.9)
CulledP0, %		26	25	20	22	20	18	18	18	19	20
CulledP1, %		37	37	34	34	32	29	31	30	33	35
CulledP2, %		45	45	42	42	42	37	40	39	42	44
SELP2	N	268	277	426	267	407	308	400	266	405	310
	Mean	10.8(1.24)	12.2(0.89)	13.4(0.84)	14.1(0.92)	15.1(0.53)	15.4(0.53)	16.6(0.49)	17.5(0.58)	19.0(0.71)	22.2(2.44)
CulledP0, %		30	24	24	19	24	24	22	16	20	13
CulledP1, %		46	36	39	36	39	35	34	27	31	24
CulledP2, %		59	47	46	44	48	41	42	39	40	35

The impact of dam parity group, where parity 1 refers to gilt litters, on outcomes for breeding females, after accounting for other significant factors, is shown in Table 8. Dam parity group was no longer significant for outcomes in the subset of mated gilts, demonstrating the primary impact of dam parity group (PGRP) was on whether gilts from gilt litters were selected and successfully mated in the first instance. Once successfully mated, dam parity group was no longer a significant factor affecting future outcomes for gilts.

Table 8. The impact of dam parity group on odds-ratios (first line) for outcomes of weaned (SEL01) or selected (MATE01, FARR01 or CULLP1) gilts, along with observed percent of gilts with that outcome by dam parity group (second line) under models which simultaneously accommodate pre-weaning gain, weight and P2 backfat at selection

Parity group	1	2	3-5	5+	
Trait					*P*-value
SEL01	NA	NA	NA	NA	ns
% of selected	34	44	42	39	
MATE01	1	1.53	1.44	1.57	<0.0001
% of selected	80	86	86	87	
FARR01	1	1.24	1.25	1.29	0.01
% of selected	72	75	77	78	
CULLP1	1	0.83	0.83	0.8	0.01
% of selected	42	36	36	35	

NA Not applicable. ns Non significant (*P>0.05)*

5.4 *Significant factors affecting lifetime performance measures*

At the end of the recording period, all sows included in the project had the opportunity to be mated and produce up to at least three parities, with the oldest sows having an opportunity to produce up to five parities. At this stage, around 50% of sows had been culled in total, including about 1% management culls (i.e. not due to individual sow failure). Lifetime productivity traits were calculated for sows which entered the herd (i.e. were mated). Traits evaluated included the total pigs produced prior to culling (TPP), as well as pigs per day (PPD), which was defined as TPP/productive days x 100, where productive days excludes variation introduced by lactation length. TTP has a strong association with the number of parities a sow is retained for (see Figure 5). However, the relationship between TTP and PPD demonstrates that there is substantial overlap of PPD across parities 3-5 (Figure 6), which has implications for the profitability of individual sows. Values for PPD are maximised by both large litter size combined with unproblematic rebreeding, and can rapidly deteriorate for sows which return for re-mating between farrowings or with persistently below average litter size.

