INTRODUCTION

The demands of particular markets for pork products will likely result in specific genotypes, managed in specific production systems, becoming the norm in our industry. Ultimately, it has been suggested that such tailor-made production systems will involve the very latest in genetic and reproductive technologies as follows:

- The application of the results of genome mapping in the pig to identify, and select for, genes controlling important production traits and product characteristics (Marker Assisted Selection)
- The transfection of these genes into somatic pig cell-lines that can be maintained indefinitely in culture to produce an unlimited source of donor nuclei for cloning
- Cloning of the nuclei of these transfected cells into perfectly matured oocytes produced en masse by in vitro maturation of primordial follicles obtained from slaughter generation gilts
- Finally, non-surgical transfer of these cloned embryos to clones of surrogate, hormonally synchronized, sows genetically engineered for maximal uterine capacity and lactation performance

Among the advantages of adopting such a strategy would be a minimal lag time in bringing the best genetics to the production level, minimal biosecurity risks and great uniformity (including sex) of production generation pigs. By comparison, present systems involving selection at nucleus level, and the transfer of these genetics through existing multiplication systems to the production level, are logistically more difficult. They involve much greater genetic lag and biosecurity risks, and produce much greater variability in production level populations.

We have known for many years that the environment (nutrition, housing, welfare, health status, etc) limits the extent to which the genetic merit of the dam and sire are expressed in the phenotypic characteristics of their offspring (the G x E interaction). This applies as much to reproductive traits as to other important production characteristics. Additionally, however, we are becoming increasingly aware of mechanisms by which the environment of the parents and the developing embryo may actually change the expression of genes inherited from the parents (epigenic or imprinting effects). Collectively, these
environmental effects create the enormous variation in performance that is evident in existing breeding herds and their progeny.

In this presentation, we will principally explore ways of addressing the problem of variability in breeding populations to build better breeding management programs in the future. In essence, we are suggesting that considerable progress can be made towards the “clone” concept, by selecting more uniform and biologically appropriate breeding stock from within existing populations. Our discussion of “fine tuning” will also include possible adoption of reproductive technologies that have the potential to improve the efficiency of our breeding programs.

ASPECTS OF REPLACEMENT GILT MANAGEMENT

Growth and Nutrition

Growth is not usually a constraint to sexual development of replacement gilts. In existing commercial, dam-line genotypes there is virtually no relationship between growth rates in gilt (0.55 to over 0.8 kg per day from birth to selection for entry to the gilt pool) and the age at which these gilts can exhibit first estrus (120 to 200 days), if provided appropriate direct contact with mature boars (Figure 1). However, when we consider the growth performance of potential replacement gilts, there are three important issues that need consideration.

1. Do we have the appropriate genotypes in terms of tissue deposition to support good lifetime reproductive performance?

The debate about the weight and fatness of gilts at the time of first breeding continues, in the absence of appropriate data on which to base good decisions. An earlier emphasis on the importance of critical levels of body fat, to protect the first parity sow against the metabolic demands of her first lactation, led to a general consensus that gilts require 18-20mm of backfat at farrowing and that levels of backfat below 12mm at weaning would have serious consequences for subsequent fertility. In the period over which this research was conducted (the 1970’s –1980’s), it is noticeable that the changes in backfat that were reported during lactation for a given overall change in body weight, were much more substantial than reported for genotypes used to conduct similar research in the last decade. It seems that the selection of existing lean dam-line females has resulted in a much more labile fat depots, that may be harder to increase during gilt development, but are also fairly resistant to change during lactation. In more recent studies in the literature, a major focus has developed on the importance of the protein mass of the sow as the primary factor in lactation performance and post-weaning fertility. When one looks at the results of these experiments, major changes in protein mass during lactation, imposed by different nutritional regimens and closely linked to fertility of the sow after weaning, are associated with non-significant changes in backfat (see Table 1). From the perspective of the metabolic regulation of the reproductive axis, this immediately begs the question as to whether fat mobilization is an important regulator of sow fertility.

If these observations lead to the conclusion that lean tissue mass is a critical determinant of sow fertility, and protein mass changes much more dramatically than body fat during lactation, this raises several questions.

• Irrespective of protein mass, what minimal level of body fat (or fatness) is still needed for good reproductive performance, and to provide the necessary physical protection to the sow to prevent culling for lameness and injury?

• If high growth rates in gilts may be producing overweight animals at breeding, yet these animals are still deficient in body fat, how do we address this problem?
  – Through extremes of nutritional management
  – Through use of more appropriate dam-line genotypes in which there is a better relationship between lean tissue accretion and deposition of minimal requirements for body fat

2. What tissue mass do we need to achieve at breeding to improve lifetime performance?

We have previously suggested that breeding gilts at body
weights as low as 120 kg can be acceptable, as long as these gilts are known to be sexually mature and their nutrient intake in the first lactation can be given special attention. However, recent data from well-controlled sow studies suggest that increased protein mass at farrowing can be protective against the loss of protein mass that is still seen in many genotypes during the first lactation (see Table 2). It is unclear where the threshold for this protective protein mass lies, but a body weight at farrowing of 175 kg or greater may emerge as the possible recommendation.

Assuming that the targeted weight gain during the first gestation will be 35-40 kg, this sets targeted breeding weights at around 135-140 kg. Given the achievable growth rates of contemporary dam-line gilts, this range of body weight at breeding can be easily achieved, especially if we generally aim to breed gilts at second estrus in well-managed gilt conditioning programs.

Generally, we must move towards much better, genotype-specific, recommendations for the appropriate body state of gilts at breeding and farrowing, taking account of expected feed intake and milk production in lactation.

