DISSERTATION

FACTORS THAT IMPACT PROBABILITY OF PREGNANCY WHEN USING AI BOARS

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ABSTRACT

FACTORS THAT IMPACT PROBABILITY OF PREGNANCY WHEN USING AI BOARS

Measurements collected during a period of 3.5 years at Tempel Genetics Inc. in Gentryville, IN were analyzed to evaluate the effects of genetic and environmental factors on pregnancy rate using data from 15,375 parity records of two breeds (Landrace and Yorkshire). Female records utilized in the current study ranged from maiden gilts to mature sows through parity 7. All matings were performed via artificial insemination by semen produced within a boar housing facility also operated by Tempel Genetics. Semen was collected, processed, and evaluated on the farm and was not frozen. Pregnancy rate (measured as probability of pregnancy at 21 days post breeding via ultra-sound) of the females was significantly affected by number of services ($P<0.05$), season of insemination ($P<0.05$) and parity category ($P<0.05$). Interactions of (season by number of services and parity by number of services) were also evaluated. Boar age ($P<0.05$) and days from collection to insemination ($P<0.05$) were also significant sources of variation for pregnancy rate, while breed did not significantly affect pregnancy rate. The highest pregnancy rate (94.29%) was observed in sows of the parity category 3-4 that were inseminated with three services and using semen from boars less than 5 years of age. Potential opportunities to optimize these three factors should be evaluated by producers who expect to attain maximum pregnancy rate of sows inseminated using fresh boar semen.

A model was also developed in Microsoft Excel format using results from the aforementioned analysis as a tool to assist swine producers in evaluating various

management options to enhance pregnancy rate. With the use of this model, smaller producers who do not have access to large amounts of internal data can evaluate the potential impact of implementing different management options evaluated within a typical commercial-based swine enterprise.

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I dedicate this manuscript to my wife Tara, and our daughters Landry and McKinley. Tara has been my “best friend” for the past 13 years. She has been a mother, a counselor, and a homemaker for our family. I am most thankful for the direction and values she has instilled in our children. Landry and McKinley are my blessings from God. They bring me much happiness, and I look forward to being involved in their bright futures.

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TABLE OF CONTENTS

ABSTRACT ii
ACKNOWLEDGEMENTS iv
TABLE OF CONTENTS v
LIST OF TABLES vii
LIST OF FIGURES viii
CHAPTER
I: INTRODUCTION 1

II: REVIEW OF LITERATURE 3
Mating Systems in the Swine Industry 3
AI in Swine 4
Boar Semen Volume 5
Sperm Motility 6
Sperm Morphology 7
Boar Semen Collection 8
Fresh Semen Dilution 9
Selection of Boars for Semen Value 10
Sow Implications 11
Seasonal Infertility in Sows 11

III: FACTORS THAT IMPACT PROBABILITY OF PREGNANCY WHEN USING AI BOARS 14
Introduction 14
Materials and Methods 15
Statistical Methods 16
Results and Discussion 19
Effect of Breed 19
Effect of Number of Services 20
Effect of Season 21
Effect of Parity Category 22
Effect of Boar Age 23

Effect of Days From Collection to Insemination 24
Conclusions……..25

IV: PREDICTING IMPACT OF MANAGEMENT PRACTICES TO MAXIMIZE PREGNANCY RATE 39
Introduction 39
Materials and Methods 39
Statistical Methods 40
Results and Discussion 40
Number of Insemination Services 41
Season of Mating 42
Parity Category 42
Boar Age 43
Days From Collection to Insemination 43
Conclusions……..44
References…… 50
APPENDIX A…… ....…61
APPENDIX B 67

LIST OF TABLES

Table 3.1 Potential Sources of variation evaluated for their relationship with pregnancy rate in swine 27

Table 3.2 Data description of final matings 28

Table 3.3 Results for tests of significance for factors included in the final model used to evaluate factors influencing pregnancy rate 29

Table 4.1 Logistic regression coefficients for factors related to probability of pregnancy 46

Table A.1 Least squares means for significant factors 62

Table A.2 Least squares means for interactions of number of services by season ... 63

Table A.3 Least squares means for number of services by parity 64

Table A.4 Correlation among collection metrics 65

Table A.5 Correlation between collection metrics and litter traits 66

Table B.1 Solutions for fixed effects in a model used to predict probability of pregnancy 68

LIST OF FIGURES

Figure 3.1 Effect of boar breed on pregnancy 30

Figure 3.2 Effect of female breed on pregnancy 31

Figure 3.3 Effect of number of services on pregnancy 32

Figure 3.4 Effect of season on pregnancy 33

Figure 3.5 Interaction of season by number of services 34

Figure 3.6 Effect of parity on pregnancy.. 35

Figure 3.7 Interaction of number of services by parity 36

Figure 3.8 Relationship of boar age and pregnancy... 37

Figure 3.9 Relationships of days from collection to insemination with probability of pregnancy……………………………………………………………………38

Figure 4.1 Success diagram when using best management practices...................... 47

Figure 4.2 Microsoft Excel pregnancy predictor model example 1 48

Figure 4.3 Microsoft Excel pregnancy predictor model example 2 .... ……………49

CHAPTER I

INTRODUCTION

The role of reproductive efficiency in economic success of livestock management systems is well documented. Likewise, the value of artificial insemination in increasing rate of genetic improvement is well established (Robinson, J. A. B., and Buhr, M. M. 2005). For the study described herein, data from over 49,000 semen collections and connected fertility records were utilized from Tempel Genetics over a period of 3.5 years. This data set included genetic, environmental and management records for sows that had been artificially inseminated with semen collected and evaluated on the farm. The Tempel Genetics multiplication system includes roughly 1,200 Yorkshire sows and 1,500 Landrace sows producing Yorkshire x Landrace F1 crossbreds for commercial use, and a nucleus population of approximately 200 Yorkshire sows and 200 Landrace sows for raising purebred replacements. This operation markets 200 boars, 1,350 gilts, 12,000 F1 crossbred gilts, and more than 20,000 doses of Yorkshire and Landrace semen on an annual basis (National Swine Registry. 2011). Tempel Genetics is an industry leader in purebred-based commercial production record implementations. This is accomplished through data partnerships with clientele, and allows for the continuous use of commercial production information to augment their genetic selection system.

The application of artificial insemination (AI) by the U.S. swine industry has dramatically increased over the past twenty years (Speight. 2010). Data has shown that pregnancy rate is a valid determinant of economic efficiency for commercial swine production units (Knox,1999). Factors that influence pregnancy rate include season

(Hurtgen and Leman, 1979), mode of insemination (Flowers and Alhusen, 1992), actual age of the boar (Kennedy and Wilkins, 1984), the number of times the female was inseminated (Dziuk, 1970; English et al., 1984), and how many parities the sow has birthed. The Tempel Genetics information management system allows evaluation of factors that can be used to maximize probability of pregnancy at 4 to 7days after weaning when using AI technology. Of course individual producers must consider their unique management and cost structure to determine which factors present practical opportunities to influence pregnancy rate, and ultimately, economic efficiency in their operation. The goal of this study is twofold: 1). To evaluate phenotypic and management sources of variation for pregnancy rate, and 2). Utilize this information to assist producers in developing management strategies that can be used to maximize pregnancy rate in systems that incorporate artificial insemination.

CHAPTER II

REVIEW OF LITERATURE

Mating Systems in the Swine Industry

The different mating systems utilized in swine production are pen mating, pasture mating, hand mating, AI, and embryo transplant. No matter which type is used, the economic driver to commercial swine producers is to optimize farrowing rates within their operations (Speight, 2010).

Hand mating occurs when one sow or gilt is mated with an individual boar. Producers observe that females are bred several times, increasing the probability that females are mated closer to ovulation during the estrus cycle (Soede et al., 1995. Speight, 2010).

AI is the most widely used method of those mentioned in the US. With AI practices, no boar is required on site, a technician breeds sows and gilts with semen collected from a boar on the farm or from an off-site private genetic supplier. Semen purchased from these off-site facilities allows for an introduction of new genetic material without the introduction of internal and external parasites while diminishing the opportunity of sexually transmitted diseases.

AI In Swine

The experimentation of artificial insemination began in Russia in the early 20th century by Ivanow (1907). These procedural techniques were established on farms in Russia in the 1930s, and investigations were also initiated in the US (Missouri) during this same time period (Foote, 2002). These methods continued to gain scientific recognition in its effectiveness and usefulness to the swine industry.

In the US, the adoption of AI technology has been on the rise for twenty years. Females bred using this technology has risen from approximately 7% of sows bred in 1990 (Burke, 2000) to approximately 90% in 2008 (Didion, 2008). Globally, 155 million doses of semen are used for AI in a single year (Weitze, 2000.)

Three components to successful AI is the quality of semen, the competence of staff in detecting estrus and insemination of the female (Holt et al., 1997). A biological factor and advantage to AI is the placement of semen that occurs more closely to ovulation during the estrus cycle. This also defines the importance of a technician that can effectively inseminate at the most opportune times of estrus.

There are a number of reasons to use AI, however the greatest is due to the economic advantage of being able to use superior sires that can be spread over a greater number of females thus in turn animal performance should be improved (Knox. 1999). There is also an opportunity to garner more profits because a producer can breed to a wider selection of boars with specific genetic performance records. Producers can use Expected Progeny Differences (EPD's), indexes, and breeding values in order to make rapid improvement to a specific group of females (Swine Genetics International. 2005).

Another advantage to commercial operations using AI is that less boar power is required for breeding thus decreasing feed and labor expenses (Key and McBride, 2007), as well as increasing overall reproductive efficiency (Flowers and Alhusen, 1992). Breeding sows by means of AI requires a reduced amount of time than the hand mating technique. As a result, there is a reduction in overall labor expenses (Flowers and Alhusen, 1992). Furthermore, when comparing AI to natural breeding, a boar should only be utilized 6 times per week in a natural mating situation due to fatigue of the boar. Whereas when boars are collected for AI purposes, 20-40 doses of semen per boar per week can be obtained (Hemsworth and Tillbrook, 2007).

Boar Semen Volume

Quantity of a single boar ejaculate can vary between 150 and 300 ml. This amount of ejaculate is subject to considerable variation. This variation can be a result of an individual boar's genetics, boar behavior such as libido, the management of the boar, along with the environment in which it is housed (Setchell, 1991).

Oliveras (2008) documented three prominent fractions in a boar ejaculate. The first is the pre-sperm rich fraction. This portion does not contain spermatozoa. It is translucent and has a volume of approximately 10-15 ml. The second portion of the fraction is the sperm-rich fraction. This part has the greatest number of spermatozoa and the volume of this fraction is between 70 ml to 100 ml and appears milky-white in color. Seminal doses are prepared from this sperm-rich fraction when collected from a boar. The final component is the post-sperm fraction which has a low concentration of spermatozoa. The volume of this fraction is about 150-200 ml and is pale white in appearance (Oliveras. 2008). These secretions have a gelatin-like thickness originating from the prostate and Cowper glands. The gel fraction is removed from this portion since it has no physiological importance in fertility. This all is a result from testicular and epididymal activity as well as secretions from accessory sexual glands within the boar (Fournier-Delpech, 1993; Oliveras. 2008).

Sperm Motility

Ejaculated sperm motility is an important condition of semen evaluation, and as time goes on it is decreased so it should be tested as soon as possible after ejaculation (Rozeboom, 2000). Most boar studs have a normal quality cutoff level of 70% or greater for use of semen for insemination. The motility is measured as the percentage of sperm that can normally move forward. A recent study suggests that farrowing rates and size of litter will decrease when semen motility is used at levels below 62.5% (Rozeboom, 2000).

Examination of sperm motility consists of defining the proportions of motile and non-motile spermatozoa (Bonet, et al., 2012). There are various ways these percentages can be determined. Visual assessment of motile sperm by light microscopy is the most widely used method (Rozeboom, 2000). However, technician proficiency impacts the precision of this procedure. Computer-assisted Semen Analysis (CASA) systems provide a higher level of precision when compared to traditional assessment of sperm parameters, thus dramatically decreasing the opportunity for error (WHO, 2000; Kvist and Bjorndahl, 2002; Oliveras, 2008).

Sperm Morphology

Sperm morphology is an effective tool in semen analysis. The effect of sperm morphology depends upon several factors like motility, sperm concentration per dose, age of semen in vivo and in vitro, the interval between insemination and ovulation, the occurrence of other sperm quality deficiencies, discrepancies between seasons, and overall care of sows (Weitze, 2012). In several studies, morphological characteristics of the sperm have been reported to effect fertility (Kruger et al., 1986). According to Hirai et al. (2001), sows inseminated with sperm with elongated heads had low return to estrus rates. Weitze (2000) also concluded that sperm morphology contributes to variation in litter size. A certain percentage of normal morphological spermatozoa are needed in an AI dose of fresh semen to heighten fertility rates (Roseboom.2000). Semen collections with less than 70% normal morphological sperm should be considered substandard (Rozeboom, 2000).

Abnormal differences in sperm can be found in either or both the head and tail of the spermatozoon. Head malformations can be caused by the spermatozoon having multiple heads, and irregular shape and size of the head. Tail deformities are caused by multiple tails, and the length and shape of the tail itself (Bonet et al., 1995).

Boar Semen Collection

In the swine industry three major semen collection methods are identified for boars. They are the artificial vagina method, gloved hand technique, and electroejaculation method (Park, 2013). Of the three the artificial vagina method and gloved hand technique are the most commonly used in the US swine industry. The electroejaculation method is mainly used for collecting difficult to handle boars. Currently, anesthesia is needed for this method to be accomplished. Thus, it is not often used due to the high cost associated with the procedure (Park, 2013). The artificial vagina was developed for boar semen collection by providing a way to apply pressure to the glans penis (McKenzie, 1931, Ito et al., 1948, Polge, 1956). This method is under used now because the gloved hand method offers more simplicity, less cost, and an elimination of having to clean and sterilize equipment (King and Macpherson, 1973). Due to these reasons in the commercial swine industry boar studs mainly collect semen using the gloved hand technique while a boar attempts to breed a dummy sow (Hancock and Howell, 1959, Singleton, 2007). Using a vinyl glove the technician grasps the end of the boar's penis while applying pressure to the distal spiral-shaped end replicating the sow's cervix. This stimulates the boar to ejaculate (Speight, 2010). However, it is important to recognize some have argued that the gloved hand technique may not provide enough stimulus for optimum sperm output. A study by King and Macpherson (1973) showed a significant difference between the collection methods of an artificial vagina versus the gloved hand technique. The results indicated that more spermatozoa can be harvested by the gloved hand method. This difference may be due to the fact that sperm losses in artificial vagina boar collection equipment does occur (Kennelly and Foote, 1964).

Fresh Semen Dilution

After semen is collected for the use of AI, it is diluted with various commercially available extenders. This allows multiple AI doses to be created from one ejaculant. Extenders contain nutrients that provide spermatozoa the opportunity to stay viable for three or more days of collection (Kuster and Althouse, 1999). Although some users of certain types of extenders claim normal fertility results up to six days in the industry; currently, very few doses are used past day three of collection. Not only is choice of extender important to keep in mind when storing semen, but the environment in which it is kept also plays a role in the overall fertility of a dose of fresh semen. A storage temperature ranging between 15-18^{o}C is considered to be ideal for maintaining fresh semen in storage prior to use (Johnson et al., 1982).

