Using Commercially Available Hormones to Enhance Swine Reproductive Efficiency in Batch Management Systems

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Abstract

The U.S. hog industry's shift to vertically-integrated, intensively-managed operations brought about a variety of management systems for breeding herds, including batch farrowing. In this system, groups of sows are weaned in 2- to 5- week intervals, making estrus synchronization of new gilts and sows critical to maintaining reproductive efficiency in the herd. The use of commercially available hormones to synchronize estrus in this system has not been extensively studied. This experiment was conducted to determine whether the use of commercially available hormones (MATRIX® and P.G. 600®; Merck Animal Health, De Sota, KS) in a 5-week batch management system had a positive impact on reproductive efficiency in gilts and sows over the course of 3 parities. Gilts were allocated to an Entry Group (A, B, or D) and then assigned to a treatment, Hormone-Assisted (HA) (5 mL P.G. 600 injection 5 days and/or fed 15 mg/day of MATRIX for 14 consecutive days prior to the breeding week) or Control (no exogenous hormones). Gilts and sows were checked daily for estrus with a mature boar, and a group was bred using AI during a 7-day breeding period every 5 weeks and allowed to farrow up to 3 parities. There was no effect of treatment on entry-to-first service interval ($P = 0.5981$) or body weight at first service (**BWFS**) ($P = 0.6382$); however, BWFS for gilts in Groups A and B were higher than Group D ($P < 0.01$). Overall, there was a weak tendency for HA sows to have lower ($P = 0.1971$) non-productive days and greater ($P = 0.1657$) total pigs weaned than control gilts; There was a strong tendency for HA sows to have a greater ($P = 0.0730$) number of parities completed than control sows; Total pigs born ($P < 0.05$) and total pigs born alive ($P < 0.05$) were greater for HA sows than control sows. In Parity 1, Group D sows had a lesser number of pigs born ($P < 0.01$) and pigs born alive ($P < 0.02$) than Groups A and B; The number of pigs weaned differed between entry groups ($P < 0.05$) (Group B > Group A > Group D); Control sows weaned more pigs ($P < 0.02$) and had a greater litter weaning weight ($P < 0.01$) than HA sows; HA sows had a lower ($P < 0.05$) wean-to-estrus interval than control sows. No significant effects of group or treatment were observed in Parities 2 and 3. The use of exogenous hormones to synchronize estrus had a positive impact on reproductive efficiency in HA gilts/sows in a 5-week batch management system.

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ADFI	Average daily feed intake
ADG	Average daily gain
AI	Artificial insemination
AIAO	All-in, all-out
BWFS	Body weight at first service
CL	Corpus luteum
E2	Estradiol
eCG	Equine chorionic gonadotropin
EFSI	Entry-to-first service interval
FSH	Follicle-stimulating hormone
GL	Gestation length
GnRH	Gonadotropin-releasing hormone
hCG	Human chorionic gonadotropin
IFA	Immunoflourescence assay
IM	Intramuscular
intra-CAI	Intra-cervical artificial insemination
LBW	Litter birth weight
LH	Luteinizing hormone
LI	Total lactation intake
LL	Lactation length
LWW	Litter weaning weight
MP	Number of mummified pigs per litter
NPD	Non-productive day
P4	Progesterone
PB	Number of pigs borne per litter
PBA	Pigs born alive per litter
PBW	Pig birth weight
PC	Number of parities completed
PEDv	Porcine epidemic diarrhea virus
PGF-2α	Prostaglandin F2-alpha
post-CAI	Post-cervical artificial insemination
PRRS	Porcine reproductive and respiratory syndrome
PW	Pigs weaned per litter
PWW	Pig weaning weight
RNA	Ribonucleic acid
SC	Subcutaneous
SP	Number of stillborn pigs per litter
TB	Total number of pigs born
TBA	Total number of pigs born alive
TGE	Transmissible gastroenteritis
TPW	Total number of pigs weaned
WEI	Wean-to-estrus interval
WSI	Wean-to-service interval

Introduction

Advances in nutrition, technology, housing, genetics, and husbandry, have allowed modern, large-scale swine production companies to produce hogs more efficiently. Reproductive efficiency in livestock operations is defined as output per breeding female on an annual basis. Thus, the number of pigs weaned per mated female per year is a measure of reproductive efficiency used to identify high-performing swine herds. Reproductive efficiency can be impacted by many factors, including, but not limited to: farrowing rates (number of females farrowing divided by the number of females exposed to a boar), litter size, pre-weaning survival rate (number of pigs weaned divided by the number of pigs born alive), and non-productive days (**NPDs**). Non-productive days are defined as days when breeding herd females are not gestating or lactating. They include the period from when a gilt is introduced into the breeding herd until she conceives her first litter, and the weaning to first service interval. Industry records indicate that NPDs, followed by litter size and farrowing rate are the three most important factors in determining herd rank at the top or bottom of a productivity group (Stein, 1992). Ketchem and Rix (2012) estimated that one NPD costs $2.25 in feed per head. Thus, an excessive number of NPDs could cost a large operation hundreds of thousands of dollars per year. Cost to the farmer ultimately affects cost to consumers, so reproductive efficiency is quite essential to producer and consumer satisfaction.

One goal in the breeding portion of a swine operation is to manipulate the estrous cycle to allow for more efficient use of labor, artificial insemination (**AI**), scheduling of facility use, and improved retention of replacement gilts (Wood et al., 1992). Many estrus synchronization protocols have been developed over the years to keep breeding females cycling together in groups so that they can follow the scheduled breeding goals of the farm. This is not only important for the sows currently farrowing in the herd, but also for replacement gilts being introduced into the operation. Managers replace more than 50% of their sows with gilts every year (Knauer and Hostetler, 2013), so the successful entry of gilts into the breeding herd has a significant effect on reproductive efficiency.

There are at least two commercially available hormonal products, which help synchronize estrus in breeding females. One is MATRIX® (Merck Animal Health, De Sota, KS), which is an orally administered progestin that can be fed to sexually mature gilts and sows displaying normal estrous cycles of approximately 21 days. Studies show that gilts and sows fed MATRIX for 14 days will display estrus 4 to 9 days after removing it from the feed, and it can be introduced to the feed during any stage of the estrous cycle (Flowers, 2001). In one study, after gilts and sows were fed 15 mg of MATRIX daily for 14 days and 10 days respectively, a greater proportion of MATRIX-fed females exhibited estrus within the first 7 to 10 days after removal from the feed when compared to the control group (Wood et al., 1992).

Another product marketed by Merck Animal Health is P.G. 600®, which is administered to prepubertal gilts and anestrous sows via an intramuscular (**IM**) injection. It is a combination of equine chorionic gonadotropin (**eCG**) and human chorionic gonadotropin (**hCG**), which stimulate follicular development on the ovary by mimicking the effects of the naturally occurring gonadotropins, follicle-stimulating hormone (**FSH**) and lutenizing hormone (**LH**), respectively (Flowers, 2001). Carabă et al. (2014) found that injections of P.G. 600 in prepubertal gilts and weaned anestrus sows produced an observed estrus in 75% of the animals within 8 days. Horsley et al. (2005) found that gilts treated with P.G. 600 on the day MATRIX was withdrawn from the feed had a decreased average injection to estrus interval compared to gilts fed MATRIX and injected with saline.

There are at least two types of production schedules used on commercial swine farms. Most large-scale operations use a high-intensity, *continuous* farrowing system, and all segments of production occur each week. For example, a 1,200-sow farm employing 3-week weaning has 20 sow groups, each containing 60 breeding females. Every week, a new sow group enters multiple cleaned rooms in the farrowing house and another sow group is weaned (typically on Thursday) and moved to the breeding-gestation barn. Sow groups at either Week 1 or Week 2 of lactation remain in the farrowing barn. In the breeding-gestation barn, sows weaned the previous week are rebred, as are replacement gilts entering the group. Sows displaying an extended weaning-to-estrus interval are not bred with group-mates, but may be bred in subsequent weeks, joining a different sow group. Replacement gilts not exhibiting estrus during a particular week have subsequent opportunities to join a sow group.

In *batch* farrowing systems, a sow group does not farrow each week, but rather groups farrow at 2- to 5-week intervals. For example, in a 5-week batch system, a sow group farrows every fifth week, is weaned after a 3-week lactation, and mating occurs the following week. The system is based on a 20-week sow cycle (0.5 week interval between weaning and estrus, 16.5 week gestation, and 3 week lactation) and there are 4 sow groups of 300 sows for a 1,200-sow herd.

Batch farrowing allows for better all-in, all-out management and disease control, as well as larger groups of same-age pigs being weaned at one time. The number of farrowing rooms is decreased and tasks such as power-washing or processing pigs are performed less frequently and perhaps more efficiently. After weeks of more intense work around breeding and farrowing with the larger sow groups, there are regular periods of less work during which facility maintenance and repairs can be scheduled.

A major challenge with batch farrowing systems is keeping sows within a group on the desired schedule. For optimum operation of the 5-week system, weaned sows must return to estrus and be mated in 4 to 5 days. Sows falling out of this breeding “window” can become difficult to manage, because another group of sows will not be mated for 5 weeks. Moreover, having the necessary number of replacement gilts **in estrus** and ready to join a sow group is critical. The use of hormones to synchronize estrus in batch farrowing systems has not been extensively studied. The objective of this thesis is to test the hypothesis that MATRIX and P.G. 600 used to synchronize estrus in a 5-week batch farrowing system will positively affect reproductive efficiency in gilts and sows over the course of 3 parities.

Chapter 1: Review of Literature

Structure and Trends in the U.S. Swine Industry

Introduction. Over the past four decades, dramatic changes in the U.S. swine industry have occurred in order to meet consumer demand for a product that is both consistent in its quality and its availability (Barkema and Cook, 1993). Changes occurred in every aspect of production, including producer size, number of farms, marketing, specialization, housing, technology, nutrition, genetic selection, breeding, and many more.

General Trends. Pork is the third highest consumed protein in the United States behind chicken and beef, with the nation's annual pork production increasing at a rate of 1.5% annually for the past 70 years (Plain and Lawrence, 2003). This increase is likely due to the U.S. becoming the number one exporter of pork in the world and an increased domestic population. Per capita consumption of pork in the United States has remained relatively steady for the past 50 years, at around 48lb per year (Plain and Lawrence, 2003), while consumption of beef has been on the decline and consumption of poultry on the rise (US Census Bureau, 2012).

The location of hog farms in the U.S. has classically been oriented proximal to where grain is produced in abundance, such as the Mid-West "corn belt" states, but that has changed a bit recently due to the improvements in shipping animals and feed sources. This has led to states like North Carolina and Oklahoma to establish a foothold in the top 10 pork producing states in the U.S. without also being large grain producers (Plain et al., 2001).

Hog prices tend to cycle throughout the year based on season. They usually rise in the spring and summer and drop in the fall and winter months, and part of that seasonality has to do with higher demand for pork and barbeque in the summer (Meyer, 2012). Rozeboom et al. (2000) conceded that this phenomenon is partially due to lower fertility of the breeding herd in the late summer and early fall months. Heat stress negatively impacts conception rates, mortality rates, farrowing rates, and even semen quality, thus, reducing hog output. A study of Large White x Landrace gilts in Australia (Swinbourne et al., 2014) found that mature gilts developed fewer large pre-ovulatory follicles (>6mm diameter) in the summer months compared to gilts observed in the winter months, and McNitt and First (1970) first reported that, compared to controls, boars exposed to temperatures of 30°C for 72 hours produced ejaculates with reduced sperm concentration and percentage of motile cells as well as increased sperm cells with morphological abnormalities.

Vertical Integration. As early as the 1960s, the United States' hog industry began a shift from a trend of many small, family-owned farms to fewer, large corporation-owned and contracted farms. Many of those smaller family-owned operations were diversified, using hog production to add value to crops, such as corn and soybean. There was open-production marketing of animals, with farmers selling their hogs to processing companies offering the highest bid (Barkema and Cook, 1993). According to Plain and Lawrence (2003), in 1960, there were approximately 1.2 million hog farms in the U.S., and by 2002, there were only 75,350.

The main driver behind this shift was the vertical integration of the swine industry by a few large corporations. Vertical integration is a method of management that involves every stage of production being owned or contracted by one large company, rather than being managed by smaller, independent operators (Reimer, 2006). Plain and Lawrence (2003) reported that, in 1988, farms that marketed less than 1000 head per year accounted for 32% of U.S. hog production, and by the year 2000, that number dropped to 2%. By 2008, 80% of the hogs produced in the U.S. were from operations with greater than 2000 head (Lowe and Gereffi, 2008). To put that into perspective, today, the smallest 60% of U.S. swine operations market 1%

of the nation's hogs, while the largest 1% markets over 60% of swine produced (Plain and Lawrence, 2003).

The acquisition and consolidation of small farms by larger companies through vertical integration has had a substantial positive impact on profitability through economies of scale (Plain et al., 2001). Large producers are able to purchase inputs at lower costs, sell higher value products, and use resources more efficiently than smaller operations. Having larger farms also allows easier implementation of newer protocols that improve production efficiency and specialization, such as artificial insemination, multi-site production, split-sex feeding, and all-in, all-out stocking of animals (Plain et al., 2001).

While there are many economic benefits of this type of production, it comes with its own set of potential problems, particularly those concerning the environment. McBride and Key (2003) point out that manure output from these large operations may create environmental risks, which could lead to increased regulations, the possibility of changing location to more suitable land for effluent spreading, and even costs to consumers. Part of this problem can be attributed to the lack of available land for adequate dispersal of manure in the areas surrounding many commercial farms today. While these risks do exist, vertical integration appears to be a permanent characteristic of a large segment of the U.S. hog industry (McBride and Key, 2003).

Specialization. With the consolidation and vertical integration of hog farms in the U.S., specialization to improve production efficiency also became a characteristic of the industry. Large corporations have been able to change the traditional farrow-to-finish operation strategy to multiple, specialized farms cooperating with each other to increase efficiency with larger numbers of hogs while also properly managing hog flow (Kliebenstein and Lawrence, 1995). Tonsor and Featherstone (2009) reported that the percentage of total U.S. hogs produced on onesite farrow-to-finish operations decreased from 65% in 1992 to less than 38% in 1998, which was coupled to an increase in the percentages of specialized hog operations (farrow-to-feeder pig, feeder pig-to-finish, farrow-to-weanling, weanling-to-feeder pig, etc.) from 22% to 58% respectively. By specializing in one aspect of management, productivity was, on average 20% greater than with a traditional farrow-to-finish operation (Tonsor and Featherstone, 2009). This can be attributed to the fact that specialized farms are able to optimize the benefits of their resources, performance, and technology. For example, before coordination of these specialized operations, hogs were mainly transported to Corn Belt states, like Iowa, for finishing because of proximity to feed sources. Now, states like North Carolina have been able to use the advantages that come with resource optimization and coordination with other specialized sectors of the commercial industry, including feed producers, to be competitive with states like Iowa and have even forced those states to improve their regional infrastructure in order to keep up (Kliebenstein and Lawrence, 1995).

Nutrition. Traditionally, feed accounted for approximately 65 to 75 percent of production costs on a swine operation, and those numbers have increased even more in recent years due to increased grain and supplement costs (Pork Checkoff, 2008). This makes feed efficiency, measured by the feed conversion ratio (lb feed/lb gain), an extremely important production factor to control. Corn and soybean meal, along with mineral and vitamin supplements, are the main components of a typical swine diet. One of the main contributors to the increase in grain costs in the U.S. is the use of corn to produce ethanol for the petroleum industry (Fortenbery and Park, 2008). In 2005, 13 percent of domestic corn production was allotted for ethanol production, and that number increased to over 20 percent by 2007. The decrease in availability for corn’s use in other production systems led to an 18 percent increase in corn prices in 2007 (Fortenbery and

Park, 2008). That number is predicted to increase as gasoline consumption increases for the 2015 and 2016 fiscal year (Capehart et al., 2015). Some producers are attempting to combat some of these increasing costs by improving general animal husbandry, technology, and specialization. Another potential solution is the supplementation of alternative feed sources, including by-products of feedstuffs processed for human consumption, such as dried distillers grains, wheat midds, meat and bone meal, and canola meal (Pork Checkoff, 2008). These feedstuffs can be used to substitute for the energy and protein needs in the swine diet; however, there have been some challenges associated with this supplementation, such as bioavailability and volume, so this practice still has some fine tuning to undergo in order to be an efficient substitute in large-scale operations (Pork Checkoff, 2008).

Housing. The change in the structure of hog farming in the U.S. has also led to changes in the method of housing animals, with a shift from outdoor (extensive), pasture-based farming to intensive (indoor) housing (Brown-Brandl et al., 2014). Indoor housing presents benefits, such as environmental control, shelter from potential predators, improved flow of animals, and improved manure management. Consumers have debated whether this change has negatively-impacted animal welfare; so many studies have been conducted to quantify the effects of this transition on animal performance and well-being.