3. How do we manage the variation in growth performance?

Our most recent data from studies of gilt development under typical commercial conditions suggest that the variability in growth rate is a major problem in standardizing the pool of bred gilts that enter production units. In a management system in which gilts were only selected for breeding if they showed a pubertal response to boar stimulation within 40 days, starting at 140 days of age, and were then bred at third heat after being moved to production units during their first cycle, weights at first estrus already ranged from less than 90 to over 140 kg (Figure 2a), and at breeding the range of weight (98 to 186 kg) and backfat (8 to 24 mm) was even more extreme (Figure 2b).

In studies, in which we attempted to slow growth in gilts with high fibre diets from 50 kg until puberty induction (Patterson et al., 2002a), we had very little impact on bodyweight at first estrus. However, experience in commercial practice suggests that modified, high energy, “conditioning” diets can have an impact on body fat stores in lean gilts. We have also explored the possibility that by inducing early pubertal estrus using direct contact with boars, we might slow down subsequent growth compared to un-stimulated littermates. Although boar exposure in this study decreased age at first estrus by some 15 days, we have been unable to establish any effect on subsequent growth (Willis et al., 2002).

These results suggest that there is a need to identify and manage the variation in gilt growth and development from an early age. We believe that both high and low extremes of body weight at breeding will result in gilts/sows being culled from the breeding herd early in their productive life. Within the next year we hope to have the data to support this view.

To overcome the problems caused by variation in growth rate in gilts, it may be essential to sort gilts by weight and growth performance at an early stage, and then use specific nutrition and management programs to bring different categories of gilts to a more uniform condition at breeding. The techniques and facility design needed to achieve this with minimal additional labor must be addressed, but a need to weigh gilts at some point in the development program seems unavoidable.

It is also possible to reduce the range of breeding weights by adopting flexible recommendations for the estrus at which gilts are to be bred.

• Heavier and faster growing gilts that mature late will be bred at first estrus
• For slower growing and leaner gilts that cycle early, breeding may need to be delayed until third of even fourth estrus.

However, even if these adjustments are made, the variation in growth performance during the following gestation period will also need to be considered to try and reduce the variability in weight at farrowing. The benefits of such programs will be a higher retention rate of gilts in the breeding herd and less variable reproductive performance after weaning the first litter. This approach should also minimize “Entry-to-first-service” intervals.

Improving “Selection” Criteria
For Replacement Gilts

This where it is definitely possible to take advantage of the inherent variability that exists in contemporary gilt pools to produce more uniform, and higher quality, production females. All the data published in the last twenty years indicate that age at first estrus is normally distributed when growth restriction is not a concern. The full extent of this variation in age at first estrus is most apparent if gilts are exposed to mature boars at an early age (say 140 days as

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**Figure 3. Number of gilts per day showing pubertal estrus after stimulation with direct boar contact from approximately 140 days of age and 100 kg body weight. (Prairie Swine Research Centre, University of Alberta Swine Research & Technology Centre; unpublished data, 2002)**

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in the study presented in Figure 3). Even when stimulation is delayed to 160 or even 180 days, it is always possible to identify a proportion of 10 to 20% of gilts that do not respond to boar stimuli within a set period of time (say 20, 30 or 40 days). In the study for which data are presented in Figure 3, 63% of the gilts were recorded as showing standing estrus within 30 days, and 79% within 40 days, of initial boar contact starting at 140 days.

There are sound biological reasons, and increasing amounts of production data, to support the suggestion that late maturing gilts will have reduced lifetime fertility. This leads to the obvious suggestion that response to a standardized protocol of boar stimulation can be used to identify the 75-80% of gilts that are likely to be most fertile. There is nothing preventing us from taking this step forward in reproductive management.

One major issue in implementing this recommendation is the high body weight of non-select gilts if puberty induction starts at a late age. For this reason, early stimulation with mature boars is recommended to avoid the economic penalty of culling non-select gilts from the gilt pool. Even in the system of early puberty induction used in our most recent studies, 82% of the gilts that were still non-cyclic by 180 days of age, were already above market weight. There would, therefore, already be a financial penalty to culling these gilts. However, retention of these gilts within the herd would:

- incur costs of unknown numbers of additional non-productive days
- represent less efficient use of pen space within the gilt pool
- still not guarantee that gilts would eventually cycle

Also, remember, even if these gilts were bred, their expected fertility would be low. Given these concerns, it seems preferable to use relatively early stimulation with boars provide an effective technique for identifying the most reproductively “fit” replacements, whilst avoiding the financial penalty of adopting this more rigorous “selection” procedure.

Alternative Strategies for Meeting Breeding Targets

The previous section suggests that we might improve breeding herd performance by taking account of inherent variability in sexual maturity. We should also consider the economic impact of adopting totally controlled breeding programs and all the tools exist to develop protocols in which both pubertal induction and the time of ovulation would be controlled by exogenous hormone treatment. However, the range of production drugs needed to implement such protocols in swine may not be presently licensed for use in pork production. The impetus to achieve this will largely be driven by convincing studies showing the overall economic advantages that could be achieved with this approach. These drugs tend to be used presently in an ad hoc and reactive way to overcome acute problems in gilt management programs. However, depending on the physical design of particular production facilities, and the relative cost and skill of available labor to work in the breeding barns, a case can be made for carefully evaluating the role of controlled breeding programs in the gilt pool. If one outcome of this approach was the ability to extend these techniques to implement fixed-time AI programs, then considerable progress would also be made to achieving some of the goals discussed later.