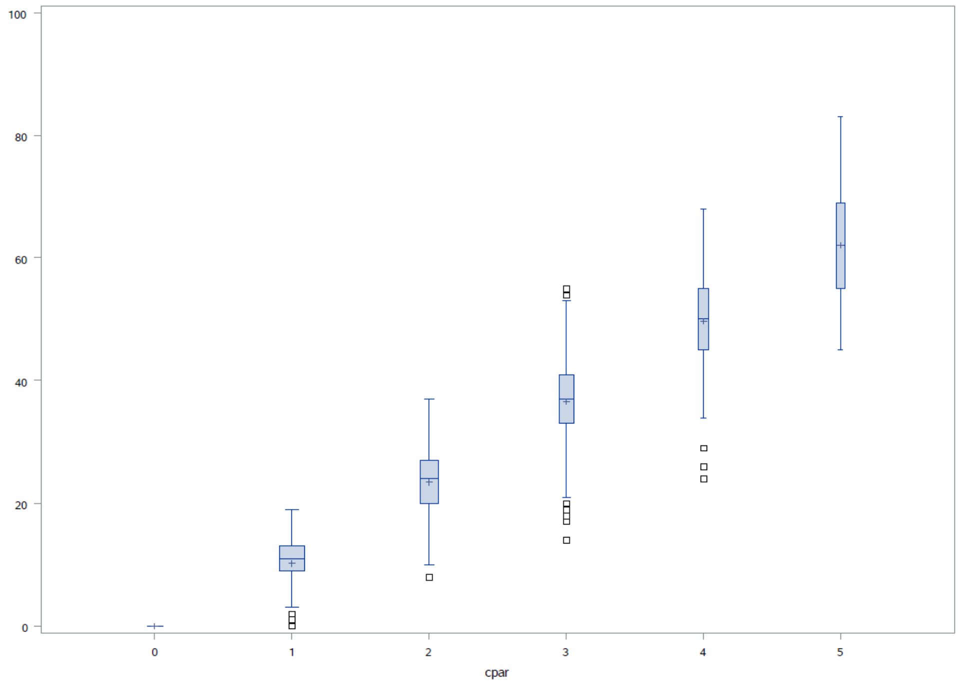

Figure 5. Boxplot of total pigs produced by parity at culling

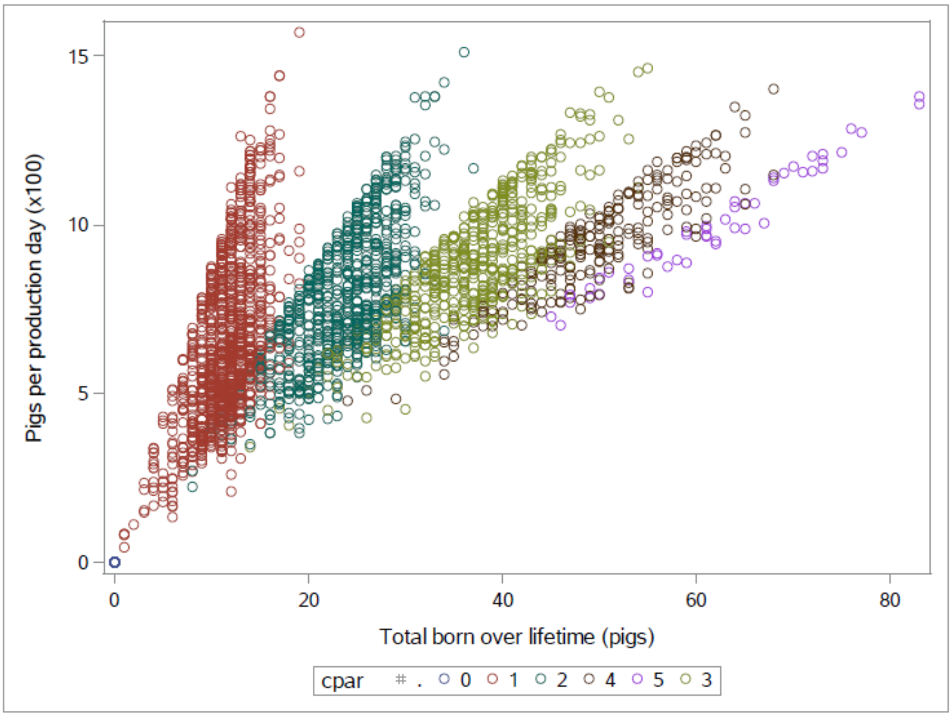

Figure 6. The scatterplot of total pigs born over sow lifetime and pigs per production day, with parity at culling highlighted in different colours