In many of these intensive systems, farrowing and gestation crates have also been implemented to increase reproductive efficiency, but they have recently come under scrutiny for their impact on animal welfare. Farrowing and gestation crates are generally 2 foot wide by 7 foot long and limit sows to standing, sitting, and lying. The main argument in the U.S. for the continued use of farrowing crates during lactation is their positive impact on piglet pre-weaning survival rate. According to Moustsen et al. (2013), there were significantly fewer live-born piglet pre-weaning deaths in litters from sows that were confined in farrowing crates during lactation compared to those from loose-housed sows. The mortality rates of piglets with loose sows were the greatest during the first 4 days post-partum. Use of gestation crates, however, has been on the decline in recent years, as large producers, such as Murphy Brown, L.L.C., the live hog production component of Smithfield Foods, Inc., the world's largest hog producer and processor, turn to the use of group-housed gestating sows to comply with the demands of consumers focused on improving animal welfare. Whether or not the use of group pens is truly an improvement in welfare is still under debate, since females tend to fight when housed together. Harris et al. (2006) reported that, while there was no significant difference in reproductive performance of gilts housed in group pens compared to those in individual stalls, there were markedly more lesions to the head, body, face, legs, and feet in group-housed animals, indicating increased fighting amongst pregnant gilts.

Technology. One of the major technological advances used to improve efficiency in the commercial swine industry is the use of AI**,** rather than natural mating. This practice gained traction in the U.S. starting in the 1990s (Gerrits et al., 2005). Large corporate producers tend to have their own selected boars, which are trained for semen collection at boar studs, in order to ensure semen quality and superior, consistent genetic progress within the herd. Artificial insemination technology also compliments the use of technology involved in estrus synchronization methods, which will be addressed extensively later in this review. It is also ideal for batch farrowing systems because these systems do not tend to follow a schedule that fits with the recommended protocols for natural mating; unless many boars are kept, the demand for individual boars would be too great with such a large group of females to breed at once (Brown, 2006).

The most widely-used protocol, intra-cervical artificial insemination (**intra-CAI**), takes place when a breeding female is in standing heat (second or third standing heat for gilts entering the breeding herd), and a technician will insert a lubricated catheter through the vulva and vagina and into the cervix, then fix a semen container to the end of the catheter for its contents to be deposited into the female's cervix (Roca et al., 2006). This process occurs multiple times during observed estrus. Farrowing rates (80 to 90%) and litter sizes tend to be greater than or equal to those resulting from natural mating when using intra-CAI (Roca et al., 2006).

Post-cervical artificial insemination (**post-CAI)** is another form of insemination used by producers, which involves depositing the semen into the uterus of breeding females rather than the cervix (Roca et al., 2006). One potential benefit of this new method compared to intra-CAI is that fewer sperm cells are necessary to achieve similar fertility outcomes. Roberts and Bilkei (2005) found that wean-to-estrus intervals, duration of estrus, pregnancy rates, and farrowing rates were not different in multi-parous sows inseminated with the traditional protocol (intra-CAI with $3x10^9$ sperm cells per dose) compared to those inseminated using post-CAI with $1x10^9$ spermatozoa per dose. The number of piglets born was less using post-CAI compared to intra-CAI; however, they claim that other studies have found there to be no effect on litter size and that this discrepancy may be attributed to the training of the technicians performing the protocols (Roberts and Bilkei., 2005).

In conclusion, the swine industry has seen significant changes over the past few decades in every aspect of production, which has changed the way commercial operations manage and market their hogs and products in the United States. There are many benefits and some drawbacks to these changes, but one of the main drivers is increasing production efficiency throughout the industry.

Reproductive Efficiency

How it is measured. In order to determine whether a herd can be classified as "high-performing", reproductive efficiency, which is defined as the output per female per year, is measured. This measure is influenced by many factors, including, but not limited to: farrowing rates, litter size, pre-weaning survival rate (number of pigs weaned divided by the number of pigs born alive), and NPD. Stein (1992) stated that, in order, NPD, litter size and farrowing rate are the three most important factors in determining herd rank at the top or bottom of a productivity group. Stein et al. (1990) observed that high-producing swine herds (selected using data provided by 54 herds from across the U.S.) reported more litters per female per year, farrowing rate, sow-gilt ratio, and live pigs born per litter, as well as lower pre-weaning mortality rate, NPD, and number of gilts proportional to herd size compared to the average and low-producing herds (herds with lowest number of pigs weaned per year). A study conducted by Koketsu (2002) reported similar results from what are considered high-performance herds using data reported by commercial operations in Japan, confirming that these parameters are considered useful for measuring reproductive efficiency throughout the global swine industry.

Sow longevity is another factor that can influence reproductive efficiency of a hog operation. Dhuyvetter (2000) reported that the number of pigs born alive per litter and the number of pigs weaned per litter peaks between parity six and eight. These values decrease in subsequent litters, as the sow ages, indicating that keeping a sow reproducing for longer periods of time can increase production efficiency to a point, and this should be considered when managing the breeding herd females and selecting replacement gilts (Dhuyvetter, 2000). More recent data, compiled by Stalder (2008), showed that the average parity of culled sows was 3.15

in the top 25% of producers in the United States. This could be attributed to the fact that genetic selection for other performance phenotypes, such as increased litter size, has reduced sow longevity and kept culling rates at 40 to 50% over the years (Lapointe, 2014).

Why it is important. Measuring reproductive efficiency is critical to maintaining profits and estimating costs in the swine industry. For example, Ketchem and Rix (2012) estimated that one NPD costs $2.25 in feed per head; an excessive number of NPD across the herd could cost a large operation hundreds of thousands of dollars per year. Todd (2005) pointed out that, for most producers, between 18 and 26 pigs are produced per breeding female per year. Since the sow herd takes up the same amount of space and labor regardless of how productive sows are, it costs about the same to produce 18 pigs as it does to produce 26 pigs. This highlights the critical importance of ensuring that sows are as efficient as possible in order to reduce costs for the maintenance of the herd over the course of a year.

Sow longevity also impacts profits and costs to producers. For example, Dhuyvetter (2000) reported that net return on investment for breeding farms could be almost twice as high if a sow is kept for 7 to 10 parities (11.1 to 11.4%) when compared to farms that only kept sows for 3 or 4 parities (6.5 to 8.8%).

Continuous Farrowing

General. The most common farrowing system employed by the commercial swine industry is *continuous* farrowing. There are multiple interpretations of the definition for this type of farrowing system, but, for the purposes of this thesis, we consider a weekly farrowing, breeding and weaning schedule to be *continuous.* With a 21-day lactation period, this type of production system requires 20 sow groups (Casanovas, 2007). For example, a 1,200-sow operation with a 3-week weaning age for piglets would have 60 sows per group when following this 20-group model. A new sow group enters the farrowing barn weekly (usually a week prior to farrowing), and another group is weaned and relocated to a breeding-gestation barn; here, sows weaned the previous week are rebred, as are replacement gilts entering groups. Two lactating sow groups (at Week 1 and Week 2 of lactation) would remain in the farrowing barn. Because breeding occurs on a weekly basis, sows that have a longer weaning-to-estrus interval have the opportunity to be bred with the next group of sows. Replacement gilts that are not displaying estrus during one week also have subsequent opportunities to be added into sow groups.

Advantages. One advantage of a *continuous* farrowing system is that there are many opportunities to get sows and gilts bred. Unlike batch farrowing, sows with an extended interval from weaning (or gilts with a delay from entry into the breeding herd) to insemination can be bred at the earliest possible time, rather than having to wait for a future breeding period that may be weeks away. This reduces NPD and decreases costs to producers (Todd, 2005). This system could potentially lead to lower culling rates for sows and gilts who do not display estrus at the desired breeding date, which would positively impact some of the problems that the industry experiences with sow longevity. According to Lammers et al. (2007), reproductive failure was responsible for approximately 29% of the culling decisions made on sow farms from years 1960 to 2000. Based on an economic model developed by Dhyuvetter (2000), producers will not see positive returns over their total cost until after a breeding female has farrowed at least 3 times, so this advantage is important to ensuring profits for the operation.

Martel et al. (2008) conducted a study to test a model they developed to simulate herd dynamics on breeding sow farms and the effect of different batch farrowing schedules on various herd productivity indicators. The schedules were as follows: 1-week (sow group farrows once a week, as in a continuous farrowing system), 3-week (group of sows farrows every three weeks) and 4-week (group of sows farrows every four weeks) systems. Lactation duration was 28 days for the 1- and 3-week model and 21 days for the 4-week model. Herd size was fixed at 210 sows, so there were 21 groups of 10 sows, 7 groups of 30 sows, and 5 groups of 42 sows for the 1-, 3-, and 4-week farrowing systems respectively. Twenty replications were done to demonstrate 20 years worth of data. Culling in this simulator could occur anytime between parity 1 and 8. Culling rules were established within the model and did vary in some ways depending on the schedule. Culling at weaning was uniform throughout and depended on parity, number of piglets born alive, and the number of weaned piglets. For the 4-week schedule, sows were culled if they did not display estrus within the week after weaning due to delayed onset, while the 1- and 3-week schedules allowed sows to be bred in later sow groups. The same rule applied with inseminated sows that returned to estrus. Culling after ultrasonography at 4 weeks post-insemination occurred if there was not enough space available in the farrowing facilities (if there were 2 sows more than available space) or if a sow was not pregnant after not coming back into heat the previous week due to infertility.

The results of this study revealed that the 1-week schedule had a lower number of sows culled per group cycle (2.2 ± 0.04), higher average parity of productive sows at culling (5.5 ± 0.09), and higher average parity of sows and gilts at culling (5.19 ± 0.1) compared to those values for the 4-week schedule (14.1 ± 0.33, 3.8 ± 0.08, and 2.9 ± 0.07, respectively) (Martel et al., 2008). These results illustrate the fact that a weekly schedule, like those used in a *continuous* farrowing operation, could have an advantage in preventing unnecessary culling decisions that may negatively impact profits for the producer. According to Mote et al. (2009), increasing the average parity of removal for breeding females by one-tenth could increase revenue per weaned pig in breed-to-wean and farrow-to-finish operations by up to $0.15 and $0.23 respectively, which translates to a possible $15 million increase in profits in the U.S. swine industry.

Challenges. The main challenges associated with a *continuous* farrowing system involve disease prevention within the herd. EPA (2012) explained that this is a problem because this system involves mixing weaned pigs of varying ages and weights rather than implementing a stricter, all-in-all-out (**AIAO**) management approach. Because of the continuous flow of hogs in the facilities implementing this strategy, all of the rooms within a building are never empty at the same time. While this is a more efficient use of space, it prevents farm managers from being able to adequately disinfect the buildings as animals move through the system and may require increased antibiotic use to keep disease levels under control.

Scheidt et al. (1995) conducted a study to compare the effect of management strategies (continuous vs AIAO) on the prevalence and impact of various pathogens on a finishing operation. Twenty-four pigs between 3 and 5 months of age were moved from a continuous grow-finish building with a known history of *M. hyopneumoniae* and *P. multocida* (two common respiratory diseases in the swine industry) to a disinfected room that would serve as the "continuous" room for the experiment. Additionally, nine 2-month old hogs from an AIAO nursery were put in this room. As these hogs reached market weight and were moved out, nursery pigs weighing about 40 lbs were moved in from an AIAO nursery environment to maintain 33 hogs. For the "AIAO" room, thirty-three 2-month old pigs were moved from the AIAO nursery to a disinfected room, and they remained in that room until they all reached slaughter weight. The next group was then moved into this room after it had been disinfected and left empty for 7 days. There were 6 replicates, and no antimicrobials were added to the feed during the course of the study (Scheidt et al., 1995).

Results showed that continuous flow hogs had a 95% prevalence of lung lesions at slaughter, while AIAO hogs had a 41% prevalence. The mean percentage of lung tissue affected was 80% greater in continuous flow animals compared to AIAO hogs. Indirect-immunofluorescence assays (**IFA**) for *M. hyopneumoniae* and cultures for *P. multocida* of 10 lungs from each group revealed a greater amount of infected lungs from continuous flow hogs (10 and 3, respectively) compared to AIAO hogs (1 and 0, respectively). Clinical symptoms of illness were seen in 43% of continuous flow animals and in 7% of AIAO animals. Average daily gain (**ADG**), days to market weight, average daily feed intake (**ADFI**), and feed conversion efficiency were all poorer in the continuous group when compared to the AIAO group (Scheidt et al., 1995).

This disease control issue has been shown to affect the farrowing portion of a continuous operation as well. Intestinal pathogens, such as transmissible gastroenteritis (**TGE**) and rotaviruses, have caused many issues in farrowing operations for the past few decades (Morin et al., 1983). According to the Ohio Agricultural Research and Development Center (2012), group C rotaviruses are detected more frequently in diarrheic piglets than other groups of rotaviruses, and the prevalence of rotaviral infection in swine herds increased from 18% in 2005 to 34% in 2012, with group C increasing the most.

Morin et al. (1983) tested the effects of spreading a group C rotavirus to piglets in a continuous swine operation because this herd had experienced cyclic episodes of diarrhea in 6 months, with a 100% morbidity rate. Experimental piglets were inoculated with a solution containing intestinal contents from piglets known to have group C rotaviral infection, and control piglets were not inoculated. They observed yellowish liquid feces within 15 hours of inoculation, as well as villus atrophy, crypt hypertrophy, and intestinal lesions in the intestines of experimental piglets. None of these were observed in control piglets. Neither TGE nor group A rotavirus were present in infected villus enterocytes, based on IFA. Viral ribonucleic acid (**RNA**) for group C rotavirus was detected in the intestines, indicating that this rotavirus was, indeed, the cause of the intestinal damage. Morin et al. (1983) implicated the cyclic nature of this pathogen in this herd to the fact that continuous flow prevented proper disinfecting of the farrowing house and predisposed the animals to contracting the virus.

This particular challenge presents a risk on hog operations, since new diseases such as Porcine Epidemic Diarrhea virus (**PEDv**), have swept the nation in recent years and increased the demand for stricter biosecurity protocols. First diagnosed in the U.S. in 2013, PEDv had spread to more than half of the states by 2014. This coronavirus causes diarrhea, vomiting and dehydration in pre-weaned piglets and is primarily transmitted through fecal contamination (Hennessey, 2014). The PEDv has similar symptoms to the group C rotavirus, killed more than 7 million pigs in one year, and was predicted to increase pork prices by between 7 and 10 percent (Karaim, 2014). Ketchem and Rix (2014) noted that the recent outbreak of this destructive pathogen has forced many producers to consider swapping their production systems over to batch farrowing to prevent the disease from spreading so quickly and effectively.

In conclusion, while there may be benefits to traditional continuous farrowing, such as increased opportunities to breed females with extended wean-to-estrus intervals and introduce new gilts to a breeding herd, as well as efficiently using housing space, the drawbacks associated with increasing the risk of spreading disease in these operations can have a detrimental impact on production efficiency and increase prices for consumers.

Batch Farrowing

General. In *batch farrowing systems*, a sow group is weaned at 2- to 5-week intervals, rather than a group being weaned each week as in a *continuous* farrowing system. The number of batches or groups in a sow herd is determined by how often sows are weaned (or farrowed) (Casanovas, 2007). For example, in a 5-week batch management system, a sow group is weaned every 5 weeks after a 3-week lactation period, and mating occurs the following week; a sow group farrows every fifth week as well. The system is based on a 20-week sow cycle (0.5 week interval between weaning and estrus, 16.5 week gestation, and 3 week lactation) and there are 4 sow groups. One large sow group enters and leaves the farrowing barn, which then leads to larger groups of similar-age weaned and grower pigs moving together through and exiting the system to go to slaughter (Roese et al., 2007). After each group is moved to the next phase of production, the entire building can be washed and disinfected prior to a new group entering the facility (Holden and Ensminger, 2006).

Advantages. The main advantage of a *batch farrowing* system is that it allows for better AIAO management and disease control within the herd, which leads to improved productivity at all levels of operation (Martel et al., 2008). Using the National Animal Health Monitoring System, Dewey et al. (1995) surveyed data on the incidence and effect of diarrhea in piglets 4 to 14 days of age from more than 700 herds. They noted that, while there are multiple factors associated with the incidence of diarrhea in piglets, there was a significant decrease ($P < 0.01$) in diarrhea morbidity in piglets housed in a farrowing facility that utilized strict AIAO management compared to those that did not (Dewey et al., 1995). These findings support assertions made by Morin et al. (1983) that piglets were likely more predisposed to contracting a group C rotaviral infection because they were housed in a farrowing facility that employed continuous flow rather than AIAO management.

For the next stage of production, Holden and Ensminger (2006) cited a study conducted at Purdue University by Cline et al. (1992), who observed that grow-finish hogs managed in an AIAO system had greater ADG (1.71lb/day), better feed conversion efficiency (3.04 lb feed/lb gain), and reached market weight in less time (173 days) when compared to a continuous use system (1.52 lb/day, 3.23 lb feed/lb gain, and 185 days respectively) because of improved herd health. This improved health status is the result of AIAO pigs being segregated by age group from weaning, which prevents the horizontal transmission of diseases from non-contemporary pigs (Holden and Ensminger, 2006). The Cline et al. (1992) findings were later confirmed in studies conducted by Scheidt et al. (1995) and Heinonen et al. (2001).

