SEASONAL FERTILITY: A NOVEL APPROACH TO ALLEVIATING SEASONAL INFERTILITY IN SOWS

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By

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Executive Summary

Seasonal infertility presents a significant economic and management challenge for Australian pork producers, due to the loss of productivity during the warmer months. While considerable work has been conducted in this area, its multifactorial origin has resulted in no conclusive solutions to date. This project explored two novel ways in which seasonal fertility could be exploited. The aims of this experiment were to quantify whether the impact of season is reduced in more fertile sows through analyses of historical data, and if post-cervical artificial insemination (PCAI) could be used to increase prolificacy and so reduce seasonal effects on reproductive traits.

Part A involved the analyses of two large, historical datasets that used herd performance recording software (Metafarms, Burnsville MN, USA). Data for Experiment 1 was obtained from a 7,500-sow commercial South Australian farm from September 2012 to September 2020. The dataset used for the analysis consisted of 36,535 farrowing records of 15,850 parity 1 to 4 sows. Observations were truncated after the fourth parity as older sows did not display seasonality in litter size. Number of piglets born alive was lowest in first- and second-parity sows across seasons. The greatest reduction in number of piglets born alive was observed in first- and second-parity sows mated in warmer months, farrowed in cooler months. Third- and fourth-parity sows had less variation in number of piglets born alive across seasons. As the largest seasonal influences were apparent in younger sows, a farm that had detailed recording of gilt arrival information was sourced. Data for Experiment 2 was obtained from a 4,500-sow commercial South Australian farm and extracted from May 2017 to April 2020 with records for 26,007 sows containing arrival, mating and farrowing information. Arrival age was a significant covariate for the number of piglets born alive, but arrival weight was not. For the trait of farrowing rate, weight at arrival tended to be a significant factor, with the highest performance observed at 115 -120 kg. The mean farrowing rate of parity 1 to 5 sows across 3 years was 85.5%, with a 3.6% drop between summer matings compared to winter matings. First- and second-parity sows had the greatest change in farrowing rate, with first parity sows incurring a 15.5% reduction and second parity sows a 13.9% reduction when mated in the warmer months.

Part B involved two experiments to test the impact of PCAI on litter size, and influence on seasonal fertility. Experiment 1 was a pilot investigation conducted outside the seasonal infertility period to test impacts of mating technique (cervical artificial insemination (CAI) vs PCAI) on total pigs born, born alive and born dead. Two hundred and seventy-seven sows were allocated based on parity to one of the two treatments and mated over a three-week period at an 8,000-sow breeder unit in Queensland. Whilst there was no difference in farrowing rate or total pigs born, pigs born alive were reduced by 1 pig per litter when PCAI was applied. Experiment 2 involved 483 sows selected from August to October 2019 from a 4,000-sow breeder unit in South Australia and allocated to using CAI (n = 252) or PCAI (n = 231). These sows were weaned during January to March 2020 and reallocated to one of the following three treatments: CC, n = 90: Sows mated during winter using CAI and re-mated in summer using CAI; PP, n = 92: Sows mated during winter using PCAI and re-mated in summer using PCAI; CP, n = 120: Sows mated during winter using CAI and re-mated in summer using PCAI. In spring matings, there was no change in farrowing rate, total born, born alive or born dead between CAI and PCAI. However, there was an increase in number of pigs weaned and a tendency for reduced pre-foster deaths in the PCAI compared to CAI sows (weaned; 10.3

vs 9.7 pigs per litter, pre-foster mortality; 0.6 vs 0.8 pigs per litter). When sows were re-mated in summer, no treatment effects were identified for farrowing rate, total born or born alive. Sows in the CC group weaned significantly fewer pigs in comparison to the CP and PP sows. Sows in the PP group gave birth to significantly fewer piglets born dead and showed a tendency for the lowest pre-foster mortality.

Overall, first- and second-parity sows used in these studies were shown to be most susceptible to seasonal infertility, with reduced farrowing rate and number of pigs born alive from summer matings. The only gilt factor that appeared to influence seasonal infertility was weight at arrival. For second-parity sows, previous litter size farrowed and weaned, and lactation length did not influence seasonal fertility, which is contrast to our hypothesis. Whilst PCAI was not shown to be effective at promoting seasonal fertility, there was evidence of an increased number of pigs weaned when implemented across both winter and summer matings. Given these main findings we recommend further exploration of gilt management options to reduce seasonal effects on reproduction, and to adopt PCAI to drive number of pigs weaned.

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1. Introduction

Reduced reproductive output during summer is an on-going global issue for Australian pork production. Performance traits that are negatively impacted during warmer months include puberty attainment in gilts, prolonged wean to service intervals, reduced pregnancy and farrowing rates, and smaller litter sizes. Because this issue is persistent and represents a significant economic and management challenge for pork producers, considerable work has been conducted in this area but given the high likelihood that the causes are multifactorial, solutions are scarce. Many studies have focused on the risk factors for seasonal infertility and these are now commonly understood. Bertoldo *et al.* (2009) used Australian data collected from three farms (~10,000 sows) mated during January to April to show that late pregnancy loss was related to age at first service, parity, wean to service interval and lactation length. Compared with European studies, though, this dataset is relatively small. Additionally, perhaps a more useful way is to identify factors or classes of individuals that display reduced risk of seasonal infertility to set selection targets.

We have conducted a preliminary analysis from data collected from one of our breeder sites. For this, over 22,000 records were analysed during summer and winter periods from 2015 to 2017. When sows were classed as 'more fertile' by grouping based on previous litter size, they recorded a 3-4% improvement in farrowing rate and a 1-1.2 pig increase in litter size when bred during the summer months ($P<0.001$; Plush, *unpublished data*). Whilst this preliminary analysis would appear to suggest that seasonal fertility may be driven by an increase in prolificacy measured in the previous litter, these results need confirming across multiple sites.

If we accept that this analysis will hold true, perhaps a simple way to improve the fertility of sows, thus buffer them against any seasonal effects, would be to use post-cervical artificial insemination (PCAI). This technique deposits semen directly into the uterine body reducing the physical length and environmental hostility the sperm must travel in order to reach the fertilisation site, and the amount of semen that is lost to backflow. Hernández-Caravaca *et al.* (2012) reported an increase in total born of 0.5 pigs when PCAI (n=1,664) was compared with cervical artificial insemination (CAI; n=1,716), and Knox *et al.* (2017) showed an improvement in total pigs born (~0.8 pig/litter) when semen dosages using the PCAI technique were maintained at similar rates to CAI. Taken together, this would suggest that the use of PCAI with traditional semen dosage rates results in improvements in litter size, and many Australian producers have anecdotally communicated similar reports to the investigators. Thus, the aim of this experiment was to quantify whether the impact of season is reduced in more fertile sows, and if PCAI can be used to increase prolificacy and so reduce seasonal effects.

2. Methodology

PART A

This study was conducted using data obtained from two commercial breeder units with a research licence obtained from the Department of Primary Industries and Regions South Australia (PIRSA; #247).

Experiment 1

Data set

Data was obtained from a 7,500-sow commercial South Australian farm that used herd performance recording software (Metafarms, Burnsville MN, USA). Arrival, mating and farrowing records of a single herd were extracted from September 2017 to September 2020 obtaining 19,637 arrival and 49,730 farrowing observations, respectively. Each arrival record included gilt/sow identification number, parity on arrival, date of arrival and genetic line. Each farrowing record included sow identification number, parity, date farrowed, number of piglets born alive, number of stillborn piglets and number of mummified piglets. This farm received sows from other farms, and so multiparous sows were removed from the arrival dataset and gilts were only removed if they did not have a farrowing record. The three highest contributing genetic lines were retained eliminating 632 gilts of six genetic lines. A fourth line of ‘unknown’ was obtained from the farrowing dataset with no arrival records. The genetic lines comprised of Cambrough 1020, F1 (Cambrough 1010 x 1020), Terminal and some sows whose genetic line was unknown (PIC Australia, NSW, AU) at approximately 9%, 40%, 14% and 37%, respectively. Observations were truncated after the fourth parity, due to older parities not displaying seasonality in litter size after a preliminary examination of the data. The final dataset used for the analysis consisted of 36,535 farrowing records of 15,850 parity 1 to 4 sows.

Climatic Data

The typical Mediterranean climate of the experimental southern Australian farm was characterised by mild, wet winters and hot, dry summers with low humidity. Daily temperatures (minimum and maximum) were available from the nearest weather station (-34.5, 138.68) 15 km southeast of the experimental farm (Figure 1). The summer (December, January and February) of 2019 had the highest number of days above 40°C at 19 days compared to 2017, 2018 and 2020 at 7, 14 and 5 days, respectively. Daily daylengths were obtained from date and time and are the same for each experimental year when rounded to the nearest minute. The shortest daylength day, 21st June, and the longest daylength day, 21st December, were 9 h 50 min and 14 h 28 min, respectively (Figure 1).

