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Relationships between gilt development and herd production efficiency are revealed by simulation

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Abstract: The gilt development level is a critical factor for profitability in the pig industry. To evaluate the impact of different gilt development levels on the age structure and production efficiency of female herds we used the performance data of a pig farm that was simulated over a ten-year period, with current production statistics from the Chinese pig industry as a basis for the model. In a herd of 600 breeding sows, we compared age structure, number born alive (NBA), longevity and sow lifetime productivity in three scenarios with gilt culling rates of 10%, 20%, and 30%. The results show that the gilt development has no significant effects on the age structure. The gilt development had no significant effects either on sow reproductive performance or production efficiency. However, the annual replacement rate, longevity, and sow lifetime productivity varied significantly in the three levels of gilt development ($P < 0.01$). We conclude that the gilt development is closely related to herd turnover and reproductive performance, and ultimately affects the cost of pig production. Gilt development is, therefore, an extremely important factor in an integrated pig production system.

Keywords: pig; computer simulation; performance of gilt; age structure; productivity

Herd reproductive performance is a critical factor for profitability in the pig industry. A variety of indicators are used to measure it, such as the NBA (number born alive) and PSY (pigs weaned/sow/year). This statistic is frequently used to compare differences in performance between herds of female pigs within or amongst countries (Koketsu 2002). Over the last three decades, PSY in European

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countries has shifted from 20 to 30 pigs or even more, and 40 pigs have been discussed as a reachable goal due to the development of molecular breeding technology and advanced management practices (Koketsu et al. 2017). Denmark has the best-developed pig industry in the world, and is now approaching PSY of 35 pigs (Willems et al. 2016). In contrast, PSY in Chinese pig production is approximately 20–22 pigs, demonstrating that substantial differences exist between the performance of Chinese and European or North American herds (Kraeling and Webel 2015).

Female age distribution within a herd has a large influence on the number of piglets produced per year (Tummaruk et al. 2009). Gilts are usually the largest single age group, comprising 17 to 24% of the females in a herd. Gilt development therefore impacts overall herd reproductive performance, age structure, herd turnover, longevity, sow lifetime productivity and production costs (Knauer et al. 2012).

Gilt development is regarded as an independent component in the integrated pig production systems in Europe and North America. The gilt population is also described as a gilt pool, gilt development unit (GDU), or fourth sites (4S) (the last term is used in Brazil) (Iida and Koketsu 2015). However, the relationship between gilt development, herd age structure, and production efficiency in female pigs is complex and remains unclear.

Although China has the largest inventory of pigs in the world, its reproduction efficiency is relatively low, and scant attention is given to gilt development or its impact on reproduction efficiency. In order to explore the relationship between gilt development level and age structure, production efficiency, longevity, and sow lifetime productivity, we simulated a pig production system using data from Chinese producers, and then simulated its 10-year performance *in silico*. The scale of the model mimics a pig farm with a breeding herd size of 600 sows capable of producing more than 10 000 commercial pigs per year, which is regarded as a 'ten-thousand pig farm' in China. The simulation allows us to demonstrate the impact of gilt development options on current Chinese practices and compare the performance of Chinese pig farms with the developed pig industry in Western countries. We conclude that improving the gilt development may be a solution to increasing the herd reproduction efficiency in Chinese agriculture.

MATERIAL AND METHODS

General considerations

This study used computer simulation by Fortran to construct the production of a pig farm with 600 sows over a 10-year period. The simulation was established using contemporary production conditions at three pig facilities in China, along with relevant data from the literature (Table 1).

The sow herd size was constant throughout the 10 years of simulation. If sows were removed from the breeding herd, they were replaced with the same number of gilts from the gilt pool. And the state of the herd was recalculated at 1-week intervals.

Batch farrowing system

This model represents a farrow-to-finish herd for mass production of sows, thus realizing batch management of pigs. The simulation was based on current pig production practices. Female herd production was simulated by modules for mating, pregnancy, farrowing, and nursing.

Mating module: the wean-to-oestrus interval was five to seven days and the success of mating was 95% in an oestrous period. The first pregnancy test was scheduled 14 to 21 days after mating, with the pregnancy detection success rate set to 90%. The second pregnancy test was 28 days after mating, with a success rate of 100%.

Pregnancy module: pregnant sows were transferred to the gestational barn 28 days after mating. The fallout rate was assumed as 10% in the first trimester (50 days) and 5% in late pregnancy (90 days). Pregnant sows were transferred to farrowing and lactation rooms a week before farrowing.