A batch farrowing system also provides the opportunity to better organize labor and tasks on the farm to fit an AIAO schedule in a way that is most beneficial to the workers and welfare of the animals. According to Brown (2006) and Roese et al. (2007), this system allows for better concentration of resources, a predictable weekly workload, more economical use of labor and time during breeding and farrowing, specialization in certain tasks for employees, and even better means to schedule ahead for holidays and time off.

As described previously, Martel et al. (2008) developed a stochastic model for simulating sow herd dynamics in a batch farrowing system. They tested for effects on animal performance, as well as the distribution of labor in this kind of operation. They showed some distinct advantages in the labor distribution in favor of the 4-week system. The model predicted that a 4-week batch management system would have a busy week post-weaning because workers would be responsible for detecting estrus in cycling females as well as farrowing a new group, but the two weeks after that would be free of periodic task events. In this case, events are defined as detection of estrus, farrowing, and weaning tasks for employees. Overall, the 4-week system had a lower number of events taking place during the weekends, a greater number of days without events on weekends, and a greater number of days without events Monday through Friday over the course of 4 weeks, than the 3-week and 1-week systems described previously (Martel et al., 2008). This supports the claims made by Brown (2006) and Roese et al. (2007) that task distribution in batch farrowing operations is better from an employee management perspective and is likely the result of having larger groups of hogs to manage all at once.

Along with labor being organized more efficiently for employers and employees, a batch system can also be beneficial to post-farrowing survival of piglets due to the scheduled presence of workers during farrowing to provide assistance to multiple litters (Bille et al., 1974).

White et al. (1996) conducted a study to test the effects of workers attending farrowings on piglet survival and performance when compared to unattended farrowings. In the experimental group, workers would attend farrowings and perform tasks such as drying the piglets, tying off the umbilical cords, removal of mucus from oral and nasal passages, administration of colostrum, orientation to a sow teat, and even administration of oxygen if needed. The control group did not receive any assistance post-farrowing until normal processing (e.g. iron injections, clipping needle teeth, injection of antibiotics) on Day 2. After Day 2, all piglets were treated the same. They found that there were greater average numbers of piglets alive at birth (10.4) and alive at 21 days (9.5) in the experimental group when compared to the control (9.7 and 8.4 respectively). There was a significant decrease ($P < 0.05$) in the overall proportion of mortality rate in piglets (10.1%) and, more specifically, a decrease in the proportion of death in piglets caused by stillbirth and starvation (15.6% and 12.5% respectively) when compared to the control group (18.2%, 32.1%, and 26.8%, respectively). The percentage of piglets dead at birth and mortality rate (deaths per litter) on Day 1 was also significantly less ($P < 0.05$) in the attended groups (1.6% and 2.2%, respectively) than the unattended groups (6.8% and 5.2%, respectively). The researchers did not find a significant difference in the number of piglets crushed between groups in this study. Birth weights were greater in the control group, but they pointed out that this was likely because piglets in the control group had ingested colostrum prior to weighing, unlike the experimental group. On Day 21, piglets from the experimental group had a significantly greater ($P < 0.05$) average body weight (5.33 kg) than the control group (5.09 kg).

These results confirm findings from a study conducted by Holyoake et al. (1995), during which they tested the effect of induction of parturition in sows and the attendance of workers at farrowings on sow and piglet performance. The researchers found no effect of farrowing induction on the mortality rate/performance of piglets. In the group with supervised farrowings, there was a greater ($P = 0.012$) number of piglets weaned per litter (10.17 ± 0.24), lower ($P=0.01$) percentage of stillborn pigs per litter (3.2 ± 0.9), and lower ($P < 0.05$) number of pre-weaning deaths per litter (0.86 ± 0.13) when compared to unsupervised farrowings (9.44 ± 0.19, 6.2 ± 0.9, and 1.29 ± 0.13, respectively). In contrast to White et al. (1996), Holyoake et al. (1995) found a significant decrease ($P = 0.009$) in the number of piglets killed by trauma/crushing in the supervised group (34) when compared to the unsupervised piglets (90). They did propose that this difference might have been the result of workers diagnosing deaths as trauma/crushing that were actually caused by other issues, such as disease or deformity.

Challenges. The main challenge associated with batch farrowing systems is keeping the sows in the breeding herd on a desired breeding schedule and introducing new gilts into the breeding herd to coincide with this strict schedule. Gilts and sows may fail to cycle within the desired period, and this results in more females needing to be mated to avoid empty farrowing crates/pens (Brown, 2006). This compensatory maneuver of breeding more females has the potential to provide an excess of pregnant females, causing the opposite problem in the farrowing house (Roese et al., 2007). Failure to cycle at the correct time may also result in increased culling rates for sows and gilts, which can lead to increased costs to producers. As previously reported, Martel et al. (2008) observed, using their sow herd dynamics model that the average parity at culling was lower and number of females culled per cycle was greater in 3- and 4- week batch management systems when compared to a weekly farrowing system. These culling decisions were determined based on whether or not a female cycled in the desired time frame, a sow's productivity, and whether there were too many pregnant females in relation to the availability of housing.

Actual data reported to the Swine Management Services (SMS) database confirmed the results predicted in the model used by Martel et al. (2008). Ketchum and Rix (2014) used data reported by farms over the course of 52 weeks in 2014 and reported that the average female culling percentage for batch farrowing operations at week 13 and 26 were 53.0% and 56.6%, respectively, while these values for traditional farms were 46.7% and 47%, respectively. They did not subject these data to statistical analysis, but the numbers help show the culling trend in practical application.

It is essential to keep the breeding herd females in the herd up to at least their 3rd parity to make sure that producers are not losing profits (Dhyuvetter, 2000). This particular challenge is what might make estrus synchronization techniques valuable in a batch management system because they could help prevent over-culling and over-breeding. Since there currently is little data on the use of estrus synchronization techniques in these systems, this thesis project may prove useful in determining any positive effects of their use in manipulating the estrous cycle in breeding females.

Estrous Cycle

General. The estrous cycle in swine is 18 to 24 days, typically averaging at 21 days (Holden and Ensminger, 2006). Of the various types of cyclicity, swine are classified as polyestrous, meaning that they have a uniform distribution of estrous cycles throughout the year, regardless of season. There are two phases of the estrous cycle, the follicular phase and luteal phase, each with its own set of dominant ovarian structures and hormone profiles, which control physiological responses in the cycling female. Ultimate control of the estrous cycle lies in the pulsatile release of gonadotropins, lutenizing hormone (**LH**) and follicle-stimulating hormone (**FSH**), from the anterior pituitary due to discontinuous stimulation by gonadotropin-releasing hormone (**GnRH**) from the hypothalamus.

During the follicular phase, which constitutes 20% of the estrous cycle (approximately 5 days), the dominant structures on the ovary are developing dominant or Graafian follicles, stimulated by LH and FSH, and the primary hormone produced by this type of structure is estradiol (**E2**). Progesterone (**P4**) levels are low during this phase, since there are no corpora lutea (**CL**) on the ovary. Low levels of P4 paired with increasing levels of E2 create a positive feedback loop on the pulsatile secretion of GnRH from the hypothalamus, which leads to an eventual GnRH surge. This surge then triggers a pre-ovulatory LH surge, which ultimately causes ovulation, from the anterior pituitary coinciding with the onset of estrus. An FSH surge does not occur because of the production of inhibin by the dominant follicles, which act on the anterior pituitary to suppress the release of FSH. Henricks et al. (1972) observed an increase in plasma estrogen levels from 10 to 30 pg/mL to 60 to 70 pg/mL the day prior to estrus, which coincided with a drop in P4 to undetectable levels. Maximal LH levels were detected in gilts on the first day of standing estrus (day 0).

Directly after ovulation, the luteal phase begins and constitutes the rest of the estrous cycle (approximately 16 days). The dominant structures on the ovary during this phase are the CL, which produce P4. These structures and this hormone are essential for maintaining pregnancy, should conception occur. Estrogen levels return to basal levels due to negative feedback of P4 on GnRH, which will have an indirect effect in reducing LH secretion. The reduction in estrogen and inhibin levels, due to the decreased presence of dominant follicles on the ovary, lowers the negative feedback on FSH, which leads to increased levels of this gonadotropin during the first 1 or 2 days post-ovulation (Soede et al., 2011). This restoration of FSH levels leads to an increase in the number of small and medium sized follicles, which then produce E2 and inhibin to lower FSH levels again. Follicle diameter usually remains relatively small, between 3 and 4 mm during this phase (Soede et al., 2011; Ryan et al., 1994). If pregnancy does not occur, prostaglandin F2-alpha (**PGF-2α**), produced by the uterus, causes luteolysis (breakdown of the CL) to occur. Luteolysis leads to reduced P4 levels and removal of negative feedback on GnRH, so that the follicular phase of the estrous cycle can begin again. Ryan et al. (1994) observed the trend of a sharp increase in follicle diameter in non-pregnant sows around day 16 of the estrous cycle, a phenomenon that was not observed in pregnant sows. This indicates that luteolysis occurred, and the growth of pre-ovulatory follicles can continue.

LH and FSH. These two gonadotropins are both peptide hormones released from gonadotrophs in the anterior lobe of the pituitary gland in response to endocrine signaling from

GnRH, a decapeptide, which is produced and released from the hypothalamus. The pulsatile release of GnRH differs in amplitude and frequency to elicit different physiological responses. It is regulated by feedback from estrogens and other steroid hormones. A high-frequency pulsatile secretion causes LH release, while a low-frequency pulsatile secretion favors FSH release (Gardner and Shoback, 2011).

Once LH is released from the anterior pituitary, it binds to receptors on thecal cells in the ovary, which produce testosterone. This testosterone is then converted to E2 in the granulosa cells, under the control of FSH, which is the basis for the two-cell, two-gonadotropin theory. The LH plays a critical role in triggering ovulation in gilts and sows and is also important for the final growth of a follicle prior to ovulation, demonstrating the shift from FSH dominance to LH dominance during the follicular phase (Guthrie, 2005). Knox et al. (2003) recorded greater ($P < 0.005$) concentrations of LH during the ovulatory period in high ovulation rate (oocytes ovulated per cycle) gilts than those with low ovulation rates. The amplitude of the LH surge that triggers ovulation is over 10 times greater than its normal tonic pulse during follicular development (Henricks et al., 1972).

The importance of LH is further demonstrated by the occurrence of lactational anestrus, which is when a sow does not cycle during lactation because of suckling action that inhibits GnRH and LH secretion. Shaw and Foxcroft (1985) found that mean serum LH concentrations increased ($P < 0.001$) in primiparous sows from 0.22 ± 0.02 ng/mL 12 hours prior to weaning to 0.38 ± 0.03 ng/mL 12 hours post-weaning and that LH concentrations prior to weaning were inversely related ($r = -0.649$; $P < 0.05$) to weaning-to-estrus interval (**WEI**). Langendijk et al. (2007) observed greater ($P < 0.05$) LH concentrations in sows physically separated from piglets compared to the concentrations in sows allowed to be intermittently suckled as normal. The pulses during periods of separation were more frequent with lower amplitude, while those during suckling were less frequent with higher amplitude. Interestingly, they also found an effect of the degree of separation of piglets from sows on responsiveness of LH concentrations. When piglets were totally separated from sows (in separate holding pens), sows had lower levels of LH than when piglets were only physically separated from them (in same pen, but piglets could not get to teats), which suggests a possible stimulus other than suckling (e.g. auditory, visual, or olfactory) that may also contribute to LH inhibition during lactation. Later research by Langendijk et al. (2009) also suggested that it might actually be follicular responsiveness to, rather than relative secretion levels of, LH and FSH which modulates anestrus and follicular development during lactation in sows that failed to ovulate.

The primary gonadotropin responsible for follicular recruitment and development on the ovary is FSH. The FSH release acts on granulosa cells of the developing ovarian follicles to convert testosterone to E2. In swine, follicles vary in size and, based on diameter, can be classified as small (<3mm), medium (4 to 6 mm), and large (>6mm). Once developing follicles have reached the large/pre-ovulatory stage, inhibin produced by granulosa cells inhibits FSH, and LH takes control, indicating that FSH's main role is recruitment and development of small- and medium-sized follicles (Guthrie, 2005). This theory is supported by multiple studies (Guthrie and Bolt, 1983, 1990; Knox et al., 2003), which have demonstrated that dominant follicle development, along with a decrease in the number of small and medium follicles, coincides with lower FSH levels during the first 2 days after luteolysis.

Release of FSH is also important for ovulation rate in weaned sows and gilts. Shaw and Foxcroft (1985) recorded a significant increase ($P < 0.001$) in serum FSH levels from 151.1 ± 6.2 ng/mL 12 hours before weaning to 187.7 ± 9.7 ng/mL 12 hours post-weaning, as well as a strong correlation between ovulation rate and peak FSH concentrations after weaning ($r = 0.746$; $P < 0.05$) or overall mean FSH levels ($r = 0.645$; $P < 0.05$). Knox et al. (2003) observed greater FSH levels during the ovulatory period ($P = 0.002$), as well as the mid- ($P < 0.05$) and late-luteal phases ($P = 0.01$) in gilts with high ovulation rates when compared to those with low ovulation rates. They were able to conclude from these observations that both LH and FSH were crucial to increasing ovulation rate during the ovulatory period, but only FSH was relevant to ovulation rate by acting to develop follicles during the luteal phase (Knox et al., 2003).

Estrus. Estrus or "heat" is the portion of the estrous cycle of a breeding female that is recognized by visible physiological and behavioral signs of sexual receptivity and mating, such as a swollen vulva with discharge, erect ears, and lordosis ("locking up" to be mounted). Female swine in estrus may also vocalize, display nervous behavior, mount other females, and urinate frequently (Estienne and Harper, 2009). Estradiol is the primary hormone during this stage of the estrous cycle and is responsible for these behaviors as well as physiological changes in the reproductive tract. The duration of estrus in swine can be 1 to 5 days (average of 2 days), and ovulation occurs roughly 12 hours before the end of estrus, although it can vary depending on parity and other factors (Holden and Ensminger, 2006). Maximum fertility occurs if sperm cells are deposited into the female reproductive tract 0 and 24 hours before ovulation, which was confirmed by Knox et al. (2003) when they observed an increase in E2 levels starting around day 15 of the estrous cycle, a peak the day prior to ovulation (Day –1), and a drop back to basal levels by Day 1. Other studies reported a range of 23 to 50 hours from the onset of estrus to ovulation (Weitze and Waberski, 1996; Martinat-Botte et al., 1995). Producers are able to time breeding schedules using these parameters as a guide and regular estrus detection. It is suggested that heat be detected twice per day with a boar and breeding occur 12 and 24 hours after the onset of estrus (Holden and Ensminger, 2006). Alternatively, if heat is detected once per day, breeding occurs 0 and 24 hours after the female is first found in standing heat. These insemination strategies are designed to increase the likelihood that at least one service occurs during the period of peak fertility (0 to 24 hours prior to ovulation).

When gilts reach puberty, usually around 4 to 6 months of age, they will begin to show signs of estrus to indicate that cycling has begun. This age varies widely due to influences of breed, environment, type of housing, level of boar exposure, nutrition level (Holden and Ensminger, 2006), and season of birth (Mavrogenis and Robison, 1976). Some gilts will have a silent estrus during their first cycle, which means that they complete an estrous cycle without any visible physical or behavioral indicators.

Mavrogenis and Robison (1976) tested the effects of season of birth, presence of a boar, and variation in stocking density on the rate of sexual development in crossbred gilts by recording weight and age at first estrus. Ovaries were also evaluated to determine whether first estrus or silent estrus had occurred. They found a decrease ($P < 0.01$) in the age at puberty for gilts born in the Fall (202.3 days), exposed to boars (207.8 days), and housed with 30 gilts per pen (207.4 days) when compared to those born in the Spring, lacking boar exposure and housed individually (237.3 days, 221.9 days, and 222.2 days, respectively). Mavrogenis and Robison (1976) also found significant interactions of season by boar exposure ($P < 0.01$) and season by group size ($P < 0.05$) on age at puberty. Gilts born in the Fall reached puberty at a minimal age and displayed a normal distribution in those ages, so boar exposure and group size did not have as much of an impact on further reducing age at puberty. Gilts born in the Spring reached first estrus when they were much older and displayed a bimodal distribution of age at puberty, so exposure to exogenous factors contributed to further reducing the age at puberty in those females. There was a difference ($P<0.01$) in the weight at puberty for gilts born in the Fall (103.0 kg versus 113.7 kg, respectively) and those exposed to a boar (104.2 kg versus 112.5 kg, respectively). There was no effect of stocking density on weight at puberty. Gilts exposed to boars had a higher ($P < 0.05$) incidence of silent estrus, which they proposed could be due to exogenous stimuli causing physiological maturity to occur before what they called “psychic estrus”.

Rampacek et al. (1981) tested the effect of confinement housing on the ability of 214 crossbred gilts, born either January to March or June to July, to reach puberty by 270 days of age. A greater proportion ($P < 0.001$) of non-confined (housed in groups outside) gilts reached puberty by day 270 (75.4%) than confined (housed individually inside) gilts (37.4%). In contrast, there was no significant difference between housing treatments in the proportion of gilts born June to July that reached puberty by 270 days of age. Adrenal weights and average age at first estrus was also unaffected by confinement. They concluded that confinement can delay puberty in gilts and that season of birth plays a role as well, confirming findings in the previous study (Mavrogenis and Robison, 1976). Because the vast majority of swine are housed in total confinement in the United States, this study bares particular importance in stressing the importance of estrus synchronization for gilts being introduced into the breeding herd with sows.

