INTRODUCTION

Three aspects of breeding herd management that can affect the bottom line of the pork industry and allow immediate savings in input costs will be summarized in this presentation. The first deals with critical factors that influence longevity of the sow in the breeding herd and the place of improved gilt development programs in addressing this issue. Large variation exists with respect to the successful introduction and retention of high value replacement gilts into the herd (Culbertson, 2008). On average, approximately 50% of sows are culled and replaced every year and wean only 30 to 40 piglets per sow lifetime. Furthermore, nearly 20% of premature culling of females from the breeding herd occurs at parity 0, with 65% of these culls attributed to reproductive disorders or failure (Lucia et al., 2000; PigChamp, 2006; Gill, 2007; Engblom et al., 2008). Developing management practices that produce gilts with the greatest potential lifetime performance is crucial to the productivity of conventional production systems. Even minor improvements in gilt management can lead to major lines already available. To realize the greatest production from sows in the breeding herd, producers in today’s swine industry must continue to specialize production efforts and enhance their managerial focus on finer details (Tonsor and Dhuyvetter, 2008). Excellent lifetime performance of sows in the breeding herd is achievable with attention to good management. However, these targets can only be achieved by recognizing the key physiological characteristics of contemporary dam-line females, and particularly their exceptional lean growth potential.

The second topic for consideration is the increased variability in grow-finish performance that can be clearly linked back to different litter birth weight phenotypes in populations of mature sows that have been selected for an overall increase in prolificacy (Foxcroft et al., 2007). Much of this variance in growth performance after birth may be pre-programmed during fetal development of the litter in the uterus (see Foxcroft and Town, 2004) and become most evident in the
late grower and early finisher stage of production. From a practical perspective, sorting pigs by weight at the nursery and grower stages will not resolve inherent variation in growth performance that is still a characteristic of particular pigs or litters. For the purposes of this review, we will advance the argument that recognizing and managing differences in birth weight and post-natal growth potential between, rather than within, litters offers the greatest potential for cost savings in the immediate future. As background information for considering production practices that might address increased variation in grow-finish performance, the major sources of variance in pig birth weight will be identified and related back to associations with prenatal programming of postnatal development. We will also briefly review possible production strategies that might address the concerns raised and trans-generational issues that are relevant to selection of replacement gilts and boars at multiplication level.

The third topic centres around the need to improve the genetic impact of elite sires in the pork industry relative to other domestic species. The overall production efficiency of the breeding herd is highly dependent on 1) the reproductive capacity (fertility) of the boars used for natural mating or AI and 2) the genetic merit of the boars for the performance of terminal line offspring. Because of the polygamous structure of swine production, poor quality boars will affect the reproductive outcome of numerous females. In the case of artificial insemination (AI) this could be thousands of females. Although we instinctively know that not all boars and ejaculates from those boars are of equal quality, the effectiveness of standard semen analysis used in commercial boar studs is limited compared to other food-animal species. Furthermore, current practices of using large numbers of sperm per litter produced in the North and South American swine industry also limits the genetic impact of superior sires. Collectively, these inefficiencies in AI use in the pork industry represent a major disadvantage to pork producers in a global food-animal marketplace and options for addressing these issues will be discussed.

**MANAGEMENT OF THE GILT AND SOW**

Producers should set high targets with respect to anticipated gilt performance. Realistic performance targets should be >86% farrowing rates (highest in the herd), >12.5 total born, >70% of gilts served farrowing the 3rd litter, no “2nd parity dip”, and >50 pigs weaned lifetime (Sporke, 2006). Measures of sow longevity include parity at removal, days in herd at removal, lifetime pigs born or weaned, removal rate, culling rate, replacement rate and parity distribution. Heritability of sow longevity is moderate at best (Stalder et al., 2007). Therefore, improvements to sow longevity must be achieved by other means.

Longevity, in terms of parities in production, is also maximized in females that are mated at a younger age. Gilts initially bred >10 months of age were less efficient, produced fewer pigs born alive per sow lifetime, were culled sooner, and showed a negative economic return over their economic lifetime (Culbertson and Mabry,
Typically, most sow removals occur in the lower parities (ranging from 3.1 to 4.6), are unplanned, and primarily due to reproductive failure; only a smaller proportion of culls are due to lameness and/or locomotive problems (Engblom et al., 2008). At least three parities are required from a sow before there is positive cash flow to a producer (as reviewed by Engblom et al., 2008).