Use of exogenous hormones to induce cyclicity. The most extensive data relate to the use of the product PG 600 (Intervet) which contains 400 iu eCG (PMSG) combined with 200 iu hCG. In gilts in the late pre-pubertal stage, induction of a fertile estrus can be achieved in a high proportion of gilts, although resulting litter size can be more variable than is seen in gilts bred to a natural estrus. A number of studies report problems with the predictability with which gilts continue to cycle after a PG 600-induced first estrus and ongoing daily exposure to boars was found to partly resolve this problem. Others reported problems with a lack of behavioral estrus, even when gilts ovulated to treatment. This was found to be related to the immediate

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ovulation of the more mature follicles on the ovary at the time of treatment, presumably in response to the hCG component of the treatment (Steadman and Foxcroft, unpublished data, Table 3).

- If PG600 is to be used to induce gilts to cycle as a means of meeting breeding targets, it is suggested that previously un-stimulated gilts be used, at an age at which good responses to boar stimulation can be expected; the heavier gilts available should be treated.
- Experience also suggests that the best approach may be to breed gilts immediately after PG600 treatment and not risk the lack of continuing cyclicity.

Another possible approach is to breed gilts at the PG 600-induced estrus and then terminate this first pregnancy before day 30 to 35 with prostaglandin-F2 (PGF2). Although this breed/abort protocol may raise ethical questions, it provides a ready supply of gilts that can be returned to estrus in a controlled way and avoids the erratic litter sizes associated with PG 600 use.

**Treatment of non-cyclic gilts.** Our experience with the management of the 20 to 30% of gilts that fail to show estrus in response to boar stimulation, suggests that they are best not included in the breeding herd, unless this is the last resort to meet weekly breeding targets. The predictability of cyclicity in these gilts can be a problem, their lifetime fertility is questionable, and they will accumulate disproportionate numbers of Non-Productive Days. Anyway, half of these gilts are never bred because they never show a standing heat. Some of these gilts will have already cycled but are never detected in estrus (silent heats), whilst the rest are truly anestrous and have still not reached puberty.

Overall, therefore, we urge caution when considering the use of exogenous hormones to induce estrus in gilts;
- The potential risks for future herd fertility of using exogenous hormones to induce pubertal estrus in gilts that are still non-cyclic after extensive exposure to boars, needs careful consideration.
- Secondly, adoption of universal hormonal treatment of gilts may remove our ability to identify the most potentially fertile animals.

**Allocation/Synchronization of Cyclic Gilts to Meet Breeding Targets**

When gilts are obtained from a multiplier, it is generally assumed that they are already cyclic, or will be induced to cycle in response to “transport” and “mixing” effects. If gilts are managed “in-house” from an earlier stage of their development, then effective stimulation of pubertal estrus becomes an important management factor.

- In both situations, estrus synchronization techniques allow breeding targets to be met on a weekly basis from a smaller sized gilt pool than is needed when synchronization of estrus is not used.
- However, the financial costs of estrus synchronization must be less than the cost of maintaining a larger gilt pool, if estrus synchronization is to be widely employed in the industry.

The size of the gilt pool needed to meet approximately 80% of breeding targets is fairly predictable. However, the gilt pool needs to be increased disproportionately to meet the remaining 20% of breeding requirements, which will not follow a predictable pattern. An alternative to this disproportionate increase in the size of the gilt pool is to use estrus synchronization techniques to meet variable weekly breeding targets.

**Use of oral progestagens.** Effective synchronization of estrus in the gilt or sow is possible, and the most commonly used technique is the feeding of the synthetic progesterone analogue, allyl trenbolone (Regumate). Feeding this orally active progestagen for 14 -18 days in randomly cyclic gilts will result in effective estrus synchronization over a 4 to 6 day period after the last day of feeding. If the stage of the estrous cycle is known, the number of days that Regumate needs to be fed can be considerably reduced, without loss of efficacy. The fertility of gilts is generally not reported to be affected by Regumate treatment, or may be improved. We find this particularly true for AI use, because fresh semen can be ordered in a very predictable way and we can concentrate on gilt breeding over a concentrated period of time. Our ongoing experimental use of Regumate for synchronizing estrus in known cyclic gilts resulted in 97% of gilts treated showing estrus within the designated breeding week (Figure 4a).

By finely adjusting the dose of Regumate fed (between the recommended range of 15 and 20mg/day), and the day preceding the breeding week on which Regumate treatment is withdrawn, it is possible to insure that all gilts are in estrus within a five-day period. This is clearly illustrated in Figure 4b, which presents the cumulative percentage of gilts in estrus. Because complete records of the date of pubertal
and second estrus are kept as part of our routine gilt pool management system, Regumate treatment is only introduced from day 12 of the previous cycle in those gilts which are not due to show spontaneous estrus in the targeted breeding week. We then continue feeding Regumate until five days before the start of the breeding week. Depending on the date of the previous estrus, this results in treatment periods ranging from 5 to 18 days, representing a considerable saving in treatment cost. To insure that problems with low-dose treatment are not encountered, we generally require a minimum treatment period of 5 days in any gilt. To-date we have no evidence that the duration of Regumate treatment has any effect on gilt fertility (Figure 5). Irrespective of the duration of Regumate treatment, data accumulated from our routine use of Regumate indicates no effect of Regumate treatment on either litter size, or the distribution of litter size, when gilts are bred by AI at either second or third estrus (Figure 6).

Therefore, recent data from our use of Regumate confirm the efficacy of the product. Our results also indicate the possibility of reducing the total amount of product used by maintaining appropriate records in the gilt pool, and only treating gilts that will not naturally cycle within the breeding week. Taking this approach, and combining Regumate use with effective puberty stimulation with boars, it is possible to meet all weekly breeding targets by treating only 25% of gilts within the gilt pool, and limiting the period of treatment to an average of 12 days. Overall, therefore, the use (costs) of Regumate treatment can be limited to an average of less than 3 days per gilt bred, and this may prove to be a very cost-effective technique for meeting breeding targets. However, economic models of effective gilt management are needed before the full economic impact of this, or any other, gilt pool management system, can be established.

