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High lifetime and reproductive performance of sows on southern European Union commercial farms can be predicted by high numbers of pigs born alive in parity one[1]

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ABSTRACT: Our objectives were 1) to compare reproductive performance across parity and lifetime performance in sow groups categorized by the number of pigs born alive (PBA) in parity 1 and 2) to examine the factors associated with more PBA in parity 1. We analyzed 476,816 parity records and 109,373 lifetime records of sows entered into 125 herds from 2008 to 2010. Sows were categorized into 4 groups based on the 10th, 50th, and 90th percentiles of PBA in parity 1 as follows: 7 pigs or fewer, 8 to 11 pigs, 12 to 14 pigs, and 15 pigs or more. Generalized linear models were applied to the data. For reproductive performance across parity, sows that had 15 or more PBA in parity 1 had 0.5 to 1.8 more PBA in any subsequent parity than the other 3 PBA groups ($P < 0.05$). In addition, they had 2.8 to 5.4% higher farrowing rates in parities 1 through 3 than sows that had 7 or fewer PBA ($P < 0.05$). However, there were no differences between the sow PBA groups for weaning-to-first-mating interval in any parity ($P \geq 0.37$). For lifetime performance, sows that had 15 or more PBA in parity 1 had 4.4 to 26.1 more lifetime PBA than sows that had 14 or fewer PBA ($P < 0.05$). Also, for sows that had 14 or fewer PBA in parity 1, those that were first mated at 229 d old (25th percentile) or earlier had 2.9 to 3.3 more lifetime PBA than those first mated at 278 d old (75th percentile) or later ($P < 0.05$). Factors associated with fewer PBA in parity 1 were summer mating and lower age of gilts at first mating (AFM; $P < 0.05$) but not reservice occurrences ($P = 0.34$). Additionally, there was a 2-way interaction between mated month groups and AFM for PBA in parity 1 ($P < 0.05$); PBA in parity 1 sows mated from July to December increased nonlinearly by 0.3 to 0.4 pigs when AFM increased from 200 to 310 d old ($P < 0.05$). However, the same rise in AFM had no significant effect on the PBA of sows mated between January and June ($P \geq 0.17$). In conclusion, high PBA in parity 1 can be used to predict that a sow will have high reproductive performance and lifetime performance. Also, the data indicate that the upper limit of AFM for mating between July and December should be 278 d old.

Key words: consecutive data, lifetime performance, parity one, pigs born alive

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INTRODUCTION

There is relatively large variation in reproductive performance between sows, even if the sows are raised on the same farm (Iida and Koketsu, 2014). Appraisal of sow performance in low parity is necessary so that when producers are making decisions about keeping or culling sows they can predict which sows will have high lifetime performance. We reported that the total number of pigs born alive (**PBA**) in parity 1 and 2 is 1 of the measurements to estimate lifetime fertility (Sasaki et al., 2011). Meanwhile, a recent U.S. study reported that sows that had high PBA in parity 1 tended to have more PBA across parity compared to those with low PBA (Pinilla et al., 2014). Therefore, we hypothesized that highly fertile sows can be predicted by using only PBA in parity 1. However, no study has examined sows with

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high PBA in parity 1 to assess their other performance measurements including farrowing rate. Equally, there are no reports about the interaction between PBA in parity 1 and gilt ages at first mating for lifetime performance, even though these 2 factors are highly associated with sow longevity (Hoge and Bates, 2011).

Gilt ages at first mating and mating seasons are associated with PBA in parity 1 (Iida and Koketsu, 2014). Even though one study recommended first mating between 200 and 220 d old to maximize lifetime profitability (Schukken et al., 1994), few studies have quantified the interaction between gilt age at first mating and mating seasons or have any determined the best range for gilt ages at first mating by mating seasons to maximize PBA in parity 1. Therefore, our objectives were 1) to compare reproductive performance across parity and lifetime performance in sow groups categorized by PBA in parity 1, 2) to quantify the interaction between the PBA groups and gilt age at first mating for lifetime performance, and 3) to examine the interactions between gilt ages at first mating and mating seasons associated with higher PBA in parity 1.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because the data were obtained from the existing database. The database was created in the following manner. Since 1998, all producers in the designated countries using PigCHAMP software (PigCHAMP, Ames, IA) have been requested to mail their data files every time they renewed their yearly maintenance contract.

Farms and Reproductive Performance Data

Data were collected from 125 out of 160 farms in southern Europe that have an agreement with the consultancy firm PigCHAMP Pro Europa S.L. (Segovia, Spain). They comprised 98 Spanish farms, 23 Portuguese farms, and 4 Italian farms. The farms use natural or mechanical ventilation in their farrowing, breeding, and gestation barns. The lactation and gestation diets are formulated using cereals (barley, wheat, and corn) and soybean meal. Also, all the farms use artificial insemination; double or triple inseminations of sows during an estrous period is the recommended breeding management. Replacement gilts on the farms were either purchased from breeding companies or were home-produced through internal multiplication programs. These farm data were also used for another study about abortion occurrences (Iida et al., 2014).

