Managing complex processes in agricultural production

Introduction

Agricultural and horticultural production is arguably no different in context to the production of any other good or product, that is to say that producing milk, pork, grain or ornamentals fundamentally is the same as producing an electronic device or a car. To clarify, each of these requires inputs, processes or steps in production that ultimately lead to an output. Production businesses would often use a diagram called a SIPOC (suppliers, inputs, processes, outputs and customers). This is also possible for agricultural businesses (see Fig. 1).

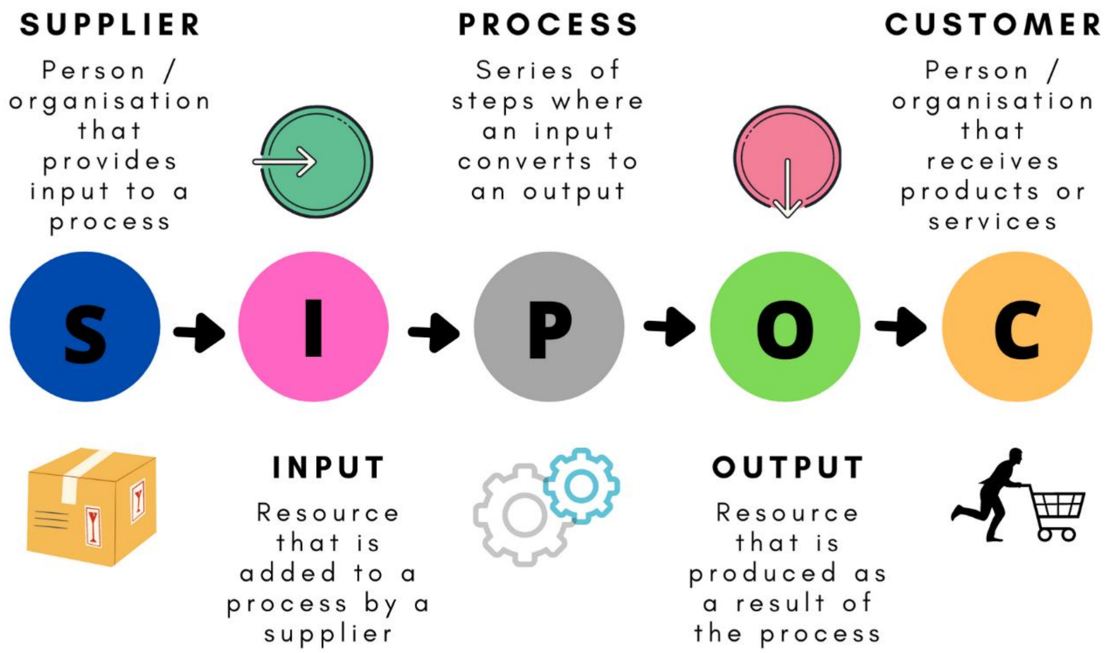

Figure 1 – What is a SIPOC? Diagram showing the definitions of each element of the tool.

Yet agricultural production is also fundamentally different from automotive or other traditional manufacturing processes. That is largely due to our 'machinery', our 'factory' and, of course, our raw materials. The machinery in all agricultural processes is actually a biological organism and, in the case of pig production, that machine is the sow. The sow is used to produce piglets, which are then fattened and processed to produce a finished pork product. The 'factory' is the farm; in outdoor production, it is completely at the mercy of the elements and the seasons. It has long been held as a premise that these substantial variations make process control techniques such as Lean management or Six Sigma unlikely to succeed in reducing the 'waste' caused by biological variation.

Increasingly, we are seeing elements of 'process control', be that officially Lean management or Six Sigma, creep into common practice on our pig units. This can be simple methods such as standard ways of working, checklists or visual controls that mark which equipment and personnel should enter which buildings for biosecurity. Some producers are trialling how the standardisation of their service groups by parity can impact the variation in performance of the litters they produce. Producers across the EU are looking at indexing and scoring sow performance based on their litter averages with outliers having additional 'maintenance' in the forms of diets or delays to re-entering service groups. This is akin to a Lean concept called total productive maintenance (TPM), in which the 'machinery' of any process is maintained as part of the typical routine, not as an additional task.

The goal of TPM is the continuous improvement of equipment effectiveness through engaging those that impact on it in small group improvement activities. Total quality management (TQM) and total productive maintenance (TPM) are considered the key operational activities of the quality management system. In order for TPM to be effective, the full support of the total workforce is required. This should result in accomplishing the goal of TPM: "Enhance the volume of the production, employee morals, and job satisfaction."[3]

The main objective of TPM is to increase the overall equipment effectiveness (OEE) of plant equipment. In the case of pig production, this is the effectiveness of the sow, measured by reproductive performance. TPM addresses the causes for accelerated deterioration while creating the correct environment between operators and equipment to create ownership.

OEE has three factors which are multiplied to give one measure called OEE: Performance x Availability x Quality = OEE.

Each factor has two associated losses, making six in total. These six losses are as follows:

- Performance = (1) running at reduced speed – (2) minor stops
- Availability = (3) breakdowns – (4) product changeover
- Quality = (5) start-up rejects – (6) running rejects

The objective finally is to identify, then prioritise and eliminate, the causes of the losses. This is done by self-managing teams that solve problems, using a system of plan, do, check, act (PDCA) to run a cycle of improvements that lead to higher efficiency.

Principles of TPM

The nine pillars of TPM are mostly focused on proactive and preventive techniques for improving equipment reliability:

1. Autonomous maintenance – routine processes built in to monitor maintenance, such as adjusted feeding covers, recording of BCS and weighing sows entering specific parities.
2. Focused improvement – identifying the outliers that are underperforming and making adjustments to feed, entry into breeding groups and durations of lactations.
3. Planned maintenance – additional vaccination strategies or key biosecurity interventions at entry of replacement gilts. Reviews of suitability of replacement gilts and planning of replacements to create a 'push' system in which replacement gilts push out older parity sows from breeding groups.
4. Quality management – clear quality specifications of replacements and of animals entering subsequent parities.
5. Early/equipment management – appropriate service ages and weights for replacements.
6. Education and training – staff skills.
7. Administrative and office TPM – is the correct data recorded in management systems to allow outliers to be identified?
8. Safety health environmental conditions – ventilation and environmental factors to maximise efficiency.
9. Routine maintenance – to the buildings and the sows, i.e. vaccinations and health interventions.