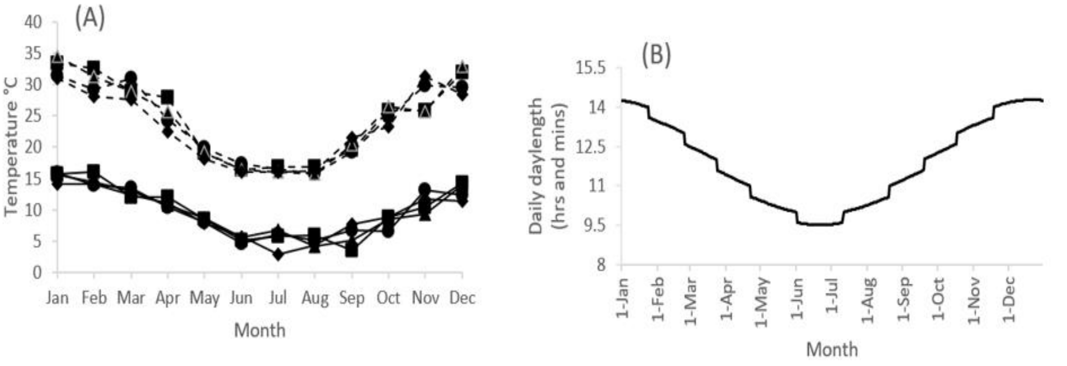

Figure 1. Monthly mean minimum and maximum temperature for each year and the daily daylength in hours and minutes for each calendar month (continued). (A*) Monthly mean minimum (—) and maximum (- - -) temperature (C°) for each year 2017 (●), 2018 (■), 2019 (▲) and 2020 (♦).* (B) *The daily daylength in hours and minutes for each calendar month.*

Artificial lighting in the farrowing sheds was used for staff purposes from 0700 to 1600, and outside of this, blinds regulated day length replicating the external conditions. The farrowing sheds were naturally, cross ventilated with ridge vents. When temperatures exceeded 28°C, neck and flank drippers coupled with ceiling fans were scheduled 1 minute on every 10 minutes.

Sow Management

Oestrous detection occurred daily at 0800 h where sows were moved in groups of five from a large pen into a detection pen, where they had fence-line contact with two mature boars. Sows were relocated into mating stations when standing heat was observed, otherwise they were returned to the large pen. In the mating station, sows were post-cervical artificially inseminated twice 24 h apart, with a pooled terminal sire dose. After the second insemination, sows were allocated to partially slatted gestation pens based on size and mating date, in groups of 50. Here, sows were fed a gestation diet (13.0 MJ DE/kg, 0.42 g SID lysine/MJ DE) at 2.1 kg/day in summer which increased to 2.4 kg/day in winter, via electronic sow feeder at a space allowance of 1.6 m^2/sow.

Lactation Sow Management

Sows entered the farrowing accommodation 5 days prior to farrowing, with an average gestation length of 116 days. Sows were housed in fully-slatted, plastic-floored farrowing crates. The crates contained a feed hopper, two nipple drinker lines (for access whilst standing or laying down) and a triangular creep area with solid flooring and a heat lamp for piglets. Farrowing occurred over an eight-day period with no sows induced to farrow. A lactation feed diet (14.3 MJ DE/kg 0.62 g SID lysine/MJ DE) was fed at 2.4 kg/day until farrowing and then *ad libitum* until weaning. Farrowing date was recorded once daily between 07:00 h and 10:00 h, and the following measurements were then recorded: number born alive, stillborn piglets and mummified foetuses. Fostering of piglets took place once daily at 1300 h and was kept minimal only occurring if the number of piglets exceeded the number of functional teats. Piglet mortality was recorded, as well as removal for ill thrift. The number of piglets at weaning was recorded as the number of pigs weaned per sow. Some sows incurred a double weaning, where they were allocated fallback piglets for a further 7 to 10 days extending the lactation length. Sows were then vaccinated against leptospirosis, parvovirus and erysipelas and returned to a large pen in the breeding barn in groups of 40. Oestrous detection started again 3 days after weaning.

Statistical Analysis

All data were analysed using SAS® software (V9.4, NC, USA) and significance recognised at $P < 0.05$. Descriptive statistics were obtained using the MEANS and FREQUENCY procedures (SAS® software, V9.4, NC, USA). Litter size was characterised by number of piglets born alive and stillborn piglets. The significance of fixed effects for the litter size characteristics were analysed using the GLM (General Linear Model) procedure (SAS® software, V9.4, NC, USA). The model included the fixed effects of genetic line, year, farrowing month and parity, and the interaction between month and parity. Least square means of the number of piglets born alive and the number of stillborn piglets from each parity by farrowing month are presented.

Experiment 2

Data Set

Data was obtained from a 4,500-sow commercial South Australian farm that used herd performance recording software (Metafarms, Burnsville MN, USA). Sow genetic lines consisted of F1 (Cambrough 1010 x 1020), Combrough, Terminal and Unknown (PIC Australia, NSW, AU), 72.4%, 14.2%, 12% and 1.3%, respectively. Arrival, insemination and subsequent farrowing and weaning data were extracted for 65,641 mating records from the 16th May 2017 to the 28th April 2020. One mating event included two inseminations 24 h apart, the second insemination record was deleted from the dataset. Observations were also removed from the dataset when:

(1) age at arrival was less than 137 days or greater than 222 days, (2) weight at arrival was less than 100 kg, but if missing it was assigned the mean, (3) if arrival parity was greater than 0, and (4) farrowing parity greater than 5, because this captured 85% of experimental animals and Experiment 1 identified first- and second-farrowing parity as being of primary interest.

The dataset used for the initial analysis to identify the effect of season on factors number of piglets born alive, number of stillborn piglets and farrowing rate of first mating consisted of 26,007 records from 10,012 sows of parity 1-5 from a single herd. Variables for each record included sow identification number, parity at arrival, origin, genetic line, date of birth, arrival date, age at arrival, weight at arrival, farrowing parity, date of first mating (within parity), date farrowed, number of piglets born alive, number of stillborn piglets, number of mummified piglets, date weaned, wean age, number of piglets weaned, lost piglets, and lactation length was computed from the variables, date farrowed and date weaned. Previous parity records were included for analysis which consisted of the same variables. Numerous sows experienced a double weaning, so two parameters were allocated to these individuals including, date weaned two, wean age two, number of piglets weaned two and lactation length two. Farrowing rate for first mating within parity was defined as a binary trait: 1 if gestation length was 121 days or less with no lower limit needed with 108 days being the lowest, 0 if gestation length was greater than 121 days or if no farrowing date. Gestation length was calculated by subtracting first mating date from subsequent farrowing date and age at first mating was calculated by subtracting date of birth from first mating date.

Two subset datasets of the above were used for the final analysis. Subset one included only first-parity sows and subset two included only second-parity sows, both of which were mated in the second (February) and third (March) month, 1,010 and 1,029 observations, respectively. The variable, age at first mating, was created for subset data one by extracting variable date of birth from date of first mating, and it was divided into six classes as follows: <200, 200-210, 211-220, 221-230, 231-240 and >240 days. Age at arrival was divided into four classes as follows: <170, 170-180, 181-190 and >190 days. Weight at arrival was divided into three classes as follows: <115, 115-120 and >120 kg. Variables previous total number of piglets born previous number of piglets born alive, previous number of piglets weaned and previous lactation length were use in subset data two. Each variable was divided into classes as follows: previous total number of piglets born <8, 8-10, 11-13, 14-16 and >16, previous number of piglets born alive <8, 8-14 and >14, previous number of piglets weaned <8, 8-10 and 11-13, previous lactation length <22, 22-25 and >25.

Climatic Data

The typical Mediterranean climate of the experimental southern Australian farm was characterised by mild, wet winters and hot, dry summers with low humidity. Daily temperatures (minimum and maximum) were available from the nearest weather station (-34.5, 138.68) 12.5 km southwest of the experimental farm (Figure 2). The summer (December, January and February) of 2019 had the highest number of days above 40°C at 19 days compared to 2017, 2018 and 2020 at 7, 14 and 5 days respectively. Daily daylengths were obtained from date and time and are the same for each experimental year when rounded to the nearest minute. The shortest daylength day 21st of June and the longest daylength day 21st of December were 9 h 50 min and 14 h 28 min, respectively (Figure 2).

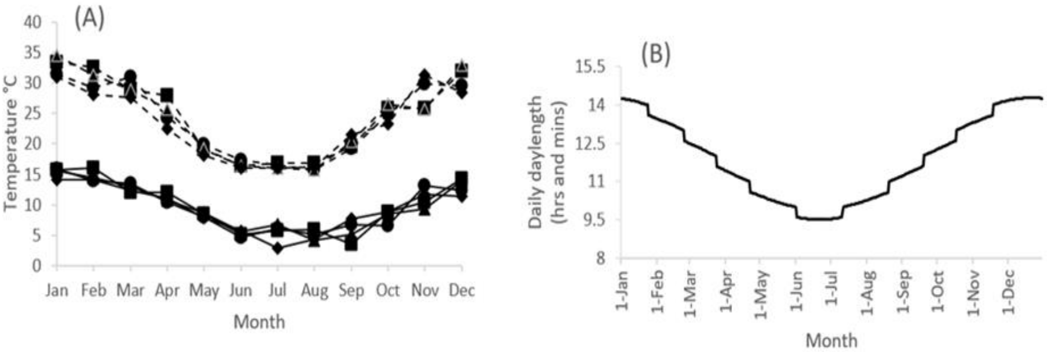

Figure 2. Monthly mean minimum and maximum temperature for each year and the daily daylength in hours and minutes for each calendar month (continued). (A) *Monthly mean minimum (—) and maximum (- - -) temperature (C°) for each year 2017 (●), 2018 (■), 2019 (▲) and 2020 (♦).* (B) *The daily daylength in hours and minutes for each calendar month.*

Artificial lighting in the farrowing sheds was used for staff purposes from 0700 to 1600, and outside of this, blinds regulated day length replicating the external conditions. The farrowing sheds were naturally, cross ventilated with ridge vents. When temperatures exceeded 28°C neck and flank drippers, coupled with ceiling fans were scheduled 1 minute on every 10 minutes.