Data for farm level measurements were obtained from the 125 farms; mean farm size (ranges) and change in farm size were 706 gilts and sows (81 to 3,222 gilts and sows) and 14.4% (–44.2 to 412.8%), respectively. The farm size was calculated by averaging the initial (January 2008) and final (June 2013) female inventories. The change in farm size was also calculated by (the final female inventory – the initial female inventory)/the initial female inventory × 100. Data from 4 farms that had 500% or greater change in farm size (initial farm size: 1–20 sows) were regarded as missing values. A missing value means that no data value was stored in the dataset for a particular observation of a variable.

Reproductive Performance Data and Exclusion Criteria

Lifetime records of sows entered from 2008 to 2010 were extracted from the PigCHAMP recording system. These sows were mated from January 2008 to June 2013. When the data were collected, 5,600 (4.4%) of the 128,534 sows had not yet been removed, and so they were excluded. Excluded data also included records of gilts removed in parity 0 (9,011 gilts) and sows with incomplete by-parity records in lifetime (1,659 sows). Further records for sows were excluded if the parity records of a sow met any of the following criteria: gestation length was either fewer than or equal to 104 d or was 126 d or longer (1,280 sows; Sasaki and Koketsu, 2007), total number of pigs born was either 0 or 26 pigs or more (413 sows; Lundgren et al., 2010), or weaning-to-first-mating interval was 61 d or longer (1,198 sows; Marois et al., 2000). Also omitted were parity records of sows in parity 7 or higher (57,673 parity records). Hence, the final data included 476,816 parity records and lifetime records for 109,373 sows that had farrowed at least once. In the present study, records of sows in parity 7 or later were not used, because large numbers of sows were voluntarily culled before reaching the seventh parity (Sasaki and Koketsu, 2011). Additionally, the following records were regarded as missing values: records of sows with gilt age at first mating of either 159 d old or earlier or 401 d old or later (Hoving et al., 2011), sows with 135 or more lifetime pigs weaned (the mean + 3 × SD; Bloemhof et al., 2013), and any parity records with 19 or more pigs weaned (the mean + 3 × SD).

Definitions and Categories

Annualized lifetime PBA, which is a measure of lifetime efficiency, was calculated as lifetime PBA divided by the reproductive herd life days multiplied by 365 d. Lifetime PBA was defined as the total of PBA in a sow's lifetime, lifetime pigs weaned was defined as pigs weaned in their lifetime, and reproductive herd life days was defined as the number of days from the date that the sows were first mated to their removal. Reproductive performance also included PBA, pigs weaned, weaning-to-first-mating interval, and farrowing rate. The by-parity farrowing rate was defined as the number of sows farrowed divided by the number of sows first serviced in that parity.

Sows were categorized into 4 groups based on the 10th, 50th, and 90th percentiles of PBA in parity 1; the groups were 7 pigs or fewer, 8 to 11 pigs, 12 to 14 pigs, and 15 pigs or more. Parity records were categorized into 2 groups based on the total number of services in any parity: serviced only once and serviced 2 or more times. Three groups for gilt ages at first mating were built on the basis of the 25th and 75th percentiles of gilt age at first mating: 229 d old or earlier, 230 to 277 d old, and 278 d old or later.

Statistical Analysis

All statistical analyses were conducted using SAS software (SAS Inst. Inc., Cary, NC). Three statistical models were created. Models 1 and 2 were applied to examine the respective associations between sow groups based on the PBA in parity 1 and either reproductive performance across parity or lifetime performance. Model 3 was constructed in order to examine the risk factors associated with PBA in parity 1. For continuous outcomes, linear mixed effects models were used to account for the clustering of sows within a farm (MIXED, random statement) or the correlation between repeated measures in the same sow (MIXED, repeated statement). A generalized estimation equation (**GEE**) model was also applied for whether or not a sow farrowed (1 or 0), using the GENMOD procedure with a logit link function and a binomial error distribution. The GEE model allows for only 1 level of clustering. Therefore, on the basis of a preliminary analysis using the VARCOMP procedure, which showed that the farm contributed very little to total variance (1.5%), it was decided to use within-sow clustering and ignore within-farm clustering of results (Schukken et al., 2003). Pairwise multiple comparisons were performed using the Tukey–Kramer test. Also, a square root transformation was used to obtain a normal distribution of weaning-to-first-mating interval.