From raw means in Table 9, it is clear that the failure to farrow of mated sows has a substantial impact on means for the lifetime productivity traits calculated. Thus, achieving a first farrowing will rapidly increase means for these traits. A summary of significant effects for age at first mating, first parity litter size characteristics, parity of culling and the total lifetime pigs produced (or pigs produced per day in the herd) for uncensored sows is shown in Table 10. As was observed for outcome traits, birth year-month and breeding herd site accounted for most of the variation accounted for by the model for the lifetime productivity measures observed, while individual gilt characteristics explained relatively little. Birth year-month and breeding site represented more than 90% of the R^2 value (compare R^2P with R^2) for TPP, PPD and CPAR, and about 85% of the model R^2 value for AGEF and the first parity litter size traits. Only estimated weight at mating and P2 backfat at selection contributed to explaining further variation in the lifetime performance measures (TPP, PPD and CPAR). Since the gilt tape also recommends not mating gilts in certain weight classes (<100kg or >150kg), part of the gilt weight effect also occurs through implementation of this decision.

Table 9. Raw data means for lifetime productivity traits

		Mated sows		Farrowed sows	
Trait	Abbreviation	N	Mean(SD)	N	Mean(SD)
Age at first mating (days)	AGEF	7619	222(20.1)	6870	222(19.8)
Total born in parity 1 (pigs/litter)	TB_P1	6869	11.6 (2.69)	6869	11.6(2.69)
Born alive in parity 1 (pigs/litter)	NBA_P1	6869	10.8 (2.62)	6869	10.8(2.62)
Total pigs produced[1] (pigs)	TPP	3393	19.7 (17.3)	2733	25.2 (15.7)
Pigs per day[2]	PPD	3307	5.93 (3.80)	2647	7.66 (2.37)
Parity at culling	CPAR	3307	1.59 (1.21)	2647	2.00 (1.06)

[1]uncensored sows only; [2]adjusting for lactation length

Table 10. Significant factors affecting lifetime productivity traits of mated sows, with regression coefficients for the full model (R^2) or the partial model (R^2_P) accounting for Farm and/or birth year-month

	BYM	FARM	AGEF	SEL_WT	SEL_P2	MWT	POSTGN	R^2_P	R^2
AGEF	<0.0001	<0.0001	NA	<0.0001	<0.0001	NA	0.0043	9.7	11.3
TB_P1	0.0016	<0.0001	<0.0001	0.015	0.062	<0.0001	ns	2.8	4.5
NBA_P1	0.0002	<0.0001	0.0043	ns	ns	<0.0001	ns	2.6	3.5
TPP	<0.0001	0.0003	<0.0001	ns	0.0092	ns	ns	13.1	14.1
PPD[1]	<0.0001	0.0033	0.0105	ns	ns	0.0247	ns	3.5	3.8
CPAR	<0.0001	<0.0001	0.0015	ns	0.0013	ns	ns	8.6	9.5

[1]days component is adjusted for lactation length. NA Not applicable. ns Non significant (*P>0.05*)

6. Results – Gonadotropin response as a selection tool

The characteristics of the young gilt in terms of post-foster litter size, average birth weight and average day 21 weight were not significantly different (P>0.05) between those gilts that responded to the low dose of PG600 and those that did not respond (Table 11). The percentage of gilt progeny selected that did or did not respond to the low dose of PG600 was not different between treatments (17 vs. 21%, respectively; χ^2=1.91, P=0.167). Age at selection did differ significantly, with gilts that responded to the low dose of PG600 being 1.5 days younger at selection compared to those gilts that did not respond (P=0.001; Table 11), which is more than likely a reflection of the different ages at injection. However, despite this difference in age, selection weight and selection P2 backfat was similar between responders and non-responders.

Of the 563 gilts selected, 48.1% were classified as Responders and 51.9% as Non-Responders. Overall, 494 (87.7%) gilts were mated at least once. There was no significant difference in the proportion of gilts mated that were classified as either Responders or Non-Responders (88.5% vs. 87.3%, χ^2=0.45, P=0.501). There were no differences in removal reasons before first mating between Responders and Non-Responders (data not shown). When mated for the first time Responder gilts were 2.6 days younger on average than Non-Responder gilts (P<0.05; Table 11).