It is normally recommended that gilts be bred during their second or third estrus rather than their first because ovulation rates and reproductive performance tend to increase significantly during those two cycles, so breeding would occur around 7 to 8 months of age in order to farrow by 1 year of age (Holden and Ensminger, 2006). However, advances in management are creating more possibilities for earlier breeding strategies for gilts in commercial settings. Archibong et al. (1987) attempted to identify factors associated with reduced reproductive performance in gilts bred during their first estrus. Mean number of ovulations and embryonic survival rate on day 5 and day 30 of gestation were lower ($P<0.05$) for gilts bred on first estrus (12.2, 78.1%, and 66.7%, respectively) when compared to those bred during third estrus (14.5, 95.4%, and 89.4%, respectively). The ratio of P4 to estrogen in gilts bred during first estrus was lower ($P<0.05$) on day 3 of gestation than in gilts bred during the third estrus, but it was greater ($P<0.05$) on day 15 and day 30, indicating that the change in hormone concentrations may cause early embryonic mortality in gilts bred earlier. Lambert et al. (1991) also reported that embryonic mortality before day 3 of gestation was the main cause of prenatal loss in gilts.

Young and King (1981) tested the effect of breeding gilts on the first and third estrus on reproductive performance. Gilts were either bred on their first or third estrus. Those that did not conceive were bred a second and third time. While there were no statistically significant differences found in the results, as determined by the chi-square test, the researchers did notice some notable trends. The conception rate during the first, second, and third breeding was lower in gilts bred on their first estrus (69.6 %, 66.7%, and 80.0%, respectively) when compared to those bred on their third estrus (77.4%, 83.3%, and 100%, respectively). There was also a tendency for increased numbers of pigs born, born alive, and weaned to be greater in gilts bred on their third versus first cycle. After three parities, sows initially bred on their third cycle weaned, on average, 1.4 more pigs than those initially bred on their first. Since there were no significant differences detected, they concluded that it may actually be possible to breed gilts earlier with success (Young and King, 1981), but it is important to remember these trends when manipulating gilts to be bred sooner than traditionally recommended.

Rozeboom et al. (1996) tested effect of gilt age and body composition on reproductive performance and longevity in sows over the course of three parities by breeding on the first, second or third estrus and employing three different feed regimens from puberty to breeding. There was no effect ($P > 0.10$) of gilt age on number of pigs born, born alive, and weaned, which confirms findings of Young and King (1981), and there was also no effect ($P > 0.10$) of gilt body composition on those items over the course of three parities. Breeding on the second estrus resulted in an increase ($P < 0.10$) in birth weights by an average of 34g during parity 1. Older gilts also had significantly greater weaning weights in parities 1 ($P < 0.05$), 2 ($P < 0.01$), and overall ($P < 0.05$) than younger gilts. In parity 2, an increase in empty body weight of gilts by 10 kg corresponded to a 120 kg increase ($P < 0.05$) in weaning weights. Overall, sow longevity was not affected by age or body composition of gilts. The scientists concluded that gilts could be bred earlier without impacting sow longevity over the course of three parities.

Sows typically display estrus within 3 to 7 days (average of 5) after weaning and ovulate 35 to 50 hours after the onset of estrus (Holden and Ensminger, 2006). The length of the WEI can be influenced by a variety of environmental and possibly genetic factors. Some of the causes of anestrus in weaned sows included reduced feed intake during lactation, lactation length, parity, and increased temperatures during the summer months (Flowers, 2001). Since this particular trait is one of the main measures of reproductive efficiency in the breeding herd, learning what influences its relative length in sows is critical to production in the industry. Leite et al. (2011) tested for the influence of environmental and genetic factors on WEI in sows using data collected from the breeding herds of two U.S. commercial producers over the course of three years. Results indicated a quadratic relationship ($P < 0.0001$) between WEI and age of sow at farrowing, with intervals being greater in young and old sows, confirming earlier reports by

Chansomboom et al. (2009). The researchers attributed this relationship to the fact that primiparous sows tend to have nutritional restrictions and difficulty maintaining condition during lactation due to the lack of protein and fat reserves that an older sow would have. Older sows (> 900 days of age) have usually passed their peak productivity, and they are producing large litters, which contribute to more strenuous demands on their bodies and increased difficulty in returning to cyclicity.

Lactation length had a positive linear relationship ($P < 0.001$) to WEI, which means that increasing lactation length increases WEI, likely due to greater weight loss after week 3 of lactation. Studies (Poleze et al., 2006; Chansomboom et al., 2009) have reported a quadratic relationship, indicating variation that could be attributed to other environmental, genetic and management effects. There was also a relationship between season of farrowing ($P < 0.0001$) and herd ($P = 0.002$) and WEI. Sows that farrowed September to November and January to February had lower average WEI (6.68 days and 6.74 days, respectively) than those that farrowed March to May and June to August (7.46 days and 7.67, days respectively). They did not find any significant effect ($P = 0.473$) of genetic line, and determined a very low heritability (0.04) of the WEI phenotype. They did find a strong genetic correlation between the first and third WEI ($R = 0.74$), so genetic selection may be used based on the first WEI, although it is lowly heritable (Leite et al., 2011).

In conclusion, reproductive performance, such as the onset of puberty in gilts and WEI in sows are influenced by many factors. This has the potential to impact reproductive efficiency for producers. It is the goal of producers to adequately understand and manipulate estrous cycles in order to introduce new gilts successfully into the breeding herd and keep sows at peak reproductive performance as long as possible to maintain proper hog flow and maximize profits.

Estrus Synchronization Techniques

Boar exposure. It has been well documented that boar exposure causes physiological and behavioral responses that lead to estrus prepubertal gilts. A pheromone, androstenone, is excreted from boars in their saliva and urine (Pearce and Hughes, 1987). This hormone interacts with olfactory receptors in the breeding female to stimulate an endocrine response in the hypothalamic-hypophyseal-ovarian axis, leading to follicular growth, estrus, and ovulation (Flowers, 2001). Olfactory cues, when combined with visual, tactile and auditory cues that ultimuately stimulates reproduction in gilts has been labeled as the "boar effect" (Stančič et al., 2012). The "boar effect" has been employed as a method of estrus synchronization on hog operations for decades because it is natural, inexpensive, and effective.

Patterson et al. (2002) concluded that direct boar contact reduced ($P < 0.05$) the interval from the start of daily boar exposure to puberty in both group- and individually-housed gilts. Caton et al. (1986) conducted a study with 100 crossbred gilts to test the effect of duration of boar exposure on the proportion of gilts that reached first estrus by 210 days of age, which was determined by observing gilts for lordosis. Overall, only 40.4% of the gilts reached estrus by 210 days of age, and the researchers attributed this low response to poor genetics and inadequate housing. They found that more ($P < 0.05$) gilts reached estrus by 210 days of age when exposed to a boar for 30 minutes daily (52.6%), 5 minutes daily (40.0%), and continuously (housed adjacent to a boar with nose to nose contact) with additional 10 to 15 minutes exposure to a different boar in an estrus detection pen (65%) when compared to just continuous exposure alone (10%). They also noticed an interactive effect ($P < 0.05$; $F = 3.55$) between season and treatment in this study on the days to puberty. Gilts that were provided boar exposure for 5 or 10 minutes daily in the fall took longer ($P<0.05$) to reach puberty (23.5 days and 21.4 days respectively) than gilts given 15 minutes or continuous exposure with an additional 10 to 15 minutes in an estrus detection pen in the fall, and gilts with 5 minutes of daily exposure in the summer (10.3 days, 11.9 days, and 11.7 days, respectively). This seasonal change in responsiveness to boar exposure, confirms findings by Mavrogenis and Robison (1976).

Prunier and Meunier-Salaün (1989) tested the effects of boar exposure and housing (tethered versus group penned) on puberty attainment in gilts. Boar exposure to both tethered and group housed gilts led to lower ($P < 0.05$) median days of age at puberty (233 days and 215 days, respectively) when compared to tethered and group housed gilts with no boar exposure (260 days and 264 days, respectively). Hormone secretions in response to the boar were not affected by type of housing, so they concluded that boar exposure is more important than housing when it comes to stimulating puberty. Findings from Patterson et al. (2002) contradict this conclusion by showing that group housed gilts reached puberty at a younger ($P < 0.05$) age than individually housed gilts.

Filha et al. (2009) found that daily boar exposure resulted in a greater ($P < 0.05$) percentage of high growth rate gilts in estrus less than 20 days after the start of exposure when exposed to the boar between 130 and 149 days of age (59.7%) than intermediate or low growth rate gilts (48.7% and 48.2% respectively), and there was no effect of growth rate on the percentage of gilts in estrus with boar exposure between 150 and 170 days of age. Age at puberty was lower ($P < 0.05$) in high growth rate gilts (159.6 days) when compared to low growth rate gilts (164.8 days) when exposed to the boar at a younger age; age at puberty was not affected by growth rate in gilts exposed to a boar. Age at puberty was positively associated with age at boar exposure ($r = 0.38$; $P < 0.0001$) and the older gilts were when exposed to a boar, the lower the interval from exposure to onset of puberty ($r = 0.19$; $P < 0.0001$). van Wettere et al. (2006) also determined that increasing age when first exposing gilts to boars can improve synchronization and timing of puberty in gilts without affecting litter size.

Boar exposure can also affect the WEI in sows. Walton (1986) exposed primiparous and multiparous sows to boars one week prior to weaning and housed them with boars post-weaning to see if there was an affect on WEI. Sows exposed to a boar after weaning had a more ($P<0.001$) rapid onset of estrus and ovulation than sows not exposed to a boar post-weaning. Primparous sows returned to estrus later ($P < 0.02$) and tended to ovulate later ($P < 0.09$) than multiparous sows, which was confirmed in other studies (Leite et al., 2011; Chansomboom et al., 2009). There was an interaction between litter size and boar exposure pre-weaning on WEI and ovulation ($P < 0.01$ and $P < 0.001$, respectively). Ovulation and WEI were not affected by pre-weaning boar exposure alone ($P = 0.62$ and $P = 0.17$, respectively). The scientists concluded that exposure to a mature boar post-weaning enhanced return to estrus and ovulation in sows.

Knox et al. (2004) tested the effect of housing and boar exposure on return to estrus in sows. The proportion of sows displaying estrus within 7 days post-weaning was less ($P < 0.05$) for sows housed in group pens adjacent to boars (80%) when compared to sows housed in group pens away from boars (98%) and in gestation crates away from boars (96%). The WEI for sows house away from boars (4.7 days) was less ($P = 0.01$) than sows housed adjacent to boars (5.2 days). Duration of estrus was shorter ($P < 0.001$) for sows housed adjacent to boars (45 hours) than sows housed in group pens away from boars (62 hours) and sows in gestation crates (58 hours). They concluded that housing weaned sows next to boars post-weaning negatively affected their return to estrus and estrus detection.

Lactational anestrus in sows has already been discussed as affecting WEI by inhibiting LH secretion and receptivity (Shaw and Foxcroft, 1985; Langendijk et al., 2007). Newton et al. (1987) decided to test the effect of boar exposure and altered suckling on the endocrine response in sows. Sows with litter separation for 6 hours a day and boar exposure had greater ($P < 0.05$) serum LH concentrations during lactation than control sows. Concentrations of FSH were greater ($P < 0.05$) in the treated primiparous sows than treated multiparous sows. All multiparous sows with litter separation and boar exposure exhibited estrus during lactation. None of the treated primiparous or control sows exhibited estrus during lactation. This may have been attributed to elevated ($P<0.05$) levels of E2 in multiparous sows, which indicates more advanced follicular development when compared to primiparous sows. High levels of E2 stimulate an LH surge and ovulation (Flowers, 2001). Newton et al. (1987) concluded that boar exposure paired with litter separation during lactation increased LH concentrations in sows, leading to estrus and ovulation.

Overall, boar exposure helps decrease age at puberty and the WEI in gilts and sows respectively. Boar exposure alone is not as effective in intensive commercial settings, especially in batch farrowing operations, where the gilt and sow to boar ratio may be very large. For this reason, commercially available hormones have been developed to help synchronize estrus in breeding females.

MATRIX/Altrenogest/Regumate. MATRIX is an orally administered progestin that can be fed to sexually mature sows and gilts displaying normal estrous cycles of approximately 21 days. It is ineffective for synchronizing gilts that have yet to reach their first estrus. It is fed for 14 days and can be used effectively during any stage of the estrous cycle (Flowers, 2001). Redmer and Day (1981) found that treating gilts with MATRIX at 15 mg/day, rather than 2.5 mg/day, during the feeding period was better to synchronize estrus. Since MATRIX mimics the effects of P4, it inhibits secretion of LH and FSH and thus, follicular development, but it does not prevent normal luteolysis and CL regression from occurring. It does prevent estrus from occurring after normal luteolysis until it is removed from the feed. Once it has been removed, LH and FSH secretion resumes, and estrus occurs (Kirkwood, 1999).

Wood et al. (1992) tested the ability of altrenogest to synchronize estrus in two different breeding herds and the subsequent long-term effects on reproductive performance in sows with 2 experiments. Herd 1 was in a controlled, university setting designed to simulate a small herd. Gilts and sows were fed 15 mg/animal/day for 14 days and 10 days respectively, and estrus was checked twice daily using a boar. A greater ($P < 0.001$) proportion of treated gilts and sows displayed estrus during the first 7 and 10 days of the 21-day heat check period than control gilts and sows. In sows, parity affected ($P < 0.001$) the days to estrus after heat check began. Gilts were detected in estrus in 7.0 ± 0.4 days, while sows took 10.5 ± 0.5 days to express estrus. Median days to estrus were less ($P < 0.01$) in treated gilts and sows than controls. Overall farrowing rates, pigs born alive, stillborns, and mummies were not significantly different between treated animals and controls bred 7 to 10 days after altrenogest was removed from the feed. Herd 2 was a commercial sow farm, and, during the 20 days after altrenogest was removed, there was no difference observed in the proportion of treated and control gilts that came into estrus. Results were the same as Herd 1 for the average number of days to estrus, the proportion of gilts that came into heat within 7 and 10 days after the beginning of the 21-day heat check period, and the subsequent reproductive performance of sows. There was a lower ($P < 0.01$) farrowing rate in treated gilts versus control gilts, but this finding is not supported by any other studies. Overall, the researchers concluded that altrenogest is effective at synchronizing estrus in gilts and non-pregnant sows.

Martinat-Botte et al. (1995) conducted a similar study, but they fed altrenogest for 18 days, rather than 14 days. Estrus synchronization occurred, with 94% of treated gilts displaying estrus within 5 to 7 days after the removal of the compound from the feed. The pregnancy rate was greater ($P < 0.05$) for treated gilts (89.3%) than control gilts (77.4%), which contradicts the findings of Wood et al. (1992). Ovulation rate was also greater ($P < 0.02$) for treated gilts (15.4 ± 0.3 oocytes) than control gilts (14.6 ± 0.3). Number of fetuses and fetal survival were not different between the two groups. The researchers attributed increased litter size to increased ovulation rates in treated gilts and similar fetal survival rates between the two groups.

When MATRIX was fed to primiparous sows for 7 days post-weaning, Boyer and Almond (2014) found no effect of treatment on farrowing rates, number of piglets born alive and weaned during parity 1, or the number of piglets weaned in parity 2. The average number of piglets born alive in parity 2 was greater ($P < 0.05$) in treated sows (10.72 ± 0.08) than control sows (10.06 ± 0.8). Control sows had, on average, 0.27 less piglets born alive during the second parity than the first, while treated sows had 0.41 more piglets born alive ($P < 0.05$). Interpretation of Parity 2 data is complicated by the fact that an outbreak of Porcine Reproductive and Respiratory Syndrome (**PRRS)** occurred during that part of the study. The proportion of sows having a weaning-to-service interval (**WSI**) of less than 7 days was greater ($P < 0.05$) for treated sows (91%) than control sows (77%). They concluded that extending the WEI in primiparous sows using MATRIX enhanced return to estrus and increased the number of piglets born alive in a subsequent farrowing. Conversely, Koutsotheodoros et al. (1998) fed MATRIX to early-weaned sows to see if it also enhanced reproductive performance in an alternate breeding scenario. They found an increase ($P < 0.05$) in the ovulation rate of early-weaned sows fed MATRIX (16.9 oocytes) when compared to non-MATRIX-fed early-weaned and conventionally-weaned control sows (weaned after a 24-day lactation) without MATRIX (15.4 oocytes and 14.9 oocytes, respectively). MATRIX-to-estrus and wean-to-estrus intervals were not different for MATRIX-fed early-weaned sows (6.2 days) and control sows (5.6 days), but both of those intervals were shorter ($P < 0.01$) than the WEI for early-weaned sows without MATRIX (7.3 days). They concluded that MATRIX had the potential be a useful tool to compensate for the reduction in reproductive performance associated with early weaning in sows by increasing ovulation rate. However, Gonçalves dos Santos et al. (2004) found that, while ovulation occurred earlier in treated sows, there were not significant effects of MATRIX on post-weaning return to estrus or farrowing rates between the two groups, so they concluded that MATRIX had no positive impact on reproductive performance in early-weaned sows.