Model 1 included the following factors as fixed effects: the 4 sow groups, parity, and the interaction between those factors. When PBA was analyzed, the following factors were used as fixed effects: number of service groups, entry year, and 4 quarterly mated-month groups (January to March, April to June, July to September, and October to December). The categorized factors were put in a model using a series of dummy variables. For models analyzing weaning-to-first-mating interval and farrowing rate, the fixed effects were entry year and 4 quarterly farrowing-month groups (January to March, April to June, July to September, and October to December). Model 2 for lifetime performance included following factors as fixed effects: the sow PBA groups, gilt age at first mating groups, the interaction between these 2 factors, herd-entry-year, and quarterly herd-entry-month groups. Model 3 included gilt age at first mating, number of services groups, quarterly mated-month groups, the biologically possible 2-way interactions between these factors, and herd-entry year. All the models included farm size and change in farm size as continuous variables and also included country as a categorical variable. Also, all the models except for the GEE model included the farm as a random intercept. In addition, a first-order autoregressive covariance structure was applied for reproductive performance across parity. Using the covariance structure, the correlation coefficients for the reproductive performance between any 2 adjacent parities were calculated.

Intraclass Correlation

The intraclass correlation coefficient (**ICC**) was calculated by the following equation to assess the variation in PBA in parity 1 that could be explained by the farm and also the variation in PBA across parity that could be explained by the sow effect (Dohoo et al., 2009),

$$\text{ICC (individual records within the same farm)} = \sigma_v^2/(\sigma_v^2 + \sigma_\varepsilon^2) \text{ and}$$

$$\text{ICC (individual records within the same sow)} = (\sigma_v^2 + \sigma_u^2)/(\sigma_v^2 + \sigma_u^2 + \sigma_\varepsilon^2),$$

in which σ_v^2 is the between-farm variance, σ_u^2 is the between-sow variance, and σ_ε^2 is the variance at the individual record level.

RESULTS

Descriptive statistics of lifetime and reproductive performance are shown in Table 1. Table 2 shows comparisons of reproductive performance across parity between the 4 sow groups categorized by their PBA in parity 1. Sows having 15 or more PBA in parity 1 had 0.5 to 1.8 more PBA in any subsequent parity than the other 3 groups ($P < 0.05$). Furthermore, they also had 0.2 to 1.5 more pigs weaned and 2.8 to 5.4% higher farrowing rate in parities 1 through 3 than those having 7 or fewer PBA ($P < 0.05$). However, there were no differences between the sow PBA groups for pigs weaned in parities 4 or 5 ($P \geq 0.98$) or for farrowing rate in parity 4 or higher ($P \geq 0.10$) or for weaning-

Table 1. Lifetime and reproductive data for 109,373 farrowed sows on 125 farms

Measurements	*n*	Mean ± SEM	Range	
			Minimum	Maximum
Lifetime performance				
Parity at removal	109,373	4.9 ± 0.01	1	13
Age of gilts at first mating, d old[1]	96,989	255.1 ± 0.14	160	400
Reproductive herd life days, d	109,373	748.5 ± 1.06	106	2,094
Lifetime pigs born alive, pigs	109,373	58.0 ± 0.10	0	202
Annualized lifetime pigs born alive, pigs	109,373	27.2 ± 0.02	0	61
Lifetime pigs weaned, pigs[1]	109,259	50.6 ± 0.08	0	134
Reproductive performance				
Parity	476,816	3.1 ± 0.01	1	6
Number of services	476,816	1.1 ± 0.01	1	10
Number of pigs born alive, pigs	476,816	11.9 ± 0.01	0	25
Number of pigs weaned, pigs[2]	470,177	10.3 ± 0.01	0	18
Weaning-to-first-mating interval, d	432,347	6.3 ± 0.01	0	60
Farrowing rate, %	432,347	86.3 ± 0.05	–	–

[1]The remaining records (109,373 – *n*) were regarded as missing records.

[2]The remaining records (476,816 – *n*) were regarded as missing records.

to-first-mating interval in any parity ($P \geq 0.37$). The correlations between any 2 adjacent parities within a sow for PBA, pigs weaned, weaning-to-first-mating intervals, and farrowing rates were 0.15, 0.12, 0.09, and 0.03, respectively. Also, ICC for PBA between individual records within the same sow was 17.6%.

There were 2-way interactions between the sow PBA groups and the gilt age at first mating groups for lifetime performance ($P < 0.05$; Table 3). For sows having 14 or fewer PBA in parity 1, the sows first mated at 229 d old or earlier had 2.9 to 3.3 more lifetime PBA, 0.3 to 0.6 more annualized lifetime PBA, 2.2 to 2.9 more lifetime pigs weaned, and 0.2 to 0.3 more parity at removal than sows first mated at 278 d old or later ($P < 0.05$). However, for sows having 15 or more PBA in parity 1, there were no such differences in lifetime performance between any of the gilt age at first mating groups ($P \geq 0.72$). In addition, in all gilt age at first mating groups, sows having 15 or more PBA in parity 1 had 4.4 to 26.1 higher more PBA and

Table 2. Comparisons of reproductive performance in consecutive parity between the 4 sow groups categorized by pigs born alive in parity 1[1, 2]

