PRE-FARROWING HEALTH AND WELFARE ASSESSMENT OF SOWS

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By

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Executive Summary

Sow replacement rates and sow mortality are relatively high in modern commercial pig production systems. This problem might be exacerbated in group housing systems for sows during gestation, due to the increased difficulty for individual observation of sows and greater interaction amongst sows. We proposed that monitoring for sow health and welfare issues before and after parturition might help identify predictors for poor outcomes, enabling earlier intervention or identification of sows for treatment. We used existing reproductive and removal data to identify poor outcomes on two farms, and recorded a range of physiological measurements, observations on feed intake or feeding behaviour, and scored for a range of health and welfare related issues pre- and post-farrowing, to identify key predictors for outcomes in pedigreed sows. We were also able to investigate if variation in genetic merit for a range of traits was associated with predictor variables or poor outcomes for sows managed as contemporaries.

The number of sows which were treated for health issues during gestation was relatively low (<5% of sows), suggesting that the overall sow health and welfare was perceived to be good under routine monitoring of sows housed in gestation groups. However, detailed examination of individual sows upon transfer to the farrowing house identified a higher percentage of sows which were potentially compromised by one or more health related issues pre-farrowing. These included a range of moderate to severe injuries (e.g. 1-11%), locomotor problems (1-3%), inferred urinary tract infection (6-1%), unusual physiological parameters (eg elevated rectal temperature or respiration) or poor body condition. Only 35.8% and 41.8% were completely 'normal' physiologically and free of any injuries, although 'affected' sows include many with relatively minor deviations from normal which might have no implications for outcomes. The incidences of culling to weaning (4.9 and 6.1%), or to day 60 (8.8 and 12.2%) or day 142 (13.6 and 14.9%) after weaning, which excluded voluntary culling for age and parity, illustrate that a significant percentage of sows were removed from the herd prematurely within a single reproductive cycle. Serious health issues were quickly recognised by staff and resulted in rapid removal of sows from the herd due to welfare implications. However, other evidence of poor health (eg physiological measurements) were not typically observed by staff, restricting opportunities to identify and treat sows to improve specific outcomes.

The percentages of sows without any adverse outcome (at farrowing or during lactation) recorded from entry to the farrowing house up until weaning was 68.6% (Farm A) and 74.1% (Farm B). Therefore, a significant percentage of sows had minor to major undesirable outcomes in the farrowing house. Numerous predictors were subsequently identified which were associated with forced removals and/or poor outcomes at farrowing and with respect to piglet survival. Some of these predictors are less relevant to other commercial populations (e.g. farm specific factors or the comparison of maternal vs terminal line outcomes, for example). However, other predictors were common across farms and/or different outcome traits and are also likely to occur in commercial populations. Specific predictors varied in both their ease of recording and the usefulness of the information they provided. Similarly, undesirable outcomes could be predicted reasonably accurately for some situations (e.g. lactation failure or sow removal before weaning), whereas predictors for other outcomes (i.e. the presence of any stillborn piglets at farrowing) were relatively inaccurate.

Data recorded by electronic sow feeders during gestation can provide useful data for predicting poor outcomes for sows and/or their piglets prior to the farrowing event, and also with respect to future removals. Low feed intake, reductions from the target feeding curve, and/or missed meals were associated with a higher incidence of detrimental outcomes. These variables also tended to be related to other pre-farrowing predictors. For example, the number of missed or partial meals during gestation was higher for sows identified at transfer to the farrowing house with locomotion problems or injuries, and the extent of feed refusals before farrowing was also associated (p=0.01) with missed meals previously recorded during gestation. Therefore, existing ESF systems require better enablement to make use of data which is currently recorded in some sow management systems, for identifying and (earlier) treatment of at risk sows.