Key risk factors for longevity. Improving sow longevity, herd stability, and maximizing lifetime performance in the sow herd represents a significant challenge that is best addressed in the GDU, by maintaining a constant input of high quality gilts into the breeding herd (the “push” concept of gilt replacement management). However, there are two key risk factors which, if not addressed by appropriate GDU management, will adversely affect lifetime productivity and overall profitability:

1) Selection of gilts with the greatest lifetime reproductive potential, and
2) Inappropriate management for body state and sexual maturity.

Selection of gilts with the greatest lifetime reproductive potential. Ideal production benchmarks for sow retention and herd parity structure indicate that 86% of “selected” gilts should farrow at least one litter, no more than 10% fallout should occur in each subsequent parity and approximately 70% of sows should farrow three litters (Kummer, 2008). Kummer (2005) showed that this target is achievable. In a controlled trial on GDU management run in collaboration with the Prairie Swine Centre Inc. (Patterson et al., 2008), approximately 60 and 50% of Select and Non-select gilts, respectively, farrowed three litters (Figure 1). Non-select gilts were removed from the herd at a higher rate than Select gilts (17.8%

Figure 1. Percentage of Select vs Non-Select gilts farrowing three litters (Patterson et al., 2008).
vs 14.3%, respectively) as reflected by the slope of the retention line. Culbertson (2008) reported that after third parity the overall retention rate improves, supporting the view that problems with young female retention are the driver of unacceptable replacement rates. Clearly, a key area for improvement is from gilt entry until farrowing the third litter, with a special focus on those gilts that never farrow a litter and that are 100% unproductive in their lifetime.

Inappropriate management for body state and sexual maturity. Gilts that do not have sufficient body condition when they are first selected and introduced to the farm generally fail to achieve a reasonable number of parities (Close and Cole, 2001). Experimental data and cost/benefit analysis clearly indicate that breeding on the basis of weight (135 – 150 kg) and recorded heat-no-serve (2nd or 3rd estrus) is the most cost-effective strategy. Breeding on the basis of age alone is considered to be an inappropriate and an inadequate benchmark. For example, in the study for which data are shown in Figure 1, 40 days of boar stimulation from a pen average of 140 days resulted in nearly 60 days variance in age at puberty, a 75 kg variation in body weight at first estrus, and the need to breed gilts at anywhere from 1st to 6th estrus if set breeding weight targets were to be met. Kummer (2005) reported that breeding faster growing gilts at similar weights, but at a younger age did not have repercussions for performance over three parities. According to Williams et al. (2005) reported that gilts weighing less than 135 kg have fewer total pigs born over 3 parities than gilts weighing over 135 kg. However, there was no further increase in total born for gilts bred between 135 and 170 kg, indicating there is no productive advantage to breed gilts at heavier weights. In fact, in two different studies (Williams et al., 2005; Amaral Filha et al. 2009) a higher percentage of gilts bred at greater than 170 kg were culled due to lameness prior to reaching 3 parities.

To meet these critical targets for breeding weight, a recorded gilt weight either at the onset of boar stimulation, or at the time of pubertal estrus, is one of the key non-negotiables of effective GDU management. Use of a weigh scale should be obligatory within the GDU or could be replaced by the simpler, but effective use of gilt “weight tapes”. These tapes involve the application of established allometric growth curves that show a high correlation between heart girth circumference and body weight (Pasternak et al., 2008; Figure 2). This estimation will allow producers to better manage gilt development for improved lifetime performance.

Physiological age (number of estrous cycles) at breeding is more important than chronological age at mating (a function of management practices). Early stimulation of gilts permits producers to take advantage of the increased productivity of gilts bred at second or third estrus. Generally, delaying breeding from 1st to 2nd estrus gives a 0.7 pig increase in first litter size. In contrast, delaying breeding from 2nd to 3rd estrus only increases litter size by 0.2 pigs for the same extra cost. Therefore, breeding should only be delayed to 3rd estrus in order to achieve acceptable breeding weights. Physical movement of gilts in the immediate
Weaned sow management

Changing relationships between lactational catabolism, the primary inhibitory effects of suckling, and reproductive performance of sows after weaning are becoming increasingly apparent. In the past, weaning-to-estrus intervals (WEI) were reported to be delayed by short lactation length, litter size weaned, season, nutrition, and management practices. However, in today’s well managed sow farms, approaching 90% of sows can be detected in estrus within 3 to 5 days after weaning and pregnancy rates in these sows can be better than 90% (see Table 1). Even after periods of experimentally induced feed restriction (up to 50% reduction in feed allowance during the last week of lactation), in primiparous sows used in a recent study, only marginal effects on WEI, and no effects on ovulation rate or numbers of embryos surviving to day 29 of gestation, were detected (Table 1). However, embryonic weight was lower in previously feed restricted sows. Collectively, the results of our recent studies suggest that although modern, primiparous sows can be consistently bred soon after weaning, the emerging pre-ovulatory follicles are of poorer quality, which may affect both the number and quality of pigs born.