Farrowing and lactation module: pregnant sows were transferred to the farrowing room one week be-

Table 1. Culling rates (CR) and number born alive (NBA) for breeding sows (parity 1–10)

Parity	1	2	3	4	5	6	7	8	9	10
CR (%)	X	10	8	8	3	50	60	70	80	100
NBA	9.5	11.5	13.5	14.0	13.5	12.5	12.0	11.0	10.0	9.0

Parameters for simulation were obtained from data reported in the literature and from actual production statistics. X represents the gilt culling rate and was set to 10%, 20%, or 30% in the simulation

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fore farrowing. The lactation period lasted 28 days. The number of pigs born alive was documented. Weaned sows were sent to the next production cycle.

The realized model is a discrete-time dynamic model. It represents the time evolution of the number of pigs in each batch and time interval is one week.

Determining the level of gilt development

Gilts and sows. The gilt was defined as an individual that was selected for piglet production but had not yet farrowed.

NBA and by-parity culling rate. Gilt development was varied by adjusting the culling rate at the weaning of parity 1. According to the rule of the culling rate in commercial pig farms, the culling rates were set 10%, 20%, and 30%. Other by-parity culling rates (i.e., after parity 1) were chosen to reflect the current population of sows in China and from data in the scientific literature (Table 1). Culling in the second to fourth parties is based on involuntary factors such as reproductive failure or feet and leg problems. For higher parity (over six) females, culling follows a voluntary removal strategy to achieve ideal herd parity distribution and aging.

Number born alive (NBA) is an indicator to measure the reproduction efficiency of breeding sows. The number of pigs born alive in each parity was determined according to current production data from three pig enterprises in China.

Statistical analysis

The data from the simulation was used to generate statistics for the herd. The NBA for parity 1 was calculated as the sum of NBA from sows farrowing at parity 1 divided by the number of sows of parity 1. NBA was calculated similarly for other parities. The effects of gilt development on age structure and reproductive efficiency of the breeding herd were summarized as annual production data for each of the 10 years of the simulation.

Data were analysed using SPSS v20.0 (IBM Corp, Armonk, NY, USA) software and R (https://www.r-project.org/). Analysis of variance was conducted using the R package Tukey HSD test. Figures were constructed using GraphPad Prism v7 for Windows (www.graphpad.com) and the R package ggplot2.

RESULTS

Effects of gilt development on herd annual replacement rate

For each year of the simulation, the replacement rate for the herd was calculated at each of the three levels of gilt development. Table 2 shows the herd average annual replacement rates as a function of gilt development. The rates corresponding to the three development levels (10%, 20% and 30%) were 32.3 ± 0.2%, 34.9 ± 0.4% and 38.0 ± 0.3%, respectively, and the differences were statistically significant ($P < 0.01$).

Effects of gilt development on herd age structure and production efficiency

The parity distribution for breeding sows was examined for the three gilt culling rates. Figure 1 shows the parity structure generated using different gilt development levels. Figure 1 represents the herd age structure based on the 10%, 20% and 30% gilt culling rate. In this simulation, gilts are the largest cohort in the population, and breeding sows with parity 1 to 5 dominate the herd.

To analyse the effect of the gilt development level in more detail, members of the breeding herd were classified into three groups based on parity. The low-parity group contained sows with parity less than 3, the middle parity group spanned parity 3 to 5, and

Table 2. Comparison of herd production performance based on different gilt development levels

Culling rate (%)	Herd ARR (%)	Annual herd NBA	Average parity at culling	Average lifetime NBA
10	32.3 ± 0.2	16 488.5 ± 247.97	7.2 ± 0.67	70.2 ± 0.17
20	34.9 ± 0.4*	16 416.0 ± 42.22	6.7 ± 0.11*	64.7 ± 1.07*
30	38.0 ± 0.3***	16 421.9 ± 84.23	6.2 ± 0.07***	59.4 ± 0.92***

