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Managing gene by environment interactions on reproductive performance of replacement gilts and boars through pre-weaning management at multiplication level – Is this a reality?

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Introduction

It commonly is accepted that management conditions to which adult sows and boars are exposed can have a significant impact on their respective reproductive functions. Ovulation rates, embryonic survival, and fetal growth in sows (Flowers, 1999) and sperm production in boars (Flowers, 1997) can either be enhanced or suppressed by a variety of things such as nutrition, temperature, humidity, and housing conditions. The primary mode of action of these environmental stimuli is to affect how efficiently adult female and male reproductive organs function. From a physiological perspective, this can be thought of as the functional period of reproductive efficiency and typically encompasses management of adult animals on commercial sow farms or in boar studs. There also is increasing evidence that management conditions early in the life of replacement gilts and boars can have important and lasting effects on their reproductive potential. This is not surprising since in both males and females there are critical organizational events that occur between the immediate prenatal period and the first 90 days of life. In gilts, the mechanisms that allow the brain, ovaries, and uterus to communicate with one another are solidified (Pressing et al., 1992; Morbeck et al., 1993), while in boars Sertoli cell proliferation is at its peak which ultimately determines the potential for sperm production as an adult (Franca et al., 2000). This can be thought of as the developmental period of reproductive efficiency and, in most production systems, involves how young, growing replacement animals are handled during the multiplication phase. The main purpose of this presentation is to present data from resent studies that illustrate the importance of the neonatal environment in shaping the reproductive potential of adult boars and sows.

Neonatal litter size and sow longevity

The concept that the litter size in which a replacement gilt nurses can influence her performance as an adult is not a new one. Almost 35 years ago, Mavrogenis and Robison (1976) reported that gilts that were allowed to nurse in small litters reached puberty sooner and had more piglets born alive than their counterparts raised in large litters. The author's attributed this advantage solely to pre-weaning growth. In the late 1960's and early 1970's lactation lengths in excess of 35 days were common and gilts from large litters most likely were exposed to a mild form of growth restriction as their weaning weights were considerably lighter compared with females that were allowed to nurse in small litters. An obvious question is whether this phenomenon still has relevance for modern production systems using hyperprolific, maternal-line genetics and much shorter lactation lengths.

A recent study conducted in an 80,000-sow commercial production system indicates that it does. In this study, replacement gilts born in litters of 10 to 12 piglets were cross-fostered so that they nursed in litters of less than 7 or greater than 10 piglets. After weaning, the females from the small and large lactation litters were sent to commercial farms and managed under the same conditions. They were given boar exposure between 140 and 150 days; bred at 240 days of age; and monitored as long as they remained reproductively active in the herd. At the end of 6 parities, 35.5% of sows raised in small litters were still in production compared with 17.3% ($P \leq 0.01$) of their counterparts from large litters. In addition, sows that nursed in litters of 7 or less had higher farrowing rates (88.7% vs. 83.3%; $P \leq 0.05$) and tended to have more born alive (11.0 ± 0.1 vs. 10.5 ± 0.2; $P \leq 0.10$) compared with sows weaned from litters of 10 or more. One interpretation of these results is that reducing competition during the neonatal period enhanced both the structural and functional development of the future replacement gilt's reproductive organs. In other words, it created a situation in which the brain, ovaries, and uterus communicated with one another with increased efficiency.

Estrous activity of these gilts when given early boar exposure supports this interpretation, at least with regards to the brain and ovaries. The main reason for giving early boar exposure in this study was to obtain a relative assessment of the maturity of the communication between the brain and ovaries. Gilts that exhibited estrus within 28 days of the onset of boar exposure were classified as early responders. The proportion of early responders was 22% higher in females raised in small than large litters (77.0% vs. 53%; $P \leq 0.05$) and early responders from the small litters tended to have more pigs born alive (11.3 ± 0.2 vs. 10.8 ± 0.2; $P \leq 0.08$) compared with their counterparts from large litters.

Production

The similarity between the improvement in sow longevity (18.2%) and the increased number of early responders (22%) probably is not a coincidence. Boar exposure stimulates secretion of the gonadotropic hormones, LH and FSH, from the brain. These stimulate the production of estrogen from ovarian follicles, which, in turn, results in the classic behaviors associated with estrus. Gilts raised in small litters were able to elicit a more robust response to hormone changes associated with boar exposure and, thus, reach puberty at an early age. These same hormonal changes are also important for determining when a sow returns to estrus after weaning and her subsequent ovulation rate. Consequently, it is physiologically reasonable to expect gilts that respond early to boar exposure during sexual maturation to behave in a similar fashion to similar hormonal changes that occur after weaning as an adult.