Figure 2. Relationship between Heart Girth and Body weight for two technicians separately. The linear regression equations for each data set overlap one another and have similar slopes and intercepts (Pasternak et al., 2008).
Options for contemporary weaned sow management. Given the positive responses in lower parity sows reported previously (Clowes et al., 1994); skip-a-heat breeding still seems to be a possible technique to consider. We have also begun to re-evaluate the use of the oral progesteragens for delaying post-weaning estrus and the role PG600 treatment at weaning in contemporary dam-lines. However, when considering the application of any of these technologies, the key factor driving the adoption of alternative management strategies in contemporary weaned sows should be a cost-benefit analysis of the trade-off between high pregnancy rates and minimal NPD after weaning in untreated sows, compared to the cost of extra NPD incurred by delaying post-weaning estrus but improving the number and quality of pigs born.

IMPACTS OF PRENATAL PROGRAMMING ON EFFICIENCY OF PORK PRODUCTION SYSTEMS

The origins of increased between-litter variation in birth weight has been studied using retrospective analysis of available phenotypic data from large breeding nucleus populations (Smit 2007), and collection of individual litter data in studies in well defined commercial sow populations (Patterson et al., 2008). Litter birth weight and between-litter variance in average litter birth weight were both consistently lower in the largest litters (> 15 total born) in these populations (see Figure 3), analogous to the situation in hyper-prolific sows discussed elsewhere (Foxcroft et al., 2007). This suggests that the birth weight of most pigs born in litters >15 is relatively low because the threshold of uterine capacity for supporting pigs within the upper percentiles of birth weight (1.6 to over 2.0 kg) is around 15 fetuses. At the other extreme, in litters of <10 pigs, low average litter birth weight should not be due to limited uterine capacity, unless high ovulation rates combined with high peri-implantation embryonic survival resulted in very serious limitations in placental development. As is evident in Figure 3, in the population of litters with

<table>
<thead>
<tr>
<th>Item</th>
<th>CON (N=57)</th>
<th>RES (N=59)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEI (days)</td>
<td>4.97 ± 0.14</td>
<td>5.44 ± 0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>Breeding rate (of sows weaned)</td>
<td>89.5</td>
<td>86.4</td>
<td>0.62</td>
</tr>
<tr>
<td>Pregnancy rate (of sows bred)</td>
<td>94.4</td>
<td>100.0</td>
<td>0.57</td>
</tr>
<tr>
<td>Ovulation rate</td>
<td>19.7 ± 0.4</td>
<td>20.4 ± 0.4</td>
<td>0.30</td>
</tr>
<tr>
<td>No. of live embryos</td>
<td>13.7 ± 0.4</td>
<td>14.3 ± 0.4</td>
<td>0.32</td>
</tr>
<tr>
<td>Embryonic survival (%)</td>
<td>69.8 ± 2.2</td>
<td>71.7 ± 2.3</td>
<td>0.54</td>
</tr>
<tr>
<td>Embryo weight (g)</td>
<td>1.55 ± 0.04</td>
<td>1.43 ± 0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Embryo crown-rump length (mm)</td>
<td>25.3 ± 0.2</td>
<td>24.7 ± 0.2</td>
<td>0.07</td>
</tr>
<tr>
<td>Placental fluid volume (ml)</td>
<td>223 ± 5</td>
<td>215 ± 5</td>
<td>0.28</td>
</tr>
</tbody>
</table>
between 10 and 15 total pigs born, large variation in average litter birth weight existed, independent of litter size, confirming the earlier report of Smit (2007).