AHDB has been benchmarking gilt and sow retention among producers as part of a programme called Gilt Watch®. Quite simply, it looks at the reasons that animals are culled from the herd and then monitors the rate of retention over time in a cohort of gilts from parity 1 to parity 6. The aim is to try to identify which factors lead gilts to be culled prior to parities 3–5, the most productive and value-producing stage of their life. The outputs have been significantly informative in that they have shown that there isn't necessarily any one factor. Unsurprisingly, the combination of highly complex multistage processes and biological variation means that any efforts to seismically shift gilt retention and overall performance requires management of the entire process.

This probably easy-to-predict realisation has been shown in AHDB's '8 kg club', in which breeders have looked at changing single elements of the production process and how they impact the average weaning weight. The drive for this is simple: a heavier piglet at weaning (8 kg) finishes significantly quicker (8–10 days) than a lighter piglet (7 kg). This in turn saves money on costs such as feed which make up 65%+ of the total cost of production. However, early trials showed that changing single components of the process of weaner management did not shift the overall performance upwards and any benefits are lost in the 'noise' of production (see Fig. 2).

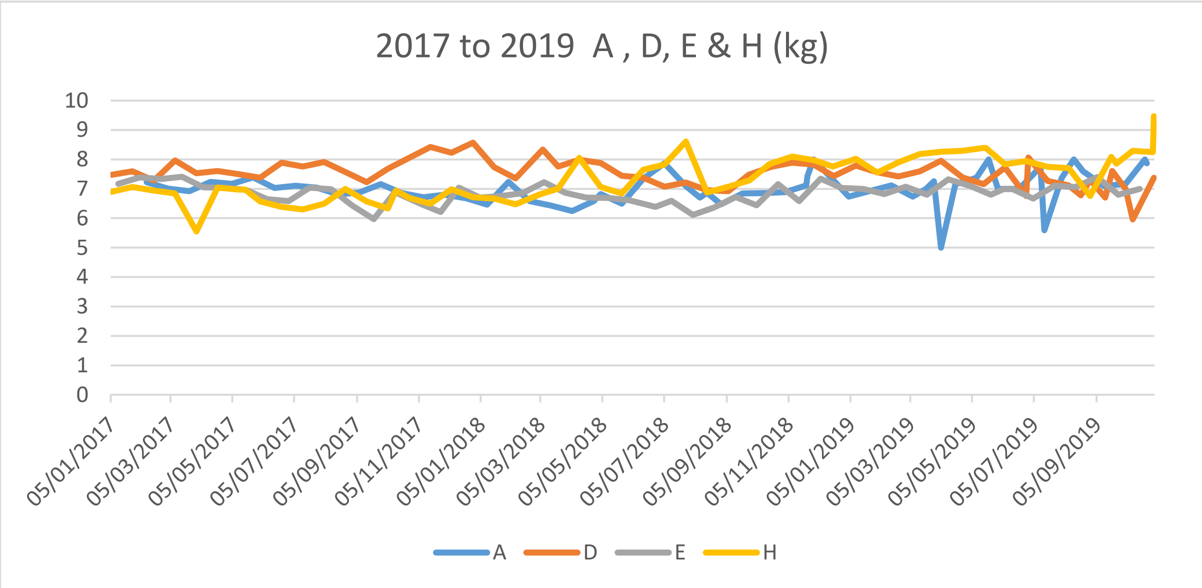

Figure 2. Graph showing the changing weaning weight between 2017–2019 across four farms (A, D, E and H) as they worked to improve weaning weights with single changes to the process of weaner management, such as iron injection of outdoor litters.

The question that remains is, as ever: So what? We have been aware for some time that these complex processes are difficult to finesse. Often, seemingly wonderful interventions at a single point of the process do not make a significant difference to performance as they are lost among the noise of the rest of the complex process. The answer is 'process control' – the use of a specific method to control the whole process of gilt or weaner management.

Methodology

To that end, AHDB has taken inspiration from the 'Pig vitality' project at Wageningen University. The Pig vitality project looked at producing a checklist that described the steps that would be required to ensure piglet survivability. The checklist is based on extensive research using the best practice found across 84 farms. The farm staff completed a questionnaire, and during a vet visit to the farm, the vets also completed the questionnaire, which looked at factors that led to reduced piglet mortality. After analysis of the 84 completed questionnaires, the most relevant factors linked to the loss of piglets in the farrowing house were identified in the checklist.

As part of the Monitor Farm programme, AHDB has mirrored the methodology of the Pig vitality project and asked producers, vets, nutritionists and academics which best practice they felt led to an increase in gilt retention and an overall increase in weaning weight. To balance these questionnaires, a literature search was performed on each best practice to identify if there was sufficient scientific literature to support anecdotal views on best practice. These literature searches can be viewed in Appendix 1 (gilt retention) and Appendix 2 (weaner weights). Examples of the questionnaires can be found as Appendix 3 and 4.

The questionnaires asked each recipient to rank the factors from 1–10. A score of 1 indicated that there was little impact of that factor on either gilt retention or weaning weight and a score of 10 meant that it was likely this had a significant impact. For gilt retention, lifted from extensive review of the Gilt Watch programme, 14 contributory factors were identified that could impact the retention of gilts and sows within the herd. In terms of affecting weaning weights, there were 17 factors. In total, there were 54 respondents to the questionnaire concerning factors affecting weaning weights, with the majority (n=43) being producers. A much smaller figure was made up of vets (n=2), academics (n=6) and allied industry, primarily nutritionists (n=3). The respondents for the factors affecting gilt retention numbered with the majority being producers (n=43), and included vets (n=2), academics (n=6) and allied industry, primarily nutritionists (n=3). Forty-five producers were identified to complete each survey and two different producers declined to score in each survey due to lack of expertise, i.e. they were finishers or worked in different stages of the process. One pork buyer was also approached but declined to comment.

Results of the questionnaire

Gilt retention

Table 1 shows how the factors were ranked based on their total scores across all completed surveys. This assumes that the factor with the highest score is perceived to have the highest impact. At this point, the scoring hasn't been cross-referenced with the research to add context or balance.