One of the most important things that these data demonstrate is that management during a 3-week period early in a replacement gilt's life can have a significant effect on her longevity and fecundity as an adult. As mentioned earlier, this should not be surprising due to the key developmental events that are occurring within her reproductive system while she is nursing her mother. Consequently, reducing competition during the suckling period of replacement gilts is likely to have positive effects on subsequent reproductive performance. The magnitude of this response, however, probably differs among different types of production systems.

The average birth weight of all the replacement gilts in this study was 2.8 lbs. Recent studies have reported a significant positive relationship between birth weight and the development of internal organs and muscle fibers in market animals – those with light birth weights had fewer muscle fibers per bundle and less developed livers and intestines (Gondret et al., 2005). As a result, they grew slower; reached market weights later; and had lower percent muscle compared with their counterparts with heavy birth weights. This phenomenon has been referred to as intrauterine growth retardation and may have important implications for replacement gilts that are from highly prolific maternal sow lines. The tendency would be for them to have reduced birth weights and perhaps reduced developmental potential due to being born in large litters. A retrospective analysis of the influence of birth weight within each lactational litter size from the study discussed previously is shown in Table 1.

It is important to remember that only litters with 10 to 12 pigs born alive were selected in an attempt to minimize any inherent differences in birth weights. As a result, the proportion of very light and heavy birth weights is small. Nevertheless, the size of the litter in which replacement gilts nursed had minimal influence on her longevity if her birth weight was greater than 3.6 lbs. In contrast, for those with lighter weights, longevity was more than doubled when they were allowed to nurse in small litters. One explanation for these results is that, in this particular system, replacement gilts weighing 3.5 lbs or less at birth may have been subjected to intrauterine growth retardation. Reduction of the litter size in which they nursed allowed them to compensate for some of this prenatal restriction after they were born with the end result being increased longevity. Collectively, the results of our experiment and those involving market swine indicate that birth weights of future replacement gilts, which are reflections of their prenatal growth, may prove to be an important factor upon which subsequent management should be based. This has practical implications. It is possible that the optimum neonatal litter size for replacement gilts may depend upon her birth weight. Clearly, additional work is needed in this area to confirm these preliminary observations.

Another unique aspect of the production system in which this study was conducted was that, on the commercial farms, sows were placed in gestation stalls for 30 days post breeding and then regrouped in pens for the remainder of gestation. As expected, there was a significant amount of fighting once the sows were moved into pens while the new "peck order" was being established. Replacement gilts that were allowed to nurse in small litters weighed more at weaning compared with gilts from large litters. They maintained this advantage throughout the rest of their productive lives. It is reasonable to speculate that the additional weight provided them with a physical advantage when placed in a competitive situation such as penned gestation. Whether or not, similar responses would be realized in production systems in which sows remain in stalls for the entire duration of gestation is not

Table 1: Effect of neonatal litter size and birth weight on sows farrowing 6 or more litters.

	Birth weight categories		
Neonatal treatment	**≤ 2.5 lbs**	**2.6 – 3.5 lbs**	**≥ 3.6 lbs**
≥ 10 piglets nursing	10.4% (10/96)	15.8% (115/727)	32.4% (32/98)
≤ 7 piglets nursing	26.2% (26/99)	39.1% (274/701)	36.3% (36/99)

known. However, given the current climate within the US, gestation pens are likely to increase in prevalence on commercial swine farms. As a result, management conditions that allow replacement gilts to achieve their full growth potential will continue to be important including interactions between their birth weights and pre-weaning growth rates.

Neonatal litter size and sperm quantity and quality in replacement boars

In contrast to the situation with replacement gilts, published studies examining relationships between litter size during lactation and subsequent reproductive performance in boars are scarce. However, from strictly a physiological perspective, a greater response should be observed in boars than gilts because of the mitotic activity of the Sertoli and Leydig cell populations during the first 30 days of life. It is generally accepted that the most active period of cell multiplication begins shortly before birth and continues for about 30 days postnatally. As a result, a study similar to the one in gilts was conducted with replacement boars. The approach was basically the same with the exception that semen was collected from boars weekly beginning when they were 7 months old and ending when they were 30 months of age.

Boars allowed to nurse in small litters were heavier at weaning and throughout the rest of their life compared to their counterparts raised in large litters. More importantly, they also had larger testicles relative to their body size beginning around 10 to 12 weeks of age. This resulted in an average of 10 billion more spermatozoa per ejaculate. This advantage was first observed at 30 weeks of age and continued until they were 2.5 years old when the experiment ended (Table 2). There were no differences in microscopic and functional estimates of semen quality, however, boars raised in small litters consistently sired more piglets as adults compared with boars that nursed in large litters in competitive fertilization trials involving heterospermic inseminations and paternity testing.