In a large survey conducted by Knox et al. (2008), of North American boar facilities he reported that boars produce a range of 51-150 billion sperm per boar on a weekly average. However, it is important that producers keep in mind doses of semen that can be obtained by an individual boar is dependent on several factors such as boar age and the length of rest between ejaculates (Singleton and Flowers, 2007).

In conclusion, it is important that boar stud owners and AI technicians understand that after ejaculation sperm cell function, as reported by Johnson et al. (2000), is predisposed by two key influencers, the temperature in which the semen is collected and stored after dilution, and the condition of the extender that is used. Although the makeup of semen extenders is not the same, they all serve as an intermediate to lengthen the survival of spermatozoa and preserve their ability to fertilize oocytes. Semen extenders functions are to increase the total volume of diluted semen and provide spermatozoa with nutrients to increase sperm cell longevity within a dose of fresh semen during storage (Speight, 2010).

Selection of Boars for Semen Value

With the goal of generating high quality offspring, boar selection is key. There has been little focus provided on the fertility attributes of the boar itself. This is crucial to keep in mind in that most sires are culled from boar studs due to reproductive problems (Knox, 1999).

A trait that is highly heritable in boars is testicular size (Huang and Johnson. 1996). It has been documented that testis size and weight are correlated with daily sperm production (Huang and Johnson, 1996). Huang and Johnson (1996) confirmed that testis size in boars is an important selection criteria relative to semen value. They also reported that increase size of testis in 150 day old boars is an effective way to increase concentration of sperm as well as total number of sperm per ejaculate. These studies suggest testis size should be considered when evaluating boars to use in an AI program. Selection of boars and its impact on semen value is an area where more data is needed to allow effective inclusion into the selection decision process (Safranski. 2008).

Sow Implications

When comparing AI boars it is also necessary to include the influence of the sow on AI pregnancy rate. A common standard used to evaluate fertility in sows is probability of pregnancy at 21 days post-partum. Other factors that must be included in the comparative evaluation of boars are sow parity, breed, and season. These factors must be accounted for to have a valid and unbiased comparison of AI boars.

Seasonal Infertility in Sows

Over several decades in the commercial swine industry dramatic changes have taken place. As the swine industry has become more specialized, reproductive performance of sows has continued to remain of constant importance (Hannenberg et al., 2001). Over time producers have experienced a large variety of reproductive management challenges in which producers are always seeking to overcome. This section will discuss the challenge of one of those traits, seasonal infertility.

Seasonal infertility in sows has been documented to be a result of high temperature (Bloemhof, et al., 2008). For lactating sows the thermo-neutral zone is between 12-22^{o}C (Black, et al., 1993). As the temperature exceeds the upper critical limit of this zone, sows are exposed to heat stress. One of the reasons pigs are vulnerable to elevated ambient temperature is their ability to lose heat by evaporation is limited (Einarsson, et al., 1996) FAO (2006) revealed high ambient temperatures limit pig production (Bloemhof, et al., 2012).

Seasonal infertility is often reported as the cause of a decline in farrowing rate within a swine enterprise (Hennessy, 1987). Due to the fact that this usually occurs in the hotter months of the year, heat stress is considered to be a major cause (Love, 1978). Seasonal infertility in pigs was investigated by Tast et al. (2002). It is reported that in winter-spring, the farrowing rate was 72% and 63% in summer-autumn. Early trials conducted by Edwards et al. (1968), utilized two different environmental chambers. In one chamber, gilts were maintained at 38.9^{o}C for 17 hours and lowered to 32.2^{o}C for the remaining 7 hours. The other chamber was maintained at 23.4^{o}C. Conception rates were lowest among gilts exposed to the elevated temperature from days 1-15 post-breeding. In an investigation of two different dam lines Bloemhof et al. (2008) observed the farrowing rate of the two lines responded differently to an increase in temperatures, suggesting that selection for heat tolerance might be possible. In a more recent study, (Bloemhof, et al., 2012) reported that farrowing rate and heat tolerance are traits with low heritability; however, these traits did display genetic variance so they could potentially be changed by selection.

Although early studies suggest high ambient temperatures are the most important factor causing seasonal infertility implicates seasonal infertility in late summer-early autumn is a result of seasonal breeding of the European wild boar in which pig breeds in the US are a derivative (Love, 1978). Studies have also demonstrated photoperiod has an effect on seasonal reproductive performance (Love et al., 1993).

There is no consensus regarding the factors that impact seasonal infertility. However, some traits involved are heat stress, photoperiod, and genetic background. In conclusion all factors must be considered relative to their impact on seasonal infertility and reduced farrowing rate in order to achieve maximum reproductive performance in commercial swine breeding systems.

CHAPTER III

FACTORS THAT IMPACT PROBABILITY OF PREGNANCY WHEN USING AI BOARS

INTRODUCTION

Improving fertility traits of pigs is a constant challenge for swine breeders who have focused on improving pregnancy rate to increase economic efficiency of the swine production cycle and pork production in general. Although both genetic and environmental factors may have a direct influence on the fertility of pigs the data used here did not demonstrate any significant specific genetic differences. A clear understanding of environmental factors and their role in increasing pregnancy rate will aid producers in understanding how to maximize pregnancy rate of sows bred using AI. Environmental factors that may influence pregnancy rate include season as stated by Scofield and Penny (1969) and Wrathall (1975), mode of insemination were factors found by Hughes and Varley (1978) and supported later by Flowers and Alhusen, (1992), age of the boar influences were established by Hughes and Varley (1978), the number of times the female was inseminated was reported by Dzuik (1970) and English et al. (1984), (Drickamer, et al., 1997).

Considering these variables, the primary objective of this investigation was to determine the impact of specific factors and their interactions on pregnancy rate in sows using AI.

MATERIALS AND METHODS

The data base was collected at Tempel Genetics in Gentryville, IN for a period of 3.5 years with 1,106 boars and 44,329 female pigs of twelve different breeds. Factors considered for their effect on probability of pregnancy can be found in (Table 3.1). The animals ranged in age from 4 months to 11 years and between zero to eighteenth parity. Most of the boars were of the Yorkshire type (591) and included the Landrace, Duroc, Hampshire, Hampshire x Duroc, and Yorkshire x Landrace (F1) lines that were available for the research project. The majority of the females were of the Landrace and Yorkshire lines; while Yorkshire x Landrace (F1), and Yorkshire x Landrace (F1) were also available. The overall management of all animals was similar. Season of mating was separated into two periods, where 'hot' represented the months of June through September and 'mild' accounted for the remaining months of the year. Pregnancy rate was determined in all females between 18 and 21 days post breeding and confirmed by ultrasound and heat detection boars.

The care and management of the boars with proper housing, treatment, and nutrition were maintained to produce high quality semen at Tempel Genetics Inc. At Tempel Genetics, Inc., semen was collected from the different lines (Landrace and Yorkshire) of boars multiple times in a week by means of a dummy sow and technician and sent to multiplier units for the purposes of developing replacement females for commercial units. Collected semen was examined routinely via the Minitube system for volume, motility of spermatozoa, concentration prior to delivery to multiplier unit. A minimum set of standards were set for each dose of semen prior to females being inseminated. These standards were: 1). Sperm cell concentration was greater than 100/million/ml. 2). Gross motility was > 90%. 3). Gross morphology had head defects < 10%. 4). Gross morphology had tail defects < 20%. 5). Gross morphology had proximal droplets < 10% 6). Gross morphology had total normal sperm cells > 70%.

Sows were artificially inseminated 8 h to 24 h after signs of estrus by trained AI technicians with fresh semen. Approximately 12 h to 24 h later, depending on the stage of estrus, females were given a second service and some females which were still in standing heat, were selected for a third service 12 h following the second AI.

Statistical Methods

Due to large computational requirements, several analyses were conducted to examine several variables as potential sources of variation for pregnancy rate (Table 3.1). Various variables Significance (P<0.05) tests for each variable were performed using univariate models and ordinary least squares procedures. LS Means were estimated using PROC GLIMMIX (SAS Inst., Inc., Cary, NC)

Using correlations and as well as variable distributions, the data was edited down to 15,375 matings records from Yorkshire and Landrace (Table 3.2) females. Records were removed for biological reasons that had potential impacts on fertility where insufficient data was available to define relationships at extremes. Parity was collapsed into categories 0, 1-2, 3-4, 5-6, 7+. After an initial analysis using month of mating as a categorical variable, a seasonal time period was defined to reflect differences between hot and mild seasons of the year (hot season = June through September and mild season = October through May). Boar age was limited to less than 5 years due to a small number of data records corresponding to boars used with an age greater than 5 years. Days from collection to insemination was restricted in the edited dataset to a maximum of 5 days to eliminate the potential impact of extreme semen age on fertility. Other edits to the data file were made to eliminate potential impacts to the results from situations where extreme values existed, variation/relationships that cannot be reliably explained in the analysis or potential data entry errors. Mixed sire matings were removed, along with sperm concentrations exceeding 7 billion sperm cells per dose, birth weight greater than 75 lbs., stillborn greater than 10 piglets per litter, this was based on data integrity. Days from last collection greater than 40 days, doses possible and doses actual less than 2 doses records were removed for biological reasons due to potential impacts on fertility, and any missing boar breed was removed due to data integrity.

The results of preliminary analysis revealed only 5 significant ($P<0.05$) factors as described in (Table 3.3). Based on the univariate analysis procedure, the significant effects included in following detailed analysis were: number of services, season, parity category, boar age, and days from collection to insemination. All potential two-way interactions were also tested, and the interaction of number of services by parity category, as well as season by number of served, was also fitted in the final model.

Least squares means, parameter estimates and corresponding standard errors were computed with the final model developed as a result of a stepwise process of fitting main effects and two-way interactions and subsequently removing non-significant (P>0.05) individual effects sequentially:

$$Y_{ijk}=I+NS_i+S_j+P_k+S^*NS_{ji}+P^*NS_{ki}+b_1{}^*B+b_2{}^*D+b_3D^2+\varepsilon_{ijk}$$

Where:

Y_{ijk}= the factors measured on each female based on the number of insemination services *i,* of season *j,* in parity *k,* from semen collected on specified day, inseminated by boars based on age (linear prediction function)

I= intercept

NS= fixed effect of number of services *i*

S= fixed effect of season *k*

P=fixed effect of parity category *k*

SNS= effect of the interaction of season *j* and number of services *i*

PNS= effect of the interaction of parity *k* and number of services *i*

b_1= linear effect of the age of boar

B= age of boar *m* (years)

b_2= linear effect of days from collection to insemination

D= days from collection to insemination of boar *m*

B_3= quadratic effect of days from collection to insemination

D^2= squared days from collection to insemination of boar *m*

ε_{ijk}= residual with $\varepsilon_{ijk} \sim N(0,\sigma_\varepsilon)$

RESULTS AND DISCUSSION

Reproductive efficiency is of importance for all livestock breeding systems and is of particular importance for swine enterprises. Pregnancy rate is a major component of reproductive efficiency and for this study a uniformly collected data set was used to document the impact of both genetic (breed) and environmental factors on pregnancy rate of sows bred AI. A summary of all sources of variation for pregnancy rate that were evaluated in the current study are shown in Table 3.1.

Effect of Breed

The effect of breed on pregnancy rate for both boars and sows are shown in Figure 3.1 and Figure 3. 2. Although relatively small differences were observed, there were no significant ($P<0.05$) effects of breed on pregnancy rate.

The non-significant differences in pregnancy rate found for the effect of boar breeds used in the current study implies that either sire breed can be used for the development of multiplier females (Figure 3.1). Additionally, there were no significant ($P>0.05$) differences in pregnancy rate among the different breeds of females utilized (Figure 3.2). The interaction of boar and female breed was also tested and found to be a non-significant source of variation for pregnancy rate (results not shown; P> 0.05). These results differ from those reported by Koh et. al. (1976), where a significant difference was found in conception rate between both breeds of males and females when comparing crossbred and Landrace females to Duroc, Yorkshire, Pietrain, and Hampshire females. In the current study, semen collections were evaluated for quality parameters prior to packaging, which may explain why differences in breed were not detected. Results from the current study suggest that breed is not a significant contributor to differences in pregnancy rate when Landrace and Yorkshire breeds are compared and when semen quality control processes are in place.

Effect of Number of Services

Time of insemination following estrus has been shown to be an important factor influencing pregnancy rate (Soede et al., 1995; Nissen et al., 1997; Kaeoket et al., 2005). It is important that sperm are present in the reproductive tract of the female in a timely manner to fertilize ova when they become available. During this study, insemination was based on the number of services (1, 2, or 3) and interactions were noted. The third service, pregnancy rate (88.13%) after onset of estrus of the females was significantly ($P<0.05$) higher than when females were serviced only one time (77.71%), and resulted in a 10.42% difference in pregnancy rate. However, statistically, the third service pregnancy rate did not show significant ($P>0.05$) differences compared to the females that had received two services (86.64%). When evaluating first service pregnancy rate, there were significant ($P<0.05$) interactions differences between both service two and three. Figure 3.3 shows that pregnancy rate increases as the number of services increases. It is concluded, on the basis of the aforementioned results, that pregnancy rate may be significantly different due to one vs. two services. It is common practice in the swine industry to inseminate more than once per cycle with doses of semen containing adequate sperm volume and concentration to achieve fertilization (Reed, et. al. 1982). However, the increase in pregnancy rate gained from three services compared to two services provided a non-significant (1.49%) increase in pregnancy rate.

Effect of Season

Several studies have indicated that summer heat stress causes infertility in sows and decreased reproductive efficiency (Beroldo et al., 2012). Parity 1 sows are especially affected by heat stress (Love. 1978). The cause of seasonal infertility is believed, in part to reside within the lactation phase of the production cycle. During lactation, heat-stress to sows reduce feed intake as a mechanism to reduce metabolic heat production (Teague et al., 1968). Decreased feed intake leads to an extended period of negative energy balance and body condition loss (Black et al., 1993) Pregnancy rate was significantly ($P<0.05$) higher (87.36%) in females that were inseminated in the mild season when compared to females inseminated in the hot season (81.50%) as shown in Figure 3.4. This results in a 5.86% improvement in pregnancy rates when sows are mated in the mild portion of the year as compared to the hot season. These results are similar to those reported by Love, R.J. (1978) who showed that farrowing rate declines after matings in late summer and early fall. Because similar results to previous reports were found with seasonal variation in pregnancy rate, significant opportunity exists to better control seasonal decrease in infertility.

The interaction of number of services by season had significant (P<0.05) effects on pregnancy rate. The highest rate of pregnancy was observed (Figure 3.5) for sows serviced three times in the mild period (92.73%) and the lowest pregnancy rate for sows serviced one time in the hot period (77.88%); result in a 14.85% difference.