Pre-farrowing predictors associated with numerous outcomes, including ultimately forced removals, and which were most consistent across farms, included variables related to the timing of transfer relative to the impending farrowing, the fit of the sow into the crate and/or teat accessibility for piglets - more so than parity group, along with locomotion problems and injuries to legs. Sows with very restricted space or poor teat access for piglets in farrowing crates (15-25% of all sows) had increased stillbirths and progeny losses. Therefore, farrowing crate size, design and adjustment, relative to sow dimensions, are contributing to poor outcomes at farrowing, particularly for older parity sows. Outcomes for the nursing sow were compromised by both low or high caliper score and low haemoglobin levels. Risks to piglets born to project sows were elevated by low haemoglobin and poor pre-farrowing udder development. Sows with injuries generally, or exhibiting high rectal temperatures, were also more likely to become forced removals. In addition, feed refusal observed in the farrowing house before farrowing was an indicator for sow removals over all time periods.

Urinalysis results were also informative for predicting unfavourable outcomes. Sows with inferred urinary tract infection (UTI), an absence of excreted vitamin C or with ketones present pre-farrowing were more likely to have stillbirths, piglet losses and lactation failure respectively. The overall percentages of sows with these observations ranged up to 6.8% for UTI, 24.5% (absent Vitamin C) and >28% of sows with protein >100 mg/dl, dominated by Farm B data. These results were consistent with the expected impacts of infection and metabolic status on outcomes, and would suggest that undiagnosed and therefore untreated UTI contributed to stillbirths occurring in these populations. It is plausible that low Vitamin C and high protein excretion might have reflected restrictive feeding strategies during gestation, and this should be investigated further given the accompanying detrimental effects. Overall, urine samples were relatively difficult to obtain with respect to optimum timing. The development of better implementation options could be considered for routine identification of UTI.

The accuracy of predicting poor outcomes varied by outcome trait, and by farm. Pre-farrowing information (excluding ESF data and urinalysis results) provided fair predictions for the probability of a failed lactation or removal at weaning (REMW) or by day 60 post-weaning (REM60) across farms. The use of post-farrowing information (particularly piglet quality attributes) further increased accuracy of predicting undesirable outcomes for biological progeny, for sows during lactation and for sow removals. The most accurate prediction for REM60 excluded variables which can be used for voluntary culling, like number weaned, since the number weaned itself was influenced by other predictors. Since REM60 is predicted more accurately than REMW, there was evidence to suggest that culling decisions could have been more precise at weaning if predictive variables were used, reducing unproductive sow days which increases costs. Alternatively, sows could have been identified for appropriate treatment at weaning to reduce this source of sow wastage.

Variation in genetic merit had favourable and unfavourable consequences for outcomes of sows and/or their progeny, as well as predictors for these outcomes. However, the project data were somewhat limited in this respect since not all sows had breeding values. The project firstly illustrated that high litter size placed sows at higher risk of poor outcomes relative to lower litter size within a common management system. This is relevant for commercial producers as it demonstrates that high litter size sows require more careful management generally. It is also pertinent for breeding companies, since management has not been adapted to the characteristics which affect specific lines (ie all sows are treated the same, regardless of line or level of genetic merit). Secondly, breeding values were predictive for the corresponding or highly correlated phenotype, as expected (eg breeding values for stillbirths or litter size predict these traits). Thirdly, some predictors (eg injuries, veterinary treatments) for poor outcomes had negligible heritability, whereas others were moderately (UTI) or highly (eg caliper score) heritable. Therefore, some predictors for poor outcomes - including physiological or health related variables, are influenced by genetic differences between sows, whereas others are independent of genetic merit. Further investigation of predictors which might have application for breeding programs aimed at more robust sow performance is warranted.

Overall, results from this study suggest that interpretation of data from ESF systems and targeted monitoring for identification and treatment of unhealthy or injured sows in both gestation housing and the farrowing house is likely an avenue for reducing poor outcomes for sows and subsequently sow wastage. Several possible causes for poor outcomes were identified, including physiological and/or nutritional (eg Vitamin C, HB), physical (crate dimensions), management (movement logistics, feed delivery) and health related (UTI, injuries, lameness) issues. In larger data sets and to a lesser extent amongst project sows, there was also evidence for the impact of genetic merit on feed requirements, various health measures and also contributing to risks for removal. To make timely use of this information would require investment in additional staff and development of appropriate interventions for gestating sows. In addition, improving information delivery to staff (i.e. ESF reporting functions, or development of a farrowing house app) regarding issues for individual sows and to assist with activity management could also be beneficial.