Overall, MATRIX has proven to be a useful tool to synchronize estrus in mature sows and gilts and perhaps offer opportunities to improve ovulation rate and potential litter size. However, it is ineffective in synchronizing estrus for anestrus sows and immature gilts, so another hormone treatment was developed to address that demographic in the breeding herd.

P.G.600. P.G. 600® is administered to prepubertal gilts and anestrus sows via an intramuscular (**IM**) injection. It is a combination of eCG and hCG, which stimulate follicular development on the ovary by mimicking the effects of the naturally occurring gonadotropins, FSH and LH, respectively (Flowers, 2001). It will not work in cycling sows and gilts because they already have systemic levels of these two gonadotropins circulating, so their ovaries will not respond to exogenous gonadotropins. Ovaries in immature gilts become responsive to exogenous gonadotropins between 120 and 180 days of age (Breen et al., 2005; Carabă et al., 2014). P.G. 600 along with boar exposure is one of the most common methods of inducing puberty in gilts (Carabă et al., 2014) and can also work to get anestrus sows to come into heat again.

Britt et al. (1989) found that a single injection of P.G. 600 could stimulate fertile estrus in prepubertal gilts. Knox et al. (2000) tested whether the route of injection for P.G. 600, subcutaneous (**SC**) or IM had an effect on estrus and ovulation responses in immature gilts. The use of P.G. 600, through both routes of injection, led to a shorter ($P<0.01$) interval from treatment to estrus (4.6 days) than control gilts (5.9 days), with no difference between routes of injection. There was also no difference between the routes of administration on the proportions of gilts that ovulated, but the use of P.G. 600 did yield a greater ($P < 0.01$) proportion of gilts ovulating than the controls. The SC injection of P.G. 600 resulted in a greater ($P < 0.01$) proportion of gilts that displayed estrus (76%) than did the IM injection (52%) or control (15%). This study revealed that a SC injection of P.G. 600 might be more effective at inducing estrus in prepubertal gilts than an IM injection. It also showed that P.G. 600 is effective at inducing estrus and ovulation in gilts (Knox et al., 2000). Carabă et al. (2014) was able to confirm the effectiveness of inducing estrus in prepubertal and anestrus gilts by observing that 75% of prepubertal and anestrus gilts displayed estrus within 3 to 5 days after the P.G. 600 injection.

Breen et al. (2005) tested the effectiveness of P.G. 600 and boar exposure on induction of puberty in gilts in two different experiments. In experiment 1, they tested whether fence-line or physical boar exposure combined with P.G. 600 injections had a more positive effect on the proportion of gilts expressing estrus within 20 days of receiving the injections. There was no difference in the proportion of gilts expressing estrus within 20 days of injection, age at estrus, duration of estrus, or ovulation rate between the two types of boar exposure. In experiment 2, they tested whether short-term boar exposure combined with age differences in the gilt and P.G. 600 injections had an effect on the onset of estrus. There was no difference in the proportion of gilts that exhibited estrus or ovulated within 7 days of the injection. However, there was an effect

(P < 0.05) of age at injection on the age at estrus. Younger gilts that received P.G. 600 achieved estrus at a younger age with or without boar exposure (174.2 days and 173.6 days, respectively) than older gilts (190.2 days and 187.8 days, respectively). The ovulation rate of younger gilts given P.G. 600 and no boar exposure was greater (P < 0.05) than younger gilts with boar exposure and both groups of older gilts. This difference was attributed to varied follicular status of the ovaries and the effect of boar on endocrine responses in the gilt. Overall, these experiments showed that age at estrus could be affected by P.G. 600 injections in younger, sexually immature gilts. The lack of variation in other parameters was partially attributed to the fact that the experiments took place during the summer months, which tend to have a negative effect on estrus and ovulation in gilts. These findings show that the efficacy of exogenous hormones and boar exposure can be impacted by elevated temperatures during the summer months, which contributes to the cyclicity in hog prices mentioned earlier in this review.

P.G 600 can also be given to sows at weaning to prevent an extended WEI and induce ovulation. Knox et al. (2001) found that a greater (P < 0.01) proportion of sows treated with P.G. 600 (94.4%) displayed estrus within 8 days of weaning than controls (78.4%). More treated sows displayed estrus by day 4 after weaning (81%) than control sows (33%). The WEI was shorter (P < 0.0001) in treated sows (3.8 ± 0.1 days) than in control sows (4.9 ± 0.1 days). The estrus-to-ovulation interval was longer for both control and treated sows displaying estrus within 3 days when compared to those that displayed estrus after 5 days. There was also a linear relationship (r = 0.43; P < 0.0001) between the WEI and estrus-to-ovulation interval. It was concluded that P.G. 600 could be used to enhance estrus and ovulation expression in weaned sows, but insemination protocols would have to be timed correctly to optimize the timing of AI in reference to the timing of ovulation. Košorok and Kastelic (2011) observed similar results in their study, as well as a slightly increased litter size, shorter period to successful insemination, and increased percentage of sows farrowing their second litter in response to P.G. 600. There was too much variation in the data set, however, for the differences between treated and control sows to be different. This highlights the critical importance of other aspects of breeding management along with hormonal intervention to synchronize estrus and improve reproductive performance. Estienne and Harper (2009) suggested that, rather than treating all sows with P.G. 600 at weaning, it would be more beneficial to treat only those at a higher risk of extended WEI, such as second parity sows or those with poor body condition.

Since variation in return to estrus can occur partially because of season, Bates et al. (2000) decided to test the effect of P.G. 600 on reproductive performance of sows weaned in the fall and winter over the course of 6 parities. They also compared responsiveness in sows that were early- (< 14 days of lactation) or conventionally- (> 14 days of lactation) weaned. During parity 2, conventionally weaned sows were more ($P < 0.05$) likely to return to estrus than early-weaned sows (99.0% versus 93.6%, respectively). There were no observed differences for parity 1, which is in contrast to earlier findings of Bates et al. (1991), who found an increased percentage of sows returning to estrus when treated with P.G. 600 after parity 1. Subsequent birth litter weights from sows given P.G. 600 after parity 1 were lower ($P < 0.02$) than early-weaned sows (15.6 kg versus 16.6 kg, respectively). The likelihood of farrowing a litter was greater during parities 3 to 6 for conventionally weaned treated sows than early-weaned sows (84.4% versus 71.3%, respectively). Early weaned sows given P.G. 600 had a greater ($P < 0.06$) number of pigs born (12.4 pigs) than controls (10.6 pigs) for parities 3 to 6. It is possible that this is the result of the additive effects of P.G. 600 and maximal reproductive status, which has been shown to occur around parity 3 and 4 in sows (Dhyuvetter, 2000). Bates et al. (2000) showed that

P.G. 600 could be used to improve reproductive efficiency and performance in sows within a specific parity and lactation length for sows weaned in fall and winter.

Combination of Techniques (Boar exposure/MATRIX/P.G.600) Estienne et al. (2001) tested the effects of combining these P.G. 600 and MATRIX in gilts with three different experiments. Experiment 1 tested the effect of Regu-mate pretreatment on the onset of estrus and ovulation rate in sexually mature gilts that were then given P.G. 600. All gilts received 15 mg/day of Regu-mate for 18 days and on day 18, were either given an injection of P.G. 600 (treatment) or deionized water (control). From day 18 to 25, gilts were checked for estrus twice a day with a mature boar. Seven days after the onset of estrus, blood samples were taken, and gilts were slaughtered 9 to 11 days after estrus to observe the ovaries. The proportion of gilts that displayed estrus within 7 days of the injection was similar ($P < 0.10$) for treated and control gilts after the 18-day Regu-mate regimen (93.8% and 90.6%, respectively). The injection-to-estrus interval also did not differ ($P = 0.37$) between groups (4.1 ± 0.1 days and 4.3 ± 0.1 days, respectively). There was an increase in ovulation rate in P.G. 600-treated versus control gilts, which was determined by an increased ($P < 0.01$) number of CL (28.8 versus 17.4, respectively) and increased ($P = 0.05$) serum concentration of P4 (50.1 ng/mL versus 35.4 ng/mL respectively).

Experiment 2 by Estienne et al. (2001) had the same basic experimental set up as experiment 1, but they tested for the effects of treatment on the onset of estrus, ovulation rate, pregnancy rates and litter size at day 30 post-mating in the gilts. Gilts were bred 12 and 24 hours after the onset of estrus. On day 7 and 28 after estrus, blood was sampled, and gilts were sacrificed on day 30 after estrus to evaluate ovaries and embryos. There was no difference in the proportion of gilts that exhibited estrus within 7 days of injection ($P= 0.45$), the injection-to-estrus interval ($P = 0.27$), or the pregnancy rates at day 30 ($P = 0.71$) between treated (82.7%, 4.0 ± 0.1 days, and 91.7%, respectively) and control gilts (89.7%, 4.2 ± 0.1 days, and 88.5%, respectively). Treated gilts had greater ovulation rates than control gilts, which was determined by a greater ($P < 0.01$) number of CL (26.2 versus 18.1, respectively) and an increase ($P = 0.02$) in serum P4 concentrations (41.2 ng/mL versus 27.1 ng/mL, respectively) on day 7 post-mating. There was no difference ($P = 0.96$) in serum P4 concentrations at day 28 post-mating between the two groups. The mean CL weight was less ($P < 0.01$) for treated gilts (0.42 g) than control gilts (0.49 g). The total number of embryos, number of live embryos, mean embryo weight, and crown rump length were similar between groups ($P = 0.46$, $P = 0.40$, $P = 0.72$, and $P = 0.39$, respectively). Embryonic survival was lower ($P = 0.03$) in P.G. 600 treated gilts (64.3%) than control gilts (78.0%).

In Experiment 3, Estienne et al. (2001) wanted to test the effects of pretreatment with Regu-mate combined with P.G. 600 on estrus and ovulation rate in prepubertal gilts. Half of the gilts received 15mg/day of Regu-mate for 18 days, while the other half were fed a control diet. P.G. 600 injections were given to all gilts 24 hours after the last feeding of Regu-mate or control diet. Gilts were checked for estrus twice daily with a mature boar. Blood samples were collected on day 7 after estrus, and gilts were sacrificed between day 9 and 11 to observe ovaries. The proportion of gilts that exhibited estrus within 7 days of the P.G. 600 injections was similar ($P = 0.49$) for Regu-mate-treated (95%) and control gilts (88.9%). The injection-to-estrus interval was also similar ($P = 0.69$) for treated and control gilts (4.3 ± 0.2 days versus 4.2 ± 0.2 days, respectively). None of the ovarian characteristics differed either.

Overall, Experiments 1 and 2 by Estienne et al. (2001) show that Regu-mate treatment effectively synchronized estrus in randomly cycling gilts when fed for 18 days at a dose of 15 mg/day. While treatment of gilts with P.G. 600 did not have an effect on the proportion of gilts that displayed estrus within 7 days of injection or the injection-to-estrus interval, it did have a positive impact on ovulation rate when compared to control gilts. Unfortunately, this did not result in higher litter size at day 30 post-mating. It is possible that the increase in ovulation rate led to some primary oocytes being ovulated (Pope, 1994), which were not activated, despite being penetrated by viable spermatozoa (Polge and Dzuik, 1965). Wiesak et al. (1990) observed differences in follicle development and maturation of oocytes between cycling and prepubertal gilts treated with P.G. 600. Higher P4 values at day 7 and similar P4 values at day 28 post-mating in treated gilts indicated that P.G. 600 treatment after removing Regu-mate from the feed, which caused the formation of CL that had a reduced capacity to secrete P4 during later stages of pregnancy. In Experiment 3, the use of Regu-mate on prepubertal gilts did not have any effect on the ability to reach estrus or ovulation rates when treated with P.G. 600, which supports previous reports (Knox and Tudor, 1999; Nephew et al. 1994).

Horsley et al. (2005) conducted a study to follow up on the Estienne et al. (2001) study to see if the treatment of altrenogest-fed gilts with P.G. 600 altered the timing of ovulation along with ovulation rate. They hypothesized that the lack of increased litter size at day 30 post-mating in gilts, despite an increased ovulation rate was due to the fact that P.G. 600 may have altered the timing of ovulation such that breeding 12 and 24 hours after estrus was displayed was not the most appropriate system. They observed an increase ($P = 0.07$) in ovulation rate in gilts treated with P.G. 600 (17.5 oocytes) when compared to control gilts (14.8 oocytes), which was similar to that found by Estienne et al. (2001). The injection-to-estrus interval and injection-to-ovulation interval (determined using real-time ultrasonography) were shorter ($P < 0.01$) in treated gilts (98.4 hours and 128.6 hours, respectively) than control gilts (110.9 hours and 141.9 hours, respectively), which, in regard the injection-to-estrus interval, was different than the results of Estienne et al. (2001). They did not, however, find a significant difference in the duration of estrus, estrus-to-ovulation interval, and the time of ovulation as a percentage of estrus duration. They concluded that, while P.G. 600 treatment of altrenogest-fed gilts increased ovulation rate and induced the onset of estrus, it did not have an impact on the timing of ovulation relative to estrus onset (Horsely et al., 2005).

Estienne and Crawford (2015) decided to take these experiments a step further and test whether the duration of MATRIX pre-treatment combined with P.G. 600 had an effect on synchronizing estrus in a group of mixed-cycling gilts. Treatment 1 involved feeding MATRIX (15mg/day) for 14 days followed by an injection of P.G. 600 24 hours after MATRIX withdrawal; Treatment 2 gilts were fed MATRIX for 7 days with a post-withdrawal injection of P.G. 600 24 hours later; Treatment 3 was an injection of P.G. 600 only; Treatment 4 was an injection of water. These MATRIX treatments were staggered, so injections were given on the same day. Gilts were checked for estrus daily with a mature boar for up to 37 days and bred 0 and 24 hours after the onset of estrus. The proportion of gilts reaching estrus within 7 days of their injections was greatest ($P < 0.05$) and the injection-to-estrus interval least ($P < 0.05$) in gilts fed MATRIX for 14 days prior to injection. The reason for P.G. 600 alone being less effective at inducing estrus was likely because there were some gilts in the group already cycling. Gilts in Treatment 3 had the greatest ($P < 0.05$) days to estrus, likely because some gilts may have been injected in the middle of their cycles, creating an extended luteal phase. These results confirm previous findings that pretreatment of gilts with altrenogest for 14 or 18 days prior to giving a P.G. 600 injection effectively synchronizes estrus in prepubertal and cycling gilts (Estienne et al., 2001; Horseley et al., 2005).

In summary, changes in the dynamics of the modern U.S. hog industry over the past few decades have led to shifts in the use of housing and technologies to increase production efficiency and lower costs to producers. This has led to a more vertically-integrated, intensive operation structure, which utilizes both *continuous* and *batch farrowing* methods combined with AI to maintain reproductive efficiency.

The main advantage of continuous farrowing management of the breeding herd is that because of the weekly breeding schedule employed, there are many subsequent opportunities to breed females that fail to display estrus by the desired breeding day. The downside to this type of system is the mixing of hogs with various ages and immunities and reduced capacity to fully disinfect entire buildings in between groups of hogs that leads to an increased risk of disease outbreak. Batch farrowing/management address this particular concern by allowing for easier all-in, all-out management of houses, with larger groups of similar-age pigs flowing through the houses at the same time. A drawback of this system is that estrus synchronization is much more critical because females that fail to cycle on time in a batch farrowing scenario would have to wait at least another 4 or 5 weeks to be bred again, which leads to increased NPD and possibly culling rates replacement gilts and anestrus sows.

A variety of estrus synchronization strategies have been developed to make it easier to introduce replacement gilts to the herd and keep sows cycling regularly with their respective groups, including boar exposure and commercially available hormones, such as MATRIX, an orally-active progestin and P.G. 600, a gonadotropin product that mimics LH and FSH. MATRIX has been proven effective in synchronizing estrus in cycling gilts and sows at all stages of the estrous cycle by mimicking the effects of P4. Its withdrawal from the feed results in the display of estrus in breeding females within 4 to 7 days. It has been shown that boar exposure, combined with a P.G. 600 injection is effective for synchronizing prepubertal gilts when injections are given starting at day 160 to 180 of age, as well as reducing the WEI for weaned sows. Studies have also shown that MATRIX pretreatment, followed by P.G. 600 injections are effective for synchronizing estrus in gilts, as well as increasing ovulation rate.

In conclusion, modern U.S. swine production has presented many benefits and challenges to producers to maintain reproductive efficiency while also keeping biosecurity and animal well being in mind and minimizing costs. Batch farrowing addresses the biosecurity aspect of these goals. Estrus synchronization using commercially available hormones in batch farrowing operations may be able provide a solution to the challenges facing producers trying to optimize reproductive efficiency and costs in these particular systems by making the introduction of replacement gilts and longevity of high-producing sows easier to manage.