The farrowing rate from the first mating for Non-Responder gilts was 90% compared to 86.6% for those gilts that responded (χ^2=1.85, P=0.173). Of those gilts that did not respond, 66.6% of pregnancy failure was due to reproductive reasons compared to 81.8% for those gilts that did respond (χ^2=4.99, P=0.026). When pregnancy failure was analysed within breeding site, Responder gilts at Site 1 and Site 2 had a significantly higher percentage of sows failing their first mating due to reproductive reasons compared to Non-Responder gilts (Table 12). When reproductive failures were compared within the Non-Responders between sites, gilts at Site 3 were significantly more likely to have a failed pregnancy due to reproductive reasons compared to Site 2 and they also tended to have a higher percentage of reproductive failure than gilts at Site 1 (Table 13). There was also a trend for gilts at Site 2 to have a reproductive failure than gilts at site 4. Reproductive failure x Site analysis within Responder gilts showed there was only a trend (P<0.10) for gilts at Site 3 to have a higher failure rate than gilts at site 5, with no differences between any of the other sites (Table 14). First parity total born and born alive did not differ between Responders and Non-Responders (Table 11).

Longevity to Parity 3 (weaned 3rd litter) was not different between Non-responder and Responder sows (64 vs. 66%, respectively; χ^2=0.11, n.s.). After their first mating there was no difference between Responders and Non-Responders in terms of the percentage of gilts removed for reproductive, management or health reasons up until the point of weaning their 3rd litter (data not shown). Total matings, total born and total born alive up to parity 3 was not different between Responders and Non-Responders (Table 11).

Table 11. Pre-selection, selection, and first mating parameters and reproductive outcomes for gilts that did (Responders) or did not (Non-responders) respond to a low dose of PG600 at 140 days of age. Data are expressed as mean ± standard error.

	Non responders	Responders	χ^2	*P*-value
Birth weight (kg)	1.68 ± 0.01	1.65 ± 0.02		0.227
Post foster litter size	11.97 ± 0.10	12.06 ± 0.10		0.537
Day 21 weight (kg)	6.36 ± 0.08	6.63 ± 0.09		0.999
N selected	292	271		
Age at injection of PG600	144.4 ± 0.21 [a]	143.7 ± 0.22 [b]		0.017
Age at selection (days)	171.2 ± 0.7[a]	169.7 ± 0.7[b]		0.001
Selection weight (kg)[1]	106.7 ± 0.7	107.0 ± 0.7		0.785
Selection P2 backfat (mm)[1]	16.4 ± 0.3	16.1 ± 0.3		0.528
N mated	254	240	0.32	0.569
Age at first mating (d)[1]	217.5 ± 0.9[a]	214.9 ± 0.9[b]		0.034
First mating weight (kg)[2,3]	142.1 ± 0.8	141 ± 0.8		0.328
N farrowed	230	208	1.85	0.173
First parity total born[4]	11.90 ± 0.17	12.0 ± 0.19		0.732
First parity born alive[4]	11.12 ± 0.17	11.24 ± 0.18		0.623
Number of matings taken to reach parity 3	3.13 ± 0.03	3.15 ± 0.3		0.494
Cumulative total born up to parity 3	38.83 ± 0.41	38.47 ± 0.44		0.545
Cumulative total born alive up to parity 3	36.54 ± 0.40	36.07 ± 0.43		0.426

[a,b]Means in a row not having the same superscript are significantly different ($P < 0.05$).
[1]Corrected for age at selection
[2]Corrected for age at mating
[3]Estimated using the Allometric Growth Tape for Gilts; SRDP, University of Alberta, Canada
[4]For gilts that had a successful farrowing from their first mating

Table 12. Number and percentage of pregnancy failures due to reproductive reasons for Non-Responders and Responders according to farm site they were bred.