The concept that low average birth weight is associated with characteristic effects of Intra-Uterine Growth Restriction (IUGR), and linked to effects of intra-uterine crowding on placental development in early gestation in “crowded” litters, was further explored by performing necropsies on still-born pigs born in a proportion of the litters represented in Figure 3, and by estimating average placental weight immediately after farrowing in these litters. An inverse relationship between average litter birth weight and wet placental weight, and between average litter birth weight and organ weights, supports the concept that low birth weight litters show characteristics of IUGR that was associated with limited placental development. Based on the prevalence of high ovulation rates, and an average of 15.7 and 17.3 embryos at day 30 in the parity 2-3 and 4-6 sows reported by Patterson et al. (2008), these data are considered to support the principal hypothesis driving our ongoing research “that changing dynamics of pre-natal loss of embryos in contemporary commercial sow populations limits placental development and indirectly causes IUGR” and that in this situation “IUGR is a characteristic of entire low birth weight litters”.

Repeatability of the litter phenotype phenomenon. If the industry seeks to manage differences in litter birth weight as a means of optimizing the efficiency of grow-finish performance stages of production and marketing strategies, the

**Figure 3.** Relation between litter average birth weight and litter size estimated in a nucleus sow population. Repeat measures of the two most extreme sows for litter average birth weight are plotted. (from Knol et al., 2010)
repeatability of this GxE (genetics x environment) interaction becomes a critical issue. This question was addressed in the recent presentation by Knol et al. (2010) at the Banff Pork Seminar. Figure 3 shows litter average birth weights of sows at different litter sizes.

The sow with the highest estimate for litter average birth weight corrected for litter size had four litters and the different litters born to this sow are connected with a line. These data suggest that there are sows which repeatedly produce large litters of heavy piglets. In this sow phenotype we assume that an ideal balance between uterine capacity and the size of the litter developing in utero has inadvertently been realized. In the near future it should be possible to link this defined and optimal phenotype to genomic markers for this complex and polygenic trait, using recently available pig SNIP chip technology. In the longer-term this will allow more effective selection for both prolificacy and litter quality in traditional genetic selection programs. The same approach is taken in Figure 3 in identifying seven litters born to a sow representing the lowest litter average birth weight in this population of litters. Again, the low litter birth weight phenotype seems to be predictable. Evidence for about 60% repeatability of a low litter birth weight phenotype was also obtained from preliminary results from a major collaborative study with JBS-United in the USA (Joel Spencer and Miranda Smit, personal communications). If low average litter birth weight can be predicted on the basis of data from early sow farrowings, this offers opportunities to manage litter flows through the nursery and grow-finish stages in a cost effective manner.

**Implications for segregated production systems**

As intensive pork production systems continue to evolve, more attention is being paid to the concept of segregated management systems. As reviewed by Moore (2005), the origins of segregated parity management systems vary, and have initially been directed to improving the management of the gilt and first litter sow. Increasingly, segregation involves separation of sub-populations on the basis of their susceptibility to disease challenges. Furthermore, Deen (2005) discussed the risk factors associated with offspring born in the lower percentile of birth weights per se. By definition, the proportion of offspring from gilts litters falling into these lower weight percentiles is higher. However, the progeny of higher parity, hyper-prolific, sows are also apparently at increased risk of producing litters that have been exposed to adverse prenatal programming. Developmental limitations will be associated with low average litter birth weights, and at least this population of litters could be designated to segregated production flows at the nursery and grow-finish stages. There is good reason to think that segregated management of these offspring in the farrowing room and nursery will also bring overall improvements in production efficiency.
BREEDING PROGRAMS TO INCREASE THE GENETIC IMPACT OF AI BOARS

Strategic advantages resulting from improved evaluation of boar fertility

Opportunities to improve the impact of elite sire genetics on the efficiency of the pork industry are founded on three basic assumptions:

1. Using sub-fertile boars and low quality ejaculates reduces production efficiency.
2. Using pooled semen from poorly defined males breaks the link between known genetic value of individual boars and the paternity of progeny produced.
3. The excessive number of sperm used per litter born (probably over 9 billion sperm using current practices), and hence the high numbers of boars needed for semen production, reduces the genetic impact of our best boars compared to the limited number of elite sires used for meat and milk production in the beef and dairy industries.

The ultimate measures of boar performance in standard production records are pregnancy rate and litter size born. However, these are retrospective measures of boar fertility and can be highly influenced by breeding management and the quality of the gilts and sows bred (Colenbrander et al., 2003). Boar stud managers have come to accept that a combination of a thorough physical examinations of the boar and conventional semen evaluation (concentration, morphology, motility) can provide an alternative to actual fertility data (Gibson, 1989). While these evaluations can establish that an animal is either sub-fertile or infertile, they cannot identify the relative fertility of boars that meet accepted industry standards for sperm and ejaculate quality (Ruiz-Sanchez et al., 2006). However, the “predictors of useable semen” currently applied in most commercial AI centers provide a very conservative estimate of the relative fertility of individual boars. The relatively high sperm numbers used in commercial AI practice (usually more than 3 billion total sperm per dose of extended semen), and the pooling of semen from boars that may have inherently different fertility, masks the reduced fertility that can be demonstrated in some of these boars when lower numbers of sperm are used for AI, or if boars are used on an individual basis.