Chapter 2: Using commercially available hormones to enhance swine reproductive efficiency in batch management systems

Introduction

Most large-scale swine farms use a high-intensity, *continuous* farrowing system and all segments of production occur each week. For example, a 1,200-sow farm employing 3-week weaning has 20 sow groups, each containing 60 brood females. Every week, a new sow group enters multiple cleaned rooms in the farrowing barn and another sow group is weaned (typically on Thursday) and moved to the breeding-gestation barn. Two lactating sow groups remain in the farrowing barn. In the breeding-gestation barn, sows weaned the previous week are rebred, as are replacement gilts entering the group. Sows displaying extended weaning-to-estrus intervals are not bred with group-mates, but may be bred in subsequent weeks, joining a different sow group. Replacement gilts not exhibiting estrus during a particular week also have subsequent opportunities to join a sow group.

In *batch farrowing systems*, a sow group does not farrow each week, but rather groups farrow at 2- to 5-week intervals. For example, in a 5-week batch farrowing system, a sow group is weaned every 5 weeks and mating occurs the following week; a sow group farrows every fifth week as well. The system is based on a 20-week sow cycle (0.5 week interval between weaning and estrus, 16.5 week gestation, and 3 week lactation) and there are 4 groups of 300 sows for a 1,200-sow herd. Interest in batch farrowing systems is increasing because they allow more stringent all-in/all-out animal flow and better disease control, and larger groups of same age pigs are weaned. The number of separate farrowing rooms is decreased, and tasks such as power-washing or processing pigs are performed less frequently and perhaps more efficiently. There are regular periods of less work during which facility maintenance and repairs can be scheduled.

The major challenge with batch farrowing systems is keeping sows within a group on the desired breeding schedule. For optimum operation of the 5-week system, weaned sows must return to estrus and be mated in 4 to 5 days. Sows falling out of this "window" can become difficult to manage, because another group of sows will not be mated for 5 weeks. Moreover, having the necessary number of replacement gilts in estrus and ready to join a sow group is critical.

Merck Animal Health (De Sota, KS) markets two hormonal products that synchronize estrus in breeding females and have the potential to maintain the integrity of sow groups in batch farrowing systems. MATRIX® (synonym = altrenogest) is an orally active, synthetic progestogen, that effectively synchronizes estrous cycles in sexually mature, cycling gilts, but does not stimulate estrus in prepubertal females (for reviews see Webel and Day, 1982; Day, 1984; Gordon, 1997). P.G. 600® is a combination of eCG (400 IU) and hCG (200 IU) that advances the onset of estrus in weaned sows and prepubertal gilts (Carabă et al., 2014) but not in sexually mature gilts that have reached puberty and commenced estrous cycles.

Using hormones to synchronize estrus in batch farrowing systems has not been extensively studied. It is the objective of this thesis to test the hypothesis that Matrix and P.G. 600 used to synchronize estrus in a 5-week batch farrowing system will positively affect reproductive efficiency in gilts and sows over the course of 3 parities.

Materials and Methods

This experiment was conducted at the Virginia Tech- Tidewater Agricultural Research and Extension Center (TAREC) in Suffolk, VA. The Institutional Animal Care and Use Committee of Virginia Tech (Blacksburg, VA) approved the experimental protocol.

Experimental Design

A total of 52 crossbred gilts of predominantly Yorkshire and Landrace breeding were randomly assigned to one of two treatment groups: Hormone-assisted (**HA**) or control (no exogenous hormones). Commercially available hormonal products (Matrix and P.G. 600) were provided by Merck Animal Health (De Sota, KS) and were both used according to the label. A five-week batch farrowing system was employed. Thus, different sow groups were weaned and mated or farrowed every 5 weeks. The 20-week cycle included 16-week gestation and 3-week lactation periods and a one-week weaning to service interval. Gilts were introduced into the five-week batch farrowing system in three groups (A, B, and D). Characteristics of gilts and treatments are summarized in Table 1. After withdrawal of Matrix from feed or treatment with P.G. 600, gilts were exposed to a mature boar for approximately 15 min each day. Control gilts received daily boar exposure but no exogenous hormones. Gilts displaying lordosis in the presence of the boar were considered in estrus. Gilts were mated 0 and 24 h after displaying lordosis using AI. Each liquid AI dose contained a total of 6 billion sperm cells pooled from at least three Yorkshire boars (Swine Genetics, Inc.; Cambridge, IA).

Gilts were allowed to farrow and were weaned after a 21-d lactation period. At weaning, HA sows were treated with P.G. 600 and exposed to a mature boar for approximately 15 min each day. Control sows received daily boar exposure but no P.G. 600. Sows in estrus were mated as described above. Pregnancy diagnosis was performed approximately 30-d after AI using Amode ultrasonography (Preg-Tone; Renco, Inc.; Minneapolis, MN). Sows were allowed to complete up to three parities, and at the parities one and two weaning events, HA sows received P.G. 600 and control sows received no P.G. 600.

Females failing to breed during specific weeks of the batch farrowing system could be mated and introduced into subsequent groups. For example, gilts in Group D not responding to P.G. 600 by displaying estrus during the specified breeding period, could be synchronized with Matrix and bred with another sow group. Control sows never received exogenous hormones. Gilts and sows were culled if they were classified as not pregnant using ultrasonography after two consecutive matings. Other reasons for culling were an abortion and failing to display estrus. One sow became sick and died during the course of the experiment.

For each of the HA and control batch farrowing systems, detailed production records were collected, including: the entry-to-first service interval, body weight at first service, non-productive days (**NPD**), number of parities completed, total pigs born, number of pigs born live, pigs born dead, mummified fetuses, and pigs weaned. Litter birth weight, pig birth weight, litter weaning weight and pig weaning weight, and the wean-to-estrus interval were also determined.

Statistical Analyses

Production data were evaluated using the mixed model procedure of SAS (SAS Institute, Inc., Cary, NC). The statistical model included group (A, B, or D), treatment (HA or control), and the interaction of group and treatment as possible sources of variation. The Tukey test with Tukey adjustments were used to compare individual means. Chi-squares analyses were used to compare items such as the percentage of entered gilts displaying estrus during the specified breeding period. A *P*-level of 0.05 was considered significant and a *P*-level of 0.05 to < 0.10 was considered a trend.

Results

Entry into breeding groups

Contained in Table 1 are the percentages of gilts in each group that initially displayed estrus during the specific breeding periods and were mated. Body weights of these subsets of gilts are also shown. Among groups, there was a tendency ($P = 0.08$) for more HA than control gilts to display estrus and be mated on schedule. For gilts within Group A, more ($P < 0.01$) HA than control females displayed estrus and were mated.

Table 1. Characteristics of hormone assisted (HA) and control gilts, treatments employed for entry of females into breeding groups[1] and proportion of gilts displaying estrus and mated during the specific breeding period of the batch farrowing system.

Group	Treatment	n	Classification	Estrus and Mated, %	Body Weight[4], kg
A	HA[2]	9	Pubertal	100.0[a]	154.2 ± 2.8
	Control	9	Pubertal	33.3[b]	144.1 ± 4.3
B	HA[2]	10	Pubertal	90.0	157.1 ± 2.9
	Control	4	Pubertal	75.0	144.1 ± 1.3
D	HA[3]	10	Prepubertal	50.0	134.5 ± 3.2
	Control	10	Prepubertal	70.0	130.3 ± 2.7
Total	HA	29	---	79.3[c]	151.1 ± 2.5
	Control	23	----	56.5[d]	136.9 ± 2.8

[1]Day of entry = first day of hormone therapy within each group.
[2]Gilts received Matrix orally at a dose of 15 mg/d for 14 d.
[3]Gilts received 5 mL P.G. 600 i.m.
[4]Body weight at mating, mean ± SE.
[a,b]Within group A, values differ ($P < 0.01$).
[c,d]Within total, values tend to differ ($P = 0.08$).

Hormone-assisted gilts in groups A and B were treated with Matrix (15 mg/d for 14 d) and across groups, 94.7% (18/19) of treated females showed estrus during the specified breeding periods. For these gilts, the interval between Matrix withdrawal from the feed and estrus was 6.3 ± 0.2 d. Hormone-assisted gilts in Group D received P.G. 600, and 50% of these gilts displayed estrus and were mated during the breeding period with a treatment to estrus interval of 7.2 ± 1.2 d (data not shown).

As mentioned previously, gilts entering the breeding herd but failing to breed during specific weeks of the batch farrowing system were mated and introduced into subsequent groups. For all gilts, there was an effect of entry group x treatment ($P = 0.02$) on the entry-to-first service interval (Figure 1). For Group A, control gilts had a greater ($P < 0.01$) interval than HA gilts. The entry-to-first service intervals, however, were similar ($P = 0.99$) for HA and control gilts in Groups B and D. Body weight at first service was affected ($P < 0.01$) by Group (159.3 ± 3.4, 154.7 ± 4.3, and 136.7 ± 3.2 kg, for Groups A, B, and D, respectively) but not treatment ($P = 0.64$) or group x treatment ($P = 0.12$).

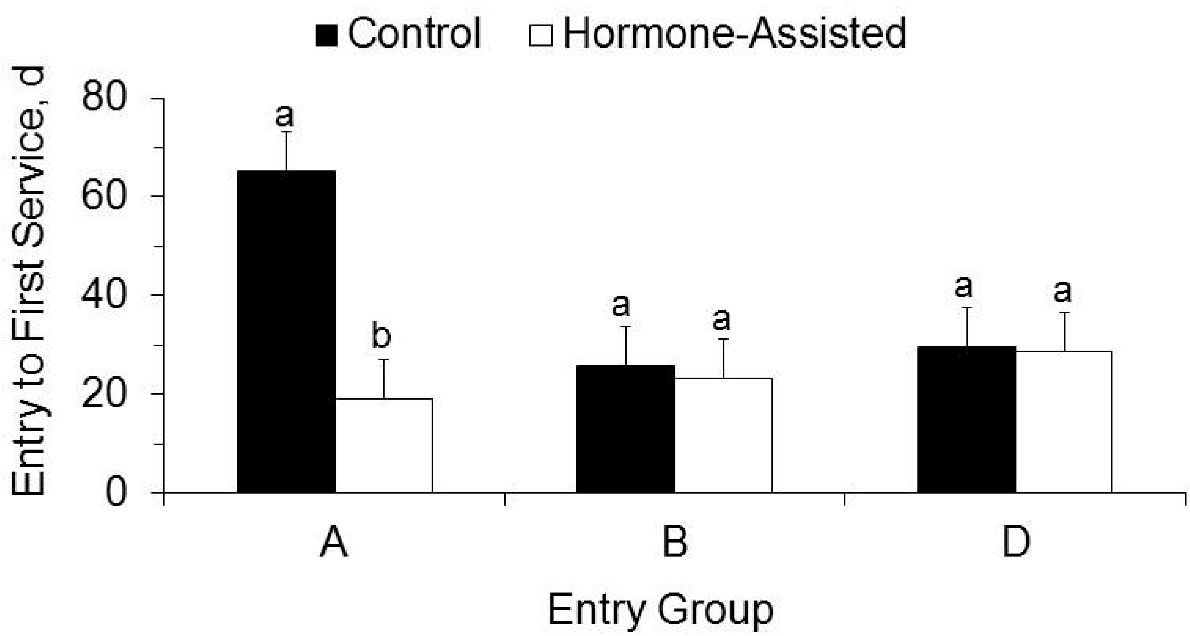

Figure 1. Entry to first service interval for control and Hormone-assisted (HA) gilts. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.01$) of group x treatment and within groups, means without a common superscript differ ($P < 0.01$).

Reproductive Performance for individual parities

Effects or tendencies for effects of entry group were detected for total born (*P* < 0.01), born live (*P* = 0.02), pigs weaned (*P* < 0.01), litter birth weight (*P* = 0.03), pig birth weight (*P* = 0.06), and pig weaning weight during parity 1; and pigs born dead (*P* = 0.08) and pigs weaned (*P* = 0.09) for parity 3. Although effects or tendencies for effects of group x treatment existed for total born (*P* = 0.06), pig birth weight (*P* < 0.01), litter weaning weight (*P* = 0.03), and pig weaning weight (*P* = 0.05) during parity 1, for each item, there was no effect of treatment (HA or control) within groups. Thus, main effects of treatment on reproductive data for females farrowing one, two and(or) three litters are shown in Table 2.

For parity 1, control females weaned more pigs (*P* = 0.02) resulting in a greater litter weaning weight (*P* < 0.01), and had a greater weaning to estrus interval (*P* = 0.05), than HA females. Pig birth weight tended to be greater (*P* = 0.06) for HA- compared with control sows. For all other items within parities there were no effects of treatment (*P* > 0.1; Table 2).

Total Reproductive Performance

There were no effects of entry group (*P* = 0.69), treatment (*P* = 0.23) or entry group x treatment (*P* = 0.13) for NPD. Overall NPD were 104.3 $\pm$ 16.5 d for HA gilts and 135.7 $\pm$ 20.1 d for controls. There was a tendency (*P* = 0.07) for an effect of treatment on the number of parities completed (2.5 $\pm$ 0.2 for HA gilts and 2.0 $\pm$ 0.2 for controls) but no effects of Group (*P* = 0.63) or group x treatment (*P* = 0.10).

Total reproductive performance in HA and control females is contained in Table 3. There were effects of treatment on total pigs born (*P* = 0.02) and total pigs born alive (*P* = 0.03), but not on total pigs weaned (*P* = 0.17). Total pigs born tended (*P* = 0.07) to differ by group. There was no effect, however, of group on pigs born alive (*P* = 0.15) or pigs weaned (*P* = 0.67).

Table 2. Reproductive performance over 3 parities for hormone assisted (HA) and control sows in Groups A, B, and D. Values are presented as LSMeans ± SE.

	Treatment		
Item	HA	Control	*P*-value
Number of gilts entering groups	29	23	---
Parity 1			
Gilts entering that farrowed, % (no.)	89.7 (26)	91.3 (21)	0.84
Total born	11.6 ± 0.6	11.2 ± 0.7	0.66
Born alive	10.3 ± 0.5	10.4 ± 0.7	0.92
Born dead	1.0 ± 0.2	0.7 ± 0.3	0.51
Mummified fetuses	0.3 ± 0.1	0.1 ± 0.2	0.24
Pigs weaned	8.8 ± 0.3	10.1 ± 0.4	0.02
Weaning to estrus interval	4.6 ± 3.8	18.4 ± 5.5	0.05
Body weights, kg			
Birth- litter	17.3 ± 0.7	16.3 ± 0.9	0.37
Birth- pig	1.60 ± 0.04	1.48 ± 0.05	0.06
Weaning- litter	53.2 ± 3.5	67.9 ± 3.6	<0.01
Weaning- pig	7.0 ± 0.3	6.6 ± 0.3	0.32
Parity 2			
Gilts entering that farrowed, % (no.)	86.2 (25)	69.6 (16)	0.14
Total born	11.0 ± 0.7	9.6 ± 1.0	0.29
Born alive	10.5 ± 0.5	9.0 ± 0.9	0.21
Born dead	0.4 ± 0.2	0.3 ± 0.3	0.86
Mummified fetuses	0.1 ± 0.1	0.2 ± 0.1	0.47
Pigs weaned	9.0 ± 0.3	9.2 ± 0.4	0.77
Weaning to estrus interval	6.7 ± 1.4	5.5 ± 2.0	0.64
Body weights, kg			
Birth- litter	18.1 ± 1.0	15.6 ± 1.5	0.17
Birth- pig	1.88 ± 0.05	1.74 ± 0.08	0.77
Weaning- litter	72.9 ± 2.95	66.6 ± 4.3	0.24
Weaning- pig	7.86 ± 0.25	7.25 ± 0.36	0.18
Parity 3			
Gilts entering that farrowed, % (no.)	75.9 (22)	52.2 (12)	0.07
Total born	10.9 ± 0.9	9.9 ± 1.3	0.51
Born alive	9.8 ± 0.5	9.0 ± 1.2	0.57
Born dead	1.1 ± 0.2	0.9 ± 0.3	0.62
Mummified fetuses	0	0	---
Pigs weaned	8.1 ± 0.4	8.3 ± 0.6	0.77
Body weights, kg			
Birth- litter	18.3 ± 1.1	15.8 ± 1.7	0.23
Birth- pig	1.78 ± 0.07	1.76 ± 0.01	0.90
Weaning- litter	72.9 ± 3.0	66.6 ± 4.3	0.24
Weaning- pig	7.9 ± 0.3	7.3 ± 0.4	0.18

Table 3. Total reproductive performance for hormone assisted (HA) and control sows in Groups A, B, and D[1] completing zero, one, two, and(or) three parities. Values are LSMeans ± SE.

Item	HA	Control	*P*-value
Number	29	23	---
Total pigs born	28.8 ± 2.2	20.4 ± 2.6	0.02
Total pigs born alive	26.3 ± 2.0	19.0 ± 2.5	0.03
Total pigs weaned	21.7 ± 1.8	17.8 ± 2.2	0.17

[1]Group A had 9 HA and 9 Control pigs; Group B had 10 HA and 4 Control pigs; Group D had 10 HA and 10 Control pigs.

Although there were effects of entry group x treatment on total pigs born ($P = 0.02$) and pigs born alive ($P = 0.03$), and a tendency ($P = 0.08$) for an effect of group x treatment on pigs weaned, for each item, within groups there were no significant effects of treatment.