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1. Introduction

In 2010, sow wastage resulting from forced culling and sow deaths was a hot research topic because the replacement rate for sows in commercial operations was increasing. In the 2006/2007 Australian Pig Annual, annual sow replacement and sow mortality rates had weighted averages of 35.1% and 8.78%. Corresponding values from 2012/2013 were around 56.1% (range: 39.8-76.1) and 10% (range: 2.5-19.1), showing no improvement.

While there could be many possible causes for increasing sow wastage, genetics as a primary cause seems unlikely given the observation of very different sow wastage and death rates typically observed amongst farms receiving common sow genetics. Nevertheless, ongoing genetic improvement, which gradually increases the resources required by sows during gestation and lactation, might also increase their risk for poor health and farrowing outcomes when genetic improvement is not accompanied by the required nutritional or management changes. Previous authors (e.g. Prunier *et al.* (2010) have reviewed how increasing the physiological demands brought about by both improved genotypes and environments (i.e. elevating production levels) affect animal health and welfare, but the impact of individual variation in genetic merit on these outcomes has rarely been characterised. The study of Hermesch (2010) demonstrated that genetic merit for growth, fatness, litter size and piglet birth weights increased sow size and leanness, along with litter size and weight, contributing to higher demands on energy reserves of sows. Trends in production level due to genetic merit might also have an impact for the expression of health and welfare issues.

Deteriorating trends might also simply reflect increasing scale of operation combined with decreasing staff units per sow, which reduces the ability to monitor and treat for optimum health and welfare of individual sows. If this is the predominant causative factor, then the move to group housing could further exacerbate detrimental trends in sow replacement rates and mortalities. There is already some anecdotal evidence for this. For example, in the recent project data of Athorn (APL Project 2012/2345), which includes a large number of group housed sows, the abortion rate of group housed early parity sows was around 4%, exceeding the 1.5 to 2% which might otherwise be expected. Sows which abort are typically culled. Sows housed in stalls during gestation were culled at a lower rate than group-housed sows fed with ESF (14.6 vs 28.6%) in the small study of Jang *et al.* (2017).

In this project we investigate two windows of opportunity potentially available to identify sows at-risk for poor health, welfare and production outcomes. These include examination of feed intake and feeding patterns from gestating sows managed in groups with ESFs, along with additional variables recorded on individual pedigreed sows immediately pre- and post-farrowing. The ESF data can be obtained from existing systems, whereas additional recording pre- and post-farrowing were required to obtain data on additional targeted variables.

The transfer of sows from gestation to farrowing accommodation should be used to motivate a simple and effective data based monitoring system which can be used to identify sows at relatively imminent risk of ill-health, death or culling. Appropriate interventions would then enable improvement, rather than further deterioration of, sow health and welfare outcomes and, concurrently, reduce sow losses and wastage. Sow removals which occur in early parities are a known contributor to reduced profit of pig breeding enterprises. These sow removals also typically represent, at least to some extent, the difficulty of identifying health and welfare issues for individual sows pre-farrowing without a routine monitoring program in place. Sow (and/or piglet) losses predominantly occur immediately prior to farrowing, or within the normal lactation period, and/or shortly after weaning. Therefore, this is an important time period in which to ameliorate risk.