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Lactation Sow Management

Sows entered the farrowing accommodation ~5 days prior to farrowing, with an average gestation length of 116 days. Sows were housed in fully-slatted, plastic-floored farrowing crates. The crates contained a feed hopper, two nipple drinker lines (for access whilst standing or laying down) and a triangular creep area with solid flooring and a heat lamp for piglets. Farrowing occurred over an eight-day period with no sows induced to farrow. A lactation feed diet (14.3 MJ DE/kg 0.62 g SID lysine/MJ DE) was fed at 2.4 kg/day until farrowing and then ad libitum until weaning. Farrowing date was recorded once daily between 07:00 h and 10:00 h, and the following measurements were then recorded: number born alive (NBA), stillborn piglets (SB) and mummified foetuses. Fostering of piglets took place once daily at 1300 h and was kept minimal only occurring if the number of piglets exceeded the number of functional teats. Piglet mortality was recorded, as well as removal for ill thrift. The number of piglets at weaning was recorded as the number of pigs weaned per sow. Some sows incurred a double weaning, where they were allocated fallback piglets for a further 7 to 10 days. Sows were then vaccinated against leptospirosis, parvovirus and erysipelas and returned to a large pen in the breeding barn in groups of 40. Oestrus detection started again 3 days after weaning.

Statistical Analysis

All data were analysed using SAS® software (V9.4, NC, USA) and significance recognised at $P < 0.05$. Descriptive statistics were obtained using the MEANS and FREQUENCY procedure (SAS® software, V9.4, NC, USA). The main dataset was used to identify the parities and months most affected by seasonal fertility, and three traits: (1) number of piglets born alive, (2) number of stillborn piglets, and (3) farrowing rate of first mating, were used as indicators. The significance of fixed effects for the three indicator traits were analysed using the GLM procedure (SAS® software, V9.4, NC, USA). The models included the fixed effects of mating month (for dependent variable farrowing rate of first mating), farrowing month (for dependent variables number of piglets born alive and number of stillborn piglets), year, genetic line and parity. Arrival age and arrival weight were added to the models as a linear covariate. Least square means of farrowing rate of first mating, as a percentage, from each parity by mating month and the number of piglets born alive and the number of stillborn piglets from each parity by farrowing month are presented.

For the two subset datasets the parameter for fertility farrowing rate of first mating was analysed using the GLM procedure (SAS® software, V9.4, NC, USA). The number of piglets born alive was not used as a parameter for fertility because there were no significant changes across seasons between parities. Age at arrival, weight at arrival and age at first mating were modelled as the main predictive factors as fixed effects for subset data one and previous total number of piglets born, previous number of piglets born alive, previous number of piglets weaned and previous lactation length for subset data two. Furthermore, year and genetic line were fixed effect cofactors. Least square means option in the GLM procedure was used to generate the least square mean estimates and their standard errors.

PART B

Two experiments were conducted to test the hypothesis surrounding the use of PCAI, litter size and impacts on seasonal fertility. Experiment 1 was a pilot investigation conducted outside the seasonal infertility period to test impacts of mating technique on total pigs born, born alive and born dead. The second was a larger experiment conducted over both spring and summer/autumn periods to examine the effects of the mating techniques on promoting seasonal fertility.

Experiment 1

Two hundred and seventy-seven sows were selected over three weeks in October and November 2018 from an 8,000-sow breeder unit (SunPork Farms, Warra QLD) and allocated to one of two treatments based on previous performance (total born and number pigs weaned) and parity (one to eight):

1. CAI, n = 130: cervical artificial insemination (Foamtip catheter 17106/5077, Minitube Australia, Smythesdale VIC);
2. PCAI, n = 147: post-cervical insemination (Postcervial catheter 17112/1010, Minitube Australia, Smythesdale VIC).

Sows were housed in a mating station from weaning, and the boar was moved past each station every morning at 0800 using a cart (Contact-o-max, Ro-main, Quebec, Canada). If the sow displayed ‘standing heat’ she was either mated immediately (CAI) or was marked. Marked sows were allowed 2 hours to complete the ‘refractory period’ and then mated using PCAI. Both treatments were mated with a 80 mL dose of 3 x 10^6 semen concentration twice, 24 hour apart using the same technique. Wean to service interval (WSI) was noted.

Forty-eight hours after the second insemination, sows were relocated to gestation pens. Pens were fully slatted, housed 55 sows with a space allowance of 1.45 m^2, and were fed via electronic sow feeder (ESF, FITMIX, Mannebeck, Germany). Sows were fed 2.2 kg per day of a standard gestation diet (13.0 MJ DE/kg, 0.42 g SID lysine). Pens housed sows from both the CAI and PCAI treatments. Pregnancy was confirmed at day 30 of gestation using ultrasonography, with non-pregnant sows removed from the pens. At day 110 of gestation, sows were moved to farrowing accommodation and performance recorded (pregnancy rate, farrowing rate, total born, born alive, born dead, mummified, pre-foster mortalities and number of pigs weaned (NPW)).

Minimum and maximum daily temperatures for each of the winter and summer experimental periods are presented in Figure 3.

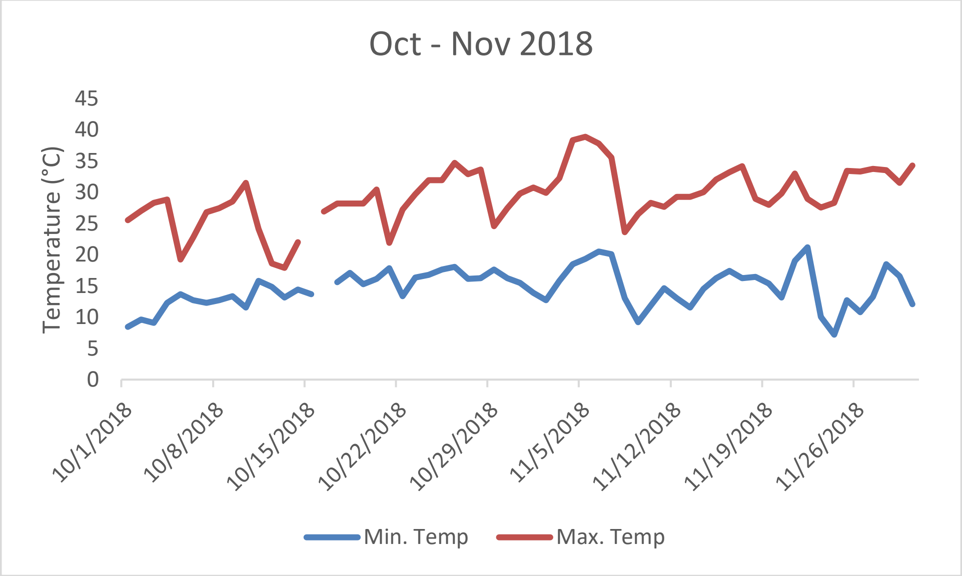


Figure 3. Daily minimum (blue) and maximum (red) temperatures (◦C) for the experimental period (October – November 2018). Data was collected from the Bureau of Meteorology weather station at Dalby (41522), 44 km from the experimental farm.

Experiment 2

Four hundred and eighty-three sows were selected [lactation length (≤ 30 days), previous performance (number pigs weaned ≥9), WSI (≤7 days) and parity (one to five)] from August to October 2019 from a 4,000-sow breeder unit (SunPork Farms, Tailem Bend SA) and allocated to one of two treatments:

1. CAI, n = 252: cervical artificial insemination (Foamtip catheter 17106/5077, Minitube Australia, Smythesdale VIC).
2. PCAI, n = 231: post-cervical insemination (Postcervial catheter 17112/1010, Minitube Australia, Smythesdale VIC).

Sows were housed in pens of 25 from weaning until standing heat, with a space allowance of 1.68 m^2 and *ad libitum* access to feed. Full boar contact was provided from day 1 after weaning onwards, for 10 minutes per pen at 0730. If a sow displayed ‘standing heat’, she was moved to a mating stall at 0900, with sows selected for PCAI marked. Boars were run at the front of all mating stalls from 1000 with CAI sows mated immediately. Approximately 1 hour after the boars had been removed, PCAI sows were mated. All sows were stood at mating and received 80 ml of 3 x 10^6 concentration semen. All sows received a second dose of semen 24 hours after the first dose using the same technique. Any sow that presented with blood or severe leakage post mating was removed from the experiment.

Twenty-four hours after entry to the mating station, sows were moved to the gestation accommodation at 0700, where they were housed in groups of 20, with a space allowance of 1.47 m^2. Sows were allocated to gestation pens based on treatment (so that both treatments were represented in each pen) and age to prevent aggression. Sows were floor-fed 2.2 kg daily at 0700 and remained in these pens until confirmation of pregnancy at day 35 via ultrasonography. Non-pregnant sows were removed, with pregnant sows relocated to pens of 60, on either slatted floors or straw based eco shelters, fed 2.2 kg daily via electronic sow feeder. At approximately day 110 of gestation, sows were moved to farrowing accommodation and performance recorded (as described above).

These sows were weaned during January to March 2020 and reallocated to one of the following three treatments:

1. CC, n = 90: Sows mated during winter using CAI and re-mated in summer using CAI;
2. PP, n = 92: Sows mated during winter using PCAI and re-mated in summer using PCAI;
3. CP, n = 120: Sows mated during winter using CAI and re-mated in summer using PCAI.