	Non Responders	Responders	X^2	P-value
Site 1	3/5 (60%)	7/7 (100%)	3.36	0.067
Site 2	1/4 (25%)	5/5 (100%)	5.63	0.018
Site 3	6/6 (100%)	9/9 (100%)	0.00	1.000
Site 4	4/6 (66%)	3/4 (75%)	0.08	0.778
Site 5	2/3 (66%)	5/7 (71%)	0.02	0.880
Overall	16/24 (66.6%)	18/22 (81%)	4.99	0.026

Table 13. Chi-square analysis (X^2) with probability values (P) for failures due to reproductive reasons in Non- Responder gilts to PG600.

	Site 1	Site 2	Site 3	Site 4
Site 1				
Site 2	$X^2 = 1.10$ P = 0.294			
Site 3	$X^2 = 2.93$ P = 0.087	$X^2 = 6.43$ P = 0.011		
Site 4	$X^2 = 0.05$ P = 0.819	$X^2 = 2.72$ P = 0.099	$X^2 = 2.40$ P = 0.121	
Site 5	$X^2 = 0.04$ P = 0.850	$X^2 = 1.22$ P = 0.270	$X^2 = 2.25$ P = 0.134	$X^2 = 0.00$ P = 1.000

Table 14. Chi-square analysis (X^2) with probability values (P) for failures due to reproductive reasons in Responder gilts to PG600

	Site 1	Site 2	Site 3	Site 4
Site 1				
Site 2	$X^2 = 0.00$ P = 0.100			
Site 3	$X^2 = 0.00$ P = 0.100	$X^2 = 0.00$ P = 0.100		
Site 4	$X^2 = 1.93$ P = 0.165	$X^2 = 1.14$ P = 0.236	$X^2 = 2.44$ P = 0.118	
Site 5	$X^2 = 2.33$ P = 0.127	$X^2 = 1.71$ P = 0.190	$X^2 = 2.94$ P = 0.086	$X^2 = 0.02$ P = 0.100

7. Discussion - Early lifetime performance indicators

The study by Knauer (2016) considered stayability for individual sows from birth through to parity 4, and examined each possible early-in-life variable fitted individually as a linear regression. Because each factor is considered in isolation, this does not accommodate the potentially strong correlations between alternative explanatory variables, or isolate which part of the growth curve might be relatively more important for future performance outcomes. Moreover, fitting a linear regression automatically implies linearity and does not identify non-linear relationships which may be present. Finally, when stayability is considered from birth, early-in-life traits can make a significant contribution to outcomes solely through their differential impact on both survival to the point of selection and selection decisions based on weight. This was also observed in our study, as early characteristics influenced both survival (before and after weaning) as well as selection outcomes.

In our study, the contributions of early-in-life traits were considered simultaneously within analyses, and with no implicit modelling of linear associations between explanatory variables and outcomes. Using rank in decile instead of trait values for analyses essentially rescaled each factor to a similar variability, which then enabled the relatively more important factors to be more clearly identified by their retention in the final model. By fitting decile as a class effect, it was also possible to illustrate the extent of non-linear relationships. Non-linear relationships, by definition, will result in reduced estimates of correlations between early-in-life effects and outcomes for recorded gilts. Knauer (2016) concluded that individually higher weaning age, heavier weaning weight and higher pre-weaning average daily gain resulted in better stayability to parity 4 and more piglets born, amongst sows delivered to commercial sow farms. Weaning age, weight and pre-weaning gain were positively correlated with each other and weight at selection, but it does not isolate whether it is these early growth periods per se which are important, or whether it is their impact on weight at selection. Knauer (2016) also indicated that for stayability from birth, lower litter size and cross-fostering were also important, because these factors are important for individual survival up until weaning. In their study, the litter size and cross-fostering effects were no longer important when birth weight was included in models for analysis, because birth weight is a relatively strong predictor of individual survival.