Developing a simple monitoring system in the farrowing house which will identify sows at risk of poor outcomes could benefit all pig producers, and potentially also supplies useful data to inform the breeding program. Bunter *et al.* (2009) demonstrated that poor sow health pre-farrowing decreased lactation intake and increased the risk of lactation failure and sow culling. The impact of infections (Hoy, 2006), lameness (Anil *et al.*, 2009) and other risk factors for sow health, performance and longevity have also been frequently illustrated, but such studies have so far not impacted on the development of monitoring systems which enable routine diagnosis and early treatment of at risk sows. For example, urinary tract infections (UTI's) are relatively common in sows but are frequently undiagnosed, despite more than 50% of sows reported as sudden deaths in Portugal having UTI's (Perestrelo *et al.*, 1988). In contrast, the relative simplicity and accuracy of urine testing to identify UTI's would suggest more routine urinalysis could be informative. Similarly, the information provided by rectal temperatures can be informative in the assessment of health related issues and outcomes for sows (Bunter *et al.*, 2011) and is also relatively easy to obtain.

More recently, detrimental changes in some physiological parameters, such as haemoglobin levels of sows (demonstrated by Auvigne *et al.* (2010), and Hermesch *et al.* (2012)) have been reported. The implications of sow anaemia have not otherwise been widely investigated, but increased still births and farrowing difficulties as a consequence of low sow haemoglobin have been suggested (Auvigne *et al.*, 2010). Depressed appetite is also commonly associated with anaemia in humans, which has not been investigated to date in sows, and which could have important consequences. Overall, numerous sources of literature suggests there are several avenues which could be considered to improve monitoring of sow health and welfare, with an aim to improve outcomes for sows and their litters.

In this project, we investigated a suite of possible variables to monitor, with the aim of identifying those which are the most informative and easy to screen in a normal commercial environment. Subsequently, these monitoring variables can be used to develop an index for the relative risk of poor sow and/or piglet welfare outcomes. This strategy would then highlight sows for which increased care and interventions may be beneficial to improve outcomes.

Aims

1. To characterise health and welfare issues affecting group housed sows upon their transfer to farrowing facilities

2. To identify the monitoring criteria associated with poor outcomes for sows or their litters which can easily be applied by stockpersons to identify, triage and potentially treat sows identified with health or welfare issues via an assessment of their risk factors

2. Methodology

In this project, we collated a range of data which included reproductive outcomes, in context with additional data recording for pre-farrowing health and welfare phenotypes, on approximately 1000 pedigreed sows sourced from two sites. These data were accompanied by information on sow medication, culling or deaths and removals. Additional data from group housed sows fed via ESFs was also available. The data recorded were extensive and details of farms and recording are only briefly described in this report.

ESF data obtained during gestation

Pre-existing data included feed event data from ESFs recorded during gestation, which can potentially be used to identify at-risk sows based on feed refusals, or other unusual feeding patterns. At Farm A, historical ESF data were available for a large number of predominantly pedigreed F1 sows recorded during 2015 (in-house feeders, dynamic system, max 300 sows). These historical sows were not able to be recorded for the additional monitoring variables pre- and post-farrowing. At Farm B, ESF data were exported from a different type of ESF system (Osborne TEAM, dynamic system) for project sows subsequently recorded for their own health and welfare characteristics within the project.

Both ESF systems identified sows which had not consumed their allowance on a daily (real-time) basis for immediate investigation. However, neither system recorded sow visits to feeders which involved no feed delivery. Therefore, the total number of visits to ESFs per sow per day is under-represented. Time stamped event data was only recorded in the ESF system located at Farm A, whereas a single record per day which reconciled feed allocation against intake, regardless of the number of visits, was available in the Farm B system.

Neither ESF system produced a summary report for individual sows based on the ESF data at the end of gestation. Therefore, for both sites, external programming was required to manipulate event based data exports obtained from these systems into a useful format for investigation. The type of variables calculated per sow per day from the time stamped event based data (Farm A only) included: number of completed and/or missed feeding events, amount of feed consumed (kg), time taken to consume feed (minutes), and the average rate of feed consumption (kg/minute). The time(s) of day when sows consumed their meals(s) was also recorded. No variable involving time could be calculated with Farm B ESF data. Instead, the number of sows allocated per feeder was based upon an assumption of 10 minutes required per meal, and 10 hours of feeding time per feeder. For both ESF systems, the feed delivery curve for individual sows was subsequently calculated. Therefore, the deviation of intake from the allocation curve could be estimated, by day and in total.