Use of luteolytic agents. In other species, the use of natural or synthetic prostaglandins to cause luteolysis in known cyclic females can be an effective synchronization technique. Some degree of synchrony can be achieved with the use of PGF2 in cyclic gilts, however, the corpora lutea of the pig are only sensitive to PGF2 from day 12 of the estrous cycle. At most, estrus can therefore be advanced by some 5 days. Nevertheless, this may still be useful in bringing a number of gilts into a tighter breeding group. However, it is essential to have accurate records of gilt cycles if this technique is to be applied effectively.

Overall Targets

Even with existing management techniques, we must be prepared to set demanding targets for gilt replacement programs, as a key step in to improving the efficiency and predictability of this key component of the production chain. Based on recent evidence from gilt and sow research, we suggest that the production targets shown in Table 4 are achievable and will greatly improve the productivity/profitability of breeding herds.

ASPECTS OF LACTATING AND WEANED SOW MANAGEMENT

The metabolic demands of lactation in the context of the tissue reserves needed by the first parity sow as she enters lactation have already been discussed. The solution to the problem of depressed fertility after weaning the first litter will probably largely be addressed by 1), decreasing the variability in the body state of sows as they enter lactation, and 2), using genetic selection and further advances in sow nutrition to meet the nutrient demands of lactation from adequate nutrient intake. However, a further challenge will still be to reduce the variability in reproductive performance after weaning to the point that all sows will be successfully re-bred within a five-day period. This does not suggest that this 5-day period will necessarily be day 1 to day 5 after weaning. Part of the problem with variable reproductive performance in weaned sows lies in the population of sows that are either showing estrus before weaning, or initiating the growth of potential pre-ovulatory follicles very close to weaning. Although this results in a minimal weaning-to-estrus interval, there is evidence that these follicles may not be optimally mature at the time of ovulation.

The possible resolution to the problem of variability in ovarian development in the weaned sow requires further study. However, with the application of new techniques of molecular genetics (such as micro-array analysis) and large-scale proteomic analysis of the regulators of ovarian follicular development, it is likely that our understanding of the key regulators of follicular development in the sow will rapidly advance and such studies are already in progress at the Swine Research & Technology Centre. Combined with the extensive use of ultrasonography to track the complex dynamics of follicular growth in the sow, this will enable us

![Figure 6. Litter size born in Regumate treated gilts and contemporary, non-treated females, showing the distribution of different litter sizes. No difference in either mean litter size, or the distribution of different sized litters is apparent (Swine Research & Technology Centre, University of Alberta, 1997-1998)](image-url)
to evaluate production and other techniques, aimed at standardizing the pattern of ovarian follicular development immediately before weaning. If this can be achieved, there would be an immediate improvement in the synchrony with which sows return to estrus after weaning and in the fertility of the sows bred during this period.

In the meantime, producers have a number of possibilities for improving the fertility of the weaned sow, based on existing research findings.

The major regulators of reproductive function in the sow during lactation and after weaning are:
- Effects of time after farrowing on the function of the reproductive system
- Suckling as the primary block to reproduction during lactation
- Effects of metabolic state during lactation and after weaning on sow fertility

The relative importance of these factors will change, depending on the sexual and physical maturity of the sow at the time that lactation is initiated. As a result, the management of the sow must become increasingly sophisticated to allow for the dynamic changes that occur in the sow over successive lactations. In practice, the improved management of the first parity sow must be given a high priority.

Effects of Time After Farrowing on the Reproductive System
- There is an unavoidable period of infertility in the early postpartum period

Pregnancy in large mammals requires massive adaptation on the part of the mother to provide for the needs of the fetus. This long-term commitment terminates in the dramatic changes associated with parturition. Generally, these changes are not conducive to good fertility immediately after birth. In the sow, the metabolic demands of lactation, on top of the earlier metabolic demands of gestation, results in a period of lactational anestrus. This period of lactational anestrus allows the reproductive system to become fully functional again and several components of the reproductive system are involved in this recovery process.

Uterine involution. This term describes the gradual return of the uterus to its non-pregnant state, having increased in all proportions during pregnancy. Although early weaning studies clearly indicate that complete uterine involution is not essential for the next pregnancy to be established, it is generally accepted that incomplete uterine involution is probably one factor that contributes to poor embryonic survival and hence reduced litter size born in early weaned sows.

Recovery of the brain and pituitary. As the sow comes into estrus, the secretion of the pituitary gonadotrophic hormones, Luteinizing Hormone (LH) and Follicle Stimulating Hormone (FSH) is responsible for the growth of ovulatory follicles and, at least in part, for the number of ovulations (ovulation rate). A major “surge” in

![Figure 5. Least Square Means (LSM) for conception rate and farrowing rate for nine boars based on at least 50 breedings per boar using 1.5 billion sperm per AI dose over a four-month period. Means with different letters within each characteristic are significantly different (P<0.05; 2 analysis). Boar G-1 was identified as being consistently less fertile.](image)

![Figure 8. Optimal timing of insemination with heat detection at 12-h intervals. The dashed bars on the AI area represent the period in which fresh semen will maintain optimal viability (about 12 h), and the blank bars represent the additional 12-h period during which semen may still produce acceptable levels of fertilization. Dash arrows indicate time at which insemination would be required to optimize fertility under different AI protocols. The open arrow represents timing of a third insemination which may be cost effective in gilts with longer estrous durations. (From Almeida et al., 2000)](image)
LH is also needed to actually cause ovulation. Existing data show that not only the uterus, but also the central components of the reproductive system (the brain and pituitary), need some time to recover after farrowing. The need for the reproductive system to recover from the effects of pregnancy explains the reduction in sow fertility as weaning age falls below 14 days.