The management of sows at mating and in gestation was as described above.

Minimum and maximum daily temperatures for each of the winter and summer experimental periods are presented in Figure 4.

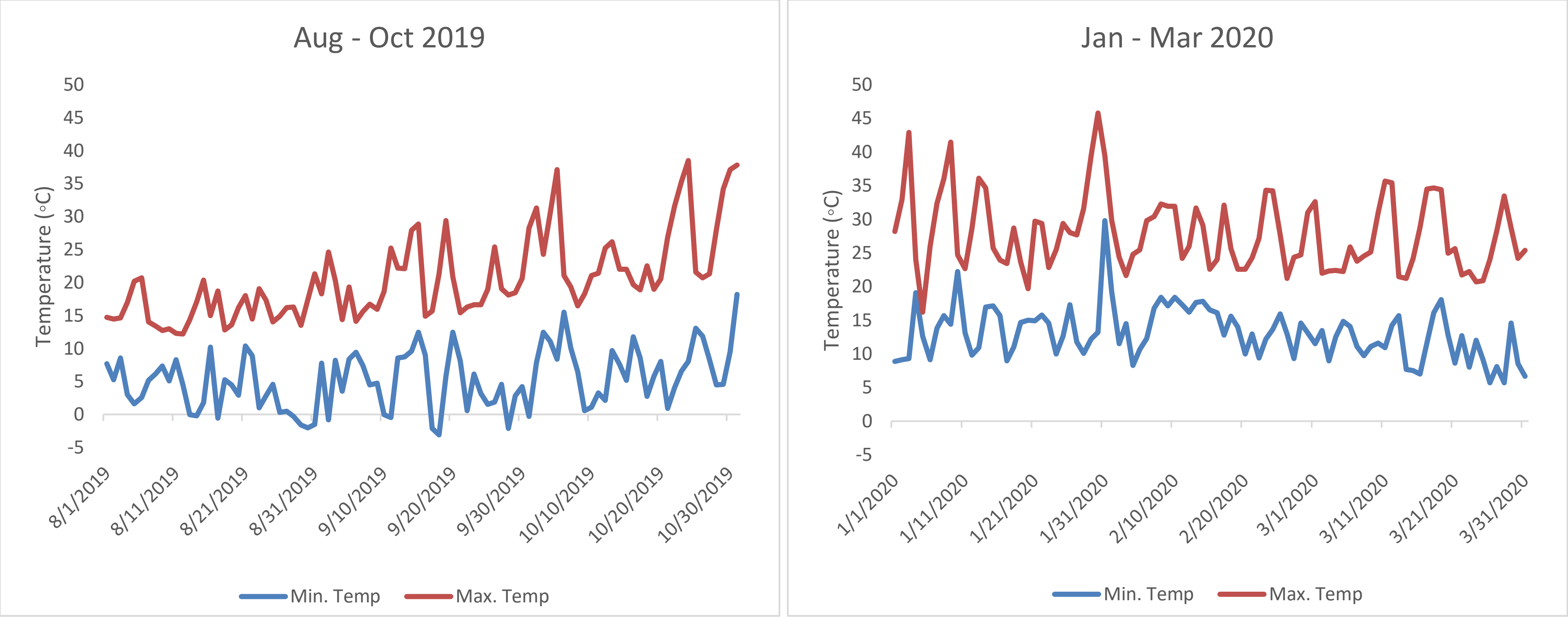


Figure 4. Daily minimum (blue) and maximum (red) temperatures (◦C) for the winter (August – October 2019) and summer (January – March 2020) experimental periods. Data was collected from the Bureau of Meteorology weather station at Murray Bridge (024584), 30.1 km from the experimental farm.

Statistics
All data (Experiments 1 and 2) were analysed in SPSS (v26 IMB, Amarnok USA) with $P < 0.05$ achieving significance and $P < 0.10$ a trend. All normally distributed data were analysed using a linear mixed model, count data using negative binomial regression, and yes/no data using binary logistic regression. Fixed effects included parity (one to five), treatment (experiments 1 and 2 CAI and PCAI; or experiment 2 CC, PP and CP) and a random term of mating week. In Experiment 2 for the spring analyses, there was a treatment difference in WSI interval (CAI 4.4 ± 0.1 days and PCAI 4.2 ± 0.1 days), and so this trait was fitted as a covariate for the analyses. For the winter and summer analyses, there was a treatment difference in parity (CC 2.6 ± 0.3, CP 1.9 ± 0.3 and PP 2.5± 0.3) and so this trait was fitted as a covariate for the analyses.

3. Outcomes

PART A

Experiment 1
The number of piglets born alive was lowest in first- and second-parity sows across seasons. A significant interaction between parity and farrowing month was identified for the number of piglets born alive (Figure 4; $P < 0.001$). The greatest reduction in the total number of piglets born alive was observed in first- and second-parity sows mated in warmer months, farrowed in cooler months. In first-parity sows there was a 0.5 piglet difference between the highest number of piglets born alive and the lowest, the highest being 11.6 in month 2 (February) and the lowest 11.1 in month 6 (June). Nearly one piglet (0.9) difference was observed between the highest and lowest number of piglets born alive in second-parity sows, the highest being 12.3 in month 12 (December) and the lowest of 11.4 in month 5 (May). Third- and fourth-parity sows had less variation of number of piglets born alive across seasons.

No significant interaction between parity and farrowing month was identified for the number of stillborn piglets ($P = 0.160$). Nevertheless, the results mirrored those of the piglets born alive with a trend of increased stillborn piglets from parity 1 to 4 sows farrowed in the cooler months. First- and fourth-parity sows displayed the most variation of the number of stillborn piglets across seasons.

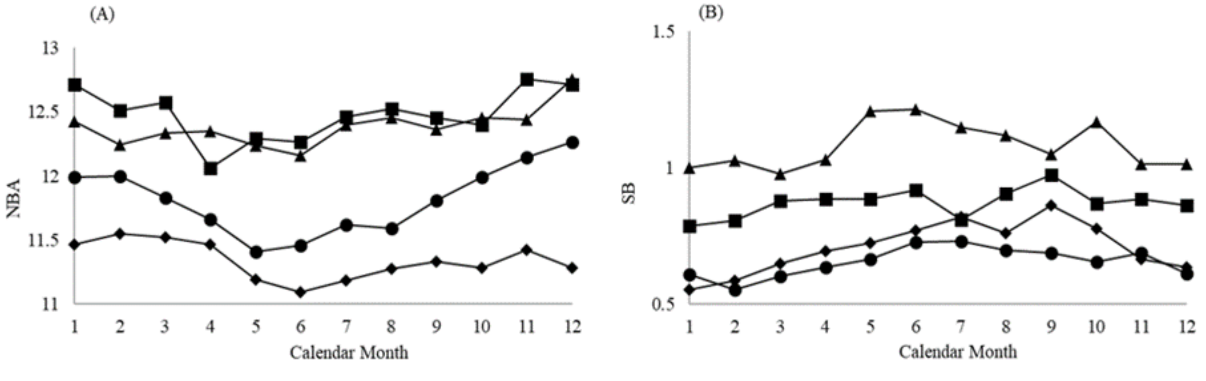


Figure 4. Least square means estimates for number of piglets born alive and number of stillborn piglets across 12 calendar farrowing months from parity 1 – 4. (continued). *Least square means estimates for* (A) *number of piglets born alive (NBA) and* (B) *number of stillborn piglets (SB) across 12 calendar farrowing months from parity 1 (♦), 2 (●), 3 (■) and 4 (▲) sows. Pooled SEM for NBA was 0.12 and SB 0.05.*

Experiment 2

Parity, genetic line, farrowing month, and year were all significant fixed effects for number of piglets born alive (*P* < 0.0001). There was no significant interaction between parity and farrowing month (*P* = 0.384). A seasonal trend was observed in first- and second-parity sows, as a reduction in the total number of piglets born alive in sows mated in warmer months, farrowed in cooler months, as shown in Figure 5. Arrival age was a significant covariate for the dependent number of piglets born alive, but arrival weight was not (*P* = 0.016 and *P* = 0.062, respectively). Parity, genetic line, farrowing month and year were all significant fixed effects for number of stillborn piglets (*P* < 0.0001), though there was no significant interaction between parity and farrowing month (*P* = 0.101). A seasonal trend was not present for the number of piglets born alive. Arrival age and arrival weight were significant covariates (*P* < 0.0001) for the dependent variable number of stillborn piglets.