ARR = annual replacement rate; NBA = number born alive

*Significant at $P < 0.05$; ***significant at $P < 0.001$ within each group

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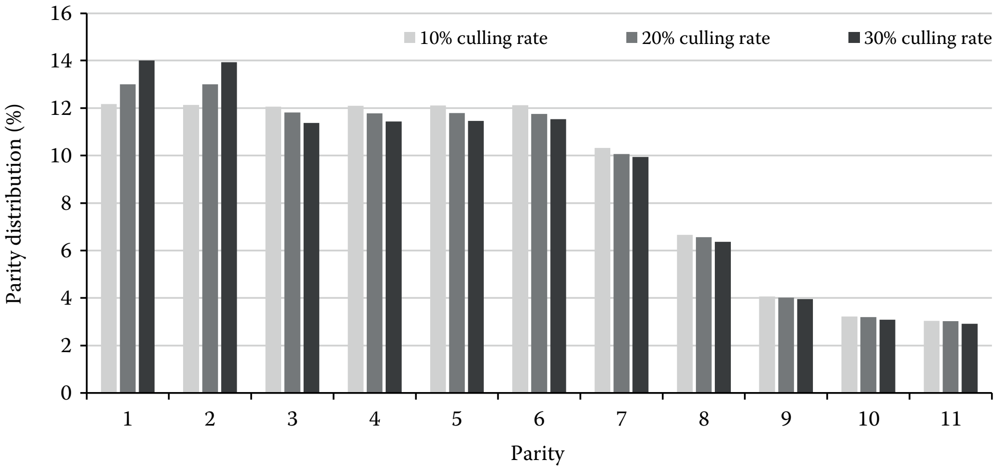

Figure 1. Parity distribution generated by different gilt development levels

the high-parity group contained sows with parity over 7. The number of breeding sows in the three categories is compared in Table 3 for the three gilt development levels. Although there were minor differences within each category, the number of sows did not differ significantly between gilt development levels ($P > 0.05$).

Table 2 shows the annual average numbers born alive (NBA) for the herd for the three levels of gilt development, expressed as an average across the 10 years of simulation. The herd annual NBA corresponding to the three development levels differed only slightly, and were statistically indistinguishable ($P > 0.05$).

Longevity and lifetime productivity at different levels of gilt development

The longevity for a given herd was measured as the mean of parity for sows removed from the herd. The annual average sow longevity is compared across culling rates in Table 2. The mean parity of sows at removal, corresponding to the three culling rates (10%, 20% and 30%), was 7.2 ± 0.67, 6.7 ± 0.11 and 6.2 ± 0.07, respectively. As the gilt culling rate increases, sow longevity exhibits a decreasing trend, and the differences between the culling rates are highly significant ($P < 0.01$).

Table 3. Breeding sow age structure

Culling rate (%)	Low-parity	Middle-parity	High-parity
10	226.8 ± 1.09	237.8 ± 0.98	82.8 ± 1.02
20	231.4 ± 2.55	236.0 ± 2.13	82.4 ± 0.90
30	236.2 ± 2.38	231.9 ± 2.22	81.7 ± 1.07

Values within each group are not significantly different $P > 0.05$

Lifetime productivity was measured as the sum of NBA throughout the life of a sow. The results for the three gilt development levels are shown in Table 2. The average NBA corresponding to the three development levels (10%, 20% and 30%) were 70.2 ± 0.17, 64.7 ± 1.07 and 59.4 ± 0.92, respectively. As the gilt culling rate increased, differences in female lifetime productivity exhibited a decreasing trend. The differences between the culling rates are highly significant ($P < 0.01$).

DISCUSSION

Gilt development and management are critical factors in the pig production industry. Genetic selection and improvement of gilt development are regarded as effective ways to improve the herd reproduction performance, as assessed by growth rate, body composition, disease status, sexual development, and the reproductive records for each dam (Engblom et al. 2008). Gilts and their subsequent reproductive performance are associated with factors such as colostrum consumption, birth weights, pre-weaning growth rate, number weaned, and parity structure. Gilt development therefore plays a key role in large pork production systems that emphasize the high output (Hoge and Bates 2011).

The success or failure in gilt development depends on numerous factors. The leading causes for removing gilts from the breeding herd are reproductive failure and problems affecting feet and

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leg soundness (Lucia et al. 1999). However, the effects of gilt development on reproductive productivity and age structure of the breeding herd have not been analysed.

Gilt development is a key factor in determining the annual herd replacement rate

A 45–55% herd replacement rate is usually recommended, according to the herd type. The higher replacement rate is necessary in nucleus herds in order to achieve a faster transfer of genetic gain, but ideally the replacement in commercial herds is lower in order to exploit the sow's reproductive potential to the greatest extent (Xiao et al. 2012). Greater annual replacement rates for breeding herd females can occur for various reasons, such as the failure of postpartum sows to return to oestrus and conceive, poor reproductive performance, poor feet and leg soundness, health challenges, and the introduction of new genetic lines (Rodriguez-Zas et al. 2006). In this study, computer simulation was used to demonstrate that the level of gilt development has a significant impact on the annual herd replacement rate. A higher culling rate for gilts results in a less efficient herd structure. In turn, to maintain a relatively stable number of female pigs and parity distribution, the gilt pool size must be increased, which raises the cost of pig production (Ulguim et al. 2014).