Table 1. Factors affecting sow and gilt retention ranked by questionnaire score

Factor – ordered by score	Total score
Stockpersons well trained in AI linked to clear SOPs/Protocols for AI	460
Appropriate nutrition, supplementary feed and condition scoring to ensure gilts/sows rear the maximum number of piglets per litter	459
Gilt selection based on high litter size	433
Ability of sow to produce a consistent litter, i.e. good numbers born alive, low mortality and, importantly, consistent weaning weights	422
The overall body condition score (BCS) entering parity 1	415
Appropriate use of hormone treatment, such as Regumate, to synchronise cycles	407
Appropriate identification of udder quality prior to breeding	407
Selection of gilts for good leg confirmation	403
Ability to remain in good health – low incidence of pneumonia, ill thrift, etc.	403
High-parity sows still yielding consistent litter numbers	387
Production of strong piglets, i.e. low levels of ill thrift	376
Overall BCS entering subsequent parities	373
Selection of gilts based on good temperament	360
Significant injury, i.e. heart attack, broken limbs, etc.	358

Table 2 shows the factors reordered when scientific literature from Appendix 1 is taken into account. This literature indicates if there is a positive impact on gilt retention in the herd. It should be noted that this review is not exhaustive and is based on current knowledge. This may be subject to change at a later date.

Table 2. Factors affecting gilt and sow retention sorted by questionnaire score and supporting literature

Factor – ordered by score and supporting literature	Total score
Appropriate nutrition, supplementary feed and condition scoring to ensure gilts/sows rear the maximum number of piglets per litter	459
The overall body condition score (BCS) entering parity 1	415
Stockpersons well trained in AI linked to clear SOPs/Protocols for AI	460
Appropriate identification of udder quality prior to breeding	407
Gilt selection based on high litter size	433
Overall BCS entering subsequent parities	373
Appropriate use of hormone treatment, such as Regumate, to synchronise cycles	407
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Significant injury, i.e. heart attack, broken limbs, etc.	358

The colour coding in table 2 refers to the degree of support between the literature and the perception that the factors overwhelmingly contribute to gilt retention by the survey participants. Those factors in green are likely to have a major contribution to gilt retention, yellow signifies either anecdotally or in terms of research there is a lot of evidence but research and producers may not always agree. Blue suggests there is evidence but it may be conflicting or more limited than other factors. There is, of course, a slight exception: overall BCS entering subsequent parities was scored relatively lowly by the respondents to the questionnaire, but there is significant collective literature that states that BCS is vital to the successful fertility and reduction of the litter variability that is known to result in removal of sows from the breeding herd.

Further analysis of the results showed some interesting features. When looking at the mean score provided by each group (producers, vets, academics and nutritionists) for each factor that could contribute to gilt retention, the scores show little difference between the groups. This suggests commonality in how each group ranked them, with vets being marginally the most generous scorers and nutritionists being the least. Nutritionists tended to score nutritional factors lower than other groups such as vets, which suggests that they either view their work as part of a more holistic approach or that, possibly, nutrition is more important in other elements of pig nutrition not gilt retention. It should be noted, however, that these subgroups were poorly represented (n2 and n3). Nutritionists scored factors relating to nutrition higher than 7 out of 10, meaning that they still view their contribution as significant, even if they did not score as highly as other subgroups. The scoring for appropriate use of hormone treatment, such as Regumate, to synchronise cycles between the subgroups showed limited variation and, supported by the literature, was scored highly across all groups. Stockpersons well trained in AI linked to clear SOPs/Protocols for AI was very high-scoring (range 8.3–9 out of 10) and is supported by literature. Management of processes in particular is shown to have significant impact on successful outcomes.

Gilt selection based on high litter size was mainly supported by academics, with vets having limited confidence in this as a factor for retention. It is possible that this relates to the fact that there is either limited significant variation in the eyes of the vets in terms of litter sizes between animals or they feel that the EBVs of sows rarely follow through to subsequent generations, at least not enough to stand out. The question made no reference to the impact of sire line and, as such, some subgroups may have factored this into their answers. In a similar manner, production of strong piglets, i.e. low levels of ill thrift showed high variation, with producers more confident that EBVs of sows can carry through to subsequent generations, i.e. a good grandparent herd in terms of litters will always give good F1 generations. As it is largely producers who make decisions on sow and gilt retention, this would be an area to explore in more detail.

The highest-scoring with least variation in opinion by subgroups centres around appropriate nutrition, supplementary feed and condition scoring to ensure gilts/sows rear the maximum number of piglets per litter. Most surprising was how this was tracked and monitored using body condition scoring (BCS). The level of variation between subgroups in this response was much higher than expected, with nutritionists scoring it substantially lower than vets (7.4 compared with 9), but also producers and academics not valuing BCS significantly. It either means that the nutritionists and producers feel the post-farrowing diets can be used to regain lost condition without impacting litters or there is a lack of research in this regard or overwhelmingly positive experiences. There is a significant body of evidence that suggests sow body condition is vital for fertility and litter quality.

Another surprising score was for the ability of the sow to produce a consistent litter, i.e. good numbers born alive, low mortality and, importantly, consistent weaning weights. This scored well (8–8.5) but not as well as expected; it certainly wasn't the highest-scoring factor. It suggests a feeling among participants that the larger macro-factors that impact final weaning weight are likely to cause such additional variation that the routineness of a sow's litter performance is of little interest. Research suggests that a litter that has consistent birth weights and realistic numbers tends to be more likely to have more consistent weaning weights. This is largely the reason for cross-fostering and is demonstrated practically by some producers who standardise the gilts entering and the sows leaving their breeding groups to give consistent numbers in each parity.

When analysing the standard deviation between the mean scores, producers showed that they scored most factors in equal importance; vets showed that, overall, they felt the factors had significant variation in their relative impacts on gilt retention.

Table 3 shows the scored results from the weaner weights questionnaire, with the highest-scoring factor assumed to be most valued by the participants in the questionnaire.