As discussed by other reviewers, if the full economic impact of the highest genetically indexed boars is to be realized in the pork industry, the number of gilts and sows bred per boar must be maximized (Gerrits et al., 2005). A number of innovations in insemination technology, including post-cervical (Watson and Behan, 2002) and deep-uterine (Vazquez et al., 2005) insemination are conducive to the use of lower sperm numbers per insemination. The further possibility of using controlled ovulation techniques to achieve single fixed-time insemination.
protocols (Baer and Bilkei, 2004; Cassar et al., 2005) would also substantially increase the utilization of genetically superior boars.

Effective predictors of relative boar fertility are essential and will allow removal of less fertile boars from commercial studs. This in turn will optimize the use of proven, high fertility, and genetically high indexed boars at lower sperm numbers per AI dose. At the nucleus level this will allow for increased selection pressure by increasing the number of offspring bred per collection from high ranking boars. At the level of terminal line production, this would allow considerable improvements in production efficiency to be realized, by capitalizing on boars with a high index for traits such as growth rate, feed conversion efficiency and the carcass characteristics of their progeny. Even if the same costs were paid in genetic royalties, by purchasing fewer total doses of semen from genetically superior boars, the cost benefits realized by producers in grow-finish performance of the progeny and the value of the carcass sold would nevertheless be very positive.

However, if these changes in production strategy are to be realized, it is critical to identify boars of relatively low fertility when used in the more challenging situation of reduced sperm numbers per AI dose or per insemination. The very definition of “useable semen” changes in this more demanding context.

**Approaches to boar semen evaluation**

There is a long history behind the search to find a single or combination of tests that can accurately predict male fertility from a semen sample (Amann, 1989). Unfortunately, there appears to be no simple answer to this very complex question (Rodriguez-Martinez, 2003). Braundmeier and Miller (2001) reviewed a number of functional and molecular tests used to assess male fertility. In this review they described two different sperm traits that affect fertility.

- **Compensable** traits are those that can be overcome by introducing large numbers of sperm during insemination. Problems with motility and morphology will reduce the number of sperm that are able to reach the oocyte, but by introducing large numbers of sperm the reduction in fertility can be minimized.
- **Uncompensable** traits are those that cannot be overcome by introducing larger numbers of sperm. These defects affect fertilization and embryo development and include nuclear vacuoles, sperm chromatin structure and morphological problems that do not inhibit movement.

Therefore, to effectively predict fertility, it is essential to discriminate between compensable and uncompensable traits in an ejaculate. Conversely, evaluation of relative boar fertility in vivo using high sperm numbers per dose (e.g. 3 billion sperm) will mask compensable traits and will not allow the industry to identify boars that can be used in more demanding applications of AI.
The data from Ruiz-Sanchez et al. (2006) shown in Table 2 suggest that existing analyses are inadequate for predicting relative fertility in healthy boars with ejaculate quality that meets normal industry standards (>70% motility and <30% abnormal sperm), confirming similar conclusions by Flowers (1997) and Alm et al. (2006). As in the study of Ruiz-Sanchez et al. (2006), differences in relative fertility become increasingly evident when low sperm doses (<2.5 billion sperm) are used for AI (Tardif et al., 1999; Watson and Behan, 2002; Ardon et al., 2003).

Table 2. Fertility data collected from the nine boars bred to gilts over a three-month evaluation period using 1.5 billion sperm per AI dose. (From Ruiz-Sanchez et al., 2006)