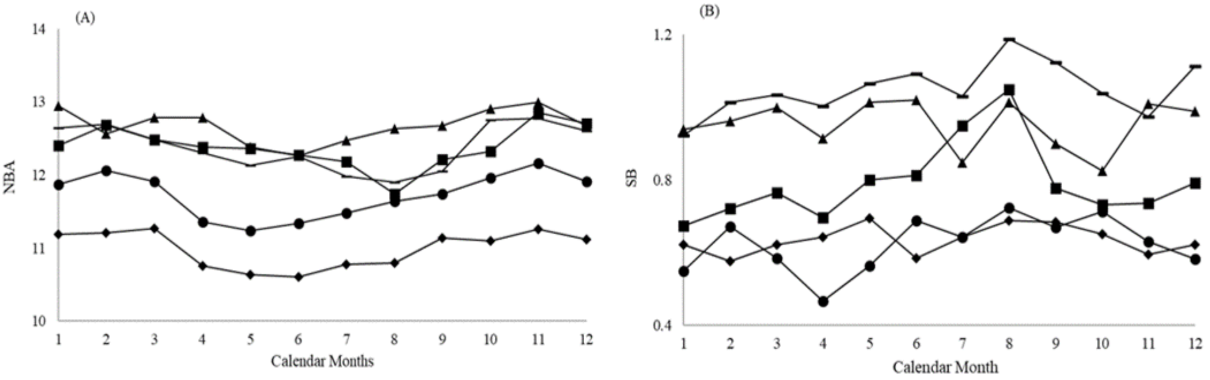


Figure 5. Least square means estimates for number of piglets born alive and number of stillborn piglets across 12 calendar farrowing months from parity 1 – 5. (continued). *Least square means estimates for* (A) *number of piglets born alive (NBA) and* (B) *number of stillborn piglets (SB) across 12 calendar farrowing months from parity 1 (♦), 2 (●), 3 (■), 4 (▲) and 5 (—) sows. Pooled SEM for NBA was 0.17 and SB 0.06.*

The mean farrowing rate for first mating within parity of parity 1 to 5 sows across three years was 85.5%, with a 3.6% drop between summer matings compared to winter matings. A greater seasonal effect on the mean farrowing rate for first mating was seen between parities across mating months. Parity, mating month, and year were all significant fixed effects for farrowing rate for first mating (*P* < 0.0001) and genetic line (*P* = 0.005). A significant interaction was identified between parity and mating month (*P* = 0.001). First- and second-parity sows had the greatest change in farrowing rate, as shown in Figure 6. Farrowing rate for first mating for first-parity sows was highest in month 8 (August) and lowest in month 2 (February), 90.4% and 74.9%, respectively, incurring a 15.5% drop. Farrowing rate for first mating for second-parity sows was highest in month 10 (October) and lowest in month 3 (March), 87.1% and 73.2%, respectively, incurring a 13.9% drop. First-parity sows had the largest drop-in farrowing rate across mating months, but second-parity sows had a significantly lower mean farrowing rate for first mating (*P* < 0.0001) of 82.1%, than all other parities. Arrival age and arrival weight were significant covariates (*P* = 0.0001 and *P* = 0.0065, respectively) for the dependent variable farrowing rate for first mating.

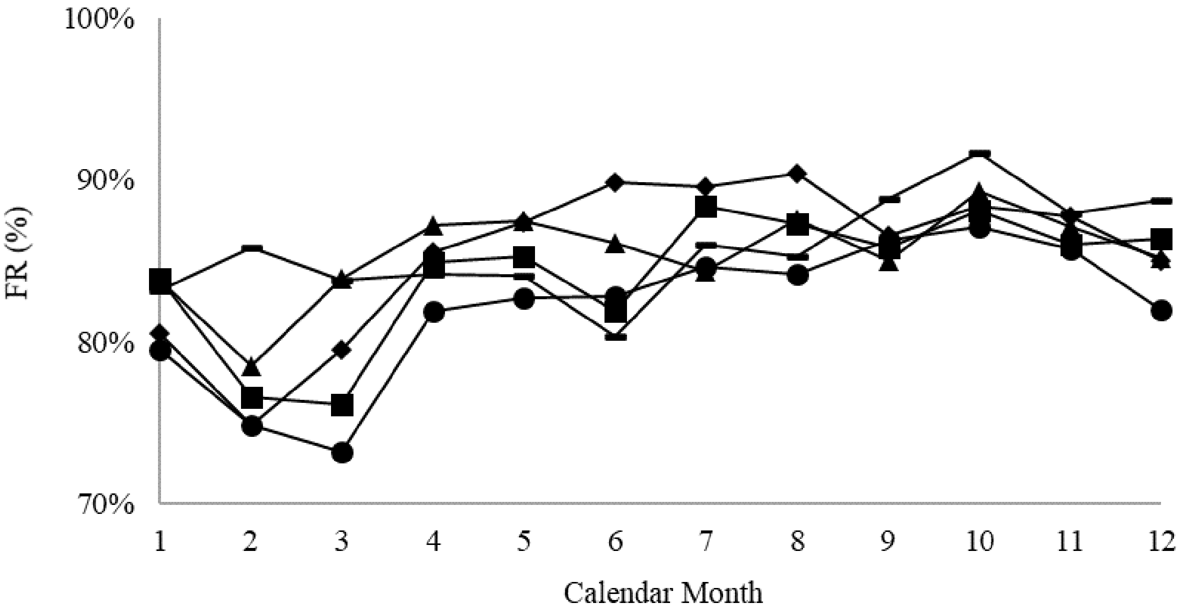


Figure 6. Least square means estimates for farrowing rate for first mating (FR) across 12 calendar mating months from parity 1 – 5 (continued). *Least square means estimates for farrowing rate for first mating (FR), as a percentage, across 12 calendar mating months from parity 1 (♦), 2 (●), 3 (■), 4 (▲) and 5 (—) sows. Pooled SEM was 0.02.*

Farrowing rate for first mating as an indicative trait of fertility of first-parity sows mated in the 2 (February) and 3 (March) month was not significantly affected by gilt-factors (Table 1): age at arrival (*P* = 0.367), and age at first mating (*P* = 0.958). There was a trend for weight at arrival (*P* = 0.087) to influence farrowing rate, with the highest performance observed at 115 -120 kg. Cofactor year was not a significant fixed effect (*P* = 0.05), but genetic line was (*P* = 0.005).

Table 1. Effects of gilt-factors on the indicative trait of fertility, farrowing rate for first mating of first-parity sows mated in the warmer months February and March.

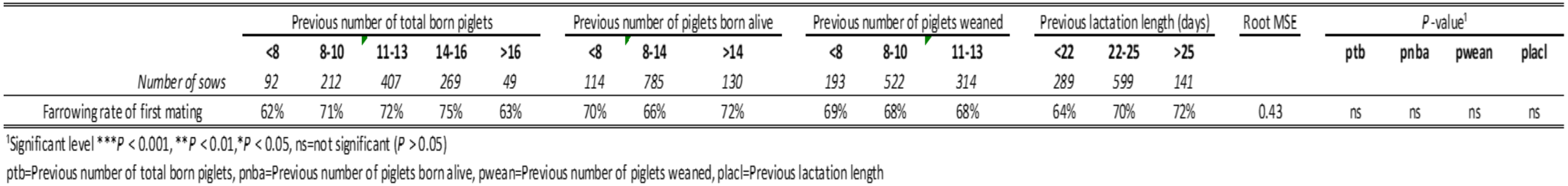
	Age at arrival (days)				Weight at arrival (kg)			Age at first mating (days)						Root MSE	P-value[1]		
	<170	**170-180**	**181-190**	**190>**	**<115**	**115-120**	**120>**	**<200**	**200-210**	**211-220**	**221-230**	**231-240**	**240>**		**ageA**	**WTA**	**AFM**
Number of sows	*142*	*355*	*361*	*152*	*328*	*450*	*232*	*148*	*181*	*272*	*162*	*103*	*144*				
Farrowing Rate of first mating	68%	73%	76%	73%	70%	77%	71%	75%	72%	71%	74%	72%	71%	0.40	ns	ns	ns

[1] Significant level ***$P < 0.001$, **$P < 0.01$,*$P < 0.05$, ns=not significant ($P > 0.05$)

ageA=Age at arrival, WTA=Weight at arrival, AFM=Age at first mating

Farrowing rate for second mating as an indicative trait of fertility of second-parity sows mated in the 2 (February) and 3 (March) month was not significantly affected by sow-factors (Table 2); previous total number of piglets born (*P* = 0.397), previous number of piglets born alive (*P* = 0.767), previous number of piglets weaned (*P* = 0.963) and previous lactation length (*P* = 0.164). Cofactor year (*P* = 0.099) and genetic line (*P* = 0.362) were also not a significant fixed effect. Due to these results no further action such as interaction of variables were necessary.

Table 2. Effects of sow-factors on the indicative trait of fertility, farrowing rate for second-parity sows mated in the warmer months February and March.



	Previous number of total born piglets					Previous number of piglets born alive			Previous number of piglets weaned			Previous lactation length (days)			Root MSE	*P*-value[1]			
	<8	**8-10**	**11-13**	**14-16**	**>16**	**<8**	**8-14**	**>14**	**<8**	**8-10**	**11-13**	**<22**	**22-25**	**>25**		**ptb**	**pnba**	**pwean**	**placl**
Number of sows	*92*	*212*	*407*	*269*	*49*	*114*	*785*	*130*	*193*	*522*	*314*	*289*	*599*	*141*					
Farrowing rate of first mating	62%	71%	72%	75%	63%	70%	66%	72%	69%	68%	68%	64%	70%	72%	0.43	ns	ns	ns	ns

[1] Significant level ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, ns=not significant ($P > 0.05$)

ptb=Previous number of total born piglets, pnba=Previous number of piglets born alive, pwean=Previous number of piglets weaned, placl=Previous lactation length

PART B

Experiment 1

There was no significant treatment effect on pregnancy rate, farrowing rate, total pigs born, pigs born dead or mummified in the litter (Table 3). However, there was a significant reduction in the number of piglets born alive in the PCAI treatment compared to the CAI (1.0 pigs per litter) in the Queensland farm.

Table 3. Reproductive performance of sows allocated to conventional artificial insemination (CAI) or post-cervical insemination (PCAI) mated during spring in a Queensland farm.