Table 3. Factors affecting average weaner weight ranked by questionnaire score

Factor – ordered by ranking (No literature)	Total score
Highly skilled specialised stockpersons, i.e. each with a specific role	502
Overall health status of the breeding herd including piglets	500
Diet of the sow	475
Access to clean water in sufficient quantity	469
Genetics, i.e. genetic combinations that yield more productive piglets	458
Udder quality – 14 working teats as a minimum, no unproductive quarters	457
Vaccination strategies	433
Diet of the piglets	418
Use of supplementary feed systems	408
New site effect – does moving to a new ground in outdoor pigs and new buildings for indoor pigs raise the weaning weight?	401
Seasonality – specifically linked to thermal stress	395
Parity – replacement gilts around 42–50% and remaining animals' parities 2–5. Few pigs parity 5+	379
Sow BCS	376
Size of farrowing ark	371
Cross-fostering	350
Longer time spent in the lairage prior to moving off the weaning site	308
Iron injection of outdoor sows year-round	255

Table 4 shows how these factors are affected once supporting evidence from literature is included. There has been a more substantial shift in distribution compared with gilt retention. This is likely due to volume of research and the relative success of its dissemination and embedding in current understanding of good practice. The shift of note is: genetics, i.e. genetic combinations that yield more productive piglets. This was scored highly by participants yet is not directly supported by literature. That is not to say that genetics has no impact, as genetics defines the biological capacity of the breeding unit and the weaner. What was very evident from the literature was that the importance of other factors, such as good management and diet, was overwhelmingly more impactful than genetics. That is to say that the literature made it clear that you could have the best genetics in the world, but poor management and poor diet would mean poor weaning weights. It also made clear that poorer genetics managed significantly better with sows fed appropriately could yield more consistent results than poorly managed systems with good genetics. The literature also suggested a trend for increased variability in litter weights caused by the pursuit of greater litter number.

Table 4. Factors affecting average weaning weight ranked by questionnaire score and supporting literature

Factor – ordered by ranking and supporting literature	Total score
Diet of the sow	475
Sow BCS	376
Highly skilled specialised stockpersons, i.e. each with a specific role	502
Access to clean water in sufficient quantity	469
Overall health status of the breeding herd including piglets	500
Iron injection of outdoor sows year-round	255
Udder quality – 14 working teats as a minimum, no unproductive quarters	457
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Size of farrowing ark	371
Cross-fostering	350
Longer time spent in the lairage prior to moving off the weaning site	308
Genetics, i.e. genetic combinations that yield more productive piglets	458

As with the table for gilt management, Table 4 is colour-coded with those factors in green likely to have a major contribution to higher weaning weights, yellow signifying either anecdotally or in terms of research there is a lot of evidence but research and producers may not always agree. Blue suggests there is evidence but it may be conflicting or more limited than other factors. The major factor that is known to increase weaning weights is increased lactation of the sow or a longer lactation period. This was taken as a given but, understandably, is less applicable across the industry with fixed places and requiring a major shift in production management.

The weaning questionnaire showed interesting differences between the groups who completed the questionnaire, with producers tending to be more generous in their scoring and academics the least, but the difference in mean scores was very small (7.19–7.53). Producers may be the highest scorers, but they are the most consistent – this suggests either an equal valuing of all factors or less consideration for the differences. Vets have the highest variation in scores, which suggests a much broader weighting and possibly a greater amount of consideration of each factor's worth. All groups, aside from producers, showed much greater variation but were smaller cohorts.

Individual factors that stood out among the subgroups included: New site effect – does moving to a new ground in outdoor pigs and new buildings for indoor pigs raise the weaning weight? The big variation in scores, with producers being very positive (7.8), compared with just 5–6 for the other subgroups, suggests this is largely anecdotal among producers. There is no significant literature that supports this directly, yet a significant body of research that refers to the impact of good biosecurity.

Genetics, i.e. genetic combinations that yield more productive piglets was scored consistently high across all subgroups, yet has little support in the literature, with several papers citing diet and management as significantly more important factors. As mentioned previously, that is not to say that the genetics of the breeding stock does not affect the biological potential of the piglets, simply that without several more impactful factors (diet and health), genetics are not maximised. Iron injection of outdoor sows year-round was also scored consistently by all subgroups but extremely poorly. This is in direct conflict with the literature that clearly demonstrates that gilt litters given iron injections year-round showed significant improvements in weaning weights than control groups. This suggests that the dissemination of this research is extremely limited or not trusted. It is also only specific to outdoor units – it is possible that we have sample bias of indoor producers and specialists who would not consider this as new or novel as it is standard practice on indoor units.

Next steps

Both the current Gilt Watch programme and the 8 kg club have examples whereby individual producers attempted to change single elements of these processes (gilt management and weaner management). The data recorded, in terms of KPIs such as weaner weight or % retention in the herd, failed to show significant improvement, i.e. at a level that was consistently above the base variation within the control groups or benchmarked comparable producers. This implies that either:

1. Neither gilt or weaner management can be improved/controlled any further due to biological variation and environmental factors,

or:

2. To make a significant change in KPIs such as gilt retention or average weaner weight requires changes across an entire process.

In the introduction, mention was made of Lean management and Six Sigma. Lean in particular aims to maximise the value in production through process control and minimisation of 'waste', i.e. increase the KPIs, such as % retention in gilts and weaner weights, while minimising those animals that fail to meet these standards. It is built around a cycle of plan, do, check and act (PDCA), which leads production teams through a cyclical journey of embedding change to thoroughly reviewed processes and checking that they are making significant differences. In simple terms, Lean is often referred to as continuous improvement as this is the ultimate goal.

A PDCA system in agriculture would resemble: a programme that aims to deliver measurable improvements in gilt or weaner performance, specifically practical applications that improve either the percentage of gilts retained in parities 3–5 and a consistent average weaning weight of 8 kg. The programme would take the most significant factors that impact gilt and weaner performance from tables 2 and 4 and task producers with designing, implementing and reviewing protocols and practices that allow them to improve these factors, such as better BCS post-parity 1, a review of post-weaning diets and iron injection for outdoor gilt litters.

How?

The success of gilt and weaner management depends on so many factors that simply changing an individual process and hoping it will make a difference is unrealistic on a working farm. Instead, a full review of the process and elements of process control can be used to improve performance.

AHDB will fund a Lean management coach to support the business in reviewing either gilt or weaner management and as the business identifies changes they wish to make, the Lean coach will help embed these changes as part of the usual routine. The Lean coach will work with the unit manager and their staff. AHDB will also offer Lean coaching to the business owner in support of the programme. Lean management has a proven track record of delivering results across multiple industries, including agriculture, and AHDB has been working with Lean consultants with great success. The unit manager would complete a BIT qualification as part of the process.