Discussion

Batch farrowing systems allow more stringent all-in/all-out animal flow and better disease control, and large groups of same age pigs are weaned. The major challenge with batch farrowing systems, however, is keeping sows within a group on the desired schedule. In a 5-week batch farrowing system, sows not returning to estrus in 4 to 5 days after weaning, and replacement gilts entering the herd, may become difficult to manage if not bred in a specific "window" because another group of sows and gilts will not be mated for 5 weeks.

In the current study, there was a tendency for more HA gilts entering the herd to display estrus and be mated during the scheduled breeding period than control gilts. Hormone-assisted gilts in groups A and B were randomly cycling prior to entry into the breeding herd, and estrus was effectively synchronized when Matrix was fed at a rate of 15 mg/day for 14 d, with nearly

95% of treated females showing estrus at an average of approximately 6 days after withdrawal from the feed. These findings are in accordance with previous work (Webel and Day, 1982; Day, 1984; Gordon, 1997). To summarize a number of earlier studies, daily feeding of altrenogest (12.5 to 15 mg/d) for 14 to 18 d synchronized estrus in approximately 90 percent of treated gilts. The onset of estrus after withdrawal of altrenogest was reported as four to ten d with most gilts beginning estrus in five to seven d. In our laboratory, gilts that had displayed at least two normal estrous cycles of 18 to 22 d were given a daily ration containing 15 mg altrenogest for 18 days and following withdrawal, 90.6% of the gilts displayed estrus in less than seven d with an average withdrawal-to-estrus interval of 5.3 d (Estienne et al., 2001).

In contrast, HA gilts in Group D were classified as prepubertal prior to entry into the breeding herd and these females were treated with P.G. 600. Only about 50% of treated HA gilts in Group D displayed estrus and were mated during the scheduled period, a percentage not different from control gilts not treated with P.G. 600. In previous work in our laboratory, Garcia et al. (2004) treated gilts that were 180 days of age with P.G. 600, and within 7 days, 83% of the treated animals displayed estrus; Of the 35 gilts responding, 97.1% subsequently displayed a second estrus, and 94.3% a third estrus at approximately 21-day intervals. Although P.G. 600 has been shown to advance the onset of puberty by stimulating follicular growth, estrus and ovulation in gilts (Carabă et al., 2014), there exists a great deal of variability in efficacy amongst commercial farms. Indeed, Britt et al. (1989) reported overall response rates to P.G. 600 (defined as displaying estrus by 7 or 28 d post-injection) on ten commercial farms in North Carolina, Illinois, and Missouri, of approximately 55% and 73%, respectively. Moreover, among farms, the percentage of P.G. 600-treated gilts in estrus within 28 d ranged from 42 to 97%.

For the current study, ages of gilts in Group D were not available, but gilts were assumed to be prepubertal based on body weight. Group D had an overall lighter body weight at first estrus than Groups A and B. Perhaps some of the gilts were too young to be responsive to the P.G. 600 treatment. Ovaries in immature gilts are not responsive to exogenous hormones until 120 to 180 days of age (Breen et al., 2005; Carabă et al., 2014). On the other hand, if some of the treated gilts had previously begun estrous cycles, then the P.G. 600 would be ineffectual or could actually cause an extended luteal phase of the estrous cycle. Estienne and Crawford (2015) demonstrated that, in approximately 33% of gilts, injection of P.G. 600 at day 12 of the estrous cycle caused follicular growth and ovulation, with the corpora lutea formed mid-cycle functioning for a normal period of 15 to 16 d, resulting in an inter-estrus interval of approximately 33 d. Finally, the lack of a treatment effect could be due to the fact that control gilts, like P.G. 600-treated gilts were exposed to boars daily which due to the "boar effect" (Prunier and Meunier-Salaün, 1989) may have caused them to reach puberty at a time similar to HA gilts.

For the study reported herein, gilts failing to breed during specific weeks of the batch farrowing system could be mated and introduced into subsequent groups. Use of an exogenous hormone (Matrix) decreased the entry-to-first service interval in Group A, but the interval was similar between treatments in Groups B and D. As discussed above, our finding that P.G. 600 failed to increase the number of gilts in Groups D displaying puberty during the desired time contrasts with previous studies such as Knox et al. (2000) and Carabă et al. (2014), both who found that P.G. 600 was effective at inducing estrus and ovulation in gilts.

Once entered into the breeding herd reproductive performance displayed by gilts completing one, two or three parities was in general, similar between the HA and control gilts with a few exceptions. Hormone-assisted sows were treated with P.G. 600 at weaning, and after parity one, but not parity two, they displayed a more rapid return to estrus compared to control sows not treated with P.G. 600. This supports findings in previous studies (Knox et al., 2001; Košorok and Kastelic, 2011). In an experiment conducted in our laboratory (Estienne and Hartsock, 1998), multiparous sows received an i.m. injection of P.G. 600 or vehicle at weaning. The weaning-to-estrus interval (3.8 vs. 4.5 d) and the percentage of sows that did not display estrus in seven or fewer days after weaning (2.9% vs. 17.1% percent) were significantly less in P.G. 600-treated sows compared with controls. In a trial conducted on eight commercial farms, Bates et al. (1991) demonstrated that administration of P.G. 600 decreased days to estrus in first and second litter sows and lowered the percentage of first litter sows not exhibiting estrus within 10 days after weaning.

Hormone-assisted, parity one sows weaned fewer pigs with a lighter litter weaning weight than did control sows. A biological explanation for these findings is not readily apparent because the number of pigs born alive was similar between groups and pig body weight at birth tended to be greater for HA females. In this study, most sows completed parity one during the warmer months, when increased ambient temperature increases the nutritional demands on gilts, causing fewer nutrients to be allocated to the growing fetuses and suckling pigs. Perhaps HA gilts were more sensitive to these metabolic perturbations than control females. Chansombloom et al. (2009) pointed out that primiparous sows tend to lack the protein and fat reserves that older sows have which could explain why this phenomenon was not observed for parity two and three sows.

Although not statistically different, the total number of NPD was approximately 31 days less for HA compared to control sows. Moreover, there was a tendency for HA sows to complete more parities than control sows. We suggest that contributing to these results was the fact that estruses in HA sows were better synchronized within the 5-week batch farrowing system employed during this study. In a commercial setting, this is imperative to maintaining profits, since it has been reported that a producer will not see returns on their replacement gilt cost until after females have farrowed at least three times (Dyhuvetter, 2000).

Martel et al. (2008) demonstrated that a 4-week batch farrowing system would have a greater culling rate and a lower average parity at culling than a weekly farrowing system. Our results suggest that these negative effects may be mitigated by use of commercially available hormones. Mote et al. (2009) reported that increasing the average parity of removal for breeding females by 10% could increase revenue per weaned pig in breed-to-wean and farrow-to-finish operations enough to increase profits in the U.S. hog industry by up to $15 million.

Overall, the total number of pigs born and the number of pigs born live favored a batch farrowing system employing commercially available hormones compared to a system not using these products. The mechanisms responsible for these effects warrant further scrutiny. Previous studies (Estienne et al., 2001; Pope, 1994; Polge and Dzuik, 1965) showed that, although ovulation rate was increased in gilts given P.G. 600, this was not coupled with an increase in litter size, likely due to an increased proportion of primary oocytes being ovulated and penetrated by spermatozoa, but not activated.

Conclusion

According to the results of this and previous studies, it was concluded that the use of Matrix and P.G. 600 to synchronize estrus in a 5-week batch farrowing system had a positive impact on reproductive efficiency in the breeding herd. Use of hormones enhanced entry of gilts into the breeding herd. The wean-to-estrus interval was less in first parity HA sows, which could, in a commercial setting, contribute to fewer NPD and lower costs to producers. Exogenous hormone use also increased the number of parities completed per treated sow. More research needs to be done on the impact of exogenous hormones on pigs produced and how it improves in batch farrowing systems.

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Appendix Tables

	Group				Treatment			Group x Trt
Item	**A**	**B**	**D**	**P-value**	**HA**	**Control**	**P-value**	**P-value**
EFS (d)	42.2 ± 6.1	24.4 ± 7.7	29.2 ± 5.8	0.16	40.2 ± 5.9[f]	23.7 ± 4.8[g]	< 0.05	0.02
BWFS(kg)	159.94 ± 3.39[a]	154.36 ± 4.27[a]	136.37 ± 3.23[b]	< 0.01	150.88 ± 4.80	148.89 ± 4.80	0.64	0.12
NPD(d)	127.44 ± 20.93	129.73 ± 26.27	103.70 ± 19.86	0.63	103.27 ± 16.51	137.31 ± 20.10	0.20	0.13
PC	2.44 ± 0.24	2.15 ± 0.31	2.15 ± 0.23	0.63	2.53 ± 0.19	1.97 ± 0.23	0.07	0.10
TB	29.11 ± 2.73	24.55 ± 3.42	20.20 ± 2.59	0.07	28.80 ± 2.15[f]	20.44 ± 2.62[g]	< 0.05	0.02
TBA	26.06 ± 2.56	22.73 ± 3.22	19.05 ± 2.43	0.15	26.25 ± 2.02[f]	18.97 ± 2.46[g]	< 0.05	0.03
TPW	19.72 ± 2.25	21.35 ± 2.83	18.20 ± 2.14	0.67	21.73 ± 1.78	17.79 ± 2.16	0.17	0.08

[1]These figures were based on 52 gilts/sows. Group A had 9 HA and 9 Control pigs; Group B had 10 HA and 4 Control pigs; Group D had 10 HA and 10 Control pigs.

[a, b] Within a row for Group or Treatment, means without a common superscript differ ($P < 0.01$).

[f, g] Within a row for Group or Treatment, means without a common superscript differ ($P < 0.05$).

A1. Table of entry and overall reproductive performance data, showing the effects of entry group, treatment, and group x treatment on performance parameters for gilts/sows from groups A, B, and D[1] for females that completed zero, one, two, and (or) three parities. Values are LSMeans ± SE with corresponding p-values.

	Group				Group x Treatment
Item	**A**	**B**	**D**	**P-value**	**P-value**
GL (days)	114.98 ± 0.52	114.12 ± 0.70	114.36 ± 0.52	0.55	0.71
TB	12.70 ± 0.70[a]	12.12 ± 0.94[a]	9.25 ± 0.71[b]	< 0.01	0.06
TBA	11.03 ± 0.67[f]	11.35 ± 0.91[f]	8.59 ± 0.68[g]	< 0.02	0.25
SP	1.39 ± 0.29	0.52 ± 0.40	0.61 ± 0.30	0.11	0.39
MP	0.28 ± 0.15	0.25 ± 0.21	0.05 ± 0.16	0.54	0.46
LBW (kg)	17.96 ± 0.90[x]	17.71 ± 1.22[x]	14.62 ± 0.91[y]	< 0.05	0.64
PBW (kg)	1.55 ± 0.05	1.51 ± 0.06	1.64 ± 0.05	0.06	< 0.01
LL (days)	23.44 ± 0.89	23.98 ± 1.21	23.56 ± 0.90	0.62	0.06
TPW	9.44 ± 0.41[x]	10.88 ± 0.55[y]	7.94 ± 0.41[z]	< 0.05	0.95
LI (kg)	116.99 ± 8.90	118.14 ± 12.07	107.61 ± 9.03	0.70	0.31
ADFI (kg)	4.76 ± 0.30	4.87 ± 0.40	4.70 ± 0.30	0.94	0.87
LWW (kg)	55.74 ± 5.00	67.93 ± 4.51	57.89 ± 3.37	0.14	0.03
PWW (kg)	6.70 ± 0.35	6.22 ± 0.39	7.36 ± 0.29	0.06	0.051
WEI(days)	17.19 ± 4.74	5.10 ± 7.34	12.23 ± 4.90	0.38	0.43

[1]These figures were based on 47 sows. Group A had 9 HA and 8 Control sows; Group B had 10 HA and 3 Control sows; Group D had 7 HA and 10 Control sows.
[a,b,c] Within a row for Group, means without a common superscript differ ($P < 0.01$).
[f,g] Within a row for Group, means without a common superscript differ ($P < 0.02$).
[x,y,z] Within a row for Group, means without a common superscript differ ($P < 0.05$).

A2. Table of performance data for sows from Groups A, B, and D[1] completing their 1st parity. Effects of group and group x treatment interactions are recorded. Values are LSMeans ± SE with corresponding p-values.

	Group				Group x Treatment
Item	**A**	**B**	**D**	**P-value**	**P-value**
GL (days)	115.91 ± 0.45	115.20 ± 0.67	116.36 ± 0.46	0.37	0.18
TB	11.36 ± 0.91	9.75 ± 1.36	9.71 ± 0.94	0.40	0.28
TBA	10.62 ± 0.82	9.35 ± 1.23	9.21 ± 0.85	0.46	0.21
SP	0.68 ± 0.23	0.05 ± 0.35	0.36 ± 0.24	0.31	0.51
MP	0.06 ± 0.11	0.35 ± 0.16	0.07 ± 0.11	0.28	0.48
LBW (kg)	18.03 ± 1.31	16.19 ± 1.95	16.44 ± 1.35	0.62	0.45
PBW (kg)	1.71 ± 0.07	1.82 ± 0.11	1.73 ± 0.07	0.69	0.11
LL (days)	21.79 ± 1.07	22.50 ± 1.53	22.64 ± 1.06	0.84	0.76
TPW	8.13 ± 0.59	9.75 ± 0.84	9.50 ± 0.58	0.17	0.83
LI (kg)	138.18 ± 9.20	145.63 ± 13.19	144.14 ± 9.11	0.86	0.29
ADFI (kg)	6.10 ± 0.23	6.49 ± 0.33	6.25 ± 0.23	0.63	< 0.02
LWW (kg)	67.29 ± 3.97	68.31 ± 5.53	75.57 ± 3.81	0.50	0.57
PWW (kg)	7.83 ± 0.34	7.03 ± 0.47	7.81 ± 0.33	0.33	0.74
WEI(days)	6.38 ± 1.83	7.15 ± 2.63	4.79 ± 1.81	0.72	0.70

[1] These figures were based on 41 sows. Group A had 8 HA and 7 Control sows; Group B had 10 HA and 2 Control sows; Group D had 7 HA and 7 Control sows.

A3. Table of performance data for sows from Groups A, B, and D[1] completing their 2nd parity. Effects of group and group x treatment interactions are recorded. Values are LSMeans ± SE with corresponding p-values.

	Group				Group x Treatment
Item	A	B	D	P-value	P-value
GL (days)	115.13 ± 0.51	114.81 ± 0.66	116.42 ± 0.48	0.10	< 0.05
TB	10.75 ± 1.22	11.44 ± 1.58	8.92 ± 1.15	0.37	0.37
TBA	9.50 ± 1.13	10.13 ± 1.46	8.58 ± 1.06	0.67	0.53
SP	1.25 ± 0.33	1.31 ± 0.42	0.33 ± 0.31	0.08	0.38
MP[2]	-	-	-	-	-
LBW (kg)	17.99 ± 1.43	16.98 ± 2.05	16.11 ± 1.50	0.70	0.90
PBW (kg)	1.76 ± 0.10	1.66 ± 0.14	1.90 ± 0.10	0.32	0.10
LL (days)	23.56 ± 0.62	23.38 ± 0.80	22.42 ± 0.58	0.37	< 0.01
TPW	7.31 ± 0.57	9.44 ± 0.74	7.83 ± 0.54	0.09	0.39
LI (kg)	143.90 ± 9.42	150.49 ± 12.17	133.13 ± 8.89	0.48	0.33
ADFI (kg)	6.09 ± 0.35	6.42 ± 0.46	5.92 ± 0.33	0.68	0.39
LWW (kg)	56.62 ± 4.09	65.33 ± 5.28	63.44 ± 3.85	0.35	0.92
PWW (kg)	7.86 ± 0.40	7.02 ± 0.52	8.37 ± 0.38	0.13	0.25

[1] These figures were based on 34 sows. Group A had 8 HA and 4 Control sows; Group B had 8 HA and 2 Control sows; Group D had 6 HA and 6 Control sows.

A4. Table of performance data for sows from Groups A, B, and D[1] completing their 3rd parity. Effects of group and group x treatment interactions are recorded. Values are LSMeans ± SE with corresponding p-values.