Pigs born alive in parity 1 sow groups	*n*[3]	Consecutive parity					
		1	2	3	4	5	6
		Pigs born alive, pigs					
7 pigs or fewer	12,889	5.1 ± 0.09^{dz}	10.8 ± 0.09^{dy}	11.5 ± 0.09^{dwx}	11.7 ± 0.09^{dv}	11.7 ± 0.09^{dvw}	11.5 ± 0.09^{dx}
8 to 11 pigs	41,795	9.9 ± 0.08^{cz}	11.3 ± 0.08^{cy}	11.9 ± 0.08^{cw}	12.0 ± 0.08^{cv}	11.9 ± 0.09^{cw}	11.6 ± 0.09^{cx}
12 to 14 pigs	40,607	12.7 ± 0.08^{bv}	11.9 ± 0.08^{bz}	12.5 ± 0.08^{bw}	12.5 ± 0.08^{bw}	12.3 ± 0.09^{bx}	12.0 ± 0.09^{by}
15 pigs or more	14,082	15.6 ± 0.09^{av}	12.6 ± 0.09^{ay}	13.1 ± 0.09^{aw}	13.1 ± 0.09^{aw}	12.9 ± 0.09^{ax}	12.5 ± 0.09^{ay}
		Pigs weaned, pigs					
7 pigs or fewer	12,720	8.8 ± 0.11^{dy}	10.0 ± 0.11^{cv}	10.0 ± 0.11^{bvw}	10.0 ± 0.11^{v}	9.9 ± 0.11^{w}	9.7 ± 0.11^{bx}
8 to 11 pigs	41,258	9.9 ± 0.11^{cy}	10.1 ± 0.11^{bv}	10.1 ± 0.11^{av}	10.1 ± 0.11^{w}	9.9 ± 0.11^{x}	9.8 ± 0.11^{abz}
12 to 14 pigs	39,991	10.3 ± 0.11^{bv}	10.2 ± 0.11^{av}	10.2 ± 0.11^{aw}	10.1 ± 0.11^{x}	9.9 ± 0.11^{y}	9.8 ± 0.11^{az}
15 pigs or more	13,884	10.4 ± 0.11^{av}	10.3 ± 0.11^{av}	10.2 ± 0.11^{aw}	10.1 ± 0.11^{x}	9.9 ± 0.11^{y}	9.7 ± 0.11^{abz}
		Farrowing rate, %					
7 pigs or fewer	11,300	79.8 ± 0.40^{cw}	83.8 ± 0.40^{cv}	84.5 ± 0.42^{cv}	85.0 ± 0.46^{v}	84.6 ± 0.52^{v}	84.1 ± 0.65^{v}
8 to 11 pigs	39,085	82.0 ± 0.22^{bw}	86.1 ± 0.21^{bv}	85.7 ± 0.22^{bcvw}	85.7 ± 0.24^{vw}	85.4 ± 0.26^{vw}	84.6 ± 0.32^{w}
12 to 14 pigs	38,294	84.1 ± 0.21^{ax}	87.0 ± 0.20^{abv}	86.5 ± 0.21^{abvw}	86.4 ± 0.23^{vw}	85.5 ± 0.26^{w}	85.6 ± 0.31^{w}
15 pigs or more	13,246	85.2 ± 0.32^{ax}	87.8 ± 0.31^{av}	87.3 ± 0.34^{avw}	86.9 ± 0.37^{vwx}	85.8 ± 0.42^{wx}	84.8 ± 0.51^{x}

[a–d]Different superscripts within a column represent significant differences in means ($P < 0.05$).

[v–z]Different superscripts within a row represent significant differences in means ($P < 0.05$).

[1]Means and SE were estimated by using mixed models.

[2]Weaning-to-first-mating interval is not shown in the table because there were no differences between the sow groups in any parity.

[3]*n* represents the initial number of sows.

Table 3. Comparisons of lifetime performance between the 4 sow groups, categorized by pigs born alive in parity 1, and 3 gilt age at first mating groups[1]