The entire project would take 12 months the training for the unit manager consists of six days completed in the first three months (these would be off-site); the rest of the task is completed on farm. The training for owners is just three days and is also completed off-site.

Producer input

Producers would need to agree to work with the programme for 12 months, provide small speaker slots advising on their progress so far at the local pig clubs and allow us to produce a case study to use at pig events.

Appendix 1

Factors affecting gilt retention

Introduction

Sow longevity is an important issue in pig breeding herds as there are economic, health and welfare problems associated with low sow retention rates (Anil et al., 2008). The current average sow replacement rate for Great Britain is approximately 55% (AHDB, 2019). It has been suggested that 15–20% of the breeding herd should be comprised of gilts (Dhuyvetter, 2000) and a significant proportion of sows should be between parities 3–5 (Wilson, 2013). Higher replacement rates are often a result of a combination of factors, including poor management and, in particular, the nutritional management of the gilt during gestation and lactation (Hughes et al., 2010). One of the major reasons for culling sows is reproductive failure, which is more prominent in younger sows, in particular in gilts and sows of parity 2 (Hughes et al., 2010). The sow herd accounts for approximately 20% of the feed costs in a commercial farrow-to-finish system. Having a high sow turnover increases the number of non-productive days that the sow consumes feed, resulting in increasing costs (Wilson, 2013). Introducing new gilts to the herd also increases the chances of exposing the herd to new diseases (Anil et al., 2008). Therefore, understanding the factors which affect gilt retention rates is important in order to help improve sow longevity.

Factors affecting gilt retention

Hormone control (i.e. Regumate) – Altrenogest (known as Regumate or Matrix) is an orally active progesterone which can cause the suppression of the follicular phase of the oestrus cycle and thus is often used for the synchronisation of the oestrus cycle in gilts (Soede et al., 2007). Previous research has demonstrated that providing an altrenogest to gilts can improve reproductive performance in terms of higher ovulation rates (Koutsotheodoros et al., 1998) and improved embryo survival (Patterson et al., 2008). Treatment with an altrenogest post-weaning can increase the wean-to-oestrus interval (WEI), which can allow primiparous sows longer to recover from lactational catabolism and has been shown to increase the percentage of sows showing oestrus after treatment withdrawal (Fernández et al., 2005).

AI – The stockmen who perform AI have been found to affect farrowing rate and litter size, therefore it is important to have dedicated and well-trained staff performing AI (Knox, 2016). Knox et al. (2013) found that 'technician effect' accounted for up to 70% of the variation in reproductive performance between sampled farms. Both Le Moan (2005) and Martel et al. (2008) found that the labour and productivity of pig farms, in particular how labour was organised around fertility and farrowing, directly affected the performance of pig farms. More recently and across multiple sectors of UK agricultural production, Redman (2015) identified it was those producers who were marginally better at specific processes, such as AI, that outperformed other farms and tended to be more profitable.

Gilt selection based on high litter size – Litter size in the first and second parity has been shown to be predictive of future performance (Patterson and Foxcroft, 2019). Litter size in the second parity often decreases compared with the first parity, which is most likely due to weight loss throughout the first lactation (Thaker and Bilkei, 2005). Bergman et al. (2018) found that gilts/sows that produce medium litters (11–15 piglets/litter) and large litters (16+ piglets/litter) had significantly reduced chances of being removed from the herd.

Nutrition – The nutritional status of the gilt before service and throughout lactation can impact its reproductive performance. Almeida et al. (2000) demonstrated that embryonic survival increased from 68% to over 80% when gilts were fed a high-plane-of-nutrition diet for two weeks before service. However, there is evidence to suggest feeding a high-plane-of-nutrition diet post-service has negative effects on embryo survival and farrowing rates (Craig et al., 2015). Gilts/sows are fed a restricted amount during gestation to prevent obesity and to try to maintain a body condition score of 3 (Craig et al., 2015). However, if the sow is too thin throughout gestation, milk production and growth of the piglets can be compromised (Whittemore and Kyriazakis, 2006). In addition, feed intake in lactation needs to meet the demand for milk production while minimising maternal fat and protein losses (Whittemore and Kyriazakis, 2006). Excessive fat loss across lactation can adversely affect fertility after weaning (Hughes et al., 2010). Whittemore and Kyriazakis (2006) reported that for every 1% loss in body fat from the sow across lactation there would be 0.1 fewer piglets born in the next litter. Voluntary feed intake of gilts in lactation is often too low to meet the demand for growth and milk production (Noblet et al., 1990) and therefore loss of body reserves is more evident in young sows (Hughes et al., 2010).

Udder quality – Sow fitness, including the presence of a sufficient number of functional teats, is important in the initial period of raising piglets, therefore teat functionality is a criterion for gilt selection in certain countries (Chalkias et al., 2013). Udder conformation in sows can influence piglets' latency to first suckle and thus overall piglet pre-weaning mortality (Balzani et al., 2016). Breed, parity and teat pair number all influence udder morphology variation (Balzani et al., 2016). Balzani et al. (2016) found that first- and second-parity sows had smaller teats and less developed udders compared with older multiparous sows. Some teats on young gilts are less functional than others, such as inverted, small or extra teats (Chalkias et al., 2013). These teats cannot be suckled by piglets or the related mammary gland produces less milk (Chalkias et al., 2013).

Leg confirmation – Lameness accounts for up to 15% of total culls throughout the first parity (Wilson, 2013). Lameness can affect sow reproduction through longer WEIs, increased non-productive sow days, smaller litter sizes and less weaned piglets (Wilson., 2013). A study by Pluym et al. (2013) found that lameness increased the number of mummified foetuses. Inflammation causes nutrients to be partitioned towards the immune system, as opposed to production, which can decrease reproductive efficiency (Wilson, 2013).

High-parity sows yielding consistent litter numbers – Research has shown that sows producing high litter sizes are more likely to remain in the herd (see gilts selected on high litter sizes) and litter sizes have been found to increase with parity (Bergman et al., 201).