Importantly, ESF data is typically not available for all commercial herds and therefore alternative predictor variables were investigated in this project.

Health and welfare data

Additional health and welfare related data were recorded pre-farrowing (upon transfer to the farrowing house), at days 2 and 5 (D2, D5) post-farrowing, and also at weaning. Full details are provided for scorings systems in Appendix 1. In brief:

Feed refusal by sows was recorded between transfers to the farrowing house until shortly after farrowing. Prior to farrowing at Farm A, all sows were typically delivered a standard amount of feed (typically <=2.5 kg dry, or 20L liquid) at first light each day. After farrowing, delivery was *ad libitum* (or 40L liquid). On Farm B, sows received a pre-farrowing diet close to *ad libitum* until three days after farrowing, followed by a lactation diet *ad libitum*. On both farms, feed hoppers for individual sows were examined mid-morning for the extent of unconsumed feed (all consumed, <1/2 consumed, or largely untouched) pre- and post-farrowing. When feed delivery was restricted (eg Farm A), full consumption of the feed delivered would be an expected outcome for healthy sows, providing farrowing was not imminent. However, the *ad-libitum* feeding schedule for the farrowing house in Farm B increased the difficulty of observing feed refusal unless sows were observed soon after the first feed delivery. Sow feed was delivered through a feeding line on the third day after farrowing at Farm B.

Pre-farrowing scores included: quality of locomotion, cleanliness, presence of injuries, along with udder and vulva scores. Sow condition was measured using a caliper. Other measures of general health included rectal temperature, respiration rate, standard urinalysis data and haemoglobin.

Post-farrowing data intended to identify specific metabolic or health issues included examination of the udder and scoring for the presence of mastitis (D2) or vulva discharge (D5).

Sow health and condition at weaning was assessed by recording caliper score, rectal temperature, and udder score.

Defining undesirable outcomes for sows

Outcomes for sows were simply defined using binary traits (0=normal outcome, 1=undesirable outcome) based on the reproductive performance and deaths or removals after entry to the farrowing house. Several definitions for adverse outcomes were considered:

FFAIL (failure at farrowing): was defined as an adverse outcome if any of the following were observed: an excessive number of stillbirths; <5 live born piglets, late stillbirths, caesarean or prolapse. Excessive stillbirths (SB) were identified relative to total born (TB) as: ≥1 SB for TB<9; ≥2 SB for TB=9-12; ≥3 SB for TB=13-16; ≥4 SB for TB=17-20 and ≥5 SB for TB>20. This trait is intended to reflect farrowing related difficulties. TB for this trait included all stillbirths (SB), mummified piglets (MUMS) and live born piglets (NBA).

SBLIT (still born piglet(s) present in litter): was defined as an adverse outcome if any piglets were stillborn within a litter. This trait is intended to represent the overall incidence of sows which have any still births. There is an expectation of <10% stillbirths overall, but stillbirths are clustered by litters. Therefore, overall still birth rate does not specifically inform producers of the incidence of sows which have still births.

SBFAIL (excessive number of stillbirths): =1 for excessive SB vs TB, as for FFAIL. For this trait, TB excluded mummies, because there is no potential to improve the survival of mummified piglets. Excessive still births identifies those sows where the number of still births exceeds expectation for a given litter size at farrowing.

LFAIL (failure occurring during lactation): was defined as an adverse outcome for the nurse sow if any of the following were observed: <7 weaned piglets; lactation length <15 days, and removal reasons such as “mothering ability”, “bad udder”, and “no milk”. Sows must commence a lactation to obtain an outcome for this trait.

PMORT (pre-weaning mortality of individually recorded biological progeny): was defined as an adverse outcome if >15% of the piglets born alive at birth died pre-weaning (i.e. >1/10-13, >2/14-19, >3/20+ become unacceptable levels of mortality). Individual piglets born to project sows were recorded for mortality, regardless of their nurse sow. This trait identified sows whose biological progeny (i.e. progeny she gestated and farrowed) had poor survival post-farrowing. This provides different information to LFAIL (which reflects the sow’s own performance as a nurse sow) in the presence of cross-fostering. Only a subset of project sows (maternal lines) were recorded for this outcome.