	Sow groups for pigs born alive in parity 1			
Gilt age at first mating	7 pigs or fewer	8 to 11 pigs	12 to 14 pigs	15 pigs or more
Numbers of sows at first farrowing				
229 d old or earlier	2,815	9,382	9,065	3,093
230–277 d old	5,626	18,142	18,098	6,172
278 d old or later	2,793	9,112	9,024	3,667
Lifetime pigs born alive, pigs				
229 d old or earlier	43.3 ± 1.42^{ay}	54.9 ± 1.33^{ax}	61.8 ± 1.33^{aw}	66.2 ± 1.42^{v}
230–277 d old	41.6 ± 1.34^{aby}	54.7 ± 1.29^{ax}	60.9 ± 1.29^{aw}	66.8 ± 1.33^{v}
278 d old or later	40.0 ± 1.40^{by}	51.8 ± 1.31^{bx}	58.9 ± 1.31^{bw}	66.0 ± 1.37^{v}
Annualized lifetime pigs born alive, pigs				
229 d old or earlier	20.4 ± 0.32^{ay}	25.5 ± 0.31^{ax}	28.5 ± 0.31^{aw}	31.4 ± 0.32^{v}
230–277 d old	20.1 ± 0.31^{aby}	25.5 ± 0.31^{ax}	28.4 ± 0.31^{abw}	31.4 ± 0.31^{v}
278 d old or later	19.8 ± 0.32^{by}	25.1 ± 0.31^{bx}	28.1 ± 0.31^{bw}	31.5 ± 0.32^{v}
Lifetime pigs weaned, pigs				
229 d old or earlier	43.4 ± 1.29^{ax}	49.6 ± 1.22^{aw}	52.2 ± 1.22^{av}	51.7 ± 1.29^{v}
230–277 d old	41.8 ± 1.23^{abx}	49.5 ± 1.19^{aw}	51.5 ± 1.19^{av}	52.3 ± 1.22^{v}
278 d old or later	40.5 ± 1.28^{bx}	46.9 ± 1.21^{bw}	49.9 ± 1.21^{bv}	51.5 ± 1.25^{v}
Parity at removal				
229 d old or earlier	4.4 ± 0.12^{ax}	4.9 ± 0.11^{aw}	5.1 ± 0.11^{av}	5.0 ± 0.12^{vw}
230–277 d old	4.2 ± 0.11^{abx}	4.8 ± 0.11^{aw}	5.0 ± 0.11^{av}	5.0 ± 0.11^{v}
278 d old or later	4.1 ± 0.12^{bx}	4.6 ± 0.11^{bw}	4.8 ± 0.11^{bv}	4.9 ± 0.11^{v}

[a,b]Different superscripts within a column represent significant differences in means ($P < 0.05$).

[v–y]Different superscripts within a row represent significant differences in means ($P < 0.05$).

[1]Means and SE were estimated by using mixed models.

2.9 to 11.7 more annualized lifetime PBA than sows having 14 or fewer PBA ($P < 0.05$). Also, sows having 12 or more PBA in parity 1 had 0.6 to 0.8 higher parity at removal than sows having 7 or more PBA over the ranges of gilt ages at first mating ($P < 0.05$).

More PBA in parity 1 was associated with higher gilt age at first mating and larger farm size ($P < 0.05$) but not with reservice occurrences or changes in farm size ($P \geq 0.06$; Table 4). Also, sows mated from January to June and from October to December had 0.13 and 0.09 more PBA in parity 1, respectively, than those mated between July and September. In the statistical models, the random farm effect on the intercept explained only 6.1% of the total variance for PBA in parity 1 (Table 4). As farm size increased from 180 to 1,300 gilts and sows (10th to 90th percentiles), PBA in parity 1 increased linearly by 0.3 pigs ($P < 0.05$; Fig. 1). Additionally, there was a 2-way interaction between mated month groups and gilt ages at first mating for PBA in parity 1 ($P < 0.05$); PBA in parity 1 sows mated from July to September and from October to December increased nonlinearly by 0.3 and 0.4 pigs, respectively, when gilt age at first mating increased from 200 to 310 d old ($P < 0.05$; Fig. 2). However, the same rise in gilt age at first mating had no significant effect on the PBA of sows mated between January and June ($P \geq 0.17$).

Table 4. Estimates of fixed effects and random effect variance included in the final linear regression model for pigs born alive in parity 1

Fixed effects[1] and variance	Estimate (±SE)	*P*-value
Constant	10.916928 (0.194939)	<0.01
Gilt age at first mating, d old	0.000819 (0.000561)	0.14
Gilt age at first mating squared	–0.000008 (0.000005)	0.11
Reservice	–0.031436 (0.032904)	0.34
Mated month groups		<0.01
January–March	0	
April–June	–0.000868 (0.028499)	
July–September	–0.133524 (0.029104)	
October–December	–0.039992 (0.028434)	
Mated month groups × gilt age at first mating		<0.01
January–March	0	
April–June	–0.000001 (0.000652)	
July–September	0.001672 (0.000682)	
October–December	0.002942 (0.000661)	
Farm size, gilts and sows	0.000267 (0.000127)	0.04
Change in farm size, %	0.002775 (0.001464)	0.06
Intercept variance at farm level	0.63 (0.08)	
Intercept variance at sow level	9.56 (0.04)	
ICC[2] (records within the same farm), %	6.1	

[1]Country and entry year are not shown in the table.

[2]ICC = intraclass correlation coefficient.