Similar to the situation with gilts, boars raised in small litters had a distinct advantage as adults in terms of sperm production and fertility. Increased spermatogenesis in these boars is consistent with their increased testicular size, which, in turn, is likely the result of an increased number of Sertoli cells. In contrast to the situation in replacement gilts, pre-weaning growth rate seemed to be the primary driving force behind the enhanced sperm production and was not related to birth weight. In other words, the advantage due to nursing in a small litter occurred across the entire spectrum of birth weights. However, the average birth weight of the boars used in this study was 3.8 lbs and there were no boars used in the study that weighed less than 3 lbs at birth. Consequently, it would be premature to assume that an interaction between birth weight and pre-weaning growth rate does not also exist for sperm production as well. At the present time, the advantage observed in relative fertility for the boar allowed to nurse in small neonatal litters remains to be elucidated. However, it does not appear to be related differences in motility or morphology of spermatozoa.

Implications for management of replacement boars and gilts during multiplication

From a physiological perspective, adult reproductive function in both boars and sows is the product of two distinct, but related periods: a developmental one in which the reproductive organs are literally built and acquire the ability to communicate with each other and a functional one in which the effectiveness of their interactions determines the relative success or failure of producing live pigs. Similarly, the developmental period can be further

Production

Table 2: Semen quantity, quality, and fertility estimates from replacement boars allowed to nurse in small or large litters (mean ± s.e.).

Variables	Neonatal lactational litter size		*P* - value
	≤ 6 piglets	≥ 10 piglets	
Total spermatozoa (x 10^9)	98.7 ± 3.2	86.7 + 3.8	0.01
Motile spermatozoa (%)	87.4 ± 5.3	83.2 ± 4.9	0.39
Normal morphology (%)	89.4 ± 6.1	83.2 ± 4.3	0.47
Normal acrosomes (%)	90.4 ± 4.5	83.7 ± 6.1	0.49
Normal capacitation (%)	83.5 ± 5.8	74.6 ± 6.7	0.26
Proportion of piglets sired in heterospermic inseminations (%)	68.7 ± 4.3	31.4 ± 5.7	0.02

subdivided into maturational events that occur either prenatally or postnatally. Finally and, perhaps, most importantly, management conditions during developmental period can have a profound effect on how both adult sows and boars perform during the functional period.

Unfortunately, there isn't enough information available at the present time to outline the best way to manage future replacement boars and gilts during their developmental period which occurs almost exclusively during multiplication. In addition, as discussed previously, it is entirely possible (and likely) that what is optimal for one production system may not be for another. However, based on what is known, there are several things that should prove useful for all types of production systems in helping them evaluate how well their future breeding animals are being managed during on multiplication farms.

First, serious consideration should be given to collecting birth weights on all future replacement boars and gilts. There is increasing evidence of a positive relationship between birth weight and the subsequent developmental potential of most organs including those involved with reproduction. Birth weights probably are the best estimate at the present time of how well the piglet developed as a fetus. As a result, there certainly is a point of no return, so to speak, that can be used to identify piglets with little chance of developing functional reproductive systems no matter how they are managed subsequently. Collection of birth weights would allow production systems to determine what this decision boundary is and manage piglets that fall below it accordingly. In addition, at least in the case with gilts, there is some evidence that adjustment of neonatal litter size can significantly enhance their longevity if their birth weight falls within a certain range. In this scenario, birth weights may prove to be useful for strategic crossfostering on multiplication farms.

Second, preweaning growth appears to be a fairly good reflection of how well both replacement boars and gilts developed while they were nursing. The primary rationale for reducing neonatal litter size during lactation was to enhance preweaning growth and the concomitant development of reproductive organs. For gilts, this resulted in an increased proportion of animals that could respond early to boar exposure and enhanced longevity. For boars, this resulted in increased testicle size, sperm production and fertility. The relationship between preweaning growth and subsequent reproduction probably will not prove to be as strong for gilts as it will for boars. The primary reason for this is that much of the architecture of the ovary is already in place at birth, while the first 30 days of life is a very active period of Sertoli cell proliferation in boars. As a result, conditions that promote preweaning growth would also be expected to have the same effect on Sertoli cell numbers. For terminal line sires, it is customary to evaluate their growth once they enter the finishing phase. This is obviously very important due to the thousands of market animals that they will sire once they enter production. However, their preweaning growth may be a better indicator of their sperm production potential and, perhaps, fertility as an adult.

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