Ability of a sow to produce a consistent litter (i.e. consistent weaning weights of piglets) – Greater litter weaning weights can be an indication of the sow's ability to produce the required quantity of milk, which is also associated with their lactation feed intake (Anil et al., 2006). Anil et al (2006) found that sows with higher litter weaning weights were more likely to have increased average daily feed intake throughout lactation and were more likely to remain in the herd.

Body condition score entering parity one – As mentioned above, excessive fat losses throughout lactation can adversely affect fertility after weaning (Hughes et al., 2010). A body condition score of three is optimal (Young and Aherne, 2005). Hughes et al. (2010) found that culled sows were lighter and back-fat depths lower than sows which remained in the herd after weaning. Vargas et al. (2009) found that return to oestrus was associated with a loss of body condition. They found that both primiparous and parity-two sows were at a higher risk of returning to oestrus if they lost more than 0.5 units of body condition score during lactation. However, body condition score is subjective and can depend on the skills of the scoring personnel (Maes et al., 2004).

Body condition score entering subsequent parities – See body condition score entering parity one.

Good temperament – It has been suggested that the temperament of the sow can affect her maternal ability (Thodberg et al., 2002). The temperament of the sow can affect the performance of her piglets. Early milk ejection is important for newborn piglets and is correlated with the prepartum behaviour of the sow (Peltoniemi et al., 2016). The most common causes of piglet mortality are starvation and injuries caused by the sow. However, high milk production is not a guarantee that the sow will provide her piglets with adequate quantities of milk and piglets that do consume adequate milk may still be injured by the sow (Rydhmer, 2000). Therefore, selecting gilts/sows based on their behaviour may improve piglet survival.

Significant injury – Lameness and uterine prolapse have been found to be major causes of sow removal. In addition, farrowing is considered a high-risk event for the removal of sows for production and welfare reasons (Anil et al., 2008). Karg and Bilkei (2002) reported that 40.2% of sow mortalities occurred during lactation.

Health – Health problems can affect sow longevity, both directly and indirectly. Severe health problems often result in the immediate removal of the sow from the herd. Indirectly, ill health can reduce feed intake and subsequent reproductive performance (Anil et al., 2008). Sows with health problems have been found to yield fewer live-born piglets if retained in the herd (Anil et al., 2008). Cytokines released by inflammatory responses to infections can lead to anorexia and lethargy (Johnson, 1997). Health problems can also compromise the welfare of the animal (Anil et al., 2008). Retaining sows despite health problems during the periparturient period may affect the overall health of the main herd in the long term (Anil et al., 2008).

Production of strong piglets – The quantity and quality of piglets produced each year is influenced by the parity distribution, with gilt progeny tending to be weaker and having lower survivability compared with higher-parity sows (Bergman et al., 2018). However, there is not much evidence to suggest that this influences gilt retention rates.

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Appendix 2

Factors affecting weaning weight

Various researchers have shown that weaning weight of piglets directly has an impact on days to finish. Research shows that generally this is between 8–10 days (Mahan and Lepine, 1991; Wolter & Ellis 2001). This offers farmers a potential to save between 80–90p/pig/day (based on a typical consumption level during the final two weeks of life and feed costs of circa £230/tonne).

Herd health – Disease pressure has been shown to have significant impacts on growth rates (Straw, 1984; Spurlock, 1997). Specifically, the following impacts will be seen. Immunological challenge will cause a decrease in insulin-like growth factor. This factor is closely associated with animal growth rates and ultimate body size. Cytokines produced as part of the immune response suppress secretion of growth-promoting hormones. Decreased feed intake or anorexia is likely due to pathogenic infection and immune system activation. The metabolic response to infection causes nutrients to be directed away from tissue growth in support of immune function. Concurrent subclinical infections will create cumulative effects, which may significantly worsen performance. As such, strategies to increase the 'health' of the piglet, either through better natural immunity (colostrum intake) or via induced immunity (vaccinations), should lead to increased growth and final weaning weight (Muirhead & Alexander, 1997). Equally, strategies to reduce exposure to disease pressures via better biosecurity should have the same measurable effects.

Genetics – This is a much more complex issue, with several studies (Camerlink et al., 2014 and 2018) showing that although there was evidence of indirect genetic effects (IGE), when looking at the IGE for growth (IGEg), there was no evidence of a link between high IGEg and improved average daily gain (ADG). Results showed a slight negative impact (not significant) on ADG. This is likely due to increased emphasis on social structure and reduced aggression and then changes to how the pigs interacted with key enrichment materials, such as jute bags. In fact, genetic selection for prolificacy in sows has been shown to have a negative effect on litter variability, as the ability of the uterus to hold viable foetuses is reached, an increase in variation is noticed in the resulting litters (Lund et al., 2002; Tribout et al., 2003; Foxcroft, 2008; Quesnel et al., 2008). Campos et al. (2010) stated that these findings suggest that increased litter size induces an increased proportion of light piglets, a concomitant decrease in litter uniformity and average piglet birth weight, having negative effects on the piglets' viability and performance. It is quite clear that the increased prolificacy of the modern sows leads to negative impacts on foetal growth and development, as large litters are associated with reduced rates of foetal oxygen and nutrient uptakes and also with reduced utero-placental blood flow per foetus (Reynolds and Redmer, 2001). Thus, these events may limit the uterine capacity, which can decrease foetal growth, increase foetal death and compromise the offspring's performance.

Diet (sow and piglet) – Feed is one of the largest costs associated with pig production, accounting for approximately 61% of the total COP (AHDB COP figures Q2 2019). Many of the factors described here show an impact on feed conversion ratios (FCR), i.e. how much feed it takes to produce 1 kg of pork. They also reference the average daily gain (ADG), which is a more reflective measure of efficiency over time. Research has shown that the diet of the sow, both before insemination as a 'dry sow' and throughout lactation, impacts the weaning weight of the piglets. When looking at primary factors that impact feed intake in sows, birth weights and correspondently weaning weight, Craig et al. (1995) found that it was lysine levels, described as 'feed quality', that corresponded with significant improvements. Interestingly, there seems to be a crossover point at which additional lysine imparts less and less benefit the higher the levels are increased. This suggests there is an optimum level for feeding to maximise the benefit to the sows and associated progeny. Sows consuming ≤3.5 kg of feed per day during the first two weeks of lactation were more likely to be removed from the herd before the next parity (Anil et al., 2006). These sows were also more likely to have litters of lower birth numbers, higher mortality and, importantly, lower weaning weights. The diet of the sow during lactation does make a slight difference, not only in terms of weaning weight (Craig et al., 2017) but also on the BCS of the sow for the next parity. Piglets from sows fed with a higher level of feed had an ADG of 190 g/d compared with the control sows fed a 'normal' diet. Lawlor and Lynch (2005) found no difference in litter performance from sows given higher-energy feed during gestation, however, the sows were grouped by parity and weight, not BCS.