REMW (forced removals prior to the end of weaning, or within 150 days of previous mating): was indicated to be adverse only for pregnant sows which died or were culled for non-management reasons. For example, culling for old age or genetic merit are not forced removals, whereas culling for lameness, sickness or failure to rebreed are forced removals.

REM60 and REM142: forced removals defined as above, but after allowing sufficient time (e.g. 60 days) post-weaning for re-mating (REM60), or identifying late removals prior to farrowing in the next parity (REM142).

Analyses of ESF, pre- and post-farrowing predictors for adverse outcomes

Monitoring variables were compared across farms for significant differences using appropriate distributions and test statistics for each variable. Preliminary characterization of the data (e.g. the distribution of sows across scores) was also required to consolidate low frequency scores into larger groups, for example, before investigating monitoring variables as predictors.

A range of analyses (logistic regression) were then performed to identify predictors for (binary) adverse outcomes from both univariate and multivariate models, for each farm alone, or from the combined farms data. Only pertinent details from these extensive analyses are reported here.

The quality of predictors from the final multivariate model(s) was illustrated using a receiver operating characteristic curve (ROC), which is a graphical plot that illustrates the diagnostic ability of a binary classifier system as the discrimination threshold is varied. The ROC curve is created by plotting the true positive rate against the false positive rate at various threshold settings, and illustrates the accuracy of prediction.

3. Outcomes

3.1 Characterisation of outcomes for sows and their piglets

Characterisation of undesirable outcomes

Parturition is a time of high risk for females of most species, including sows. Excluding SBLIT (which affected many sows) and PMORT (which reflected recording for only a subset of sows), the percentage of sows without any adverse outcome at all recorded from entry to the farrowing house up until weaning was 68.6% at Farm A and 74.1% at Farm B (p=0.07). Around 14.2% (Farm A) and 10.1% (Farm B) of sows had a single adverse outcome recorded, and the remaining sows (17.2% and 15.8%) had more than one adverse outcome. Therefore, a substantial percentage of sows which entered the farrowing house had an undesirable outcome during farrowing (16.5 and 16.9%), during lactation (9.7 and 9.9%) or post-weaning, and around 14% of sows at both farms did not achieve a subsequent farrowing (excluding removals due to age, management or poor genetic merit). In addition, between 42-49% of sows had a least 1 still born piglet (SBLIT), and >40% of sows had progeny survival of <85% (PMORT, Table 1) even if they had satisfactory performance themselves as a lactating sow.

Table 1: Sow outcomes by farm

Outcome	N	Location	0	1	Chi-sq
FFAIL	558	A	466 (83.5%)	92 (16.5%)	
	545	B	453 (83.1%)	92 (16.9%)	ns
SBLIT	555	A	284 (51.2%)	271 (48.8%)	
	545	B	317 (58.2%)	228 (41.8%)	0.02
SBFAIL	555	A	472 (85.0%)	83 (15.0%)	
	545	B	471 (86.4%)	74 (13.6%)	ns
PMORT	449	A	254 (56.7%)	195 (43.4%)	
	256	B	156 (60.9%)	100 (39.1%)	ns
LFAIL	555	A	501 (90.3%)	54 (9.7%)	
	545	B	491 (90.1%)	54 (9.9%)	ns
REMW	558	A	524 (93.1%)	34 (6.1%)	
	545	B	518 (95.1%)	27 (4.9%)	ns
REM60	558	A	490 (87.8%)	68 (12.2%)	
	545	B	497 (91.2%)	48 (8.8%)	0.08
REM142	558	A	475 (85.1%)	83 (14.9%)	
	545	B	471 (86.4%)	74 (13.6%)	ns