Effect of Parity Category

Pregnancy rate of sows was studied from zero to 7th parity and was analyzed by comparing 0, 1-2, 3-4, 5-6, and 7+ parities (Figure 3.5). The pregnancy rate increased up to the parity category 3-4 and then decreased up to the last parity category (7+). But, it was also observed that the pregnancy rate in parity category zero differed significantly (P<0.05) to categories 1-2, with a 5.38% reduction in pregnancy rate for zero parity gilts compared to parity category1-2. Category zero also was lower than category 3-4 with a pregnancy rate difference of 10.23% and lower than category 5-6 (8.22% difference). It is also important to note that parity category 1-2 was significantly (P<0.05) lower than category 3-4 with a 4.85% lower pregnancy rate. These results are similar to those reported by Koketsu and Dial (1996). Reproductive efficiency was relatively poor in parity 1 sows. Koketsu and Dial (1996) clarified that low reproductive function of younger parity sows can be attributed, somewhat to nutrition. Due to the fact the immature sows had not achieved a mature size and weight, while nutritional requirements were different from those of older parity sows (Koketsu and Dial. 1996). Lower parity sows also had less feed intake then their higher parity counterparts during lactation. Consequently, these younger females may not be receiving necessary nutrition for ideal reproductive function. It has been reported that gilts may be more susceptible to lower pregnancy rates in less than ideal environmental situations then higher parity sows (Koketsu and Dial. 1996).

The steady decline in pregnancy rate may be clearly observed after parity category 3-4 (Figure 3.5). The interaction of parity and number of services also had significant ($P<0.05$) effects on the rate of pregnancy (Figure 3. 7). The highest likelihood of pregnancy rate was observed for sows serviced three times in the 3-4 parity category (94.29%) and the lowest outcome was in sows serviced one time in the 0 parity category (71.02%), resulting in a 23.27% difference in pregnancy rate. The results of the data in this study demonstrate the significant effects of parity and number of services on pregnancy rate in sows. These variables should be accounted for when trying to create an optimal breeding program using AI.

Effect of Boar Age

Boar age had a significant ($P<0.05$) effect on the rate of pregnancy as shown in Figure 3.8. The boars in this study used boars ranging in age from 5 months to 5 years. This may be attributed to the results found by Kennedy and Wilkins (1984), in which they compared age of boar effects for semen volume, sperm concentration, percentage of live sperm, motility and potential doses of semen. Age of boar effects was significant for all traits. Maximum volume, concentration and potential doses were from 24-29 month old boars. Young boars less than 9 months had the lowest volume, concentration and potential doses. Yet, percentage of live sperm and motility were highest for young boars and decreased with an increasing age of the boars.

Data in this study suggests that maximum pregnancy rate is obtained from younger boars. In fact the data presented suggests that producers use semen from the youngest boars available for semen collection.

Effect of Days From Collection to Insemination

Days from collection to insemination, when ranging from days 0 to 6, also had a significant ($P<0.05$) effect on pregnancy rate as shown in Figure 3.9. Liquid extended semen has been shown to improve fertility when used within 3-5 days after collection (De Ambrogi et al., 2006; Vyt et al., 2004). Thus, producers can expect farrowing rates ranging from 65% to 70% if the semen is used within 48 hours of collection, and a reduction to approximately 50% with 5 day old semen (Johnson, et. al. 1988). The results from the current study show as the number of days from collection to insemination increase the quality of sperm decreases, thus it can be concluded semen quality plays a role in pregnancy rate.

Conclusions

From a practical production standpoint, there is a possibility to significantly improve general swine pregnancy rate by incorporating specific management strategies when using AI. Number of services, season, parity, boar age, and days from collection to insemination were all shown to be significant factors that impact the rate of pregnancy of sows mated using AI. Non-significant differences between boar breed and sow breed indicated that breed does not play a role in determining the rate of pregnancy in swine. These results point out that management decisions at farm level is a prerequisite for maximizing pregnancy rate.

Specifically, the results imply that breeding in the mild season offers a greater chance of maximizing pregnancy rate. In addition, artificially inseminating females with at least two services will significantly improve pregnancy rate compared to only one service. Also, the study shows that breeding females with a parity category of 3-4 results in the highest pregnancy rate. Comparing the Yorkshire and Landrace breeds showed no difference in pregnancy rate for both males and females. Therefore, the choice of breed may be based on more differentiating criteria, such as their meat and carcass quality, or maternal traits.

Due to the increasing costs of production as the swine industry becomes more competitive, it is important for producers to have knowledge of environmental correlations and the relative economic importance of traits of interest used to calculate the pregnancy rate. Data from the current study as well as previous reports suggest that management tools that incorporate non-genetic variables, makes increasing pregnancy rate feasible. Of the total population, 86.26% of the experimental group of female swine actually exhibited a “pregnant” breeding result from the study, indicating it is possible to obtain acceptable pregnancy rate results with proper management. By increasing producers’ knowledge of factors affecting pregnancy rate, other management and economic advantages can progress as well. Considerable progress has been made in determining which factors are important in increasing pregnancy rate. Continued efforts should be made to devise means such as a selection index approach to further increase pregnancy rate to educate producers on advantages of specific management decisions.

Table 3.1: Potential sources of variation evaluated for their relationship with pregnancy rate in swine

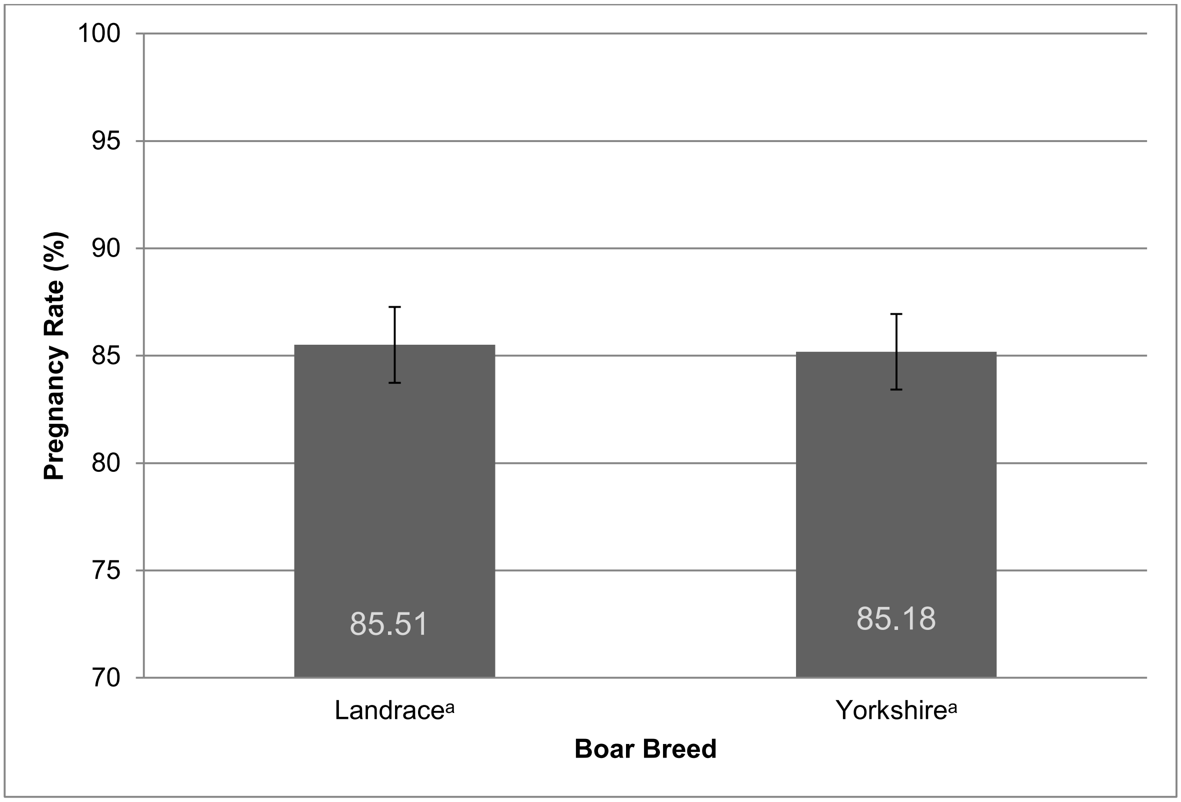
Environmental Factors	Boar Components	Semen Parameters	Sow Components
Season Collected	Age	Motility	Pregnancy Results
Collection Technician	Breed	Concentration	Parity
Farm Location	Sire & Dam	Volume	Previous Litter Weight
	Days from Last Collection	Morphology	Previous Number Weaned
	Days form Collection to Insemination	Distal	Number of Services
		Proximal	Service Sire
			Breed of Sow
			Previous Wean to Estrus
			Breeding Technician

Table 3.2 Data description of final matings

Parity	TOTAL	Breed of Sow		Mating Combination				Season		Number of Services		
				Yorkshire Female		Landrace Female						
		Yorkshire	Landrace	Yorkshire Boar	Landrace Boar	Yorkshire Boar	Landrace Boar	Hot	Mild	1	2	3
0	2,799	1,299	1,500	278	1,021	1,215	285	901	1,898	214	2,494	91
1-2	5,219	2,390	2,829	402	1,988	2,380	449	1,736	3,483	273	4,699	247
3-4	3,573	1,620	1,953	238	1,382	1,647	306	1,168	2,405	125	3,277	171
5-6	2,392	1,008	1,384	160	848	1,171	213	762	1,630	96	2,200	96
7+	1,392	499	893	110	398	756	137	455	937	38	1,309	45
TOTAL	15,375	6,816	8,559	1,188	5,624	7,169	1,390	5,022	10,353	746	13,979	650

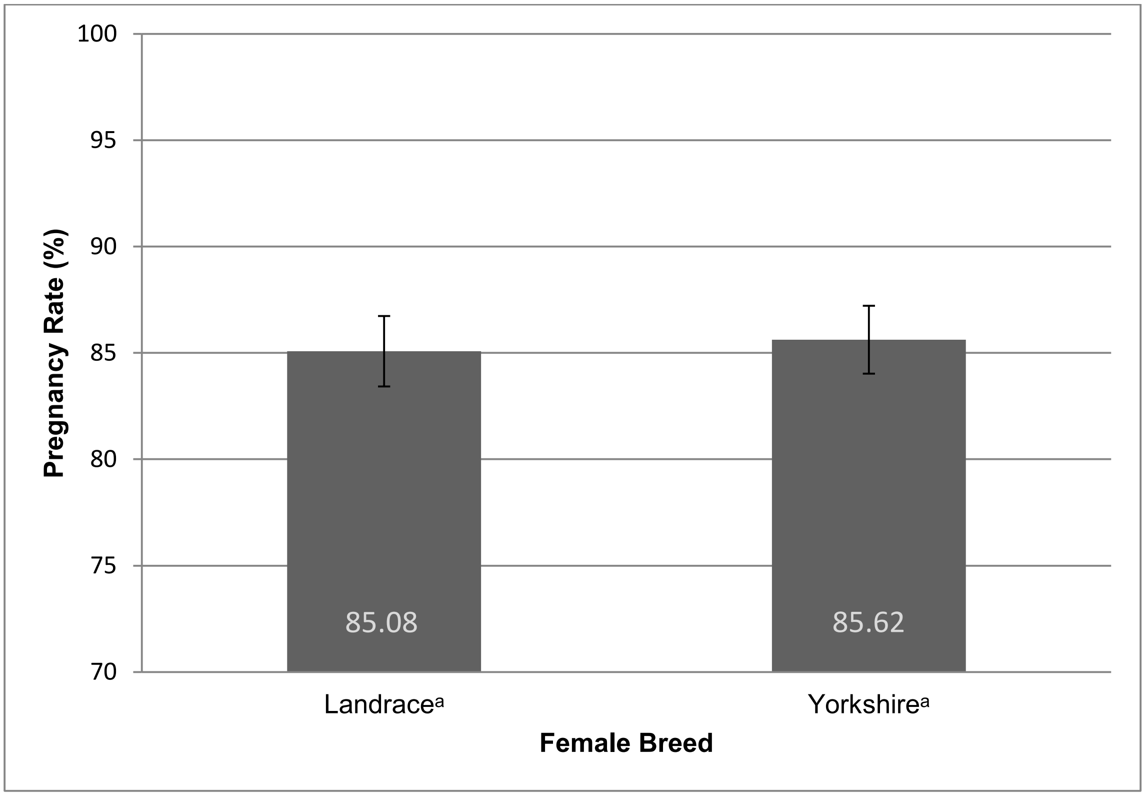
Table 3.3: Results for tests of significance for factors included in the final model used to evaluate factors influencing pregnancy rate

Fixed Effects	**Description**	**P Value**
Categorical Variable		
Parity (P)	0.1-2,3-4,5-6,7+	0.0022
Season (S)	Hot (June-September) Mild (October-May)	0.0022
Number of Services (NS)	1,2,3	<0.0001
Covariates		
Age of Boar (B) (linear)	Years	0.0002
Days from Collection to Insemination (D) (linear)	Days	<0.0001
Days from Collection to Insemination (D^2) (quadratic)	$Days^2$	0.0148
Interactions		
Number of Services by Season (SNS)		0.0240
Number of Services by Parity(PNS)		0.0099



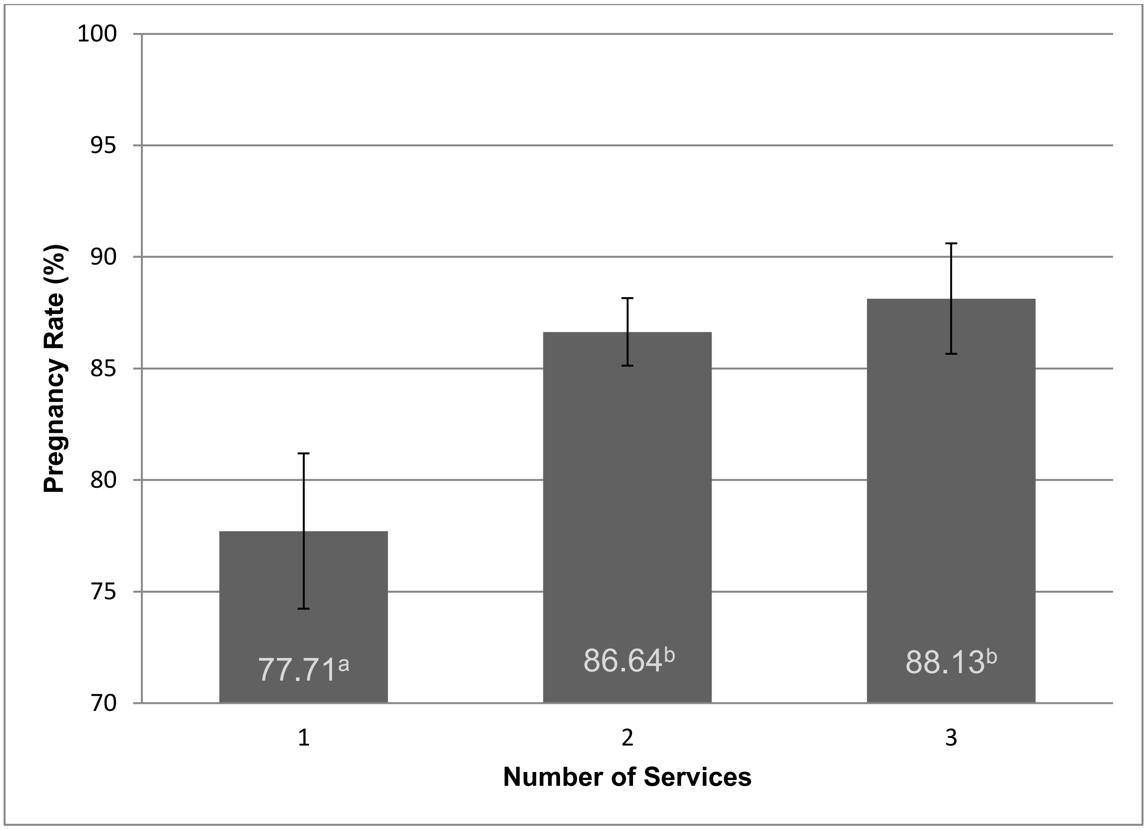
a, means with common superscript do not differ (P>0.05)