Appendix Figures

<table>
<tr><th rowspan="2">Sow Group #</th><th colspan="20">Week Number</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>1</td><td>W</td><td>B</td><td colspan="15">G</td><td>F</td><td colspan="2">L</td></tr>
<tr><td>2</td><td>L</td><td>W</td><td>B</td><td colspan="15">G</td><td>F</td><td>L</td></tr>
<tr><td>3</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="15">G</td><td>F</td></tr>
<tr><td>4</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="15">G</td></tr>
<tr><td>5</td><td>G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="14">G</td></tr>
<tr><td>6</td><td colspan="2">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="13">G</td></tr>
<tr><td>7</td><td colspan="3">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="12">G</td></tr>
<tr><td>8</td><td colspan="4">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="11">G</td></tr>
<tr><td>9</td><td colspan="5">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="10">G</td></tr>
<tr><td>10</td><td colspan="6">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="9">G</td></tr>
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<tr><td>12</td><td colspan="8">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="7">G</td></tr>
<tr><td>13</td><td colspan="9">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="6">G</td></tr>
<tr><td>14</td><td colspan="10">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="5">G</td></tr>
<tr><td>15</td><td colspan="11">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="4">G</td></tr>
<tr><td>16</td><td colspan="12">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="3">G</td></tr>
<tr><td>17</td><td colspan="13">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="2">G</td></tr>
<tr><td>18</td><td colspan="14">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td>G</td></tr>
<tr><td>19</td><td colspan="15">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td></tr>
<tr><td>20</td><td>B</td><td colspan="15">G</td><td>F</td><td colspan="2">L</td><td>W</td></tr>
</table>

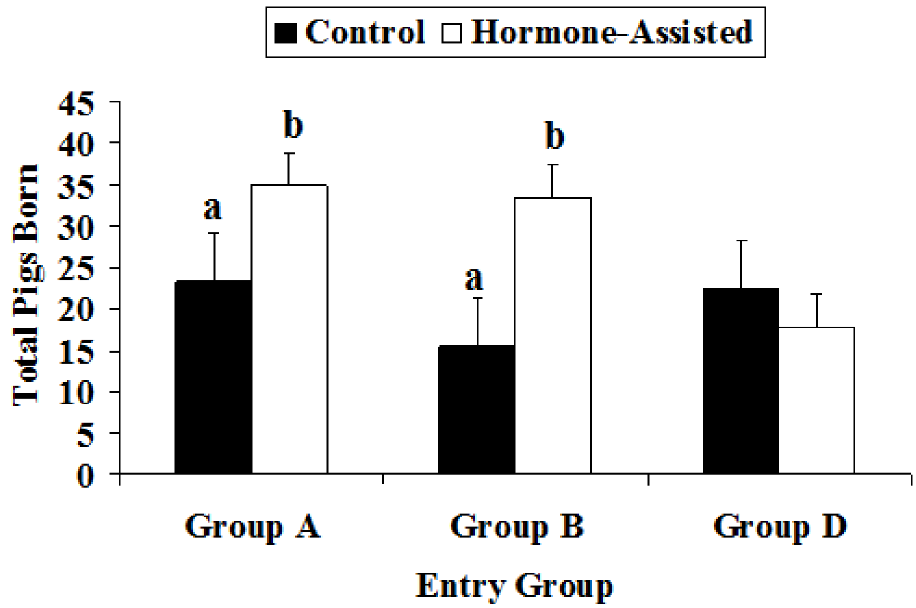
Legend:
W: Weaning B: Breeding L: Lactation G: Gestation

A1. Schematic of a continuous (weekly) farrowing system with a 3-week lactation period (20-week sow cycle).

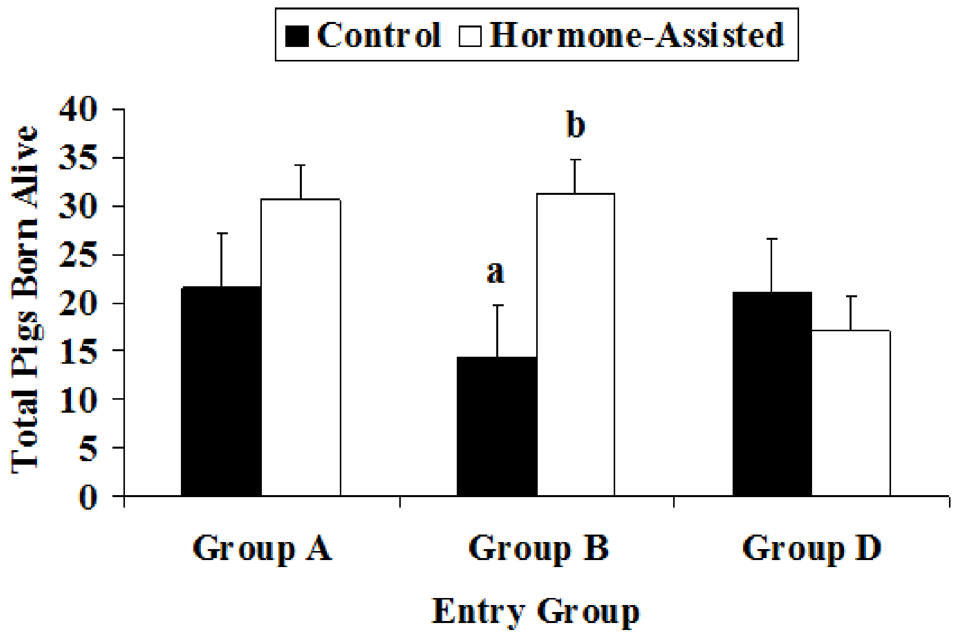
<table>
<tr><th rowspan="2">Sow Group #</th><th colspan="20">Week Number</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>1</td><td>W</td><td>B</td><td colspan="15">G</td><td>F</td><td colspan="2">L</td></tr>
<tr><td>2</td><td colspan="2">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="13">G</td></tr>
<tr><td>3</td><td colspan="7">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="8">G</td></tr>
<tr><td>4</td><td colspan="12">G</td><td>F</td><td colspan="2">L</td><td>W</td><td>B</td><td colspan="3">G</td></tr>
</table>

Legend:
W: Weaning B: Breeding L: Lactation G: Gestation

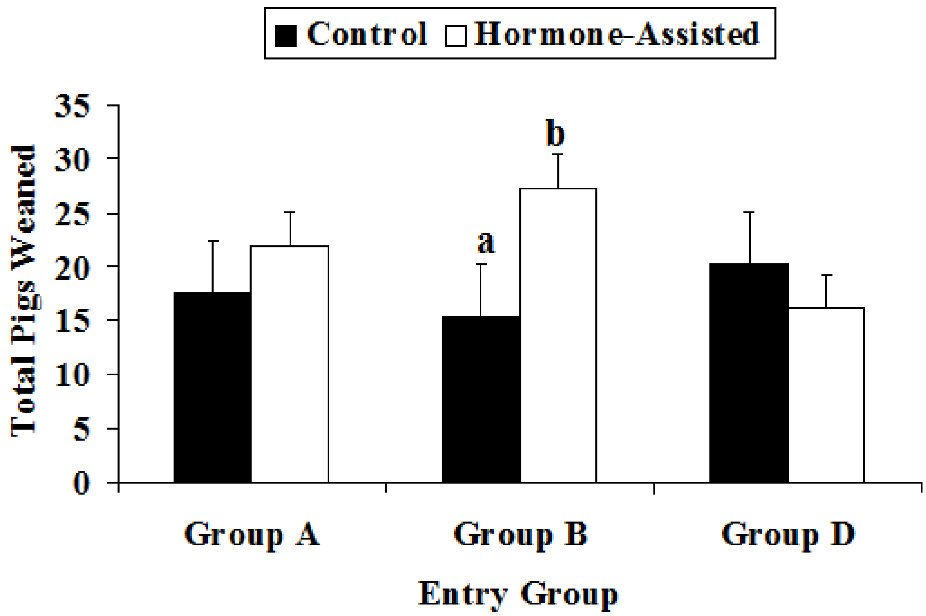
A2. Schematic of a 5-week batch farrowing system with a 3-week lactation period (20-week sow cycle).



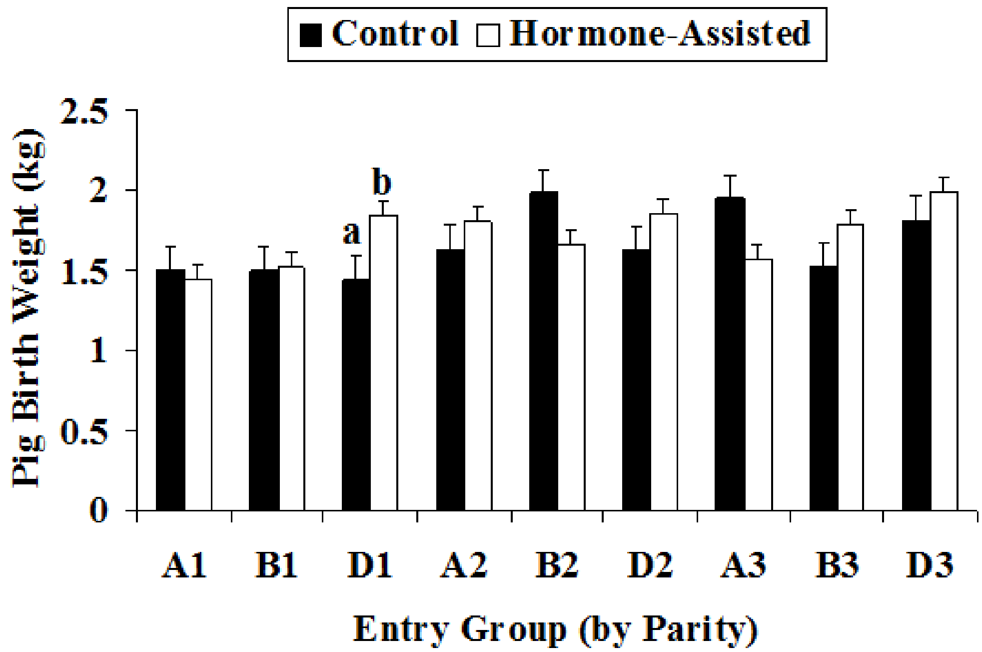
A3. Total Pigs Born for control and Hormone-assisted (HA) gilts. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.05$) of group x treatment and within groups, means without a common superscript differ ($P < 0.05$).



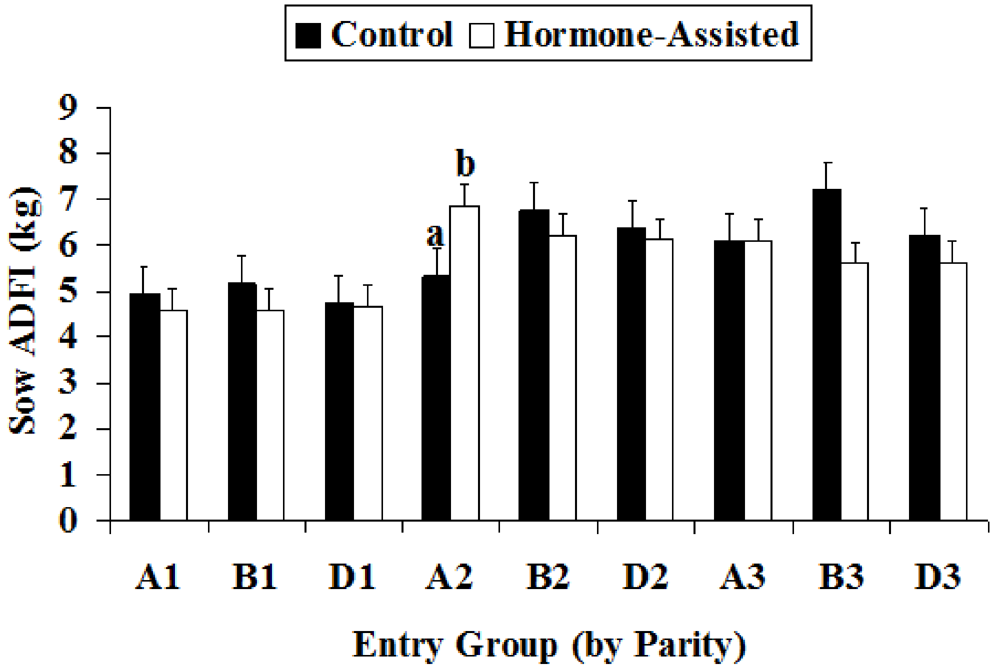
A4. Total Pigs Born Alive for control and Hormone-assisted (HA) gilts. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.05$) of group x treatment and within groups, means without a common superscript differ ($P < 0.05$).



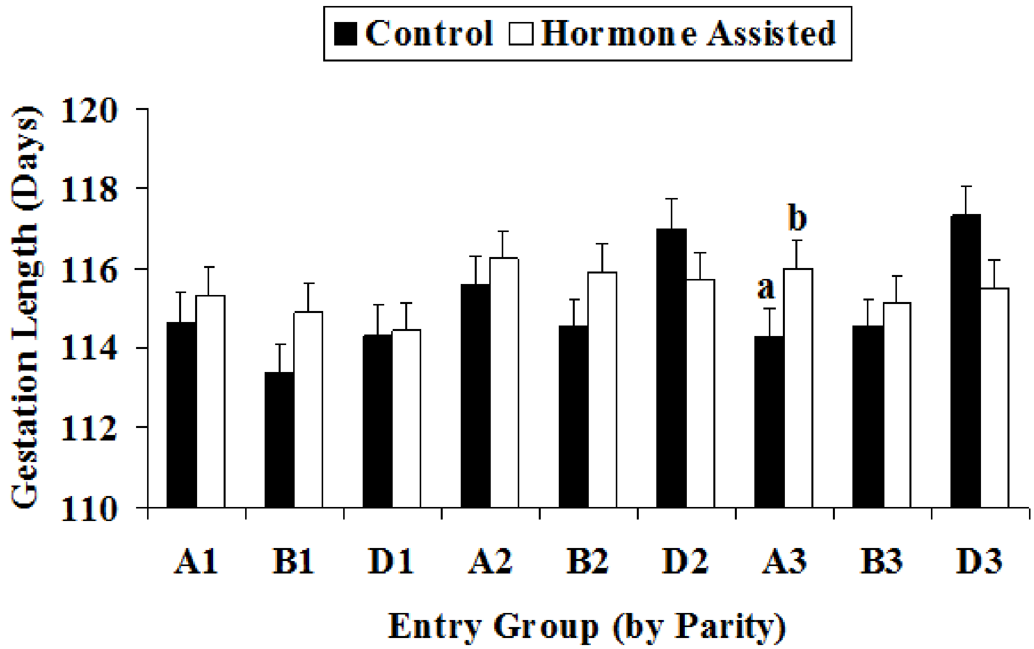
A5. Total Pigs Weaned for control and Hormone-assisted (HA) gilts. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.05$) of group x treatment and within groups, means without a common superscript differ ($P < 0.05$).



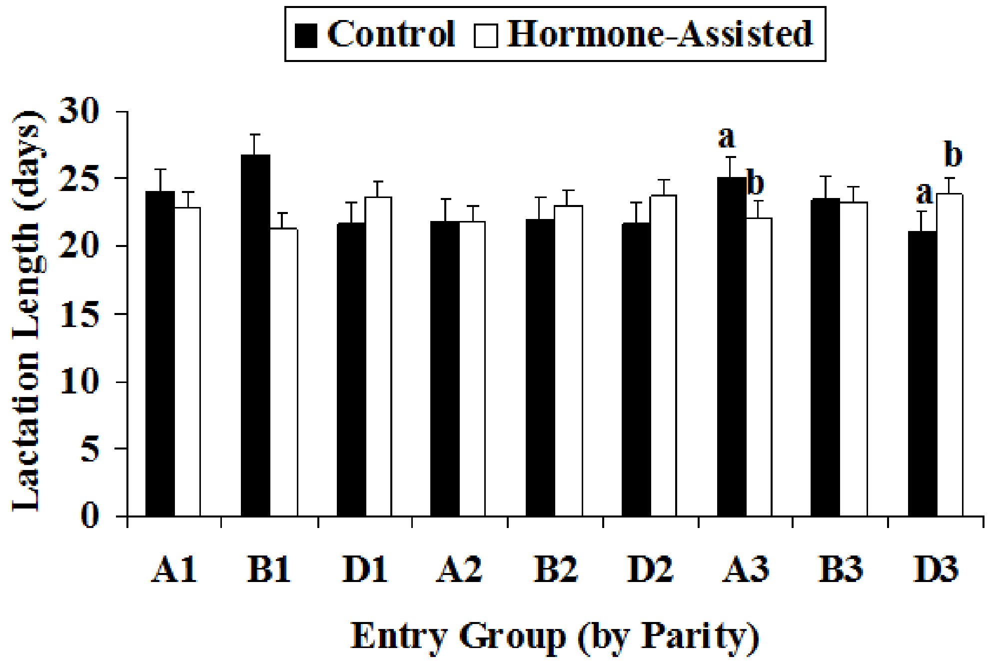
A6. Pig birth weight for control and Hormone-assisted (HA) gilts for parities 1, 2, and 3. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.01$) of group x treatment and within groups, means without a common superscript differ ($P < 0.01$).



A7. Sow ADFI for control and Hormone-assisted (HA) gilts for parities 1, 2, and 3. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.02$) of group x treatment and within groups, means without a common superscript differ ($P < 0.02$).



A8. Gestation length for control and Hormone-assisted (HA) gilts for parities 1, 2, and 3. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.05$) of group x treatment and within groups, means without a common superscript differ ($P < 0.05$).



A9. Lactation length for control and Hormone-assisted (HA) gilts for parities 1, 2, and 3. The HA gilts in Groups A and B were treated (15 mg/d for 14 d) with Matrix (Merck Animal Health; De Sota, KS) and HA gilts in Group D were treated with P.G. 600 (Merck Animal Health). Data are represented as least square means ± SE. There was an effect ($P < 0.01$) of group x treatment and within groups, means without a common superscript differ ($P < 0.01$).