	CAI		PCAI		
	Mean	SEM	Mean	SEM	*P-value*
n	130		147		
Parity	3.2	0.2	3.1	0.2	*NS*
Previous total born (TB)	13	0.3	12.8	0.3	*NS*
Previous No. piglets weaned (NPW)	10.4	0.1	10.5	0.1	*NS*
Wean-service interval (WSI) (days)	4.8	0.3	5.6	0.3	*NS*
Pregnancy rate (%)*	89.3	81.3-94.1	93.7	86.6-97.1	*NS*
Farrowing rate (%)*	88.1	79.7-93.3	85.4	77.2-91.0	*NS*
TB	12.7	0.4	11.8	0.4	*NS*
Born alive (BA)	11.5	0.5	10.5	0.5	< *0.05*
Born dead (BD)	0.9	0.1	1	0.1	*NS*
NPW	9.6	0.2	9.5	0.2	*NS*

* 95% confidence intervals rather than standard error of the mean shown for binary traits.

Experiment 2

There were no significant differences in most traits prior to treatment application for sows mated in spring at the South Australian farm, but WSI did differ by 0.2 days between CAI and PCAI (and so was included as a covariate for all subsequent traits; Table 4). There was no significant difference in total pigs born, pigs born alive or pigs born dead or mummified.

Table 4. Reproductive performance of sows allocated to conventional artificial insemination (CAI) or post-cervical insemination (PCAI) mated during spring in a South Australian farm.

	CAI		PCAI		
	Mean	SEM	Mean	SEM	*P-value*
n	252		230		
Mating parity	2.3	0.12	2.4	0.13	*0.704*
Previous TB	13.1	0.19	13.5	0.21	*0.170*
Previous NPW	10.4	0.2	10.3	0.21	*0.627*
WSI (days)	4.4	0.1	4.2	0.1	***0.025***
Pregnancy rate (%)*	96.5	93.3-98.2	96.2	92.8-98.0	*0.855*
Farrowing rate (%)*	96.2	92.9-98.0	95.4	91.8-97.4	*0.645*
TB	14	0.2	13.7	0.21	*0.409*
BA	13.1	0.2	12.8	0.3	*0.324*
BD	1.1	0.1	1.2	0.1	*0.596*
Mummified	0.5	0.1	0.5	0.1	*0.574*

* 95% confidence intervals rather than standard error of the mean shown for binary traits.

There was an increase in the number of pigs weaned (NPW) in the PCAI (10.3 ± 0.2) compared to CAI (9.7 ± 0.2) sows (Figure 7) mated during spring. There was also a tendency for reduced pre-foster deaths in the PCAI (0.6 ± 0.1) compared to the CAI (0.8 ± 0.1) sows (*P* = 0.06).

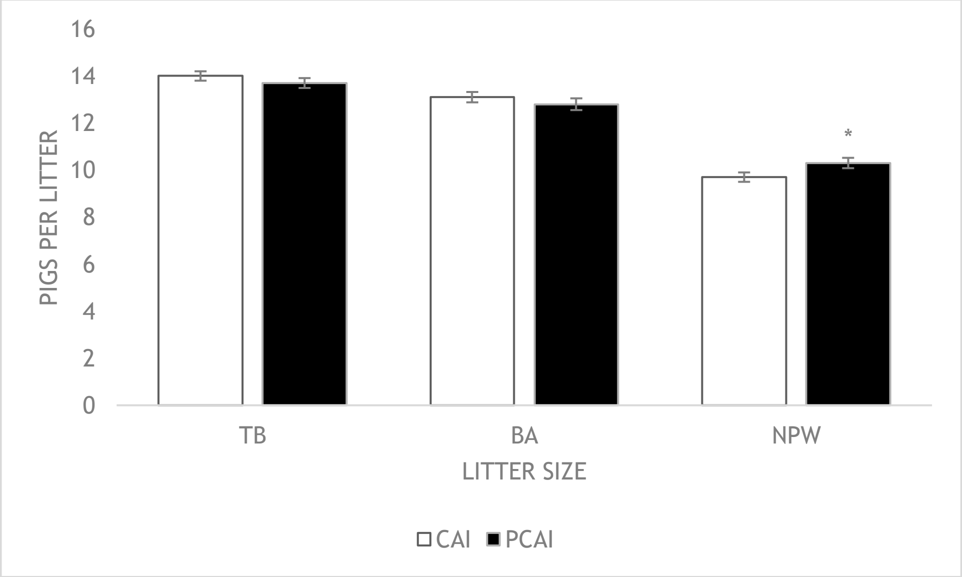


Figure 7. Mean ± SEM litter size (total born (TB), born alive (BA) and number of pigs weaned (NPW)) for sows mated using conventional artificial insemination (CAI) and post-cervical insemination (PCAI) in spring in a South Australian farm. * Denotes significant difference (*P* = 0.05) between treatments.

There was a significant treatment difference in first mating parity (and so was included as a covariate for all subsequent traits; *P* = 0.0008; Table 5). There was no treatment difference between any other previous performance traits, but pregnancy and farrowing rate were lowest in the CC treatment compared to the CP and PP treatments (X^2 = 6.086 and 9.098 respectively). No treatment effects were identified for litter size farrowed (TB, BA, BD and mummified) after treatments were imposed for the spring mating. There was a significantly lower NPW observed in the CC group (9.2 ± 0.3 pigs) than the CP and PP group (10.1 ± 0.3 and 10.4 ± 0.3 pigs respectively; $P < 0.001$) (Figure 8). There was a tendency for the lowest pre-foster mortality to be observed in the PP sows ($P = 0.06$).

Table 5. Reproductive performance of sows from a spring mating allocated to conventional artificial insemination in spring and conventional artificial insemination in summer (CC), conventional artificial insemination in spring and post-cervical insemination in summer (CP) or post-cervical insemination in spring and summer (PP) in a South Australian farm.

	CC		CP		PP		*P-value*
	Mean	SEM	Mean	SEM	Mean	SEM	
n	90		91		120		
First mating parity	2.6	0.3	1.9	0.25	2.5	0.31	***0.008***
TB	12.9	0.38	12.8	0.4	13.2	0.4	*0.598*
BA	12.1	0.35	12.1	0.38	12.4	0.37	*0.576*
BD	1.1	0.12	0.8	0.11	1	0.11	*0.207*
NPW	10.4	0.32	10.3	0.35	10.4	0.31	*0.991*
Spring mating							
WSI (days)	4.4	0.2	4.3	0.2	4.2	0.2	*0.734*
Pregnancy rate (%)*	97.1		100		100		
Farrowing rate (%)*	95.7		100		100		
Gestation length (days)	115.6	0.2	115.6	0.2	115.9	0.1	*0.226*
TB	13.9	0.3	13.7	0.3	13.8	0.3	*0.948*
BA	13.1	0.3	12.9	0.3	12.9	0.3	*0.904*
BD	1.0	0.1	1.1	0.1	1	0.1	*0.909*
Mummified	0.5	0.1	0.5	0.1	0.5	0.09	*0.866*

* Treatment effects examined using chi-squared analyses for binary traits as logistic regression would not converge.

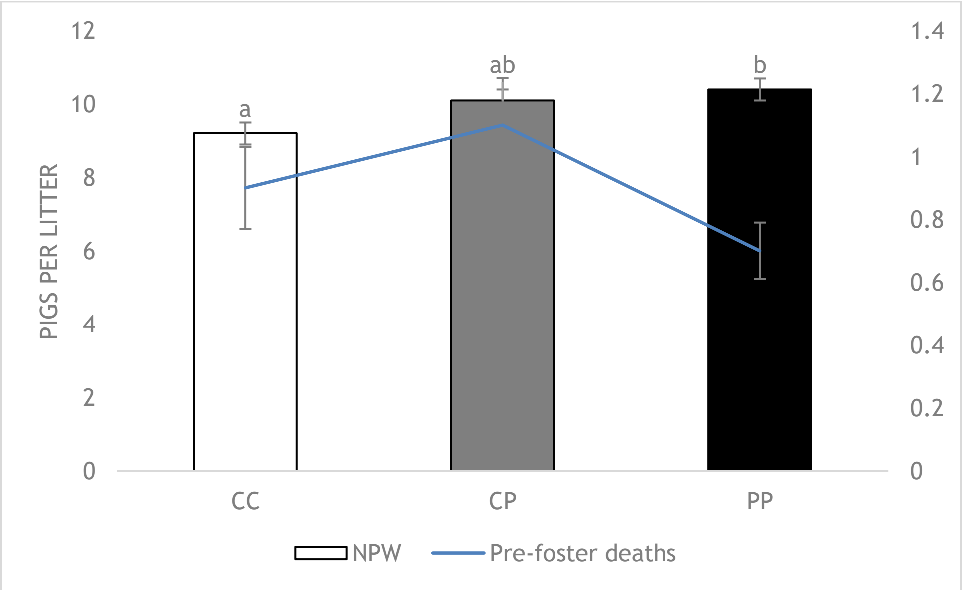


Figure 8. Number of pigs weaned (NPW) and pre-foster deaths of sows from a spring mating in 2020 allocated to conventional artificial insemination in spring and conventional artificial insemination in summer (CC), conventional artificial insemination in spring and post-cervical insemination in summer (CP), or post-cervical insemination in spring and summer (PP) in a South Australian farm. ^{a,b} Denotes significant difference between treatments ($P < 0.001$).

No treatment effects were identified for pregnancy and farrowing rate, total born or born alive after treatments were imposed for the summer mating. There were significantly fewer piglets born dead in the PP group (Table 9). Additionally, there was a tendency for NPW to be increased in the PP sows.