Figure 3.1: Effect of boar breed on pregnancy



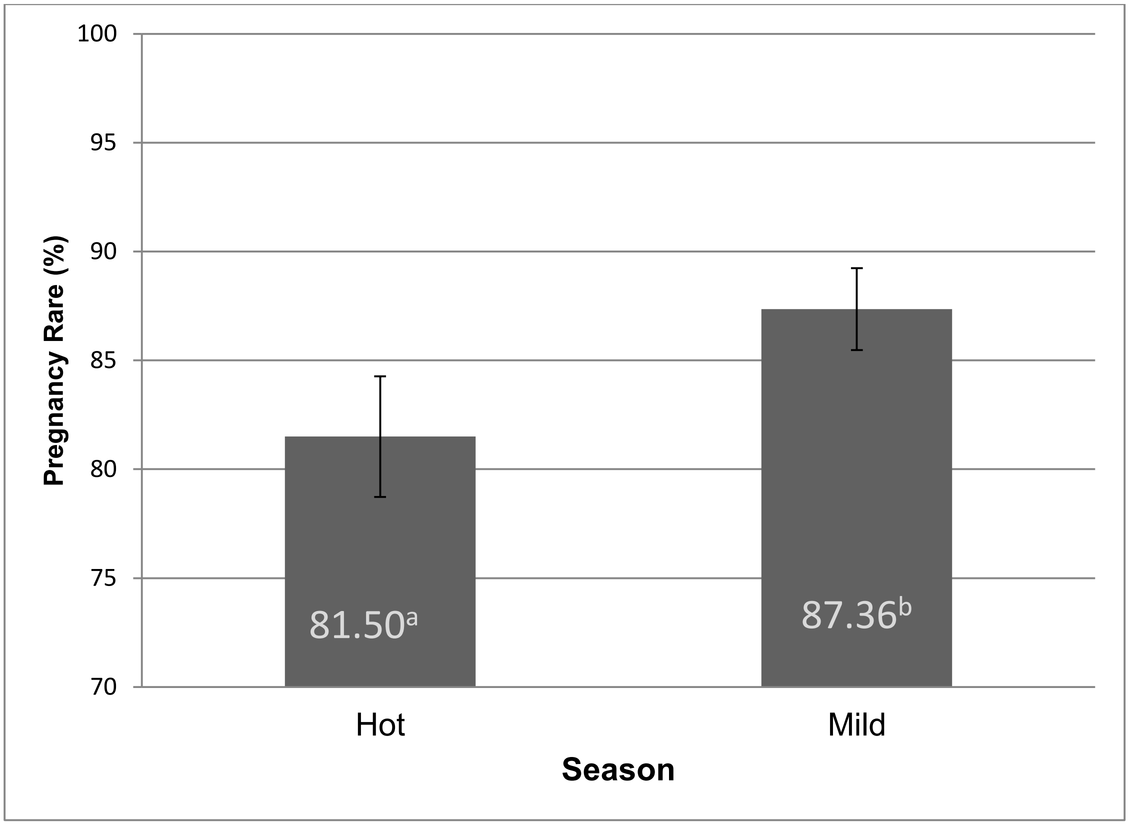
a, means with common superscript do not differ (P>0.05)

Figure 3.2: Effect of female breed on pregnancy



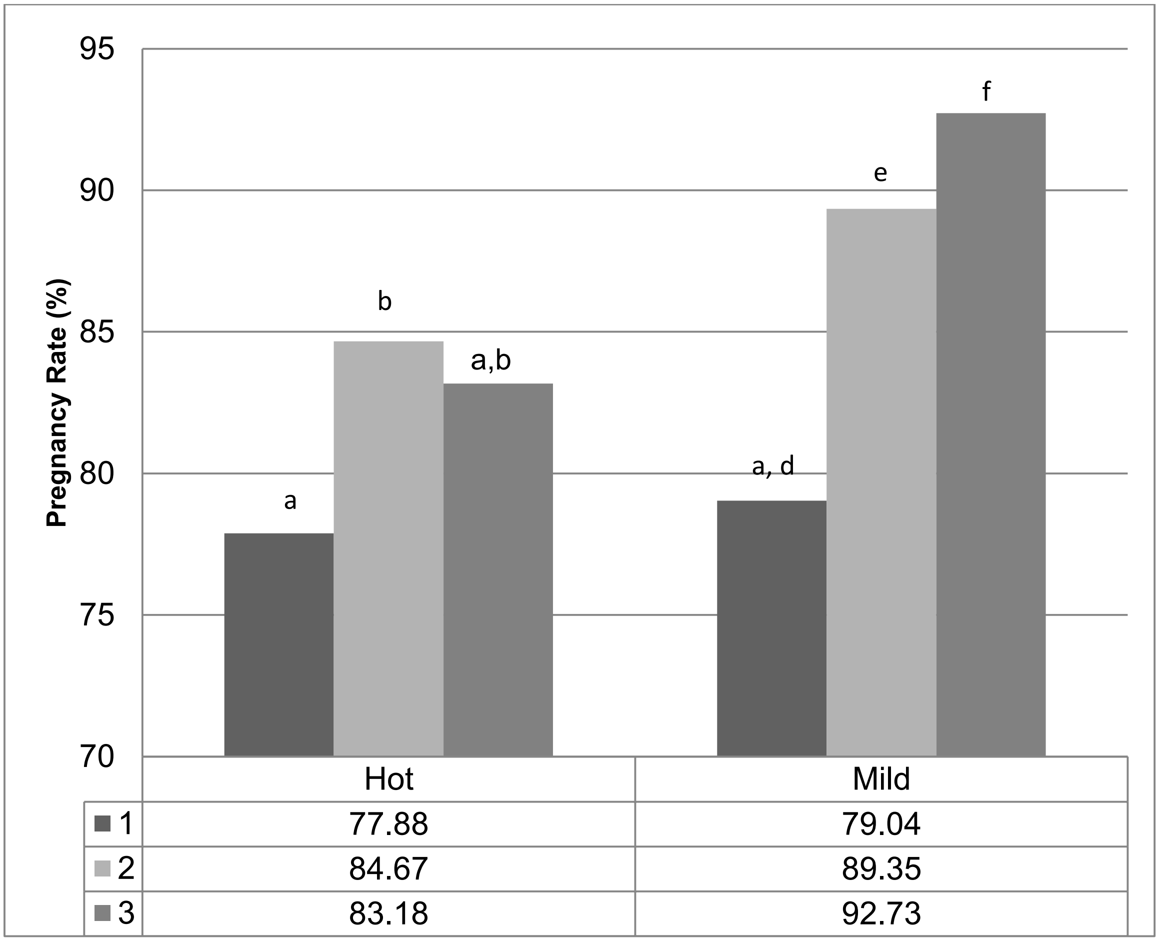
Means with common superscripts do not differ (P>0.05)

Figure 3.3: Effect of number of services on pregnancy



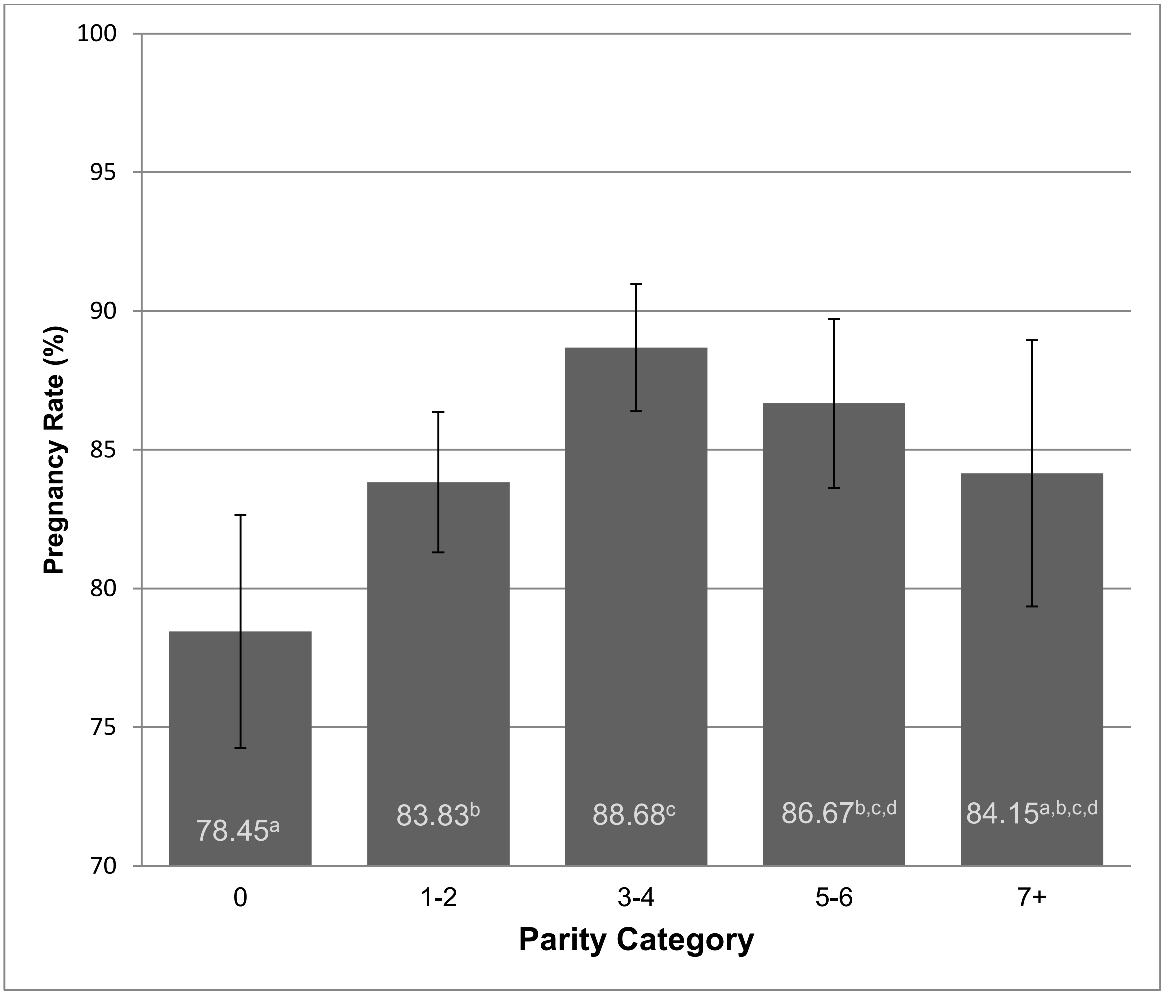
Means with common superscripts do not differ (P.0.05)

Figure 3.4: Effect of season on pregnancy



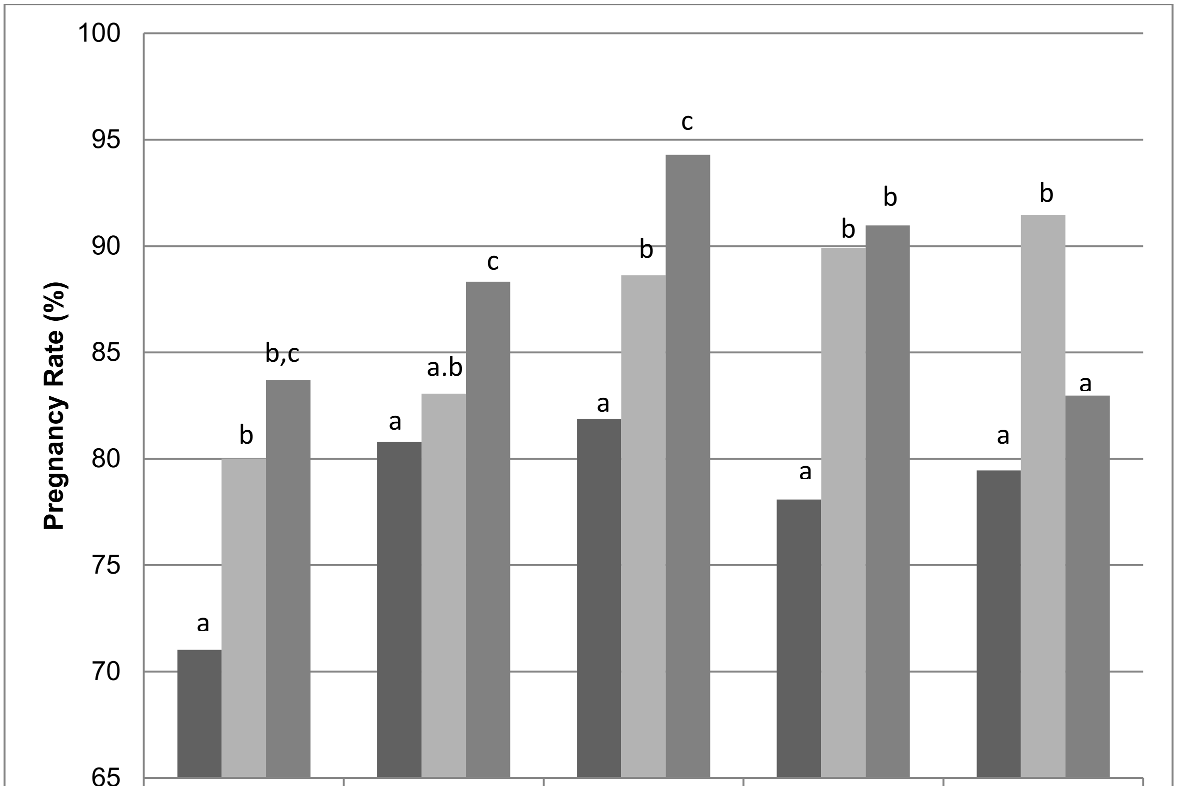
Means with common superscripts do not differ (P>0.05)

Figure 3.5: Interaction of number of services by season



Means with common superscripts do not differ (P>0.05)

Figure 3.6: Effect of parity on pregnancy



	Parity 0	Parity 1-2	Parity 3-4	Parity 5-6	Parity 7+
1	71.02	80.8	81.88	78.09	79.45
2	80.01	83.06	88.62	89.91	91.47
3	83.71	88.32	94.29	90.97	82.98

Means with common superscripts within a parity category do not differ (P>0.05)