Suckling as the primary block to reproductive activity in lactation. Active gonadotrophin (LH and FSH) secretion can be observed in sows immediately after farrowing and this period has therefore been described as the “Hypergonadotrophic” phase of lactation. If the litter remains with the sow, this uninhibited period of LH secretion is eventually suppressed around day 3 of lactation, as the inhibitory effects of suckling become established at the level of the brain and pituitary. This would then represent the “Hypogonadotrophic” phase. Suckling is the primary inhibitor of LH secretion. As lactation progresses, there appears to be a gradual increase in LH secretion (a “Recovery” phase), as long as the sow does not become seriously catabolic.

Table 1. Sow and nutrient variables in first-parity sows that lost a low, moderate, or high amount of body protein during lactation (From Clowes et al., 2002)

<table>
<thead>
<tr>
<th>Protein Loss in Lactation</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed, kg/d</td>
<td>4.49 ± 0.14 a</td>
<td>4.33 ± 0.14</td>
<td>4.03 ± 0.13</td>
<td>0.103</td>
</tr>
<tr>
<td>Energy, MJ ME/d</td>
<td>63.7 ± 1.93</td>
<td>61.0 ± 2.01</td>
<td>56.9 ± 1.91</td>
<td>0.089</td>
</tr>
<tr>
<td>CP, g/d</td>
<td>878 ± 19 b</td>
<td>647 ± 19 b'</td>
<td>491 ± 18 b'</td>
<td>0.001</td>
</tr>
<tr>
<td>Lysine, g/d</td>
<td>50.2 ± 1.06 b</td>
<td>34.6 ± 1.10 b</td>
<td>24.2 ± 1.04 b</td>
<td>0.001</td>
</tr>
<tr>
<td>Weight, kg:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrow</td>
<td>195 ± 3.6</td>
<td>197 ± 3.8</td>
<td>200 ± 3.4</td>
<td>0.516</td>
</tr>
<tr>
<td>Loss in lactation</td>
<td>12.9 ± 2.3 b</td>
<td>16.9 ± 2.4 b</td>
<td>28.4 ± 2.1 b'</td>
<td>0.001</td>
</tr>
<tr>
<td>Backfat, mm:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrow</td>
<td>15.4 ± 1.18</td>
<td>15.0 ± 1.24</td>
<td>16.3 ± 1.10</td>
<td>0.712</td>
</tr>
<tr>
<td>Loss in lactation</td>
<td>0.89 ± 0.32</td>
<td>1.45 ± 0.34</td>
<td>1.57 ± 0.30</td>
<td>0.340</td>
</tr>
</tbody>
</table>

*Least-square means ± standard error of the mean.
†Tissues were collected 2 to 4 h after weaning, on d 23 of lactation, at the time of slaughter.
*Liver protein calculated as 6.25 x N.
xyz Within a row, means without a common superscript letter differ by the significance level in that row.

The pattern of follicular development observed during lactation reflects the pattern of gonadotrophin secretion. A number of large ovarian follicles may be present immediately after farrowing but a week later follicular development is minimal. Then, as lactation progresses there is a gradual increase in the number of medium to large sized follicles.

- This is why manipulation of litter size before weaning (split-weaning) can be an effective management tool for increasing ovarian development at final weaning, and consequently, sow fertility.

Because the gonadotrophin response to split weaning is transient, it has been suggested that split weaning should only occur 2 to 3 days before final weaning. However, we believe this recommendation needs further evaluation, and any period of reduced suckling input may give beneficial results. Further research on split-weaning strategies is a focus of current collaborative studies between the University of Alberta and Prairie Swine Centre.

An immediate increase in LH secretion in response to weaning and is the stimulus for ovarian follicular development that will bring the sow back into estrus and the magnitude of the increase in LH secretion after weaning has been related to the weaning-to-estrus interval or to ovulation rate at first post-weaning estrus.

- Evidence that changes in LH and FSH secretion in late lactation and immediately after weaning affect sow fertility, probably explains the efficacy of treating sows with low doses of exogenous gonadotrophins (products like PG600) at weaning.

Overall, therefore, these data tell us that;

- Suckling is the primary inhibitor of the reproductive system during lactation. Therefore, an effective way to improve fertility in the sow would be to reduce the effects of suckling (i.e. split-weaning).
- The inhibitory effects of suckling, on top of the effects of postpartum recovery, create a period in early lactation when the reproductive system is very inactive. Weaning during this period will inevitably result in low fertility. Unfortunately this period coincides with the time of weaning in SEW systems!

Effects of Nutrition and Metabolic State During Lactation

Inadequate voluntary feed intake during lactation in first parity sows is often a problem.

- Loss of body condition in lactation can have very negative effects on sow fertility after weaning. Notwithstanding the dominant inhibitory effect of suckling, differences in the pattern of feed intake during lactation produced significant effects on post-weaning fertility (see Table 5) and these fertility effects were reflected in differences in LH secretion during lactation.
• These results clearly indicate that the pattern of metabolic change during lactation can affect different components of sow productivity (ovulation rate and embryonic survival, and thus potential litter size; weaning to service interval and thus non-productive days).

• In particular, periods of catabolism in late lactation, which will carry over into the period after weaning when ovarian development occurs, will be most detrimental to fertility.

The data in Table 5 illustrate another important feature of recent studies of the primiparous lactating sow. Even when fed to appetite throughout lactation, these sows still lost 11 kg of bodyweight and 2 mm of backfat over a 28-day lactation. The poor appetite of many primiparous sows results in tissue catabolism during lactation, whereas higher parity sows are able to satisfy the demands of lactation through adequate feed intake.