<table>
<thead>
<tr>
<th>Boar</th>
<th>Farrowing Rate (%)</th>
<th>Total born</th>
<th>Fertility index</th>
<th>Motility day 3</th>
<th>Motility day 7</th>
<th>Motility day 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-2</td>
<td>98</td>
<td>11.7±0.4 a</td>
<td>11.4±0.6 a</td>
<td>79 ± 1.3 a</td>
<td>71 ± 1.9 a</td>
<td>60 ± 2.0 a</td>
</tr>
<tr>
<td>Y-2</td>
<td>89</td>
<td>12.0±0.5 a</td>
<td>10.9±0.6 a</td>
<td>77 ± 1.3 ab</td>
<td>70 ± 1.9 a</td>
<td>61 ± 2.0 a</td>
</tr>
<tr>
<td>Pu-3</td>
<td>91</td>
<td>11.2±0.5 abc</td>
<td>10.2±0.6 b</td>
<td>72 ± 1.3 bc</td>
<td>64 ± 1.9 abc</td>
<td>55 ± 2.1 ab</td>
</tr>
<tr>
<td>B-1</td>
<td>94</td>
<td>10.7±0.5 a</td>
<td>10.2±0.6 ab</td>
<td>71 ± 1.3 b</td>
<td>61 ± 1.9 bc</td>
<td>52 ± 2.3 abc</td>
</tr>
<tr>
<td>R-3</td>
<td>95</td>
<td>10.9±0.4 a</td>
<td>10.1±0.6 ab</td>
<td>76 ± 1.3 ab</td>
<td>67 ± 1.8 ab</td>
<td>60 ± 2.1 a</td>
</tr>
<tr>
<td>G-2</td>
<td>91</td>
<td>10.1±0.5 a</td>
<td>9.5±0.6 abc</td>
<td>76 ± 1.3 ab</td>
<td>67 ± 1.8 ab</td>
<td>55 ± 2.0 ab</td>
</tr>
<tr>
<td>B-3</td>
<td>93</td>
<td>9.6±0.5 cd</td>
<td>8.8±0.6 abc</td>
<td>73 ± 1.3 abc</td>
<td>66 ± 1.9 ab</td>
<td>59 ± 2.1 a</td>
</tr>
<tr>
<td>R-1</td>
<td>84</td>
<td>10.0±0.4 bcd</td>
<td>8.4±0.6 bc</td>
<td>62 ± 1.5 d</td>
<td>55 ± 2.0 c</td>
<td>47 ± 2.5 bc</td>
</tr>
<tr>
<td>G-1</td>
<td>71</td>
<td>8.4±0.6 d</td>
<td>6.0±0.6 c</td>
<td>69 ± 1.3 c</td>
<td>59 ± 1.9 bc</td>
<td>42 ± 2.3 c</td>
</tr>
</tbody>
</table>

P: probability of main effect of boar
abcd: LSM with different superscripts within each column differ (P <0.05).
Values in the table are least means (LSM) ± standard errors (SE) of LSM.

Although numerous other potential markers of semen quality and boar fertility have been investigated (see reviews of Foxcroft et al., 2008) and might eventually simplify the evaluation process, sufficient information already exists on which to make dramatic improvements in AI technology in the pork industry.

Evidence for differences in relative boar fertility in commercial studs

The almost universal use of pooled semen doses in commercial boar studs severely limits the collection of data on relative boar fertility at production level. However, the limited data available continues to suggest a substantial range of fertility exists in contemporary populations of boars. Indeed, in the absence of routine procedures for identifying relative boar fertility, and hence an ability to effectively select stud boars for relative fertility at a genetic nucleus level, a normal distribution of fertility traits should be expected. In recent discussions of overall breeding herd performance (Billy Flowers – personal communication) the point has also been made that limitations in AI technology may lead the industry to continually
underestimate the existing productivity of contemporary commercial dam-lines. All these points are evident in recent data obtained from single-sire matings at the multiplication level (Figure 4).

**Figure 4.** Data on litter size born in sows bred to commercial Landrace boars using single-sire matings with 3 billion sperm per AI dose. (Tony Chandaruk - Personal communication)

These results indicate that the productivity of the top two thirds of these boars is very high, and at an average of over 13 pigs total born, would allow ambitious targets for breeding herd performance to be achieved. However, when the productivity of the lower one third of these boars is included, overall productivity falls by over one pig born. This relatively inferior performance of 20 to 30% of boars evaluated is consistent with the more extensive data presented in Table 2. Moreover, if the genetic merit of the three boars in Figure 4 that averaged over 14 total born was high, the application of more efficient AI technologies would allow the merits of these “elite” boars to spread across a larger proportion of sows bred. However, in current AI practice, these substantial differences in boar productivity and the link to known progeny produced by individual boars are confounded by 1) the use of pooled semen and 2) high sperm numbers per AI dose.