Figure 3.7: Interaction of number of services by parity

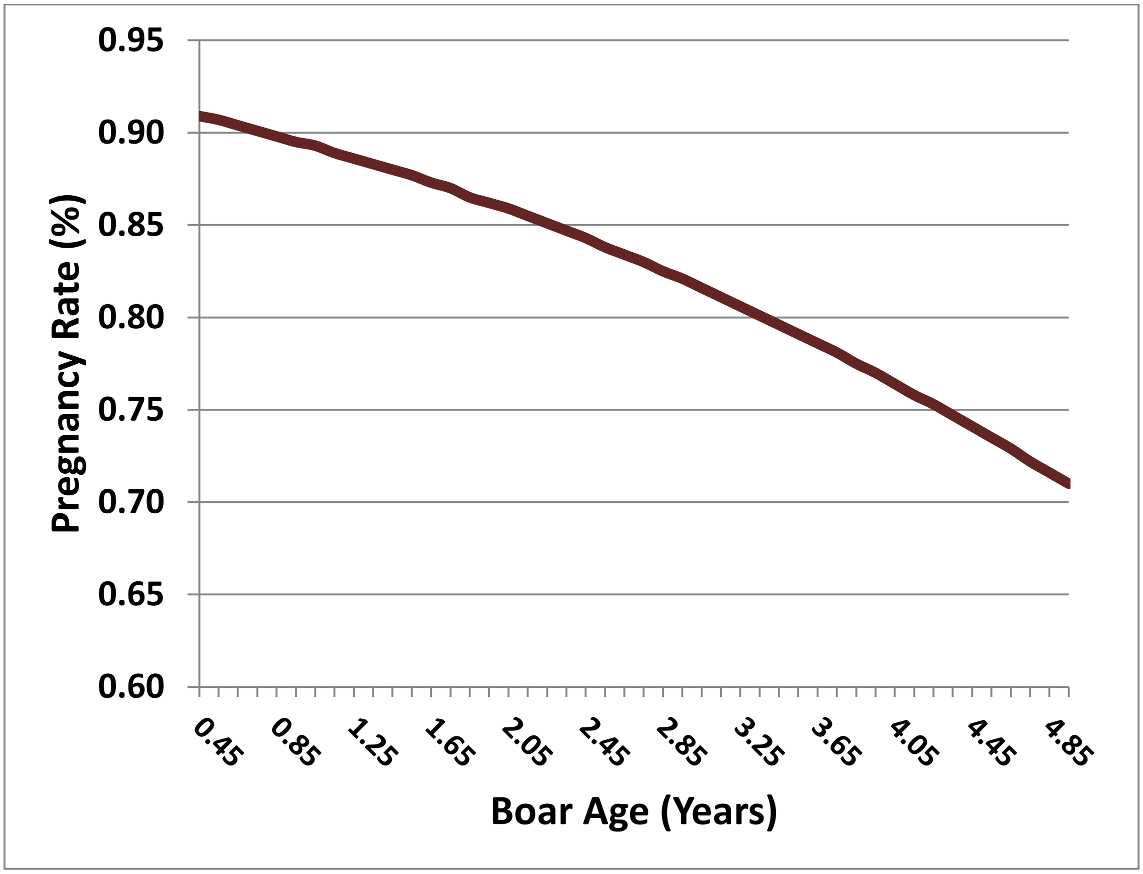


Figure 3.8: Relationship of boar age and pregnancy

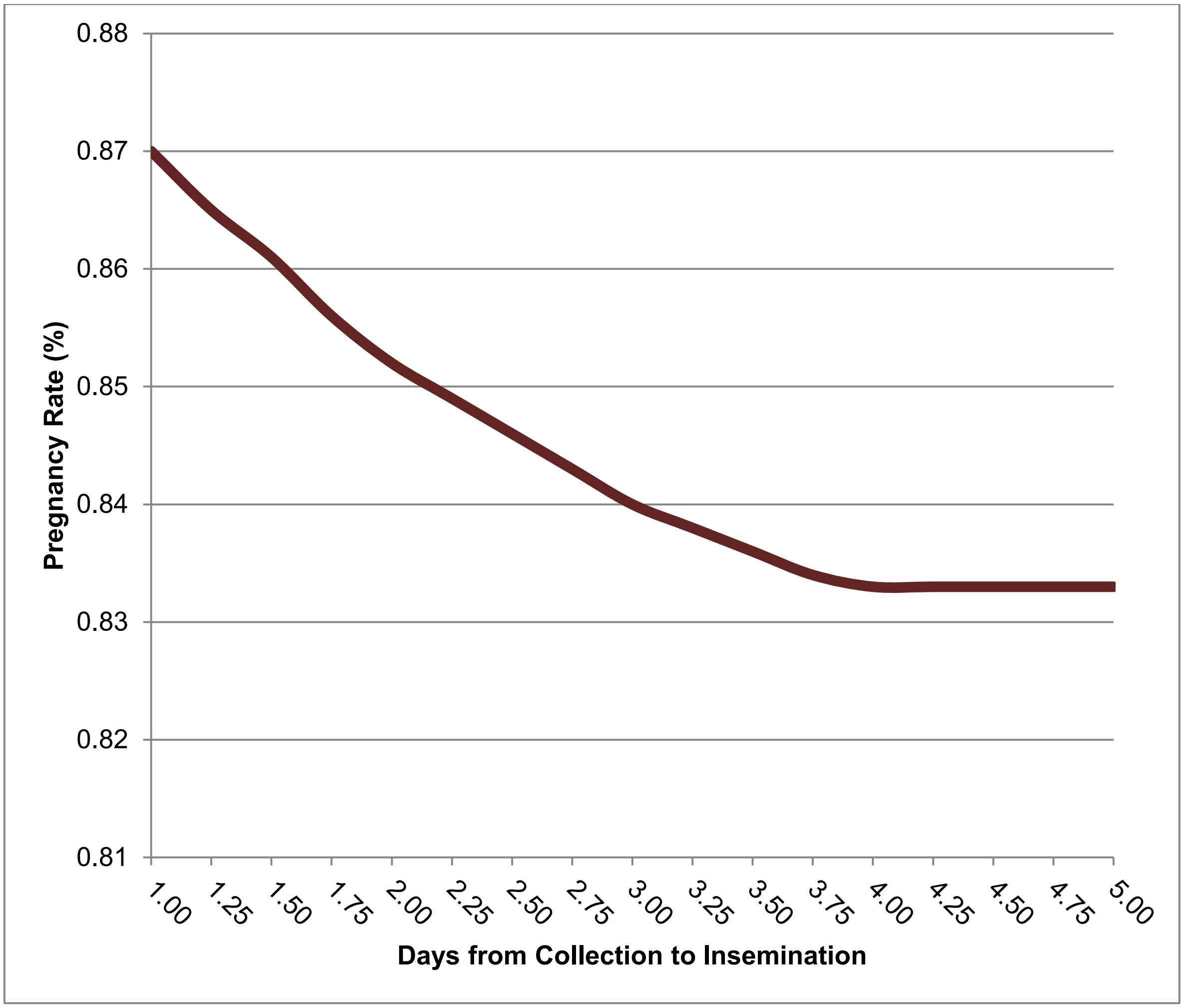


Figure 3.9: Relationship of days from collection to insemination with pregnancy

CHAPTER IV

PREDICTING IMPACT OF MANAGEMENT PRACTICES TO MAXIMIZE PREGNANCY RATE

INTRODUCTION

For this study, the objective is on the regression model developed for predicting pregnancy rate using Proc GLIMMIX in SAS. Producers can utilize this model to estimate various factors on herd pregnancy rates, thereby, improving their management practices. With the estimated model parameters, Microsoft Excel can be used to calculate predicted pregnancy rates for different values of independent predictor variables.

MATERIALS AND METHODS

Data from previous studies were used to evaluate the probability of swine pregnancy rate of different breeds, and to estimate the associations of number of insemination services, season of insemination, parity category of the females, boar age, and days from collection to insemination with pregnancy rate.

Statistical Methods

To estimate the rate of pregnancy, a prediction model was developed in Microsoft Excel using fixed effect solutions from previous analysis, where changes to model variable can be incorporated to evaluate the impact on pregnancy rate.

For the pregnancy model in Microsoft Excel, the five factors discussed earlier were set up in rows and were assessed with either a numerical '0' or '1' in each category except for continuous variable of boar age and days of insemination. For number of services, producers have the option of indicating the proportion of matings represented by 1, 2, or 3 matings. For season, producers have the option of selecting a binary indicator variable of hot or mild. For parity category of females, producers can select one binary indicator variable of the five options available. When considering the boar age, producers have the option of choosing any numerical value between 0 .42 (5 months of age) and 5 years since most boars are not used after age 5. Finally, the days from collection to insemination field must be an integer between 0-5. These restrictions keep the range of the predictors to be the same as those used to estimate the model, so extrapolation outside of the data range used to estimate the multivariate function will not occur.

RESULTS AND DISCUSSION

The main purpose for developing a selection index model is to find the precision of the selection criteria one wishes to achieve. The accuracy in prediction of probability of pregnancy has an important impact on the genetic improvement that can be expected as a result of both management and selection, and therefore is a useful measure. The results presented in Table 4.1 show observational components of considered traits. Interested individuals need to only focus on the numbers they are inputting for the factors in the Microsoft Excel model including; number of services, season, parity, boar age and days from collection to insemination. Once these components are added, interactions are computed and a pregnancy probability rate is expressed. The interactions are hidden within the Microsoft Excel model and are not mathematically computed by the interested person(s) (Refer to Table 4.1 for interactions that are computed in Microsoft Excel behind-the-scenes). It is based on previously developed data on factors and personal management decisions of the person(s) manipulating the model to produce the wanted pregnancy outcome.

Number of Insemination Services

For fresh semen, it has been reported that AI with different volumes effects fertility (Baker et al., 1968; Soede and Kemp, 1997). The industry recommendation is to give a sow or gilt at least two doses of semen, twelve to 24 hours apart. This is because most females ovulate during the end of standing heat and viable sperm must be present at ovulation if the animal is to become pregnant. This recommendation is supported by the result from the aforementioned study within this dissertation that concluded there is a significant pregnancy rate achieved in females inseminated with two doses versus a single dose of fresh semen.

Season of Mating

The domestic pig has a lowered fertility in the ‘hot’ season (June-September). An increase in ambient temperature leading to heat stress has been related with seasonal infertility (Love, 1978; Stork, 1979; Reilly and Roberts, 1992; Peltoniemi et al. 1999). A reduced farrowing rate, and a prolonged weaning to estrus period are also apparent with seasonal infertility. Gilts and primiparous sows are the most significantly affected by seasonal infertility (Love 1978; Peltoniemi et al., 1999). Due to the argument stated, it is a lesser ideal option to choose the ‘hot’ season to attempt to elevate pregnancy rate.

Parity Category

Parity profile influences both the biological and economic performance of swine herds. In turn, the length of time a sow is in the herd has a major impact on overall profitability (Young, et al., 2008). Studies show that via culling practices most sows are replaced by the fourth parity (Rodriguez-Zas, et al., 2006). Producers must make these decisions on biological and economic principles (Rodriguez-Zas, et al., 2006). The average annual replacement rate in commercial sow herds usually ranges between 42-59% (Young, 2008).

The longer a sow is retained in the herd the more opportunity exists to recover the initial expenses invested in the sow. The other advantage to an older parity sow could be fewer non-productive days (Rodriguez-Zas, et al., 2006). The down side to this is the longer a sow remains in the herd her salvage value declines.

Most producers cull sows near the optimal parity that maximizes profitability (Rodriguez-Zas, et al., 2006). As stated by Hypor (2009), the most highly productive parities range between 3-6. This is somewhat confirmed by the aforementioned study earlier in this dissertation that concludes that parities in the 3-4 range have the highest pregnancy rate. Therefore, it is suggested producers try to expand the number of sows within this parity category.

Boar Age

The number of ejaculated sperm varies with the age of the boar (Knox. 1999). In previous studies, sperm output increased with the boar's age within the first three years. Sperm output peaked at age of 3.5 years and declined after (Smital, 2009). An additional study by Serniene (2002) found that the percentage of viable sperm decreased with age. For these reasons, choosing older boars is not the best option to achieve a high pregnancy rate.

Days From Collection to Insemination

Two studies reported aging of spermatozoa occurs during storage of fresh semen as well as after the female has been inseminated (Johnson, et al. 2000, Haugan, et al. 2005). Storing semen for a significant length of time after collection reduces the fertilizing capability of the spermatozoa. Swine semen volume and overall quality decreases over time especially beyond day 5 of collection. It is the most ideal to use fresh semen collected from boars as quickly as possible to maximize pregnancy rate.

Conclusions

Based on the reasons stated previously in this discussion in order to maximize pregnancy rate, producers should inseminate the females with at least two services to ensure a higher pregnancy rate. Also, inseminating during the ‘mild’ season will reduce the chances of lower pregnancy rates. Other management practices to improve pregnancy rate would be to select sows with a 3 or 4 parity profile as these are the most productive parities and to utilize younger boars to maximize pregnancy rate. Finally, days from collection to insemination should be as short as possible to enhance pregnancy rate. By incorporating these management practices, producers will have the ability to maximize pregnancy rate for the females on their farms and better their reproductive efficiency (Figure 4.1).

With proper management and decision making, producers can improve rate of pregnancy for swine bred using AI which should lead to economic advantages. Figure 4.2 and 4.3 show examples of the Microsoft Excel model that compares the impacts of a different management decision, Figure 4.2 shows the response to negative management practices that result in a lower than acceptable pregnancy rate of 50%.

However, when the producers modify their management decisions and incorporate the practices suggested in this study using the Excel Analysis Toolpak the results are shown in Figure 4.3, resulting in a 98% pregnancy rate. The observed results support the use of regression analysis as a tool to improve pregnancy rate of sows bred using AI.

Table 4.1: Logistic regression coefficients for factors related to probability of pregnancy

Effect	Season	Parity	N of Serv	Coeff	SE	P value
Intercept				2.8081	0.5063	<.0001
Number of Services (NS)			1	-0.6717	0.5235	0.1995
			2	0.524	0.3879	0.1768
			3	0	.	
Season (S)	Hot			-0.9473	0.2719	0.0005
	Mild			0	.	
Parity (P)		0		0.05259	0.5373	0.922
		1-2		0.4395	0.4634	0.3429
		3-4		1.2198	0.5052	0.0158
		5-6		0.7255	0.4968	0.1442
		7+		0	.	.
Age of Boar (B) (linear)				-0.3137	0.08404	0.0002
Days from Collection to Insemination (D)				-0.2146	0.04564	<.0001

Age of Boar ranges from 0.42 to 5.

Days from Collection to Insemination ranges from 0 to 5.