Access to clean water – Water should be considered 'the consistent nutrient' at all stages of production, from conception through to farrowing, lactation and, of course, growth. Water is the biological solvent in which metabolic processes occur. A lack of water quantity and, of course, a lack of or reduced quality will have an impact on performance. Stull et al. (1999) found that performance indices, such as mortality, feed intake, growth rates, feed efficiency and, most critically, profitability, may be affected by the quality of water provided. Studies into water quality and specifically weaning weights is limited. Commercial entities such as Ximax have completed commercial trials, with results suggesting a significant impact on FCR depending on clean, high-quality water. In growers, clean water has been shown to add 0.2 to FCR efficiency and reduce days to slaughter/finishing by four. In terms of water quantity, trials by Denkavit in the Netherlands (van Enckevort, 2018) show a clear need for water as part of feed intake. However, providing quantities over and above what is required for metabolic functions does not add to either FCR or show a corresponding change in ADG. This implies there is a plateau at which additional water intake will not impact growth, i.e. a piglet can only consume so much feed and water. Water intake is, of course, impacted by seasonality and changes in climate, but perhaps less well recognised are the changes that diet can have. Increases in fats, energy contents or crude protein at a level above requirements lead to an additional water demand. While this has not been linked specifically to weaning performance, it does impact farm profitability through excessive slurry generation.

Fostering – Research suggests (van Erp-van der Kooij, 2003) that there is little impact on performance between litters of cross-fostered pigs, providing this is done within the first week from farrowing and a more uniform batch of pigs is produced. In a study of Irish commercial pigs, Calderon Diaz et al. (2018) found that while early cross-fostering, i.e. within week one, has little impact in performance, it does have implications for welfare in terms of signs of aggression and distress. Equally, late fostering, i.e. two weeks after farrowing, showed a significant impact on performance and welfare.

Production system – When looking at the advantages of production systems on final weaning weights, the assessment needs to identify the entire production process and, importantly, the relative costs associated (Vermeulen et al., 2017). Batch systems and continuous production systems have varying impacts on final weights but will also have other fixed cost considerations, such as labour. Only when considering the COP as a whole should any inferences be made about the efficacy of a system. The impact of labour on productivity should be noted and not underestimated. Main et al. (2004) state that longer weaning periods have a positive effect on unit performance across multisite operations, as mentioned, the ability to increase weaning periods is limited by available farrowing places and would require significant investment into the UK breeding herd.

Iron injecting – Iron injection in indoor production systems is considered routine to avoid piglet anaemia due to lack of access to iron-rich soil on the sow's teats or from the environment. Routine iron injection in outdoor sows is significantly less common due to the availability of said soil. Iron levels in soil can show significant seasonal variability, with increased leaching during winter months. Commercial trials of iron injection of outdoor piglets have shown a significant increase in performance (Pearson, 2010), with piglets in the control group showing an average weaning weight of 7.11 kg and those given supplementary iron weighing 7.37 kg – an average increase of 3.6%. This study also associated improved post-weaning performance due to the increased weaning weight with an ROI of 10:1 when using supplementary iron. It did also note a strong seasonal impact.

Parity profile – While not always adopted by industry, the importance of parity profiles led by push models of replacement, i.e. new gilts push out old sows, is highly recommended by scientific literature based on economic modelling (Faust et al., 1992, 1993) and real-world experience. Gilts typically have a lower litter size compared with multiparous sows and their piglets are lighter at birth and weaning compared with those from older parity sows. In addition to being lighter, research has also demonstrated that pre-weaning growth rates for gilt progeny are 12–17% less than sow progeny (Anil et al., 2006 and 2008). This means gilt progeny are on average 1 kg lighter at weaning and 6 kg lighter at sale (24 weeks of age). Research suggests maintaining sows to parity 5 delivers a better return on the COP of the breeding herd, but more importantly for the growing herd, maintaining a gilt replacement rate of 42–45% allows for an optimisation in growing herd performance and lower COP (Wilson, 2013). Takai (2007) showed that those animals at parity 1 had a significantly higher chance of becoming at-risk females, suggesting a higher percentage of replacements increases the risk of having a larger subgroup of less productive animals. At-risk females in the study had 11.1% lower farrowing rates than non-at-risk females and their performance declined significantly over those females defined as non-at-risk. Stalder et al. (2004) compiled a recommended distribution of parities by percentage (see below).

Ideal parity distribution percentages recommendations.[a]

Study	Parity								
	0	1	2	3	4	5	6	7	>7
Straw [238]	20	18	17	16	15	14	-	-	-
Parsons *et al.* [18]	30	23	19	14	10	5	2	1	0
Muirhead & Alexander [239]	17	15	14	13	12	11	10	5	3
Morrison *et al.* [34]	19.1	16.5	16.9	14.1	10.2	8.2	5.1	4.9	4.9

[a] Values by parity within a row indicate the percentage of females that should be in each classification for an ideal distribution.

Sehested (1996) showed that increasing the longevity of sows by a parity of 1 (as an average for the herd) was the equivalent in terms of profitability of increasing lean meat percentage by 0.5% for the finishing herd. This means that while money is paid against the finishing herd, the breeding herd has a significance to profitability in reducing the cost of production. Parsons et al. (1990) report that there is little impact on profitability of increasing the breeding herd beyond parity 5, suggesting a heavy bias to the younger parities. Faust et al. (1992, 1993) and Morrison et al. (2002) agree, with their modelling showing a bigger impact on profitability of moving to an older parity profile in parities 1–5, i.e. retaining a higher percentage of parity 1 and 2 sows than increasing the parity profile in parities 5–10.

Sow body condition – Body condition score (BCS) is directly impacted by diet, previous litters and health and should be considered in terms of genetics, with maintenance of BCS seen as a heritable trait. When looking at the relationship between diet and BCS, lactation feed intake and dietary energy and lysine intake in the second half of lactation were the main drivers of litter weaning weight (Craig et al., 1995). In simple terms, appropriate feed type and intake impact BCS.