Our study yielded similar results, with a few exceptions. One exception was birth of origin litter size and gestation length, which were not significant for any future reproductive outcomes of the potential breeder gilt, as estimated in a multivariate model. From this result, we can conclude that it is very likely that these factors were only important in the study of Knauer because of their known impact (particularly with respect to litter size) on birth and therefore early weights, which were retained in preference to litter size variables in our models. Secondly, dam parity group remained significant in our study for outcomes recorded to parity 1, which contains the presence or absence of a first mating event. Dam parity remained significant to this point in time, even after early weight traits were included in models for analyses. After closer examination of solutions, the dam parity effect was solely represented by a significant difference between outcomes for daughters of gilts vs sows, after accounting for weight, but this difference was no longer present in the subset of data for mated gilts ($P>0.05$). This essentially indicates that dam parity (gilt litters vs sow litters) has an impact on the probability of daughters being weaned in the first instance, as well as the probability of their selected daughters getting mated. Once mated, the impact of dam parity was significant to parity 2 longevity. A similar result has been observed in maternal breeds of sheep joined to lamb at a young age, which show lower progesterone and fertility levels in ewes born to yearling dams and, by implication, delayed puberty (Bunter et al., 2017). This phenomenon warrants further investigation for pigs. The third exception was that linearity, assumed by Knauer (2016), was not consistently observed and, if weight or P2 backfat at selection were known and included in models for analysis, typically early in life traits were no longer significant because of the correlations between early in life and selection traits. Compared to early in life predictors, characteristics recorded at selection were the best indicators of subsequent performance outcomes for selected gilts, because they more closely represent the sow's phenotype which will be subjected to the prevailing management regime and environment.

The odds-ratio analysis provided information as to possible threshold levels of each trait on the reproductive outcomes of breeder gilts. The lowest decile for weaning age (mean 24 days), birth weight (mean 1.0 kg), and post-weaning growth (7.2 kg between 21 to 46 days) were least likely to be selected as a breeder gilt by 24 weeks of age. The lowest 20% of females for pre weaning growth (< 2.6 kg gain by 21 days) and 21 d weight were also least likely to be selected (< 4kg at 21 days of age). Although increasing weaning age and pre-weaning growth improved the probability of a weaned breeder female to be selected, there was no statistical likelihood of being selected when birth weights, 21 d weights or post-weaning growth was improved above the mean values stated above. When the outlook for a selected gilt to be mated is looked at, pre weaning growth values less than 2.6 kg gain (approx. 125 g/day), was identified as being at risk.

The odds-ratio analysis also highlighted the importance of selection fatness on reproductive outcomes for lifetime performance and longevity. At each increase in decile for selection P2 backfat, there was a linear increase in the likelihood of gilts being mated and farrowing. Whereas for selection weight, only the lightest 20% of the selected gilts (< 92 kg) resulted in a lower mating and farrowing outcome. Increasing P2 backfat was related to an improvement in farrowing success at parity 1 from 62 to 84%. Even from the mid-population decile (decile 5) that averaged 15.1 mm at selection, had a substantially lower farrowing outcome compared to the fattest 10% (average 22.2 mm P2) of selected gilts (73% vs 84%, respectively). Fatter gilts also were least likely to be culled by parity 2. This was in a linear relationship as selection P2 backfat increased with decile (59% to 35% culled by parity 2 between the leanest and fattest decile). This was independent of selection weight which was no significantly related to culling likelihood by parity 2. The importance of P2 backfat in this population for sow longevity has been observed previously (Bunter et al. 2010, Lewis and Bunter, 2011, Lewis and Bunter, 2013).

The effect of the dam parity of the breeding female was also shown to be limited to the weaned female being selected and mated in the first instance. Thereafter, dam parity had little impact on longevity or lifetime reproductive performance. If a potential breeding female is born light or has a low pre weaning growth rate because she is from a gilt litter, then as discussed above, this early-in-life parameter has an effect on selection and mating. Importantly, these results have identified that there is not a lifetime impairment of reproductive outcome if the daughter of a gilt is selected. Increasing the likelihood of being selected and mated could be improved by choosing breeding females from gilt litters that are heavy at day 1 and have a high pre-weaning growth.