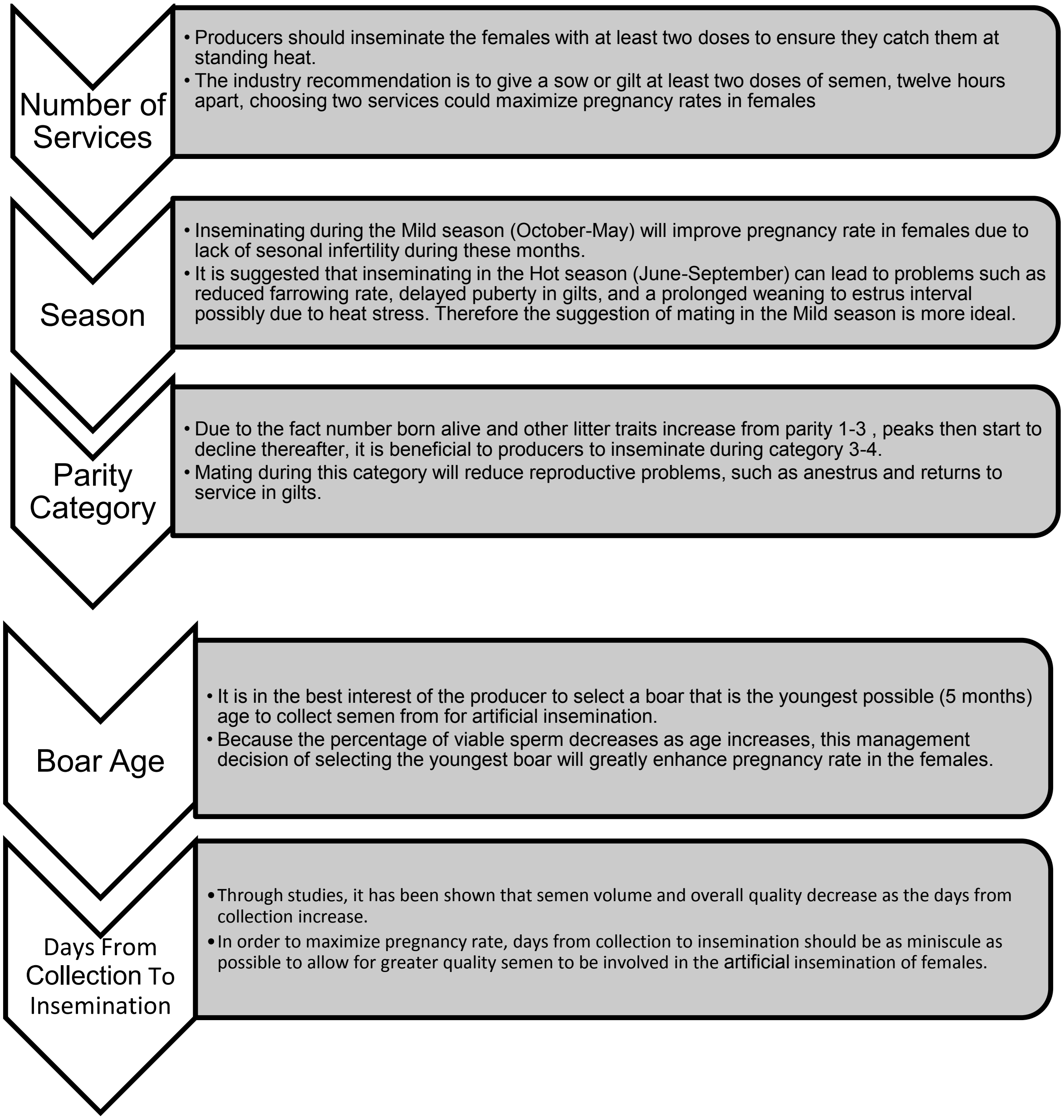


Figure 4.1. Success diagram when using best management practices.

*This is the best situation to maximize pregnancy rate in females throughout all significant factors considered in the study. Ideally, producers may not be able to accomplish all of these selection criteria suggested. However, through best management practices and knowledge of the significant factors affecting the females, pregnancy rate can be manipulated to improve production for the facility.

EFFECT						
NumberofServices			1	1	Enter 1 for only one of three options	
			2	0		
			3	0		
season	hot			1	Enter 1 for only one of two options	
	mild			0		
prev_parity		0		0	Enter 1 for only one of five options	
		1-2		0		
		3-4		0		
		5-6		0		
		7+		1		
boar_actual_age				5		
days_collect_insemin				5		
				Result	Prob(preg)=	0.505287

*5 refers to approximately 5 years of age

Figure 4.2: Microsoft Excel pregnancy predictor model example 1

EFFECT							
NumberofServices			1	0	Enter 1 for only one of three options		
			2	0			
			3	1			
season	hot			0	Enter 1 for only one of two options		
	mild			1			
prev_parity		0		0	Enter 1 for only one of five options		
		1-2		0			
		3-4		1			
		5-6		0			
		7+		0			
boar_actual_age				0.42			
days_collect_insemin				0			
				Result	Prob(preg)=		0.980085

*0.42 refers to approximately 5 months of age

Figure 4.3: Microsoft Excel pregnancy predictor model example 2

REFERENCES

Allrich, R.D. 1981. Pubertal development of the boar: age-related changes in testicular morphology and selected endocrine parameters. University of Nebraska-Lincoln. Lincoln, NE.

Andresen, O. 1976. Concentrations of fat and plasma 5α-androstenone and plasma testosterone in boars selected for rate of body weight gain and thickness of back fat during growth, sexual maturation and after mating. J. Reprod. Fertil. 48:51-59.

Aneas, S.B., B.G. Gary, and B.P. Bouvier. 2008. Collectis® automated boar collection technology. Theriogenology. 70:1368-1373.

Baker, R.D., Dzuik and H.W. Norton. 1968. Effect of volume of semen, number of sperm and drugs on transport of sperm in artificially inseminated gilts. J. Anim.Sci 27: 88-93.

Baum, M.J. and J.T.M. Vreeburg. 1973. Copulation in castrated male rats following combined treatment with estradiol and dihydrotestosterone. Science. 182:283-285.

Berger, T., D.L. Anderson, and M.C.T. Penedo. 1996. Porcine sperm fertilizing potential in relationship to sperm functional capacities. Animal Reproduction Science. 44:231-239.

Bertoldo, M.J., P.K. Holyoake, G. Evans, and C.G. Grupen. 2012. Seasonal variation in the ovarian function of sows. Reprod. Fertil. Dev. 24:822-834.

Beyer, C., G. Morali, K. Larsson, P. Sodersten. 1976. Steroid regulation of sexual behavior. Journal of Steroid Behavior. 7:1171-1176.

Black, J.L., B.P. Mullan, M. L. Lorschy, and L.R. Giles. 1993. Lactation in the sow during heat stress. Livestock Prod. Sci. 35: 153-170.

Bloemhof, S., H. van der Waaij, J.W.M. Merks and E.F. Knol. 2008. Sow line differences in heat stress tolerance expressed in reproductive performance traits. J. Anim. Sci. 86:3330-3337.

Bloemhof, S., A. Kause, E.F. Knol, J.A.M. Van Arendonk and I. Misztal. 2012. Heat stress effects on farrowing rate in sows: Genetic parameter estimation using within-line and cross bred models. J. Anim. Sci. 90:2109-2119.

Bonet, S., J. Briz, E. Pinart, R. Cumps, A. Fradera, and M. Casadevall. 1995. Light microscopy characterization of sperm morphology. Microscopy and Analysis. 9:29-31.

Bonet, S, M.D. Briz, and M. Yeste. 2012. A proper assessment of boar sperm function may not only require conventional analyses but also others focused on molecular markers of epididymal maturation: Markers of epididymal maturation in boar semen. Reproduction in Domestic Animals 47: 52-64.

Booth, W.D. 1980. A study of some major testicular steroids in the pig in relation to their effect on the development of male characteristics in the prepubertally castrated boar. J. Reprod. Fertil. 59:155-162.

Brandt, H. 1998. Boar fertility. Institute for Animal Breeding and Genetics. AGBU Pig Genetics Workshop. 22-26.

Britt, J.H.1986. Improving sow productivity through management during gestation, lactation and after weaning. J. Animal Sci. 63:1288-1296.

Britt, J.H. 1992. Progress in improving fertility through simultaneous efforts in the research laboratory and on the farm. Proc. Minnesota Swine Conference for Veterinarians. 19: 57-74.

Brock, L.W. and R.P. Wetteman. 1976. Variations in serum testosterone in boars. J. Anim. Sci. 42:244.

Burke, P. 2000. Productivity assessment of liquid boar semen usage. In: (eds) L.A. Johnson and H.D. Guthrie. Boar Semen Preservation IV. pp. 149-152. Allen Press, Inc., Lawrence, KS.

Carlson, I.H., F. Stratman, and E. Hauser. Spermatic vein testosterone in boars during puberty. J. Repro. Fertil. 27:177-180.

Chen, P., T.J. Baas, J.W. Mabry, K.J. Koehler, and J.C.M. Dekkers. 2003. Genetic parameters and trends for litter traits in U.S. Yorkshire, Duroc, Hampshire, and Landrace pigs. J. Anim. Sci. 81:46-58.

Claus, R. and B. Hoffman. 1980. Oestrogens compared to other steroids of testicular origin, in blood plasma of boars. Acta Endocrinol. 94:404-411.

Coffey, R., Parker, G., Laurent, K., 1995. Management of swine mating. University of Kentucky, College of Agriculture Cooperative Extension Publication: 1-5.

Colenbrander, B., F.H. de Jong, and C.JU.G. Wensing. 1978. Changes in serum testosterone concentrations in the male pig during development. J. Reprod. Fertil. 53:377-380.

Cothren, J. 2012. What are the advantages of using artificial insemination in your livestock breeding program. North Carolina State University Cooperative Extension. http://wilkes.ces.ncsu.edu/2012/what-are-the-advantages-of -using-artificial-insemination-ai-in-your-livestock-breeding-program/ (Accessed 1 August 2013)

De Ambrogi, M. , J. Ballester, F. Saravia, I. Caballero, A. Johannisson, M. Walgren, M. Andersson, and H. Rodriguez-Martinez. 2006. Effect of storage in short-and long-term commercial semen extenders on the motility, plasma membrane and chromatin integrity of boar spermatozoa. International Journal of Andrology 29: 543-552.

Didion, B.A. 2008. Computer-assisted semen analysis and its utility for profiling boar semen samples. Theriogenology 63: 431-444.

Diehl, J.R., B.M. Day, and E.J. Stevermer. 1984. Artificial insemination in swine. Publication No. PIH 64, The Pork Industry Handbook, Purdue University, West Lafayette, IN.

Dorrington, J.H., I.B. Fritz, and D.T. Armstrong. 1978. Control of testicular estrogen synthesis. Biology of Reproduction. 18:55-64.

Drickamer, L.C., R.D. Arthur, and T.L. Rosenthal. 1997. Conception failure in swine: importance of the sex ratio of a female's birth litter and tests of other factors. J. Anim. Sci. 75: 2192-2196.

Dziuk, P. 1970. Estimation of optimum time for insemination of gilts and ewes by double-mating at certain times relative to ovulation. J. Reprod. Feril. 22:277-282.

Edwards, R.L., I.T. Omtvedt, E.J. Stephens, D.F. and G.W.A. Mahoney. 1968. Reproductive performance of gilts following heat stress prior to breeding and in early gestation. J. Anim. Sci. 27: 1634-1637.

Einarsson, S., A. Madej, V. Tsuma. 1996: The influence of stress on early pregnancy in the pig. Animal Reproduction Science 42: 165-172.

Ellendorff, F., N. Parvizi, D.K. Pomerantz, A. Hartjen, A. Konig, D. Smidt, and F. Elsaesser. 1975. Plasma luteinizing hormone and testosterone in the adult male pig: 24 hour fluctuations and the effect of copulation. J. Endocrinol. 67:403-410.

Elsaesser, F., F. Ellendorff, D.K. Ponerantz, N. Parvizi, and D. Smidt. 1976. Plasma levels of luteinizing hormone, progesterone, and 5α-dihydrotestosterone in male and female pigs during sexual maturation. J. Endocrinol. 68:347-348.

English, P., W. Smith, and A. MacLean. 1984. The sow: improving her efficiency. Farming Press Ltd., Ipswich, England.

Feder, H.H. and L.P. Morin. 1974. Suppression of lordosis in guinea pigs by ethamoxy-triphetol (MER-25) given at long intervals (34-46 hr) after estradiol benzoate treatment. Hormones and Behavior. 5:63-71.

Flor-Cruz, S.V. and K.R. Lapwood. 1978. A longitudinal study of pubertal development in boars investigation of the relationships between gonadal and epididymal development and plasma and luteinizing hormone and testosterone profiles. International Journal of Andrology. 1:317-330.

Flowers, W.L. 1997. Management of boar for efficient semen production. J. Repro. Fertil. 52:67-78.

Flowers, W.L. and H.D. Alhusen. 1992. Reproductive performance and estimates of labor requirements associated with combinations of artificial insemination and natural service in swine. J. Anim. Sci. 70:615-621.

Foote, R.H. 2002. The history of artificial insemination: selected notes and notables. J. Anim. Sci. 80:1-10.

Ford, J.J. and B.D. Schanbacher. 1977. Luteinizing hormone secretion and female lordosis behavior in male pigs. Endocrinology. 100:1033-1038.

Ford, J.J., R.K. Christensen, and R.R. Maurer. 1980. Serum testosterone concentrations in embryonic and fetal pigs during sexual differentiation. Biology of Reproduction. 23:583-587.

Fournier-Delpech, S. 1993. Acquisition of sperm fertility. In: (eds) C. Thibault, M.C. Leuasseur, and R.H.F. Hunter. Reproduction in Mammals and Man. Ellipses. pp. 369-386. Paris, France.

Frohlich, W. and B. Schenck. 1977. Effect of oestradiol-17β on Leydig cell function in rats. Acta Endocrinol. 84:58.

Fujii, J., K. Otsu, F. Zorzato, S. de Leon, V.K. Khanna, J.E. Weiler, P.J. O'Brien, and D.H. MacLennan. 1991. Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. Science. 253:448-451.

Gorski, R.A. 1971. Gonadal hormones and the perinatal development of neuroendocrine function. Frontiers in Endocrinology. 2:237-290.

Gray, R.C., B.N. Day, J.F. Lasley, and L.F. Tribble. 1971. Testosterone levels of boars at various ages. J. Anim. Sci. 33:124-126.

Hancock, J.L. and G.J.R. Howell. 1959. The collection of boar semen. Vet. Rec. 71:664-664.

Hanenberg, E.H.A.T.E.F Knol, and J.W.M. Merks.2001. Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs. Livest. Prod. Sci. 69: 179-186.

Haugan, T., O. Reksen, Y.T. Grohn, A.H. Gaustad, P.O. Hofmo. 2005. A retrospective study on effects of storage time of liquid boar semen on reproductive performance in Norwegian swine. Theriogenology 64: 891-901

Hay, W.H. 1981. Hormonal patterns in the adult boar. Ph.D. Dissertation, Auburn University.

Hazel, L.N. 1943. The genetic basis for constructing selection indexes. Genetics. 28:476-490.

Hemsworth, P.H. , and A.J. Tillbrook, 2007. Sexual behavior of male pigs. Hormones and Behavior 52 (Issue 1): 39-44.

Hennessy, D.P. 1987. A symposium: seasonal infertility in the pig. In: APSA Committee (Editors), Manipulating pig production, Australasian Pig Science Association, Werribee, Vic., Australia, pp.40-73

Holm, B., M. Bakken, G. Klemetsdal, and O. Vangen. 2004. Genetics correlations between reproduction and production traits in swine. J. Anim. Sci. 82:3458-3464.

Holt, C., W. V. Holt, H.D. Moore, H.C. Reed, R.M Curnock, 1997. Objectively measured boar sperm motility parameters correlate with the outcomes of on-farm insemination: results of two fertility trials. J. of Andrology 18(Issue 3): 312-323.

Huang Y.T. and R.K. Johnson. 1996. Effect of selection for size of testes in boars on semen and testis traits. J. Anim. Sci. 74: 750-760.

Hurtgen, J.P., A.D. Leman. 1979. Use of PMSG in the prevention of seasonal post-weaning and estrus in sows. Theriogenology. 12: 207-214.

Hypor. 2009. Impact of herd parity. http://www.hypor.com/en/Breeding/~media/Files/Hypor/Weaning%20Capacity%20Articles/English/WC10%20Impact%20of%20herd%20parity.ashx (Accessed July 22, 2013).