Appropriate feed type and intake decide weaning weight. Therefore, there is a correlation between BCS and weaning weight.

Size of farrowing ark and set-up – Anecdotal evidence. There appears to have been little to no scientific study that examines directly the impact of sow ark size on weaning weights. Anecdotally and as a mention in some literature, sow size has an impact on mortality in relation to ark size, i.e. increasingly larger sows in the same-size arks are more likely to lay over piglets, causing increased mortality.

Time spent in lairage prior to movement off farm – Anecdotal evidence.

Seasonality – Thermal stress (extremes of heat or cold) particularly affect outdoor-reared sows (Auvigne et al. 2000; Bloemhof et al., 2008) but also indoor-reared. Weaning weight of piglets has been shown to be adversely affected by all traits affected by seasonality, such as sow BCS, birth weights and mortality (Knecht, 2015). Minimising the impacts of thermal stress, such as insulation of arks and provision of adequate water and wallows, can have a significant impact on weaning weights.

Gilt litters – See parity.

Udder quality – In terms of teat structure, research shows that deviations from 'normal' affects the ability of piglets to maximise growth. Impact of poor teat morphology results in lower weaning weights (4.8 kg average in piglets suckling from small teats with low mammary mass), while some studies also show a numerical (not always statistically significant) difference in growth rates in favour of 'normal' morphology. Normal teats also show a higher fidelity of 82%, suggesting there may be a link between teat morphology and welfare in terms of reduced piglet anxiety and aggression.

Supplementary feed systems/strategies – Various systems suggest an increase in weaning weights. Each requires a bespoke review in terms of ROI for each production system, i.e. it may well offer some return, but will it offset the price based on the system of production and labour?

Stockperson skills and training – Management of any system is only as good as the stockperson overseeing it. Inadequate training in health, including biosecurity, feed systems and general husbandry, will lead to lower outcomes. Redman (2015) suggested that those producers that were able to make marginal gains across all production were likely to be the most profitable. While not entirely responsible for the difference, appropriate training in key processes is an important element of pursuing and achieving marginal gains in production. Knox (2013) identified that in processes such as AI, the 'technician effect' accounted for up to 70% of the variation in productivity between farms sampled.

New site effect –New sites should, having been free of pigs, be free of diseases. This lowers the pressure on metabolic pathways, leading to higher growth rates. There is some suggestion that deep-cleaning between litters can result in similar effects seen. In short, this comes down to biosecurity as a function of good herd health.

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Appendix 3 – Gilt Watch ® survey

To what extent (1 being an insignificant amount and 10 being extremely significant/common) do you feel the following contribute to gilt retention in the herd?

Circle a value below

Appropriate use of hormone treatment, such as Regumate, to synchronise cycles	1	2	3	4	5	6	7	8	9	10
Stockpersons well trained in AI linked to clear SOPs/Protocols for AI	1	2	3	4	5	6	7	8	9	10
Gilt selection based on high litter size	1	2	3	4	5	6	7	8	9	10
Appropriate nutrition, supplementary feed and condition scoring to ensure gilts/sows rear the maximum number of piglets per litter	1	2	3	4	5	6	7	8	9	10
Appropriate identification of udder quality prior to breeding	1	2	3	4	5	6	7	8	9	10
Selection of gilts for good leg confirmation	1	2	3	4	5	6	7	8	9	10
High-parity sows still yielding consistent litter numbers	1	2	3	4	5	6	7	8	9	10
Ability of a sow to produce a consistent litter, i.e. good numbers born alive, low mortality and, importantly, consistent weaning weights	1	2	3	4	5	6	7	8	9	10
The overall body condition score (BCS) entering parity 1	1	2	3	4	5	6	7	8	9	10
Overall BCS entering subsequent parities	1	2	3	4	5	6	7	8	9	10
Selection of gilts based on good temperament	1	2	3	4	5	6	7	8	9	10
Significant injury, e.g. heart attack, broken limbs, etc.	1	2	3	4	5	6	7	8	9	10
Ability to remain in good health – low incidence of pneumonia, ill thrift, etc.	1	2	3	4	5	6	7	8	9	10
Production of strong piglets, i.e. low levels of ill thrift	1	2	3	4	5	6	7	8	9	10

Appendix 4 – 8 kg club (Weaners)

To what extent (1 being an insignificant amount and 10 being extremely significant/common) do you feel the following contribute to producing a heavier pig at weaning, i.e. 8 kg at weaning rather than 7 kg at weaning?

Circle a value below

Overall health status of the breeding herd including piglets	1	2	3	4	5	6	7	8	9	10
Genetics, i.e. genetic combinations that yield more productive piglets	1	2	3	4	5	6	7	8	9	10
Diet of the sow	1	2	3	4	5	6	7	8	9	10
Diet of the piglets	1	2	3	4	5	6	7	8	9	10
Access to clean water in sufficient quantity	1	2	3	4	5	6	7	8	9	10
Cross-fostering	1	2	3	4	5	6	7	8	9	10
Iron injection of outdoor sows year-round	1	2	3	4	5	6	7	8	9	10
Parity – replacement gilts around 42–50% and remaining animals parities 2–5. Few pigs at parity 5+	1	2	3	4	5	6	7	8	9	10
Sow BCS	1	2	3	4	5	6	7	8	9	10
Size of the farrowing ark	1	2	3	4	5	6	7	8	9	10
Longer time spent in the lairage prior to moving off the weaning site	1	2	3	4	5	6	7	8	9	10
Seasonality – specifically linked to thermal stress	1	2	3	4	5	6	7	8	9	10
Udder quality – 14 working teats as a minimum, no unproductive quarters	1	2	3	4	5	6	7	8	9	10
Use of supplementary feed systems	1	2	3	4	5	6	7	8	9	10
Vaccination strategies	1	2	3	4	5	6	7	8	9	10
Highly skilled, specialised stockpersons, i.e. each with specific roles	1	2	3	4	5	6	7	8	9	10
New site effect – does moving to new ground in outdoor pigs and new buildings for indoor pigs raise the weaning weight?	1	2	3	4	5	6	7	8	9	10