A common problem in current Chinese pig production systems and many other systems around the world is that too many young sows (gilts or sows with less than three parities) are culled. 32% of sows are removed before their third parity, resulting in an unstable herd parity distribution and a requirement for a large pool of replacement gilts (Hoge and Bates 2007). The herd age structure is determined by parity-specific culling rates. Increasing the percentage of sows with higher parities within a herd has a positive effect on herd management costs. Conversely, a high herd replacement rate increases costs due to the purchase of gilts.

Relationship between gilt development and herd age structure

The age structure of sows is closely related to their production efficiency because reproductive performance in each parity is different. When sow parity is 3 to 5, reproductive performance peaks, and then fertility efficiency gradually decreases (Hoge and Bates 2011). Contrary to the results of previous studies, we found that the gilt development level has no effect on herd age structure and production efficiency. The discrepancy may be due to the fact that we simulated a relatively small population of only 600 sows, and explored only three gilt development levels.

The parity profile is determined by gilt development, by parity culling, and loss by death. The ideal parity profile for maintaining higher herd reproductive efficiency is described in a PIC technical guideline (http://www.picscheme.org) and is similar to our findings. The parity profile affects the biological and economic performance of a herd. Understanding the factors that influence parity structure, and the ability to manipulate them, is critical for optimizing long-term profitability in pig production. When gilts are slaughtered, it is assumed that the replacement sows have a better chance of giving birth and producing heavier, healthier pigs. It is also assumed that the new sow will return to oestrus earlier after weaning and has a higher probability of producing a good litter in the subsequent cycle.

Gilt development is closely related to longevity and lifetime productivity

Sow longevity is defined as the number of days from the first farrowing to removal from the herd. Lifetime productivity is the total number of pigs produced in the lifetime of a female. The average parity of a female at culling has been used as a proxy for longevity, as it is not typical to record female age in the pig industry (Rozeboom et al. 1996). High average parity at removal has been associated with high breeding herd productivity (Sukumarannairs et al. 2008), and lower average parity at removal increases expenses due to gilt replacement, and creates subpopulations of low parity animals with low disease resistance (Serenius et al. 2006). Numerous observational studies have demonstrated that multiple factors can impact sow longevity, such as genetics, nutrition, housing, disease, lameness, age at first mating, assistance at farrowing, length of lactation, growth rate, body condition, and performance at parity one (Koketsu 2006).

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An important result in this study is that differences in sow longevity can occur due to differences in gilt development.

The parity of culled sows is averaged over a period of time using females born in different years. Parity 1 sows have the highest frequency of culling, although culling at parity 0 (gilt) has not been well documented (de Sevilla et al. 2008). Poor sow longevity reduces the opportunity for a sow to be sufficiently productive and achieve a return that exceeds the cost of a replacement gilt. This study confirms that when gilt development is at a higher level, the female herd has greater longevity.

Lifetime productivity is critical for producers managing commercial herds (Kim et al. 2013). The lifetime NBA is defined as the sum of NBA throughout the life of a sow. High-producing sows should remain in the herd for a longer time to exploit their reproductive potential to the greatest extent. A lower culling rate results in a higher level of gilt development, and an increase in production efficiency is observed. Although there is an opportunity to optimize gilt development in the Chinese pig industry and in all pig producing countries, there has been no effort to do so. Lifetime performance varies according to the rationale for culling. For example, females culled for a reproductive failure have the most lifetime non-productive days of all culled females (de Jong et al. 2012). Females with poor leg conformation tend to be culled at low parity, and thus they also have poor lifetime performance. The lifetime efficiency of females is therefore affected by culling management practices, which vary among commercial producers.

CONCLUSION

Herd reproductive performance is a critical factor for profitability in the pig industry. Gilts are usually the largest single age group, thus gilt development impacts overall herd reproductive performance, age structure, herd turnover, longevity, sow lifetime productivity and production costs. The simulation allows us to demonstrate the impact of gilt development options on current Chinese practices and compare the performance of Chinese pig farms with the developed pig industry in Western countries. We conclude that improving gilt development may be a solution to increasing herd reproduction efficiency in Chinese and world agriculture.

Conflict of interest

The authors declare no conflict of interest.

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