Table 9. Reproductive performance of sows from a summer mating allocated to conventional artificial insemination in spring and conventional artificial insemination in summer (CC), conventional artificial insemination in spring and post-cervical insemination in summer (CP) or post-cervical insemination in spring and summer (PP) in a South Australian farm.

	CC		CP		PP		*P-value*
	Mean	SEM	Mean	SEM	Mean	SEM	
WSI (days)	4.2	0.5	4.1	0.5	4.1	0.4	0.987
Pregnancy rate (%)	93.5	85.6-97.2	95.6	88.4-98.4	96.4	91.1-98.6	0.621
Farrowing rate (%)	89.5	80.3-94.7	94.6	87.0-97.9	95.2	89.6-97.8	0.247
TB	13.4	0.4	13.6	0.4	13	0.3	0.358
BA	13.1	0.4	13.4	0.4	13	0.3	0.685
BD	0.4^a	0.1	0.3^a	0.1	0^b	0	0.011
Mummified	0.03	0.02	0.06	0.03	0	0	0.344
24h deaths	0.8	0.2	0.9	0.2	0.8	0.1	0.792
NPW	9.7	0.2	10.1	0.2	10.2	0.1	0.100

^{a,b} Values with different superscripts within a row are significantly different.

4. Application of Research

PART A

Indicative traits of seasonal fertility

The initial objectives of this investigation were to identify whether key manifestations of seasonal infertility, farrowing rate and litter size, were observed and which parity groups and months were largely impacted to classify a sow group of focus. Farrowing rate as an indicator trait could only be computed using Part A: Experiment 2 data. A reduced mean farrowing rate of 83% in summer compared to 87% in winter was identified. A significant interaction between parity and mating month at first insemination for farrowing rate was observed with the greatest reduction of 15.5% seen in first-parity sows and 13.9% in second-parity sows mated in month 2 (February) and month 3 (March), respectively First-parity sows had the greatest reduction in farrowing rate from winter matings to summer matings, but a relatively high mean farrowing rate for first mating (85.5%). In contrast, second-parity sows incurred the lowest mean farrowing rate (82.1%), suggesting second-parity sows were still recovering from the stressors of their first gestation and lactation. Consistent with these results are those of Bunz *et al.* (2019), which identified a significant interaction between parity and temperature grouping at mating, where high temperatures reduced farrowing rates with the greatest reduction observed in first-parity sows. These outcomes could be explained by the findings of Gourdine *et al.* (2017) where sow thermal response to heat stress differed between primiparous and multiparous sows, with increased metabolic rate in primiparous sows increasing their basal temperature due to heat production from both their own growth and milk production. In response, the primiparous sows also showed a reduced summer lactational feed intake of up to 7% less than the multiparous sows. The negative impacts of lactation catabolism on reproduction are well understood (Einarsson and Rojkittikhun 1993).

Part A: Experiment 1 identified that changes in litter size across seasons differed between parities, with a considerable reduction in first- and second-parity sows. Due to insufficient availability of arrival data of gilts from this farm, a second experimental herd was selected and analyses repeated. Experiment 2 showed a similar seasonal trend for first- and second-parity sows but significance was not obtained. This suggests that management may play an important role in litter size. Changes in the number of stillborn piglets across seasons did not significantly differ between parities for Experiment 1 or Experiment 2. Whilst the number of piglets born alive decreased in the cooler months the number of stillborn piglets increased. This similar pattern is likely due the conditions the sows farrowed in causing misclassification of exposure deaths for stillborn piglets, due to the experimental farrowing sheds using natural ventilation. A study by Plush *et al.* (2019) also suggested it may be the result of seasonal variation in litter weight, with the smaller piglets being at greater risk of mortality.

The significant detrimental impact of season on farrowing rate and number of piglets born alive in first- and second-parity sows meant that further efforts were focused on these groups of sows to identify gilt and sow-specific factors that contributed to seasonal fertility. The mating months of particular interest were month 2 (February) and month 3 (March).

Predictive gilt-(first-parity sow) level factors of seasonal fertility

The two predictive gilt-level factors, age and weight at arrival, were not significant for farrowing rate of sows mated in February and March. However, there was a tendency for sows 115 – 120 kg at arrival to have the highest farrowing rate when mated in summer / autumn. If age and weight were transformed into a growth rate to arrival, this possibly would have reached statistical significance, but these data could not be obtained. Additionally, weight at mating and growth rate to this point may arguably have been more important but were not recorded. Nevertheless, what the findings suggested is that the length of time a gilt spends in the breeding herd before she is mated does not influence her ability to cope with heat stress; however, it likely influences lifetime performance and has an impact on the farm's economic performance (Iida and Koketsu 2013). It is likely that a majority reached the industry standard of 135-150 kg at mating (Athorn and Plush 2019) given the age and weight at arrival information. Over 50% of the gilts were first mated at the Australian industry standards for best practice gilt management of 210-238 days of age (Athorn and Plush 2019). Just under 15% were below 200 days and above 240 days of age. Farrowing rate of February and March matings did not differ with age at first mating. In support of this, Magnabosco *et al.* (2014) found age at boar exposure did not affect first farrowing rate. The findings of this current study suggest the age a gilt is first mated does little to protect against heat stress, and that all gilts are particularly susceptible during the time of conception and early pregnancy. This is supported by an early study by Wettemann and Bazer (1985) which reported reduced conception rates of gilts who were exposed to high ambient temperatures during the day of mating and up to 16 days after mating. Changes to the reproductive endocrine system were identified in the way of reduced peripheral progesterone plasma concentrations during days 13-19 after mating and extended luteal function to day 25 in gilts that did not conceive. It was also suggested that maternal recognition of pregnancy may have been reduced by elevated concentrations of oestradiol. Bertoldo *et al.* (2012) also hypothesised that oocyte developmental competence is reduced when sows are under summer environmental stressor, because of reduced follicular progesterone levels, resulting in conception and pregnancy maintenance failure. If photoperiod was the major influencing environmental factor, it could be assumed that a larger group of older gilts at first mating would have been obtained, indicating delayed puberty and that earlier first mated sows (puberty achieved earlier) would achieve greater fertility, due to higher prolificacy.

Predictive sow-level factors of seasonal fertility in second-parity sows

The previous number of total piglets born, and the previous number of piglets born alive, did not affect the farrowing rate of second-parity sows mated in month 2 (February) and month 3 (March). To the authors' knowledge, there is no current research into the effects of litter size on subsequent fertility, particularly across seasons. It was assumed that first-parity sows who farrowed larger litter sizes than their counterparts would have obtained a lower subsequent farrowing rate, due to increased stress on their metabolic and reproductive systems impairing their endocrine recovery with the added stressors of summer. The current study did not support such an assumption, and this may be explained by farrowing rate simply being affected by an individual sow's ability to cope with heat stress around parturition and lactation, independently from the previous gestation. Alternatively cross fostering strategies employed after farrowing would lessen the demand of large litter sizes on the sow, as numerous piglets would usually be fostered to a sow with a smaller litter.

Farrowing rate for second-parity sows mated in month 2 (February) and month 3 (March) increased as the previous lactation length increased, but the affect was not significant. A study by Tantasuparuk *et al.* (2000) also acknowledged that farrowing rate is not significantly affected by previous lactation length, but season was not taken into consideration in that study. Bertoldo *et al.* (2009) on the other hand, identified previous lactation length had a constant significant effect on late pregnancy loss during the summer months, such that as lactation length increased so too did the probability of late pregnancy piglet loss. As such it was recommended that short lactation length (early weaning) be commercially adopted to maintain the sow in ideal condition to successfully breed again. However, when subsequent breeding occurs in summer, increased previous lactation lengths are recommended to allow sows time to fully return to optimal endocrine functionality (Van Wettere *et al.* 2012).

In this respect, perhaps lactation length is less important in promoting subsequent fertility, but rather lactational nutrient intake during this time is a key driver. First-parity sows have reduced lactational feed intake than multiparous sows (Bertoldo *et al.* 2009), lactational body weight loss of greater than 10% has been shown to negatively impact subsequent farrowing rates at first mating (Thaker and Bilkei 2005), and lactational feed intake differs considerably among individual sows (Koketsu *et al.* 1999). Therefore, individual sows with a reduced lactational feed intake may potentially be more susceptible to heat stress at their subsequent mating, due to poorer metabolic status because of lactational pressures and inadequate nutrition. In a similar vein, the previous number of piglets weaned was included as a predictive sow-factor based on the assumption that lower litter sizes at weaning would infer a reduced milk output and so better body condition of sows at mating. The current study showed no significant effect of previous number of piglets weaned on farrowing rate, and Bertoldo *et al.* (2009) identified the nursing pressures of a large litter did not affect subsequent pregnancies regarding late pregnancy losses. Alternatively, due to improvement in the modern genotype of Australian sows, it is possible that high lactational output is having a reduced effect on subsequent reproduction. A recent review by Muller *et al.* (2022) concluded modern sows are not mobilizing muscle and adipose tissue in the same manner previously observed, and that due to changes in metabolic requirements and genetic improvement, any previously observed negative impacts on subsequent rebreeding are now minor if present at all.