For most outcome traits the farms were similar (Table 1). However, there were numerous potential sources of differences between farms. Farm A sows were housed during gestation in small static groups of approximately 10 sows/pen, and fed manually. Farm B sows were housed in large (>250) dynamic groups and fed with electronic sow feeders. The reproductive outcomes for both farms also reflected multiple, independent selection lines (grouped into terminal vs maternal), parities, housing, diets, management and the environmental conditions (including health status) specific to each farm at the time of recording. Litter size did significantly differ between farms for the sample of sows recorded (p<0.05 for NBA). Therefore, there could be an expectation for significant differences between farms for characteristics at farrowing known to change with litter size, such as incidence of litters with stillbirths (SBLIT, p=0.02), or the number of stillbirths or PMORT (ns, Table 1). Health status also has significant implications for piglet survival and the incidence of sow removals. Farm A had a poorer health status than Farm B, and the difference between farms in the percentage of sows removed approached significance (p=0.08, REM60). In contrast, despite several very different farm characteristics, the incidence of FFAIL, LFAIL, SBFAIL and removals before the next parity did not significantly differ between these farms.

The percentages of sows with more than one undesirable outcome are shown in Table 2. Traits derived with some common criteria (FFAIL, SBLIT and SBFAIL) had a relatively high number of cross-classified sows. For example, 14.4/16.5=87.3% of sows with FFAIL=1 had litters affected by stillbirths (Farm A). As an indicator of farrowing difficulties, SBFAIL was more strongly associated with more frequent losses of biological piglets (PMORT) than nurse sow performance (LFAIL). Thus, the significance of stillbirths as an indicator for ongoing piglet losses and later sow removals is likely unappreciated in commercial systems due to the way data is recorded for evaluating satisfactory sow performance (i.e. typically as a nurse sow). Sows with evidence of any stillbirths (SBLIT) or subsequently high losses of biological piglets (PMORT) appear compromised for more than one outcome, more so than sows identified with a lactation failure (Table 2). For example, 5.79/12.2=47.5% of sows with PMORT=1 were removed by D60 after farrowing, compared to 28% observed with lactation failure, on Farm A, and a similar result was observed on Farm B.

Table 2: The percentage of sows cross-classified across two undesirable outcomes (Farm A above diagonal; Farm B below diagonal)

		Farrowing outcomes			Nursing outcomes		Removal outcomes		
Trait		FFAIL	SBLIT	SBFAIL	PMORT	LFAIL	REMW	REM60	REM142
	%	16.5	48.8	15.0	43.4	9.7	6.1	12.2	14.9
FFAIL	16.9		14.4	14.2	6.46	2.88	1.79	2.87	3.05
SBLIT	41.8	14.1		15.0	21.2	5.23	2.53	5.23	6.49
SBFAIL	13.6	13.4	13.6		6.01	2.70	1.25	0.92	2.34
PMORT	39.1	7.81	21.9	7.42		8.69	3.12	5.79	6.24
LFAIL	9.9	2.39	4.77	1.84	9.38		3.24	3.42	3.78
REMW	4.9	2.02	2.57	1.28	2.34	2.94		6.09	6.09
REM60	8.8	2.75	4.22	1.83	3.52	2.94	4.95		12.2
REM142	13.6	4.04	6.06	2.75	5.86	3.67	4.95	8.81	

Characterisation of monitoring variables

Similar distributions were observed across farms for LOCO, suggesting similar locomotion quality despite very different housing systems during gestation (Table 3). However, sows in the large ESF groups at Farm B were generally dirtier (DIRTY, DIRTV) and had more injuries, mostly due to an increased rate of vulva injuries (INJUR, INJURV), coinciding with higher scores for lesions due to fighting (FIGHT). Design of the ESF at Farm B was thought to contribute to the increased incidence of vulva injuries. Vulva and udder development pre-farrowing differed between farms (Farm B more developed), along with the percentages of sows with bloodshot eyes, and the distributions of scores for CFIT and TACC.