**The problem of pooling semen when trying to optimize production efficiency**

In one recent preliminary study, we evaluated the performance of two boars which routinely met our normal criteria for acceptable semen quality (better than 80% motility and <15% abnormal sperm). Both boars had a history of good fertility when used in experiments requiring adequate numbers of pooled semen doses to normalize any confounding “boar effect” on the fertility of gilts and sows allocated to different experimental treatments. Before going on to use these boars for homospermic (single sire) inseminations in later studies, we evaluated the
performance of two of these boars (Blue and Red) using both pooled and homospermic AI protocols. In all cases, a total of 2 billion sperm per AI dose were used. As shown in Table 3, both boars were very productive in single-sire inseminations and in pooled semen also performed well. There was, nevertheless, a 2.5 pig difference in total embryos at day 30 of gestation between these boars, due to 10% difference in either fertilization rate and/or embryonic survival to this stage of pregnancy, and the outstanding performance of the most fertile (Blue) boar was masked by using pooled semen. Overall, adoption of a single sire (homospermic) AI strategy would improve the total numbers of pigs born, by allowing the Blue boar to express his true potential. It seems reasonable to assume that a similar “averaging effect” would result from the pooling of semen from the best boars shown in Figure 4 with less productive boars in this population.

Table 3. Results from two fertile boars when used in homospermic or heterospermic AI protocols with 2 billion sperm per AI dose. (SRTC – unpublished data, 2009)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pooled Doses</th>
<th>Blue Boar – Single-Sire AI</th>
<th>Red Boar – Single-Sire AI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of breedings</td>
<td>32</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Ovulation rate of sows bred</td>
<td>20.3</td>
<td>20.7</td>
<td>20.3</td>
</tr>
<tr>
<td>Live embryos at d30</td>
<td>15.2</td>
<td>17.7</td>
<td>15.0</td>
</tr>
<tr>
<td>Embryo survival at d30 (%)</td>
<td>75</td>
<td>85</td>
<td>75</td>
</tr>
</tbody>
</table>

Simply from the perspective of optimizing breeding herd productivity, a move to single-sire AI programs seems to be justified. The very best boars will express their real potential, and overall herd productivity appears to increase. Furthermore, the small percentage of very inferior boars will quickly be identified and can be removed from commercial production. In time, it is realistic to suggest that both phenotypic and genomic markers will be developed that can be used prospectively to remove inferior boars before they are extensively used for commercial AI. However, the data presented above suggest that progress can be made by adopting single-sire mating strategies and evaluating boars on the basis of routine production criteria.

Application of fixed-time AI programs to optimize genetic transfer

Putting all the above information together, the logical conclusion about future developments in AI technology would be a move to single-sire inseminations with the lowest possible doses of semen using ejaculates from boars with high genetic value and proven fertility in a “low semen dose” environment. As in other domestic species, the logical way to achieve this outcome is with the introduction of single fixed-time AI programs. The substantial body of data describing the development of hormone treatment protocols for induced ovulation in the pig was extensively reviewed by Brüssow et al. (2009). Linked to this discussion is the interesting
conclusion that contemporary commercial sows in well managed breeding herds show increasingly less variation in the weaning-to-estrus interval and may not even show a clear response to eCG treatment at weaning (Patterson et al., 2009). As a result, there are already reports of acceptable outcomes when implementing a single intervention strategy with either pLH (Zak et al., 2009) or GnRH (Johnson et al., 2009) to induce ovulation in sows at a fixed time after weaning (see Table 4).

Table 4. Fertility of sows bred by 10 days post-weaning (21-d lactation and average 10.7 pigs weaned) as Controls (no treatment) or after synchronization of ovulation with a GnRH agonist *per vaginum* in a gel-based vehicle (OvuGel). (From Johnson et al., 2009)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>OvuGel</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial No. Sows</td>
<td>150</td>
<td>150</td>
<td>*</td>
</tr>
<tr>
<td>No. Sows Bred</td>
<td>123</td>
<td>150</td>
<td>*</td>
</tr>
<tr>
<td>In Estrus at AI, %</td>
<td>100</td>
<td>83.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>No. of Services/Sow</td>
<td>2.3</td>
<td>1.0</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Wean to Estrus, d</td>
<td>4.7</td>
<td>4.4</td>
<td>0.06</td>
</tr>
<tr>
<td>Sows Farrowed/Weaned,%</td>
<td>72.7</td>
<td>76.7</td>
<td>0.43</td>
</tr>
<tr>
<td>Total Born/Litter</td>
<td>12.2</td>
<td>12.6</td>
<td>0.41</td>
</tr>
<tr>
<td>Total Born/Semen Dose</td>
<td>5.3</td>
<td>9.6</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