Month of birth and breeding site (defining the management environment) were the best predictors of outcomes for gilts, more so than variables for weight or fatness recorded on individual gilts. This highlights how important seasonal effects are for the development of gilts, as well as the management and environment provided at entry to the breeding herd for outcomes of gilts. Given that all gilts were born and reared until selection on one site, before being moved to four additional sites, this outcome demonstrates the importance of differences in gilt management and environment to immediate outcomes for gilts, even when the genetic source and prior rearing environment are common.

This study population is similar to others reported where around half of the breeding sows are culled by the time they reach 5th parity (Koketsu et al, 1999; Hughes et al. 2010; Levis, 2005). The use of total pigs produced prior to culling (TPP) and pigs produced per day (PPD) as performance indicators are useful when looking at both early litter size and high non-productive days as they impact on herd profitability. Total lifetime performance, measured as lifetime born live or TPP, doesn't include inefficient return mating or extended weaning to oestrus intervals, whereas this is captured with a PPD trait.

In conclusion, this study has identified that there are some early-in-life indicators that are associated with breeder gilts being selected and mated, however these are not well related to further reproductive outcomes. The early-in-life parameters of most significance were weaning age, pre-weaning growth, 21 day weight and Selection P2 backfat was linearly related with reproductive outcome from gilt mating all the way through to culling at parity 2. There is clear evidence that increasing the fatness of the gilt will improve the reproductive outcome over her lifetime. We have also identified that breeding females chosen from gilt litters can reduce the likelihood of these gilts being selected and mated, and lasting to beyond parity 1. Finally, breeding season at birth and farm-specific management practices have a significant impact on gilt selection, gilt mating, sow longevity and lifetime performance.

8. Discussion – Gonadotropin response as a selection tool

Overall, 48% of gilts exposed to a low dose of gonadotropins at 140 days of age showed a physical response in terms of reddening and swelling of the vulva within 7 days of injection. This was lower than that of the response rate seen in the study of Flowers (2014) who had an overall response of 85%. However, interestingly in their study when the size of litter the gilt was raised in was taken in to consideration only 50% of gilts showed a physical response to the PG600 where litter size was greater than 10. It has been shown that reducing neonatal competition during lactation appears to have a positive association with gilts being able to respond to early boar exposure (Flowers, 2014). In the current study litter size was not manipulated other than that of the commercial practice of foster piglets between sows in order to even up litters and ensure sows carry no more piglets than they have functional teats. Average post-foster litter size was 12 and was not different for animals that responded or did not respond to the low dose of PG600. Given that in the study of Flowers (2014) only a 50% response rate was seen for gilts raised in litters greater than 10, the response rate 48% in the current study was reasonable.

Interestingly, gilts that did respond to the PG600 were significantly younger (0.7 days) on average at time of injection than those that didn't. This pattern continued with responder gilts also being significantly younger at selection and at mating, 1.5 and 2.6 days younger respectively, than non-responder gilts. However, weight at selection and mating was not different, which would indicate that gilts that responded to the PG600 reached heavier weights (particularly for mating, as mating is dependent on reaching a minimum threshold – 135 kg) at an earlier age than non-responder gilts. Weight may also explain why responder gilts were younger than non-responder gilts at PG600 injection as they were more than likely the heavier gilts of the group, however this cannot be certain as gilts were not weighed at the time of response detection.

Parity 1 performance did not differ between Responders and Non-Responders, however more responder gilts had a failed pregnancy due to reproductive reasons than non-responders. Overall, reproductive performance to parity 3 also did not differ between responders and non-responders. Up to 66% of sows that responded to the low dose of PG600 were still in the herd at parity 3. This was comparable to the retention level of responder gilts in the study of Flowers (2014). However, retention rate to parity 3 for non-responder gilts was 64% and did not differ from gilts that responded. This is in contradiction to the findings of Flowers (2014) who reported that only 12% of gilts that did not respond to the PG600 were retained up until weaning of their 3rd parity. Additionally, Flowers (2014) reported superior longevity in gilts that responded to the PG600 and were nursed in litters ≤7 and however, this was not investigated in this study. It is not clear why Flowers (2014) saw a reduction in the longevity of gilts that did not respond to PG600 whereas, essentially, there was no difference in responders and non-responders in the current study. However, possible explanations could be due to genetics and management regimes of the differing breeding sites.