Ito, T. T. Niwa, and A. Kudo. 1948. Studies on artificial insemination in swine. Zootech. Exp. Sta. Res. Bull. 55:1-74

Ivanow, E. I. 1907. De la fecondation artidicielle chez les mammiferes. Arch.Sci. Biol. 12:377-511

Johnson, L.A., J.G. Aalbers, C.M.T. Willems, J.H.M. Roudemaker and C.E. Rexroad, Jr. 1982. Use of boar spermatozoa for artificial insemination III. Fecundity of boar spermatozoa stored in Beltsville Liquid and Kiev Extenders for three days at 18 C. J. Anim. Sci. 54: 132-136

Johnson, L.A., J.G. Aalbers, H.J.G. Grooten. 1988. Artificial insemination of swine: fecundity of boar semen stored in Beltsville TS BTS., modified modena (MM), or MR-A and inseminated on one, three and four days after collection. Zuchthygiene 23: 49-55.

Johnson, L.A., K.F. Weitze, P. Fiser, and W.M.C. Maxwell. 2000. Storage of boar semen. Anim. Reprod. Sci. 62:143-172.

Joshi, H.S. and J.I. Raeside. 1973. Synergistic effects of testosterone and oestergens on accessory sex glands and sexual behavior of the boar. J. Repro. Fertil. 33:411-423.

Juniewicz, P.E. and B.H. Johnson. 1982. Ability of cortisol and progesterone to mediate the stimulatory effect of adrenocorticotropic hormone upon testosterone production by the porcine testis. Biology of Reproduction. 30:134-142.

Kaeoket, K., W. Tantasuparuk and A. Kunavongkrit. 2005. The effect of post-ovulatory insemination on the subsequent oestrous cycle length, embryonic loss and vaginal discharge in sows. Reprod. Dom. Anim. 40: 492-494.

Kattesh, H.G., E.T. Kornegay, F.C. Gwazdauskas, J.W. Knight, and H.R. Thomas. 1979. Peripheral plasma testosterone concentration and sexual behavior in young prenatally stressed boars. Theriogenology. 12:289-305.

Kennedy, B.W. and J.N. Wilkins. 1984. Boar, breed and environmental factors influencing semen characteristics of boars used in artificial insemination. Can. J. Anim. Sci. 64: 833-843.

Kennelly, J.J, and R.H. Foote. 1964. Sampling boar testes to study spermatogenesis quantitatively and to predict sperm production. J. Anim. Sci. 23: 160-167.

Key, N., W. McBride. 2007. The changing economics of U.S. hog production. USDA: Economic Research Report 52: 1-38.

King, G.J., and J.W. Macpherson. 1973. A comparison of two methods for boar semen collection. J. Anim. Sci. 36: 563-565.

Koh, T.J., B.G. Crabo, H. L. Tsou, and E. F. Graham. 1976. Fertility of liquid boar semen as influenced by breed and season. J Animal Sci. 42: 138-144.

Koketsu, Y., and G.D., Dial. 1996. Factors influencing the postweaning reproductive performance of sows on commercial farms. Therogenology 47: 1445-1461.

Knox, R. 1999. Artificial insemination of swine: improving reproductive efficiency of the breeding herd. http://www.gov.mb.ca/agriculture/livestock/pork/pdf/bab13s04.pdf (Accessed 24 July 2013).

Knox, R., D. Levis, T. Safranski, and W. Singleton. 2008. An update on North American Boar stud practices. Theriogenology. 70:1202-1208.

Kruger, T.F., R. Menkueld, F.S. Stander, C.J. Lombard, J.P. van der Merwe, J.A. van Zyle, and K. Smith. 1986. Sperm morphologic features as a prognostic factor in in vitro fertilization. Fertility and Sterility. 46:1118-1123.

Kuster C.E. and G.C. Althouse. 1999. The fecundity of porcine semen stored for 2-6 days in androhep and X-cell extenders. Theriogenology 52: 365-376.

Kvist, U. and L. Bjorndahl, eds. 2002. Manual on basic semen analysis. ESHRE by Oxford Press University. Oxford, UK.

Landsverk, K. 2000. In: (eds) L.A. Johnson and H.D. Gutherie. Packaging and distribution-their impact on fertility. Proceedings of the 4th International Conference on Boar Semen Preservation. Pp. 137-139. Allen Press Inc. Lawrence, KS.

Lawrence, J. and G. Grimes. 2001. Production and marketing characteristics of U.S. Pork Producers. Iowa State University, Department of Economics. Ames, IA. http://www.econ.iastate.edu/faculty/lawrence/Acrobat/Staffppr343FNL.pdf (Accessed July 17, 2013)

Lellbach, C., C. Leiding, D. Rath, and B. Staehr. 2008. Effects of automated collection methods on semen quality and economic efficiency of boar semen production. Theriogenology. 70:1389.

Liptrap, R.M. and J.I. Raeside. 1978. A relationship between plasma concentrations of testosterone and corticosteroids during sexual and aggressive behavior in the boar. J. Endocrinol. 76:75-85.

Love, R.J. 1978. Definition of a seasonal infertility problem in pigs. Vet. Rec. 104: 238-240.

Love, R.J., G. Evans, and C. Klupiec. 1993. Seasonal effects on fertility in gilts and sows. J. Reprod. Feril. Suppl. 48:191-206.

Ludwig, G. and J. Frick. 1990. Spermatology: Atlas and manual. Springer-Verlag. New York, NY.

Mann, T. and C. Lutwak-Mann. 1981. Male reproductive function and semen. Springer-Verlag.

McKenzie, F. F. 1931. A method for collection of boar semen. J. Am. Vet. Med. Assoc. 78: 244-246.

Narendran, R., R.J. Etches, R.R. Hacker, and G.H. Bowman. 1982. Effect of sexual stimulation on concentrations of 5α-androsterone and testosterone in the peripheral plasma of boars housed individually. Elsevier. 4:227-235.

National Swine Registry. 2011. Tempel Genetics lauded for record performance. http://nationalswine.blogspot.com/2011/06 (Accessed July 24, 2013)

Nissen, A.K., N.M. Soede, P. Hyttel, M. Schmidt and L. D. Hoore. 1997. The influence of time of insemination relative to time of ovulation on farrowing frequency and litter size in sows, as investigated by ultrasonography. Theriogenology 47:1571-1582.

Nozu, K., A. Dehejia, L. Zawistowich, K.J. Catt, and M.L. Dufau. 1981. Gonadotropin-induced receptor regulation and steroidogenic lesions in cultured Leydig cells. J. of Biological Chemistry. 256: 12875-12882.

Oliveras, M.Y. 2008. New insights into boar sperm function and survival from integrated laboratory and field studies. PhD Diss. University of Girona.

Park, S. 2013. Effects of sow, boar and semen traits on sow reproduction. Masters of Science Thesis. University of Nebraska-Lincoln. Lincoln, NE.

Parrott, R.F. and W.D. Booth. 1984. Behavioral and morphological effects of 5α-dihydrotestosterone and oestradiol-17β in the prepubertally castrated boar. J. Reprod. Fertil. 71:453-461.

Patten, B.M. 1948. Embryology of the pig. Embryology of the pig 3rd ed. Philadelphia, PA: The Blakiston Company.

Peltoniemi, O.A., R.J Love, M. Heinonen, V. Tuovinen, H. Saloniemi. 1999. Seasonal and management effects on fertility of the sow: a descriptive study. Anim. Reprod. Sci. 55: 47-61.

Perez-Llano, B., J.L. Lorenzo, P. Yenes, A. Trejo, and P. Garcia-Casado. 2001. A short hypoosmotic swelling test for the prediction of boar sperm fertility. Theriogenology. 53:387-398.

Pinart, E., R. Camps, M. Biiz, S. Bonet, and J. Egozcue. 1998a. Unilateral spontaneous abdominal cryptorchidism: structural and ultrastructural study of sperm morphology. Animal Reproduction Science. 49:247-268.

Pinart, E., S. Sanchos, M. Briz, S. Bonet, and E. Badia. 1998b. Efficiency of the process of meiosis in scrotal testes of healthy boars and unilateral abdominal cryptorchid boars. Teratology. 60:209-214.

Polge, C. 1956. The development of artificial insemination service for pigs. Anim. Breed Abstr. 24: 209-217.

Raeside, J.I. 1965. Urinary excretion of dehydroepiandrosterone and oestrogens by the boar. Acta Endocrinol. 50:611-620.

Rasbech, N.O. 1984. The male and fertility and domestic animals. In: Court, M., ed. The male in farm animal reproduction. Martinus Nijoff Publishers. pp. 2-23. Dordrech, The Netherlands.

Reed, HCB, 1982: Artificial insemination. In: Cole, DJA., Foxcroft GR (eds), control of pig reproduction. Butterworths, London, 272-280.

Reilly, J.D., Roberts, A.J., 1992. An investigation into summer infertility in a commercial pig unit. Pig Vet. J. 27: 157–168.

Robinson, J.A.B. and M.M. Buhr. 2005. Impact of genetic selection on management of boar replacement. Theriogenology. 63: 668-678.

Rodriguez-Zas, S.L., C.B. Davis, P.N. Ellinger, G.D. Schnitkey, N.M. Romine, J.F. Connor, R.V. Knox and B.R. Southey. 2006. Impact of biological and economic variable on optimal parity for replacement in swine breed-to-wean herds. J. Anim. Sci. 84: 2555-2565.

Romanowicz, K., R. Stupnicki, B. Barcikowski, A. Madej, and M. Walach. 1976. Plasma testosterone and LH in growing boars. VIIIth Int. Cong. Anim. Reprod. 3:89.

Rommerts, F.F.G. and A.O. Brinkman. 1981. Modulation of steroidogenic activities in testes Leydig cells. Molecular and Cellular Endocrinology. 21:15-28.

Rothschild, M.F., L. Messer, A. Day, R. Wales, T. Short, O. Southwood, and G. Plastow. 1996. Investigation of the retinol-binding protein 4 (RBP4) gene as a candidate gene for increased litter size in pigs. Mammalian Genome. 11:75-77.

Rozeboom, K.J. 2000. Evaluating boar semen quality. Animal Science Facts ANS00-812S. www.ncsu.edu/project/swine_extension/publications/factsheets/812s.htm (Accessed May 23, 2013).

Safranski, T.J. 2008. Genetic selection of boars. Theriogenology 70 (Issue 8): 1310-1316.

Sanford, L.M., E.E. Swierstra, W.M. Palmer, and B.E. Howland. 1976. The profile of LH and testosterone secretion in the boar. Proc VIII Int Congr Anim Reprod AI. 3:96-99.

Serniene, L., V. Riskeviciene, B. Antanas, and H. Zilinskas. 2002. Effects of age and season on sperm qualitative parameters in Lithuanian white and Pietrain boars. Lithuanian Vet. Academy. 18: 3022.

Setchell, B.P. 1991. Male reproductive organs and semen. In: (ed) P.T. Cupps. Reproduction in Domestic Animals. Academic Press Inc. pp. 221-249. San Diego, CA.

Singleton, W.L. and B. Flowers. 2007. Managing boars in artificial insemination centers. Publication No. PIH 08-02-01, The Pork Industry Handbook. Purdue University. West Lafayette, IN.

Smital, J. 2009. Effects influencing boar semen. Animal Reproduction Science. 110:335-346.

Soede, N.M., C.C. Wetzels, W. Zonday, M.A. de Koning, and B. Kemp. 1995. Effects of time of insemination relative to ovulation as determined by ultrasonography, on fertilization rate and accessory sperm count in sows. J. Reprod. Fertil. 105:99-106.

Soede, N.M., and B. Kemp. 1997. Expression of oestrus and timing of ovulation in pigs. J. Reprod. Fertil. Suppl. 52: 91-103.

Soto, A. and C. Sonnenschein. 1979. Estrogen receptor levels in estrogen sensitive cells in culture. J. of Steroid Biochemistry. 11:1185-1190.

Speight, S. 2010. Growth performance, carcass traits, and reproductive characteristics in boars fed diets supplemented with an organic source of selenium. PhD Diss. Virginia Polytechnic Institute and State Univ., Blacksburg, VA.

Stork, M.G., 1979. Seasonal reproductive inefficiency in large pig breeding units in Britain. Vet. Rec. 104: 49–52.

Swine Genetics International. 2005. Online AI manual. http://www.swinegenetics.com/downloads/ai_manual.pdf (Accessed October 5, 2013)

Tan, H.S. and J.I. Raeside. 1980. Developmental patterns of plasma dehydroepiandrosterone sulfate and testosterone in male pigs. Animal Reproduction Science. 3:73-81.

Tast, A., O.A.T Peltoniemi, and J.V. Virolainen. 2002. Early disruption of pregnancy as a manifestation of seasonal infertility in pigs. Animal Reproduction Science 74c1:75-86.

Teaugue, J.S., W.L. Roller, and A.P. Grifo Jr. 1968. Influence of high temperature and humidity on the reproductive performance of swine. J. Anim. Sci. 27: 408-411.

Terlouw, S., C. Skimmet, T. Schlimgen, J. Schenck, E. James, G. Gunderson, and J. Dobrinsky. 2008. Comparison of AutoMate® and the gloved-hand method for boar semen collection. Theriogenology. 70:1388-1389.

Thibier, M., and O. Rolland. 1976. The effect of dexamethasone (DXM) on circulating testosterone (T) and luteinizing hormone (LH) in young postpubertal bulls. Theriogenology. 5:53-60.

Topel, D.G. and L.L. Christian. 1968. Porcine stress syndrome. Estonian Agricultural University, Tartu, Estonia.

Trudeau, V.L. and L.M. Sanford. 1989. Influence of season and social environment on the reproductive-endocrine status of the adult Landrace boar. Can. J. Anim. Sci. 70: 121-128.

Tummaruk, P., W. Tantasuparuk, M. Techakumphuk, and A. Kunavongkrit. 2004. Effect of season and outdoor climate on litter size at birth in purebred Landrace and Yorkshire sows in Thailand. J Vet. Med. Sci. 66: 477-482.

Velle, W. Isolation of oestrone and oestradiol-17 beta from the urine of adult boars. Acta Endocrinol. 28:255-261.

Vyt, P. D. Maes, E. Dejonckheere, F. Castryck, and A. Van soom. 2004. Comparative study on five different commercial extenders for boar semen. Reprod Domest Anim 39: 8-12.

Weitze, K.F. 2000. Update on the world wide application of swine AI. Boar Semen Preservation IV: 141-145.

Weitze, K.F. 2012. The importance of boar sperm motility and morphology for fertility. International Pig Topics. 27: 13-15.

WHO, World Health Organization. 2000. WHO Laboratory Manual for the Examination of Human Semen and Sperm-Cervical Mucus Interaction 4th Ed. Cambridge University Press. Cambridge, UK.

Woelders, H. 1990. Overview of in vitro methods for evaluation of semen quality. Proceedings of the 2nd International Conference on Boar Sperm Preservation. Pp. 145-164. Beltsville, MD.

Young, M.G, M.D. Tokach, F.X Aherne, S.S. Dritz, R.D. Goodband, J.L. Nelssen and T.M. Loughin. 2008. Effect of space allowance during rearing and selection criteria on performance of gilts over three parities in a commercial swine production system. J. Anim. Sci. 86: 3181-3193.