PART B

Performance of PCAI in comparison to CAI
The first experiment conducted in Queensland identified that PCAI actually reduced the number of pigs born alive by a magnitude of one pig per litter, which has been reported (Mellado et al. 2018), but was an unexpected and surprising finding and is difficult to explain. Whilst there was no significant treatment difference in the WSI, of the 16 sows that were bred at greater than 7 days, 13 were allocated to the PCAI treatment. Inadvertently, the experimental farm may have allocated more sub-fertile sows to this treatment which acted to reduce the number of pigs born alive (Tantasuparuk *et al.* 2001). This finding was not observed in the second experiment conducted in South Australia. Results from this farm demonstrated that sows mated using PCAI weaned 0.6 of a pig more, likely justified by the tendency for improved perinatal piglet survival. The semen dose in the PCAI treatment was maintained at 3 x 10^9 sperm cells (not reduced to 1 or 2 x 10^9), and PCAI deposits this semen in the uterine body as opposed to the cervix in CAI. When CAI is used, billions of spermatozoa are deposited, but only thousands reach the oviduct and site of fertilization, with the cervix being a major site for filtration (Soriano-Úbeda *et al.* 2013). The site of deposition in PCAI increases the chance of more semen reaching the oviduct (Lopez Rodriguez *et al.* 2017) and so increased competition for fertilisation. Sperm competition has profound fitness consequences in other special such as mice (Firman and Simmons 2010), and so this may be the mechanism that explains the increased survivability and so number of pigs weaned from sows mated using PCAI.

Impacts of using PCAI during summer and autumn
The strategy used in the mating prior to summer, or the one applied during summer, bore little impact on traditional manifestations of seasonal fertility with no differences in pregnancy rate or total pigs born between CC, CP and PP sows. This was in contrast to our hypothesis whereby using PCAI in the lead-up to the summer mating was expected to increase litter size (Hernández-Caravaca *et al.* 2012; Knox *et al.* 2017), boosting fertility and negating the negative effects observed during summer breedings. The analyses in Part A showed that the litter size a first-parity sow farrowed prior to a summer mating in the second parity had no influence on reproductive output. What was not tested in this current experiment was the use of PCAI in primiparous sows, which were identified as being the most at-risk population. This was because of previous reports that the internal catheter does not pass easily through the cervix due to the smaller physical size of the gilt. However, work has identified that PCAI can be applied to gilts with a > 85% success rate (Sbardella *et al.* 2014). Thus, future focus could target the use of PCAI in primiparous sows to promote seasonal fertility. Second-parity sows were recruited to this experiment, and Part A did identify that these animals were also prone to negative effects of heat stress, but sample size was too low (n = 50 – 70 sows) to conduct statistical analyses and so draw any meaningful conclusions.

5. Conclusion

Overall, first- and second-parity sows used in these studies were shown to be most susceptible to seasonal infertility, with reduced farrowing rate and number of pigs born alive from matings conducted in February and March. The only gilt factor that appeared to influence seasonal infertility was weight at arrival. For second-parity sows, previous litter size farrowed and weaned, and lactation length did not influence seasonal fertility. When PCAI was implemented to promote seasonal fertility, no changes in performance were observed. There did however appear to be evidence of increased number of pigs weaned when PCAI was implemented across both winter and summer matings. Given these main findings, our hypothesis is not supported.

There is little influence of sow related factors that can promote seasonal fertility, and PCAI did not improve performance of sows mated in summer.

6. Limitations/Risks

Whilst the farms chosen for Part A were both confirmed appropriate to study the effects of season on sow fertility, the performance of the animals recruited to Part B to test insemination techniques was above average for Australian herds. Farrowing rate was approximately 95% during spring matings, and 90-95% for summer/autumn matings despite the high ambient temperatures experienced. It is also worth noting that both the Queensland and South Australian farms were very familiar and comfortable using CAI and had limited exposure (and even some hesitation) to applying PCAI which may have influenced the findings.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. First- and second-parity sows are more susceptible to the negative impacts of heat stress on reproduction and so should be the target population for any strategy employed to promote seasonal fertility. Older sows are more resistant to seasonal fertility which may be a consequence of metabolism or culling strategies used on farm.
2. There was some indication that gilt entry weight may drive seasonal fertility for first parity sows, with an optimum of 115-120 kg, but future work should also examine weight at mating, or even better, growth rates to mating.
3. Performance in the first lactation had no impact on seasonal fertility in second-party sows.
4. Use of PCAI does not improve performance either leading into summer matings, or when applied during seasonal infertility risk period. However, number of pigs weaned is improved when sows are bred using PCAI and this is driven improvements in piglet viability.

8. References

Athorn, RZ, Plush, K (2019) Best practice gilt management for fertility and longevity. Australia Pork Limited.

Bertoldo, M, Grupen, CG, Thomson, PC, Evans, G, Holyoake, PK (2009) Identification of sow-specific risk factors for late pregnancy loss during the seasonal infertility period in pigs. *Theriogenology* **72**, 393-400.

Bertoldo, M, Holyoake, P, Evans, G, Grupen, C (2012) Seasonal variation in the ovarian function of sows. *Reproduction, fertility and development* **24**, 822-834.

Bunz, A, Bunter, K, Morrison, R, Luxford, B, Hermesch, S (2019) 'Genotype by temperature grouping interaction for farrowing rate at first insemination, Proc. Assoc. Advmt. Anim. Breed. Genet.'

Einarsson, S, Rojkittikhun, T (1993) Effectsof nutrition on pregnant and lactating sows. *Journal of Reproduction and Fertility Supplement* **48**, 229-239.

Firman, RC, Simmons, LW (2010) Experimental evolution of sperm quality via postcopulatory sexual selection in house mice. *Evolution: International Journal of Organic Evolution* **64**, 1245-1256.

Gourdine, J-L, Mandonnet, N, Giorgi, M, Renaudeau, D (2017) Genetic parameters for thermoregulation and production traits in lactating sows reared in tropical climate. *animal* **11**, 365-374.

Hernández-Caravaca, I, Izquierdo-Rico, MJ, Matás, C, Carvajal, JA, Vieira, L, Abril, D, Soriano-Úbeda, C, García-Vázquez, FA (2012) Reproductive performance and backflow study in cervical and post-cervical artificial insemination in sows. *Animal Reproduction Science* **136**, 14-22.

Iida, R, Koketsu, Y (2013) Interactions between climatic and production factors on returns of female pigs to service during summer in Japanese commercial breeding herds. *Theriogenology* **80**, 487-493.

Knox, R, Esparza-Harris, K, Johnston, M, Webel, S (2017) Effect of numbers of sperm and timing of a single, post-cervical insemination on the fertility of weaned sows treated with OvuGel®. *Theriogenology* **92**, 197-203.

Koketsu, Y, Takahashi, H, Akachi, K (1999) Longevity, lifetime pig production and productivity, and age at first conception in a cohort of gilts observed over six years on commercial farms. *Journal of veterinary medical science* **61**, 1001-1005.

Lopez Rodriguez, A, Van Soom, A, Arsenakis, I, Maes, D (2017) Boar management and semen handling factors affect the quality of boar extended semen. *Porcine Health Management* **3**, 15.

Magnabosco, D, Cunha, E, Bernardi, M, Wentz, I, Bortolozzo, F (2014) Effects of age and growth rate at onset of boar exposure on oestrus manifestation and first farrowing performance of Landrace× large white gilts. *Livestock Science* **169**, 180-184.

Mellado, M, Gaytán, L, Macías-Cruz, U, Avendaño, L, Meza-Herrera, C, Lozano, EA, Rodríguez, Á, Mellado, J (2018) Effect of climate and insemination technique on reproductive performance of gilts and sows in a subtropical zone of Mexico. *Austral journal of veterinary sciences* **50**, 27-34.

Muller, T, Hewitt, R, Plush, K, Souza, DD, Pluske, J, Miller, D, van Barneveld, R (2022) Does the relationship between sow body composition change in lactation and re-breeding success still exist? *Animal Production Science* **62**, 1173-1180.

Plush, K, Glencorse, D, Alexopoulos, J, Tritton, S, Kirkwood, R, D'Souza, D (2019) Effect of Dextrose Supplementation in the Pre-Ovulatory Sow Diet to Reduce Seasonal Influences on Litter Birth Weight Variation. *Animals* **9**, 1009.

Sbardella, P, Ulguim, R, Fontana, D, Ferrari, C, Bernardi, M, Wentz, I, Bortolozzo, F (2014) The post-cervical insemination does not impair the reproductive performance of primiparous sows. *Reproduction in Domestic Animals* **49**, 59-64.

Soriano-Úbeda, C, Matás, C, García-Vázquez, F (2013) An overview of swine artificial insemination: retrospective, current and prospective aspects. *J Exp Appl Anim Sci* **1**, 67-97.

Tantasuparuk, W, Lundeheim, N, Dalin, A-M, Kunavongkrit, A, Einarsson, S (2000) Effects of lactation length and weaning-to-service interval on subsequent farrowing rate and litter size in Landrace and Yorkshire sows in Thailand. *Theriogenology* **54**, 1525-1536.

Tantasuparuk, W, Lundeheim, N, Dalin, AM, Kunavongkrit, A, Einarsson, S (2001) Weaning-to-service interval in primiparous sows and its relationship with longevity and piglet production. *Livestock Production Science* **69**, 155-162.

Thaker, M, Bilkei, G (2005) Lactation weight loss influences subsequent reproductive performance of sows. *Animal Reproduction Science* **88**, 309-318.

Van Wettere, W, Herde, P, Hughes, P (2012) Supplementing sow gestation diets with betaine during summer increases litter size of sows with greater numbers of parities. *Animal Reproduction Science* **132**, 44-49.

Wettemann, R, Bazer, F (1985) Influence of environmental temperature on prolificacy of pigs. *Journal of reproduction and fertility. Supplement* **33**, 199-208.