In conclusion, giving selected gilts a low dose of gonadotropins as PG600 did not improve reproductive outcome in the proportion of gilts mated, or subsequent reproductive performance or longevity.

9. Implications & Recommendations

- This study has identified that there are some early-in-life indicators that are associated with breeder gilts being selected and mated, however these are not well related to further reproductive outcomes.
- The early-in-life parameters of most significance were weaning age, pre-weaning growth, 21 day weight and the later-in-life trait of selection P2 backfat:
    - Higher pre-weaning gain (rather than heavier birth weight) had the most consistent outcome for improving the probability of gilt selection.
    - F1 gilts from the lowest 10% of weights at 21 days (or gain to 21 days) were unlikely to be selected and also had a substantially reduced probability of being mated or farrowing if they were selected. These females should not be reared as replacement females.
    - Females ranked up to the second decile for pre-weaning growth (<125 g/d) or <4 kg at 21 days of age were also compromised for selection success, but to a lesser extent. There was no advantage to being from deciles above the lowest 20% for birth weight, day 21 weight or post-weaning growth for selection outcomes.
    - Increasing weaning age linearly improved the probability of a gilt being selected.
    - Increasing the fatness of the gilt will improve the reproductive outcome over her lifetime. At each increase in decile for selection P2 backfat, there was a linear increase in the likelihood of gilts being mated and farrowing. Whereas for selection weight, only the lightest 20% of the selected gilts (<92 kg) resulted in a lower mating and farrowing outcome.
    - Increasing P2 backfat was related to an improvement in farrowing success at parity 1 from 62 to 84%. Even the mid-population decile (decile 5) that averaged 15.1 mm P2 at selection, had a substantially lower farrowing outcome compared to the fattest 10% (average 22.2 mm P2) of selected gilts (73% vs 84%, respectively). Fatter gilts also were least likely to be culled by parity 2. This was in a linear relationship as selection P2 increased with decile (59% to 35% culled by parity 2 between the leanest and fattest decile).
- Gilts born to parity 1 dams (gilt litters) were significantly more likely to be culled without a mating, or due to pregnancy failure in their first gestation, or due to failure to be rebred after their first farrowing. The mechanism for this phenomenon warrants further investigation, given that 20-30% of multiplication litters will come from first parity dams. It is possible this effect would be alleviated by strategies which will reduce pre- or post-weaning checks. Physiological studies in other species suggest that delayed puberty or poor reproductive tract development are possible mechanisms for the impact of poor early growth on reproductive performance.
- More than 90% of the variation which could be explained by known factors for outcomes or lifetime performance measures were attributable to season of birth and site to which the gilt was managed after selection. Therefore, characteristics of individual gilts recorded early in life or at selection had relatively little impact on outcomes. Season of birth and farm-specific management practices have a significant impact on gilt selection, gilt mating, sow longevity and lifetime performance.
- After the point of selection, it becomes increasingly difficult to identify factors which were associated with outcomes for individual gilts. The model R^2 values reduced from 14.1% for selection success, to 10.5% for gilt mating success, to between 4-6% for first farrowing success, between 3.3-4.6% for culling before P1, to <3% for culling in P2. Therefore, early in life and

other known variables are relatively poor predictors of outcomes for individual gilts as they remain in the herd over time.

- Physiological response to a low dose of gonadotropin at approximately day 140 of age was not associated with improved longevity or reproductive performance. There seemed to be an advantage of being heavier at a younger age in terms of showing a physical response, however this did not equate to superior longevity or reproductive performance to parity 3. Further work, looking at PG600 or even just eCG (equine chorionic gonadotropin) as a follicle (and thus oestrogen) stimulant may be warranted in a more controlled management environment. Additionally, the physiological response to a low dose of gonadotropin could be used to assess neonatal and pre-selection management of potential replacement gilts.

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