In situations in which the synchrony of estrus after weaning may not allow the effective application of either pLH or GnRH at a fixed time after weaning, the alternative strategy of using ovulation-induction after an initial treatment at weaning with eCG continues to be explored with acceptable results (Cassar et al., 2005). However, the responses to single GnRH/pLH treatment protocols are promising, as shown in Table 4. These and other results suggest that the implantation of single fixed-time AI programs in well managed sow herd can be a reality. Linked to the use of proven superior sires, post-cervical insemination catheters and lower doses of semen, this new technology will allow the pork production industry to apply the genetic value of elite boars to breeding programs that are competitive with other livestock species.

Conclusions on impacts of improved AI technologies

The differentiation of relative fertility amongst commercial AI boars and a move to single-boar AI programs appears to have a significant economic benefit to the swine industry. Information would also be rapidly available that would allow elimination of less fertile boars at an early stage. The characterization of AI boars that maintain high productivity at lower numbers of sperm per AI dose will also allow the industry to capitalize on established and emerging AI technologies like post-cervical insemination and single, fixed-time insemination. Moreover, all these changes can be made without any loss in productivity as measured in terms of pigs
born per sow per year. However, the higher genetic merit of boars that could be used across a greater number of gilts and sows bred would provide substantial benefits to the producer in terms of the performance of terminal line progeny, without affecting (or perhaps even increasing) the total genetic royalties paid to breeding companies and commercial boar studs that are willing to facilitate these improvements in efficiency and financial performance in the pork production industry.

OVERALL CONCLUSIONS

The three topics discussed above provide immediate opportunities to reduce the costs of production in well managed production units. In the case of gilt and sow management, the main focus should be on selection of replacements that have greatest longevity in the breeding herd, offsetting the replacement and genetic royalty costs of these females. The optimal strategies for managing weaned contemporary sows should be based on appropriate cost-benefit analysis within a particular production system. Generally, good management after weaning produces a prompt and synchronous return to estrus and this will facilitate the adoption of improved AI technologies in the pork industry. A low birth weight litter phenotype is a major cause of variance in performance at the nursery and grow-finish stages of production. This offers opportunities for segregation of production flows to achieve savings in feed costs analogous to separate-sex feeding. Different marketing strategies may also optimize economic returns in such segregated systems. Finally, the application of more advanced AI technologies, linked to better evaluation of individual boar performance, will allow the pork industry to gain better commercial returns from genetically elite boars.

REFERENCES


Moore, C. 2005 The beginnings of parity segregation, what we have learned, and how it will evolve. Proceeding of Pre-conference Seminar #12 on Parity Segregation: Application in the industry, AASV Annual Meeting, pp1-4.


Patterson, J., Wellen, A., Hahn, M., Pasternak, A., Lowe, J., DeHaas, S., Kraus, D.,
Williams, N. & Foxcroft, G. 2008 Responses to delayed estrus after weaning in
on: June 6, 2006.
Rodríguez-Martinez, H. 2003. Laboratory semen assessment and prediction of
W. T. & Foxcroft, G. R. 2006. The predictive value of routine semen evaluation
and IVF technology for determining relative boar fertility. Therio. 66: 736-748.
Smit, M. 2007 Genetic background of prenatal programming in pigs. MSc Minor
Spörke, J. Heat induction and boar exposure techniques. 2006. In: AASV Pre-
conference Seminar.4. Gilt Development, Kansas City, MS. Kansas City, MS.
Discovery Conference on Food Animal Agriculture: Sow Productive Lifetime,
Nashville, Indiana.
should I be targeting. MSU Pork Quart., 13, n.1, p.1-3, 5-7.
Vazquez, J. M., Martinez, E.A., Roca, J., Gil, M.A., Parrilla, I., Cuello, C., Carvajal,
technologies in pigs: The value of deep intrauterine insemination. Therio. 
63:536-547.
sperm numbers: Results of a commercially based field trial. Therio. 57:1683-
1693.
Williams, N., Patterson, J. & Foxcroft, G.R. 2005. Non-negotiables in gilt
Benefits of synchronizing ovulation with porcine luteinizing hormone (pLH) in
a fixed time insemination protocol in weaned multiparous sows. In: Control of
Pig Reproduction VIII, Eds. H. Rodriguez-Martinez, J.L. Vallet and A.J. Ziecik,
Nottingham Univ. Press, Nottingham, UK,