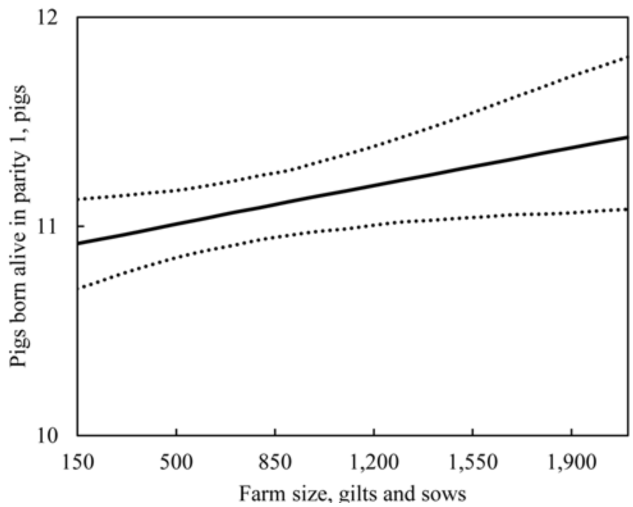

Figure 1. The prediction line of pigs born alive in parity 1 with changing farm size (dotted lines show 95% confidence intervals which were defined as the mean ± 1.96 × SE.).

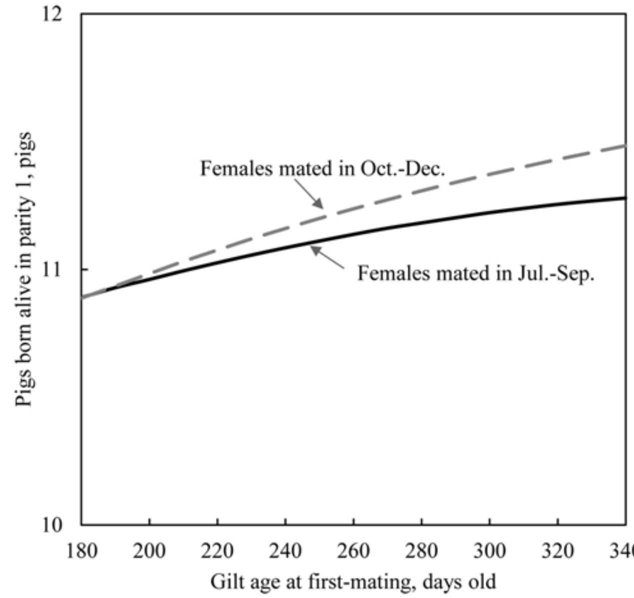

Figure 2. The prediction lines of pigs born alive in parity 1 for sows that mated at different ages at first mating, in different seasons. The predicted lines of pigs born alive in parity 1 for sows mated between January and June are not shown because the Wald's test failed to reject the null hypothesis that the regression coefficients of age at first mating and age at first mating squared terms for the sows were simultaneously equal to 0 ($P \geq 0.17$).

DISCUSSION

In this study, the constant high PBA across parity and high farrowing rate in parities 1 through 3 in sows that had high PBA at first farrowing confirms that PBA in parity 1 is a useful indicator to help producers to identify highly fertile sows at an early stage. Also, the fact that there was a relatively higher correlation between adjacent parities for PBA than for farrowing rate indicates that PBA can be better predicated by using PBA in parity 1 than by using farrowing rate. In addition, the constant high PBA across parity and high longevity for sows that had high PBA in parity 1 resulted in these sows having more lifetime PBA than sows that had low PBA in parity 1.

Our study showed no difference between the sow PBA groups for weaning-to-first-mating interval, which is a key nonproductive day, and this suggests that there was no negative effect of high PBA at first farrowing on the first estrus cycle after weaning. The lack of any negative effect can probably be explained by the fact that the mechanisms and genetics related to the weaning-to-first-mating interval and to having high PBA are different; weaning-to-first-mating interval is strongly related to LH secretion through the hypothalamic–pituitary–gonadal axis of sows (Koketsu et al., 1996). Additionally, PBA in parity 1 was not clearly associated with the number of pigs weaned in parity 2 or later. This result can be explained by cross-fostering practices and preweaning mortality. Higher mortality has been shown to be associated with more PBA and high parity sows (Koketsu et al., 2006), and with regard to fostering practices, producers often make less prolific sows foster extra piglets from highly prolific sows (Usui and Koketsu, 2013).

In the sow groups having 14 or fewer PBA in parity 1, sows first mated at a high age had lower lifetime productivity than those mated at an earlier age, even though higher gilt age at first mating was associated with more PBA in parity 1. This contradiction can be explained by the fact that sows with high gilt age at first mating are likely to become low-efficiency sows as a result of increased culling due to reproductive failure (Takanashi and Koketsu, 2011) and therefore have lower longevity than sows first mated at a low gilt age (Knauer et al., 2010; Patterson et al., 2010). However, our results showed that sows having 15 or more PBA in parity 1 had constant high lifetime performance regardless of first mating age. These sows appear to be innately fertile sows, and it is possible that such fertile sows were part of excessive sows whose estrus cycles in parity 0 were deliberately skipped by the producers to maintain stable output.