• Differences in metabolic state of sows of different parities emphasizes the need to consider different management strategies for primiparous, as compared to multiparous, sows.

It is imperative to understand the characteristics of individual genotypes in the farm environment in order to make informed decisions about the management of the early weaned sow. It appears that once a sow mobilizes more than around 10% of her protein reserves at farrowing, there will be negative effects on the reproductive system, resulting in fewer and poorer quality ovarian follicles at weaning. An important question is whether the body size of a sow at farrowing is important for subsequent milk production, litter growth and fertility after weaning. As discussed earlier, initial data suggest that there may be an interaction between size at farrowing and the amount of tissue that can be mobilized before milk production and fertility is affected, particularly at the lower end of farrowing weights (150 – 180kg) and if excessive weight loss (more than 10 to 15% of farrowing weight) is anticipated.

• Although more information is needed on this subject, we should aim to have management systems in place that would avoid both the factors that would drive sows over the threshold in terms of excessive tissue loss in lactation.

REPRODUCTIVE STATUS AFTER WEANING

Variability in the weaning-to-estrus interval is a major problem in sows breeding management. Extensive delays in the onset of estrus increase non-productive days. Variation in WEI makes it difficult to meet breeding targets and to concentrate breeding management into defined periods. In recent years, work from The Netherlands has focused attention on the relationship between onset of estrus, estrus duration and the timing of ovulation. Key factors that have been identified are:

• ability to detect standing heat and estimates of heat duration varies greatly between farms
• ovulation occurs approximately 70% of the way through the estrous period
• WEI and estrus duration are inversely related

Based on this information,

• it is recommended that farms should obtain information about estrus duration in their weaned sows and use this information to develop specific breeding strategies.

In general, breeding should be delayed in early returning

### Table 2. Ovarian measures and plasma hormone concentrations at weaning in first-parity sows that had a standard or high body mass at parturition and lost a moderate or high amount of protein during lactation (after Clowes et al., 2002, unpublished data, University of Alberta)

<table>
<thead>
<tr>
<th>Parturition Mss (PM)</th>
<th>Standard Body Mass (165 ± 1.7 kg)</th>
<th>High Body Mass (193 ± 1.9 kg)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lean Loss in lactation (LLL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Wt. Loss in lactation (kg)</td>
<td>High 23.1 ± 2.4</td>
<td>Moderate 17.6 ± 2.2</td>
<td>High 29.7 ± 2.5</td>
</tr>
<tr>
<td>Backfat loss in lactation (mm)</td>
<td>3.9 ± 0.9</td>
<td>4.6 ± 0.8</td>
<td>4.6 ± 0.9</td>
</tr>
<tr>
<td>Uterine weight(^a), kg</td>
<td>0.24 ± 0.02</td>
<td>0.22 ± 0.02</td>
<td>0.23 ± 0.02</td>
</tr>
<tr>
<td>Percentage of largest 16 follicles:</td>
<td>3.5mm diameter</td>
<td>73.9</td>
<td>61.4</td>
</tr>
<tr>
<td>Largest 16 follicles:</td>
<td>Sows represented in the data</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Diameter, mm</td>
<td>3.4 ± 0.31</td>
<td>3.3 ± 0.26</td>
</tr>
<tr>
<td></td>
<td>Follicular fluid E2, ng/mL</td>
<td>0.22 ± 0.12</td>
<td>0.29 ± 0.10</td>
</tr>
</tbody>
</table>

\(^a\) Uterine weight at weaning from all sows, trimmed of excess connective tissue. Values are Least-square mean ± standard error of the mean.
sows (Monday, Tuesday, Wednesday sows in a Thursday weaning program) but should take place as soon as estrus is detected in later returning (Thursday, Friday and weekend) sows. This will give the best chance of mating in the optimal 12-20 hour period before ovulation.

Management Options for Reducing Variability in Post-Weaning Fertility

First, we must define the response of particular genotypes to particular patterns of management, and in particular the response to early weaning. Only then can we make sensible suggestions about strategies to improve weaned sow fertility. However, it is likely that in all genotypes, early weaning will result in some increase in the weaning-to-estrous interval and that WEI will be more variable. Additionally, most primiparous sows will show reduced fertility in terms of conception rate and litter size. Depending on the genotype and its response to early weaning, this may be associated with increased early embryonic mortality after weaning, a decrease in ovulation rate, or both. Therefore, an imposed delay in the return to estrus would be expected to improve fertility after weaning early. The extra non-productive days and slight decrease in litters/sow/year may be more than offset by an increase in litter size born. Several options exist:

- The impressive response of primiparous sows to “skip-a-heat” breeding, even at the expense of 21 non-productive days, may be financially justified.
- If sows show an extended, but predictable, weaning-to-estrous interval, then the best option may be to simply breed at this estrus and accept that fertility may be reduced compared to higher parity sows.
- If there is either an unacceptable increase in the weaning-to-estrous interval, or problems with variability, then treatment with PG 600 at, or on the day after weaning, can be effective in increasing the number of sows bred by a specific target day.
- If an inconsistent pattern of weaning-to-service intervals disrupts breeding programs, or if a delay to first breeding is needed to enhance overall fertility or move sows to a different breeding week, then another strategy is to feed sows Regumate from the day of weaning until 5 days before sows are required to be bred. This will block the onset of estrus and provide good heat synchrony after withdrawal.

Finally, producers should always try and design their breeding barns to take advantage of the stimulatory effect of boars in reducing the weaning-to-estrous interval and improving fertility. As the boars are likely present anyway, it makes good sense to design facilities to take advantage of this extra contribution to breeding herd performance.