APPENDIX A

Table A.1: Least squares means for significant factors

Effect	Estimate	Error	t-value	P	Mean	SE
Service 1	1.2925	0.1273	10.15	<.0001	0.7771	0.02152
Service 2	1.9296	0.06589	29.29	<.0001	0.8664	0.007295
Service 3	2.0648	0.1542	13.39	<.0001	0.8813	0.01541
Season Hot	1.5390	0.1127	13.65	<.0001	0.8150	0.01640
Season Mild	1.9856	0.1019	19.48	<.0001	0.8736	0.01082
Parity 0	1.3389	0.1625	8.24	<.0001	0.7945	0.02673
Parity 1-2	1.7007	0.1142	14.89	<.0001	0.8383	0.01491
Parity 3-4	2.1051	0.1486	14.16	<.0001	0.8868	0.01439
Parity 5-6	1.9341	0.1770	10.93	<.0001	0.8667	0.01953
Parity 7+	1.7326	0.2478	6.99	<.0001	0.8415	0.03164
Boar Age (0.42 to 5 years)	-0.2829	0.08512	-3.32	<.0009		
Days from Collection to Insemination (linear)	-0.2425	0.04751	-5.11	<.0001		
Days from Collection to Insemination (quadratic)	0.02832	0.009972	2.84	0.0148		

Table A.2: Least squares means for interactions of number of services by season.

Effect	Service	Season	Estimate	Error	t-value	P >	Mean	SE
Number of Services by Season (SNS)	1	Hot	1.2687	0.1792	7.08	<.0001	0.7788	0.03070
Number of Services by Season (SNS)	2	Hot	1.7278	0.08416	20.53	<.0001	0.8467	0.01078
Number of Services by Season (SNS)	3	Hot	1.6205	0.2066	7.84	<.0001	0.8318	0.02848
Number of Services by Season (SNS)	1	Mild	1.3162	0.1439	9.14	<.0001	0.7904	0.02400
Number of Services by Season (SNS)	2	Mild	2.1315	0.07226	29.50	<.0001	0.8935	0.006852
Number of Services by Season (SNS)	3	Mild	2.5090	0.2066	12.14	<.0001	0.9273	0.01437

Hot Season = June-September

Mild Season = October-May

Table A.3: Least squares means for number of services by parity

Effect	Parity	Service	Estimate	Error	t-value	P	Mean	SE
Number of Services by Parity (PNS)	0	1	0.9552	0.1965	4.86	<.0001	0.7102	0.03942
Number of Services by Parity (PNS)	0	2	1.4289	0.1260	11.34	<.0001	0.8001	0.01965
Number of Services by Parity (PNS)	0	3	1.6325	0.3303	4.94	<.0001	0.8365	0.04518
Number of Services by Parity (PNS)	1-2	1	1.4255	0.1779	8.01	<.0001	0.8080	0.02779
Number of Services by Parity (PNS)	1-2	2	1.6227	0.08203	19.78	<.0001	0.8306	0.01129
Number of Services by Parity (PNS)	1-2	3	2.0539	0.2264	9.07	<.0001	0.8833	0.02281
Number of Services by Parity (PNS)	3-4	1	1.4840	0.2422	6.13	<.0001	0.8188	0.03649
Number of Services by Parity (PNS)	3-4	2	2.0650	0.08064	25.61	<.0001	0.8862	0.008055
Number of Services by Parity (PNS)	3-4	3	2.7663	0.3363	8.23	<.0001	0.9429	0.01872
Number of Services by Parity (PNS)	5-6	1	1.3024	0.2614	4.98	<.0001	0.7809	0.04392
Number of Services by Parity (PNS)	5-6	2	2.1754	0.1231	17.68	<.0001	0.8991	0.01127
Number of Services by Parity (PNS)	5-6	3	2.3246	0.3622	6.42	<.0001	0.9097	0.02940
Number of Services by Parity (PNS)	7+	1	1.2952	0.4019	3.22	0.0013	0.7945	0.06783
Number of Services by Parity (PNS)	7+	2	2.3561	0.1944	12.12	<.0001	0.9147	0.01537
Number of Services by Parity (PNS)	7+	3	1.5464	0.3986	3.88	0.0001	0.8298	0.05771

Table A.4: Correlation among collection metrics

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Total Sperm Volume			0.69	0.69	-0.58	0.00	0.01	0.00	0.00	0.03	0.01	0.03	0.03	0.00	0.00	0.00	0.75	0.75	0.69	0.05	0.02	-0.01
Semen Volume Used			0.69	0.69	-0.58	0.00	0.01	0.00	0.00	-0.03	0.01	0.03	0.03	0.00	0.00	0.00	0.75	0.75	0.69	0.05	0.02	-0.01
Doses Possible	0.69	0.69			0.01	0.06	0.04	-0.03	0.01	-0.02	0.03	0.05	0.05	-0.02	-0.02	-0.02	0.93	0.93	0.99	-0.28	-0.30	0.01
Doses Actual	0.69	0.69			0.01	0.06	0.04	-0.03	0.01	-0.02	0.03	0.05	0.05	-0.02	-0.02	-0.02	0.93	0.93	0.99	-0.28	-0.30	0.01
Sperm Concentration	-0.58	-0.58	0.01	0.01		0.02	0.02	-0.01	0.01	0.05	-0.01	0.03	0.02	-0.03	-0.03	-0.03	0.01	0.01	0.01	-0.02	-0.03	0.03
Composite	0.01	0.01	0.06	0.06	0.02		0.51	-0.04	-0.05	-0.03	0.06	0.00	0.03	-0.02	-0.02	-0.02	0,02	0.06	0.06	-0.09	0.01	-0.01
Motility	0.01	0.01	0.04	0.04	0.02	0.51		-0.06	-0.02	0.00	0.08	0.00	0.03	-0.03	-0.03	-0.03	0.03	0.05	0.04	-0.09	-0.05	0.02
Progressive	0.00	0.00	-0.03	-0.03	0.00	-0.04	-0.06		0.33	0.00	-0.02	0.04	0.01	-0.03	-0.03	-0.03	0.00	0.00	-0.03	0.11	0.04	0.01
Tails	0.00	0.00	0.01	0.01	0.01	-0.05	-0.02	0.33		0.01	-0.05	0.01	0.01	0.00	-0.01	-0.01	-0.02	0.02	0.01	0.01	0.01	-0.01
Distal	-0.03	-0.03	-0.02	-0.02	0.05	-0.03	0.00	0.00	0.01		-0.07	0.02	0.03	-0.02	-0.01	-0.01	-0.02	-0.02	-0.02	0.00	0.01	0.02
Proximal	0.01	0.01	0.03	0.03	-0.01	0.06	0.08	-0.02	-0.05	-0.07		-0.01	-0.01	-0.03	-0.03	-0.03	0.01	0.01	0.03	-0.04	-0.03	0.01
Days from Last Collection	0.03	0.03	0.05	0.05	0.03	0.00	0.00	0.04	0.00	0.02	0.00		-0.02	-0.01	-0.01	-0.01	0.05	0.05	0.05	0.02	0.01	0.02
Days from Collection to Insemination	0.03	0.03	0.05	0.05	0.02	0.03	0.03	0.01	0.01	0.03	-0.01	-0.02		-0.34	-0.36	-0.36	0.06	0.06	0.05	0.02	0.01	-0.07
Boar Age	0.00	0.00	-0.02	-0.02	-0.03	-0.02	-0.03	-0.03	-0.01	-0.02	-0.03	-0.01	-0.34		0.97	0.97	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02
Boar Actual Age	0.00	0.00	-0.02	-0.02	-0.03	-0.02	-0.03	-0.03	-0.01	-0.01	-0.03	-0.01	-0.36	0.97		0.99	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01
Boar Age in Months	0.00	0.00	-0.02	-0.02	-0.03	-0.02	-0.03	-0.03	-0.01	-0.01	-0.03	-0.01	-0.36	0.97	0.99		-0.02	-0.02	-0.02	-0.01	-0.01	-0.01
Total Number Sperm	0.75	0.75	0.93	0.93	0.01	0.02	0.03	0.00	0.02	-0.02	-0.01	0.05	0.06	-0.03	-0.02	-0.02		0.99	0.93	0.04	-0.02	0.00
Live Sperm	0.75	0.75	0.93	0.93	0.01	0.06	0.05	0.00	0.02	-0.02	0.01	0.05	0.06	-0.03	-0.02	-0.02	0.99		0.93	0.04	-0.02	0.00
Doses Made	0.69	0.69	0.99	0.99	0.01	0.06	0.04	-0.03	0.01	-0.02	0.03	0.05	0.05	-0.02	-0.02	-0.02	0.93	0.93		-0.28	-0.30	0.01
Dose Concentration	0.05	0.05	-0.28	-0.28	-0.02	-0.09	-0.09	0.11	0.01	0.00	-0.04	0.01	-0.02	-0.01	-0.01	-0.01	0.04	0.04	-0.27		0.99	-0.03
Effect. Dose Concentration	0.02	0.02	-0.30	-0.30	-0.03	0.01	-0.05	0.04	0.01	0.01	-0.04	0.01	0.01	-0.02	-0.01	-0.01	-0.02	-0.02	-0.30	0.99		-0.03
Pregnancy	-0.02	-0.02	0.01	0.01	0.03	-0.01	0.02	-0.01	-0.01	0.02	0.01	0.02	-0.07	-0.01	-0.01	-0.01	-0.01	0.00	0.01	-0.03	-0.01	

Table A.5: Correlation between collection metrics and litter traits

Trait	DC	DI	BA	BAA	BAM	TNS	LS	DM	DC2	EDC	Pr	TSV	SVU	DP	DA	SC	C	M	P	T	D
Number of Services	0.03	0.00	0.02	0.03	0.03	0.03	0.03	0.03	-0.01	0.01	0.05	0.04	0.04	0.03	0.03	-0.01	0.00	0.00	-0.01	0.00	0.01
Parity	0.00	-0.29	0.98	0.98	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.01	-0.02	-0.02	-0.01	-0.01
Total Born	0.00	-0.07	0.03	0.03	0.04	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	-0.02	-0.02	-0.01
Born Alive	-0.01	-0.05	-0.03	-0.03	-0.03	0.00	0.00	0.01	-0.01	-0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.02	-0.01	0.00	0.00
Birth Weight	-0.01	-0.02	-0.04	-0.03	-0.03	0.02	0.02	0.03	-0.02	-0.02	0.01	0.02	0.02	0.03	0.03	0.01	0.00	0.03	-0.01	0.00	0.00
Stillborn	0.00	-0.05	0.17	0.17	0.17	-0.01	-0.01	-0.01	0.00	0.00	0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	-0.03	-0.01	-0.02	0.00
Mummies	0.03	0.09	-0.11	-0.13	-0.13	0.05	0.05	0.05	0.00	0.00	0.02	0.03	0.03	0.05	0.05	0.00	0.03	0.02	-0.01	-0.02	-0.01
Boars	-0.02	-0.06	0.01	0.02	0.02	-0.03	-0.03	-0.02	-0.01	-0.02	-0.02	-0.03	-0.03	-0.02	-0.02	0.02	0.00	0.01	0.00	0.00	-0.01
Gilts	0.01	0.00	-0.05	-0.05	-0.05	0.03	0.03	0.03	0.01	0.01	0.02	0.04	0.04	0.03	0.03	-0.01	0.01	0.02	-0.01	0.00	0.01
Parity	0.00	-0.28	0.94	0.98	0.98	-0.01	-0.01	-0.01	-0.01	-0.02	0.03	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01
Number After Transfer	0.01	-0.02	0.00	0.00	0.00	0.02	0.02	0.03	-0.01	-0.02	0.01	0.02	0.02	0.03	0.03	0.00	0.00	-0.01	0.00	0.00	-0.01
Number Weaned	0.01	0.08	-0.10	-0.11	-0.11	0.05	0.05	0.05	-0.01	-0.01	0.01	0.06	0.06	0.04	0.04	-0.02	0.02	0.02	0.01	0.01	-0.01
Wean Weight	-0.03	0.03	-0.05	-0.06	-0.06	0.01	0.01	0.02	-0.02	-0.03	0.01	-0.01	-0.01	0.02	0.02	0.02	0.02	0.03	-0.01	0.00	-0.02
Weaned to Estrus	0.01	0.28	-0.13	-0.13	-0.13	0.02	0.02	0.02	0.00	0.01	0.01	0.02	0.02	0.02	0.02	-0.01	0.01	0.03	0.00	0.00	-0.01
Pregnant	0.02	-0.06	0.02	0.02	0.02	0.01	0.01	0.01	-0.01	-0.01		0.00	0.00	0.01	0.01	0.01	0.00	0.01	-0.01	-0.01	0.01

TSV=total sperm volume; SVU=semen volume used; DP=doses possible; DA=doses actual; SC=sperm concentration; C=composite; M=motility; P=progressive; T=tails; D=Distal; Pr=Proximal; DC=days from last collection; DI=days from collection to insemination; BA=boar age; BAA=boar actual age; BAM=boar age in months; TNS=total number sperm; LS=live sperm; DM=doses made; DC2=dose concentration; EDC=effective dose concentration

APPENDIX B

Table B.1: Solutions for fixed effects in a model used to predict probability of pregnancy

Effect	Season	Parity	N of Services	Coeff.	SE	P-Value
Intercept				2.8081	0.5063	<.0001
Number of Services (NS)			1	-0.6717	0.5235	0.1995
			2	0.524	0.3879	0.1768
			3	0		
Season (S)	Hot (Jun-Sept)			-0.9473	0.2719	0.0005
	Mild (Oct-May)			0		
Parity (P)		0		0.05259	0.5373	0.922
		1-2		0.4395	0.4634	0.3429
		3-4		1.2198	0.5052	0.0158
		5-6		0.7255	0.4968	0.1442
		7+		0		
Number of Services by Season (SNS)	Hot		1	0.8788	0.3241	0.0067
Number of Services by Season (SNS)	Hot		2	0.5287	0.2687	0.0491
Number of Services by Season (SNS)	Hot		3	0		
Number of Services by Season (SNS)	Mild		1	0		
Number of Services by Season (SNS)	Mild		2	0		
Number of Services by Season (SNS)	Mild		3	0		
Number of Services by Parity (PNS)		0	1	-0.5084	0.6061	0.4016
Number of Services by Parity (PNS)		0	2	-1.0381	0.4768	0.0295
Number of Services by Parity (PNS)		0	3	0		
Number of Services by Parity (PNS)		1-2	1	-0.3541	0.5653	0.531
Number of Services by Parity (PNS)		1-2	2	-1.2221	0.4208	0.0037
Number of Services by Parity (PNS)		1-2	3	0		
Number of Services by Parity (PNS)		3-4	1	-1.0633	0.6399	0.0966
Number of Services by Parity (PNS)		3-4	2	-1.5402	0.4915	0.0017
Number of Services by Parity (PNS)		3-4	3			
Number of Services by Parity (PNS)		5-6	1	-0.8064	0.6486	0.2138
Number of Services by Parity (PNS)		5-6	2	-0.911	0.5013	0.0692
Number of Services by Parity (PNS)		5-6	3	0		
Number of Services by Parity (PNS)		7+	1	0		
Number of Services by Parity (PNS)		7+	2	0		
Number of Services by Parity (PNS)		7+	3	0		
Age of Boar by Years (B) (linear)				-0.3137	0.08404	0.0002
Days of Collection to Insemination (D) (linear)				-0.2146	0.04564	<.0001
Days of Collection to Insemination (D^2) (quadratic)				0.02379	0.00976	0.0148