This is the first reported study about the interaction between gilt age at first mating and mating season for PBA in parity 1. Gilts mated during summer or early autumn appear to grow poorly due to heat stress. A previous study showed that gilts reared from April to October had low growth rate and delayed puberty compared to those from October to April (Christenson, 1981). So, producers should use well-matured gilts for mating between July and December. However, considering the low lifetime performance for sows that were higher aged gilts at first mating, the data suggest that 278 d old should be the upper age limit for first mating during this period on the studied farms. Meanwhile, there was no such association in winter and spring. So, we recommend mating sows as soon as possible during this period. Also, the association between larger farm size and an increase in PBA can be explained by the hypothesis that there is faster genetic improvement and a better production system on larger farms than on small farms.

Finally, the 17.6% ICC in PBA for individual records within the same sow in the present study can be explained by the variation of PBA between parity records. Such a variation could be due to differences in management practices between different parity records. This indicates the importance of management practices at each parity such as increasing lactational feed intake (Koketsu and Dial, 1997), the optimal timing of mating (Kaneko et al., 2013), and reducing environmental stresses. Also, in the present study, the relatively low ICC in PBA in parity 1 for farm variance indicates that there were few unexplained effects of the farm on PBA.

There are some limitations that should be noted when interpreting the results of this study. This study was an observational study performed using commercial farm data. Farm health, nutrition, genotype, and boar fertility or service sire effects were not taken into account in the analyses. However, even with such limitations, this research provides valuable information about the effect of PBA in parity 1 on reproductive productivity and lifetime efficiency for swine producers and veterinarians.

In conclusion, high PBA in parity 1 can be used to predict highly prolific sows. Also, the upper limit age of gilts at first mating in summer to autumn may be at most 278 d old because any further delay in first mating could not improve lifetime performance. Additionally, sows with low PBA in parity 1 should not be readily culled as long as they do not have reproductive failure, because economic analysis has indicated that positive lifetime net income would not be obtained until parity 3 (Lucia et al., 2000; Stalder et al., 2003; Sasaki et al., 2012). In fact, there are few occurrences on commercial farms of culling low parity sows due to low litter size (Engblom et al., 2007; Sasaki and Koketsu, 2008). However, country- or farm-specific opportunity costs of postponed replacement should also be considered, in order to make decisions about keeping or culling a low PBA sow.

LITERATURE CITED

Bloemhof, S., P. K. Mathur, E. F. Knol, and E. H. van der Waaij. 2013. Effect of daily environmental temperature on farrowing rate and total born in dam line sows. J. Anim. Sci. 91:2667–2679. doi:10.2527/jas.2012–5902

Christenson, R. K. 1981. Influence of confinement and season of the year on puberty and estrous activity of gilts. J. Anim. Sci. 52:821–830.

Dohoo, I. R., S. W. Martin, and H. Stryhn. 2009. Veterinary epidemiologic research, 2nd ed. VER Inc., Charlottetown, PE, Canada.

Engblom, L., N. Lundeheim, A.-M. Dalin, and K. Andersson. 2007. Sow removal in Swedish commercial herds. Livest. Sci. 106:76–86. doi:10.1016/j.livsci.2006.07.002.

Hoge, M. D., and R. O. Bates. 2011. Developmental factors that influence sow longevity. J. Anim. Sci. 89:1238–1245. doi:10.2527/jas.2010–3175.

Hoving, L. L., N. M. Soede, E. A. M. Graat, H. Feitsma, and B. Kemp. 2011. Reproductive performance of second parity sows: Relations with subsequent reproduction. Livest. Sci. 140:124–130. doi:10.1016/j.livsci.2011.02.019.

Iida, R., and Y. Koketsu. 2014. Interactions between pre- or post-service climatic factors, parity, and weaning-to-first-mating interval for total number of pigs born of female pigs serviced during hot and humid or cold seasons. J. Anim. Sci. 92:4180–4188. doi:10.2527/jas.2014–7636.

Iida, R., Y. Koketsu, and C. Piñeiro. 2014. Abortion occurrence, repeatability and factors associated with abortions in female pigs in southern EU commercial herds. In: Proceedings of the Conference of Research Workers in Animal Diseases, Chicago, IL. p. 94.

Kaneko, M., R. Iida, and Y. Koketsu. 2013. Herd management procedures and factors associated with low farrowing rate of female pigs in Japanese commercial herds. Prev. Vet. Med. 109:69–75. doi:10.1016/j.prevetmed.2012.09.014.

Knauer, M., K. J. Stalder, T. Serenius, T. J. Baas, P. J. Berger, L. Karriker, R. N. Goodwin, R. K. Johnson, J. W. Mabry, R. K. Miller, O. W. Robison, and M. D. Tokach. 2010. Factors associated with sow stayability in 6 genotypes. J. Anim. Sci. 88:3486–3492. doi:10.2527/jas.2009–2319.