ACHIEVING FIXED-TIME AI WITH A SINGLE DOSE OF FROZEN SEMEN

A number of factors can contribute to achieving this goal within the next decade. However, one of the driving forces behind such developments would be the expectation that the use of a much more limited group of elite AI boars will be linked to a proportional increase in the genetic merit of these boars for important production traits. Without both these outcomes being achieved, it is unlikely that the concerted effort needed to rapidly advance this area of reproductive technology will be achieved. These changes will also require a considerable restructuring of the industry, in terms of the reduced number of boar studs that would be

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Number Gilts Treated</th>
<th>Number Gilts Treated</th>
<th>Mean ± SEM Ovulation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>21</td>
<td>6</td>
<td>4.17 ± 0.30</td>
</tr>
<tr>
<td>82</td>
<td>9</td>
<td>4</td>
<td>2.25 ± 0.63</td>
</tr>
<tr>
<td>94</td>
<td>9</td>
<td>4</td>
<td>4.50 ± 1.65</td>
</tr>
<tr>
<td>118</td>
<td>17</td>
<td>13</td>
<td>12.69 ± 2.28</td>
</tr>
<tr>
<td>142</td>
<td>10</td>
<td>9</td>
<td>14.22 ± 2.90</td>
</tr>
<tr>
<td>238</td>
<td>33</td>
<td>32</td>
<td>16.91 ± 1.51</td>
</tr>
</tbody>
</table>

*Ovulation rate = total number of corpora lutea/number of gilts per group treated.

Table 4. Possible future benchmarks for gilt production systems that involve the early induction of pubertal estrus using early boar contact from 140 days of age.

<table>
<thead>
<tr>
<th>Age at stimulation</th>
<th>140 – 150 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at puberty</td>
<td>145 – 180 d</td>
</tr>
<tr>
<td>% cyclic within 30d of entry</td>
<td>75-80</td>
</tr>
<tr>
<td>Age at first mating</td>
<td>170 – 220 d</td>
</tr>
<tr>
<td>Estrus at mating</td>
<td>1st – 4th</td>
</tr>
<tr>
<td>Weight at breeding</td>
<td>130 – 150 kg</td>
</tr>
<tr>
<td>First litter size (total born)</td>
<td>&gt;10.5</td>
</tr>
<tr>
<td>Lifetime litters</td>
<td>5.0</td>
</tr>
<tr>
<td>Annual replacement rate %</td>
<td>&lt;40.0</td>
</tr>
</tbody>
</table>
required to meet the AI needs of the production units. However, given the major problems with biosecurity encountered within the last two years, more rigorous control of a more limited number of semen producing facilities may be a benefit in maintaining the health status of our breeding herds. In the longer term, the remaining high quality boar studs and their highly trained personnel, would become the locations that are also eventually responsible for implementing the production of in vitro derived embryos and the dissemination of these female genetics through non-surgical embryo transfer.

### Table 5. Effects of Pattern of Feed Intake Over a 28-day Lactation on Postweaning Fertility in Primiparous Sows Bred at First Postweaning Estrus. Sows were either fed close to appetite throughout a three-week lactation (AA), were subjected to feed restriction in weeks 1-2 and then re-fed in week 3 (RA), or were restricted only in the last week of lactation (AR)

<table>
<thead>
<tr>
<th></th>
<th>Group AA</th>
<th>Group AR</th>
<th>Group RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss</td>
<td>11.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.75&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>In lactation (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backfat loss</td>
<td>2.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.38&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>In lactation (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovulation</td>
<td>19.86&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.44&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embryo Survival (%)</td>
<td>87.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>64.43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>86.50&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>to day 28 WHOI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(days)</td>
<td>3.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Superscripts b and c denote treatment differences at P<.002, and c denotes differences at P<.05. (Zak et al., 1997)

---

**Boar Selection Programs To Improve Overall Fertility**

A number of laboratories have published good evidence to suggest that selection of AI boars can be substantially improved. Dr. Billy Flowers and his colleagues have provided evidence that “dominant” boars can be identified that have superior performance in competitive insemination programs, even though they could not be identified as being superior by routine laboratory analysis of sperm motility and morphology. Our own group has produced similar data by comparing boars on the basis of proven fertility when using relatively low sperm numbers for AI (Figure 7). Our data suggests that 10-20% of boars identified as being fertile by existing techniques, are sub-fertile if low sperm numbers are used for AI. We can assume that even with higher sperm numbers per AI dose, the performance of these boars will be a problem if breeding conditions are not ideal. Although the relatively lower performance of these boars may be masked by the use of pooled semen, there is little purpose in covering the maintenance and collection of semen from these boars.

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costs of these boars if they are not contributing to the production of progeny.

- if we wish to move towards the use of lower sperm numbers and less inseminations, we must identify the most fertile boars in our populations as part of this process.

Our recent data suggest that it will be possible to develop fertility evaluation protocols that could involve as few as 20 single-boar matings during the training and early collection period and that data on the predicted fertility of these boars could be available by day 45-50 of gestation. Several groups also continue to look for other markers of boar fertility and semen quality that would be even more immediately available in production units. Preliminary results indicate that analysis of the protein profile of seminal plasma may be one such approach.

**Reducing the Number of Sperm per Insemination**

Reducing sperm number per insemination would be a key factor in producing more breedings per boar per year and thus allowing a reduction in the number of boars maintained at stud. This has obvious advantages in terms of efficiency in boar stud management, but is unlikely to have a major impact on the semen cost allocated per bred female. This is particularly true if the boar stud is an independent unit selling semen to a variety of commercial producers. However, if the reduction in the number of boars at stud is associated with a proportional increase in the genetic merit of these boars for important production and carcass traits, then there is a major economic benefit to the whole production chain.

Two factors will already allow the industry to move rapidly in this direction. The first, just discussed, will be the selection of AI boars with the very highest proven fertility. The second will be the use of post-cervical insemination. By combining these approaches to AI, existing data already indicate that sperm numbers could already be reduced to 1.0 billion sperm, and probably lower, without any measurable drop in production. With enhanced extenders and even better methods for identifying the very top AI boars, it may be possible to move to 0.5 billion sperm per AI dose within the next five years.

**Reducing the Number of Inseminations per Sow Bred**

A critical evaluation of existing data on the characteristics of the estrous period in gilts and sows, the time of ovulation within this period, and known time of insemination relative to time of ovulation and reproductive performance, suggests that we can be more aggressive in defining breeding programs that involve fewer inseminations per female bred. As an example, use of such information for our gilt population led us to delay the first insemination in gilts to 24 hours, rather than 12 hours, after the onset of standing heat (Figure 8). In a comparative study of boar fertility using two inseminations at 24 and 36 hours after onset of standing heat and only 1.5 billion morphologically normal sperm per AI dose, our best boars still produced over 11 pigs born and a farrowing rate of over 90% over 60 gilts bred. Based on these collective data, we then looked at the effect of the predicted interval from the last insemination to ovulation, on farrowing rate and litter size born (Table 6). These results suggest that we can probably implement even more stringent breeding protocols with little impact on productivity.

- A realistic goal will be to breed gilts at 24-hour intervals, starting 24 hours after onset of standing heat, with the expectation that approximately 30, 70 and 10% of gilts will receive single, double or triple inseminations, respectively, with once-a-day heat checking.

This will already represent a considerable reduction in the number of inseminations per gilt bred. Adoption of similar protocols in weaned sows, based on good information about within-herd relationships between weaning-to-estrus interval and time of ovulation, should also be possible.

Two factors will contribute to the adoption of single insemination protocols in the future. The first will be further information of the characteristics of boars producing semen that appears to have a very extended functional life in the reproductive tract. If an adequate population of boars exists with these characteristics, the interval between inseminations could be increased from 24 hours, which in a proportion of females would already limit us to a single

<table>
<thead>
<tr>
<th>Estrus Duration (h)</th>
<th>Nos. Gilts (5)</th>
<th>#s AIs</th>
<th>Farrowing Rate (%)</th>
<th>Average Total Born</th>
<th>% Litters With &lt;8 Born</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 24 (not bred)</td>
<td>15 (5)</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>9.4</td>
</tr>
<tr>
<td>36</td>
<td>48 (15)</td>
<td>1</td>
<td>73</td>
<td>9.4</td>
<td>23</td>
</tr>
<tr>
<td>48</td>
<td>111 (36)</td>
<td>2</td>
<td>85</td>
<td>10.8</td>
<td>18</td>
</tr>
<tr>
<td>60</td>
<td>80 (26)</td>
<td>2</td>
<td>90</td>
<td>10.0</td>
<td>15</td>
</tr>
<tr>
<td>72</td>
<td>48 (15)</td>
<td>2</td>
<td>100</td>
<td>9.7*</td>
<td>15</td>
</tr>
<tr>
<td>84</td>
<td>10 (3)</td>
<td>2</td>
<td>40</td>
<td>10.0</td>
<td>25</td>
</tr>
<tr>
<td>108</td>
<td>2 (0)</td>
<td>2</td>
<td>50</td>
<td>(14.0)</td>
<td>25</td>
</tr>
</tbody>
</table>

Note: * Litter size probably confounded by boar effect.
insemination. The other factor will be the development of fixed-time AI protocols using treatment with exogenous hormones. The need to produce ideal synchronization of follicular development at the time these protocols are initiated will probably be a limiting factor in improving the protocols already reported in the literature. This again emphasizes the need for more information on how to regulate follicular development in the gilt and sow. However, there should be no technical reasons why these objectives cannot be realized in the next decade.

The adoption of fixed-time AI protocols will need careful economic analysis and high quality semen must be available for the single insemination used. However, the reduction in boar use within breeding barns, and the removal of poor estrus detection as a major constraint to achieving consistent breeding herd performance across the industry, would be major benefits to adopting fixed-time AI strategies.

**Use of Improved Extenders and Ultimately the Use of Frozen Semen**

There can be considerable optimism that the introduction of a range of alternative insemination catheters that allow routine post-cervical insemination, will soon be accompanied by quantum improvements in the extenders used for preservation of fresh semen. This will not only facilitate the transportation of fresh semen and the efficiency of oar studs, but will also increase the consistency and quality of the extended semen used for AI. In turn, this will allow some of the more stringent breeding protocols discussed above to be implemented without serious concerns for loss of productivity.

Collectively, the above aspects of AI technology will produce major improvements in breeding efficiency. A number of these are open to exploitation immediately. The full economic benefit of adopting these changes requires an integrated set of management decisions and fair recognition of the benefits that such changes bring to the economic performance of the entire production chain. In other words, breeding units must be credited with increasing the quality, as well as the quantity, of product produced.

**CLOSING COMMENTS**

In the area of breeding herd management, standardized production flow and maximized output are still major drivers of management decisions, with little time or effort apparently spent in considering the real alternatives to existing production systems. We already have the technology and knowledge to adopt several different strategies for improving breeding herd performance, yet decisions about a particular component of the breeding program often seem to be taken in isolation, and not as part of an integrated economic analysis of the potential benefits of implementing changes. Such analysis would be very valuable, not only to guide the development of optimized production systems, but also to help direct R & D activity into the most meaningful directions from an industry perspective. We have tried to identify a number of ways of “Fine tuning” the breeding program. However, adoption of some of these ideas may require an overall review of the most profitable production strategies.

**ACKNOWLEDGMENTS**

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