Koketsu, Y., and G. D. Dial. 1997. Factors influencing the postweaning reproductive performance of sows on commercial farms. Theriogenology 47:1445–1461. doi:10.1016/S0093-691X(97)00135-0.

Koketsu, Y., G. D. Dial, J. E. Pettigrew, W. E. Marsh, and V. L. King. 1996. Influence of imposed feed intake patterns during lactation on reproductive performance and on circulating levels of glucose, insulin, and luteinizing hormone in primiparous sows. J. Anim. Sci. 74:1036–1046.

Koketsu, Y., S. Takenobu, and R. Nakamura. 2006. Preweaning mortality risks and recorded causes of death associated with production factors in swine breeding herds in Japan. J. Vet. Med. Sci. 68:821–826. doi:10.1292/jvms.68.821.

Lucia, T., Jr., G. D. Dial, and W. E. Marsh. 2000. Lifetime reproductive and financial performance of female swine. J. Am. Vet. Med. Assoc. 216:1802–1809. doi:10.2460/javma.2000.216.1802.

Lundgren, H., L. Canario, K. Grandinson, N. Lundeheim, B. Zumbach, O. Vangen, and L. Rydhmer. 2010. Genetic analysis of reproductive performance in Landrace sows and its correlation to piglet growth. Livest. Sci. 128:173–178. doi:10.1016/j.livsci.2009.12.002.

Marois, D., J. R. Brisbane, and J. P. Laforest. 2000. Accounting for lactation length and weaning-to-conception interval in genetic evaluations for litter size in swine. J. Anim. Sci. 78:1796–1810.

Patterson, J. L., E. Beltranena, and G. R. Foxcroft. 2010. The effect of gilt age at first estrus and breeding on third estrus on sow body weight changes and long-term reproductive performance. J. Anim. Sci. 88:2500–2513. doi:10.2527/jas.2008–1756.

Pinilla, J. C., R. Molinari, J. Coates, J. Piva, B. Thompson, R. Teuber, and S. Canavate. 2014. Gilt management for 35 PSY. In: Proceeding of the American Association of Swine Veterinarians, Dallas, TX. p. 217–220.

Sasaki, Y., and Y. Koketsu. 2007. Variability and repeatability in gestation length related to litter performance in female pigs on commercial farms. Theriogenology 68:123–127. doi:10.1016/j.theriogenology.2007.04.021.

Sasaki, Y., and Y. Koketsu. 2008. Sows having high lifetime efficiency and high longevity associated with herd productivity in commercial herds. Livest. Sci. 118:140–146. doi:10.1016/j.livsci.2007.12.029.

Sasaki, Y., and Y. Koketsu. 2011. Reproductive profile and lifetime efficiency of female pigs by culling reason in high-performing commercial breeding herds. J. Swine Health Prod. 19:284–291.

Sasaki, Y., I. McTaggart, and Y. Koketsu. 2012. Assessment of lifetime economic returns of sows by parity of culled sows in commercial breeding herds. J. Vet. Epidemiol. 16:37–45. doi:10.2743/jve.16.37.

Sasaki, Y., H. Saito, A. Shimomura, and Y. Koketsu. 2011. Consecutive reproductive performance after parity 2 and lifetime performance in sows that had reduced pigs born alive from parity 1 to 2 in Japanese commercial herds. Livest. Sci. 139:252–257. doi:10.1016/j.livsci.2011.01.017.

Schukken, Y. H., J. Buurman, R. B. Huirne, A. H. Willemse, J. C. Vernooy, J. Van den Broek, and J. H. Verheijden. 1994. Evaluation of optimal age at first conception in gilts from data collected in commercial swine herds. J. Anim. Sci. 72:1387–1392.

Schukken, Y. H., Y. T. Grohn, B. McDermott, and J. J. McDermott. 2003. Analysis of correlated discrete observations: Background, examples and solutions. Prev. Vet. Med. 59:223–240. doi:10.1016/S0167-5877(03)00101-6.

Stalder, K. J., R. C. Lacy, T. L. Cross, and G. E. Conatser. 2003. Financial impact of average parity of culled females in a breed-to-wean swine operation using replacement gilt net present value analysis. J. Swine Health Prod. 11:69–74.

Takanashi, A., and Y. Koketsu. 2011. Factors associated with sows having low lifetime efficiency in commercial herds. J. Vet. Epidemiol. 15:10–14. doi:10.2743/jve.15.10.

Usui, S., and Y. Koketsu. 2013. Effect of increased number of pigs weaned compared to pigs born alive on sows' subsequent reproductive performance in Japanese commercial breeding herds. J. Vet. Epidemiol. 17:36–43. doi:10.2743/jve.17.36.