Table 3. Distribution of sows across scores (rounded up to the nearest percentage), by Farm, along with the significance of the difference between farms (Chi-sq)

Score*	N	Farm	Normal 0	1	2	3	Chi-sq
LOCO	558	A	498 (89%)	41 (7%)	14 (3%)	5 (1%)	
	545	B	486 (89%)	45 (8%)	12 (2%)	2 (<1%)	ns
FIGHT	558	A	224 (40%)	211 (38%)	103(19%)	20 (4%)	
	545	B	68 (12%)	189(35%)	186 (34%)	102 (19%)	<0.0001
VSCORE*	558	A	328 (59%)	217 (39%)	13 (2%)	na	
	545	B	39 (7%)	462 (85%)	44 (8%)	na	<0.0001
USCORE*	557	A	156 (28%)	286(51%)	115(21%)	na	
	545	B	9 (2%)	241 (44%)	295 (54%)	na	<0.0001
Mastitis	557	A	502 (90%)	55 (10%)	na	na	
	545	B	531 (97%)	14 (3%)	na	na	<0.0001
EYE	558	A	509 (91%)	49 (9%)	na	na	
	545	B	523 (96%)	21 (4%)	1 (<1%)	na	<0.001
CFIT	552	A	na	290 (53%)	181 (33%)	81 (14%)	
	545	B	na	240 (44%)	177 (32%)	128 (23%)	<0.0001
TACC	552	A	na	369 (67%)	97 (18%)	86 (15%)	
	545	B	na	218 (40%)	189 (35%)	138 (25%)	<0.0001
DIRTY	558	A	529 (95%)	29 (5%)	na	na	
	545	B	495 (91%)	50 (9%)	na	na	<0.05
DIRTV	558	A	555 (100%)	3 (<1%)	na	na	
	545	B	526 (97%)	19 (4%)	na	na	<0.01
DIRTU	558	A	540 (97%)	18 (3%)	na	na	
	545	B	520 (95%)	25 (5%)	na	na	ns
DIRTVU	558	A	550 (99%)	8 (1%)	na	na	
	545	B	539 (99%)	6 (1%)	na	na	ns
INJUR	558	A	335 (60%)	223 (40%)	na	na	
	545	B	223 (41%)	322 (59%)	na	na	<0.0001
INJURS	558	A	508 (91%)	36 (7%)	9 (2%)	5 (1%)	
	545	B	535 (98%)	10 (2%)	na	na	<0.0001
INJURV	558	A	451 (81%)	75 (13%)	20 (4%)	12 (2%)	
	545	B	294 (54%)	167 (31%)	61 (11%)	23 (4%)	<0.0001
INJURL	558	A	415 (74%)	95 (17%)	35 (6%)	13 (2%)	
	545	B	407 (75%)	113 (20%)	19 (4%)	6 (1%)	<0.05

*Normality is not defined by score zero for traits marked with *; LOCO: locomotion; FIGHT: fight lesions; VSCORE: vulva development score; USCORE: udder development score; Mastitus: mastitis score; EYE: bloodshot eyes; CFIT: crate fit; TACC: teat access; DIRTY: sow is dirty on vulva (DIRTV), udder (DIRTU) or both (DIRTVU); INJUR: sow is injured on shoulder (INJURS), vulva (INJURV) or legs (INJURL)

The number of injured teats did not significantly differ between farms (Table 4), but the number of distinct, well-developed glands (TEATF) at transfer to farrowing house was higher at Farm B, coinciding with a more developed USCORE (Table 3). Caliper score (CAL) was also higher at Farm B, despite lower feeding levels during gestation, demonstrating that feeding level in the current gestation alone is not the sole determinant of sow condition. Pre-farrowing udder development is expected to be higher with better sow condition (Farmer *et al.*, 2017), although considerable mammary development also occurs post-partum (Hurley, 2001). Relatively poorer udder development at Farm A was accompanied by higher pre-farrowing feeding levels but lower caliper score.

Based on normal values noted in Table 4, the percentages of sows with above normal RECT were 5.85 and 1.65% or above normal RESP were 70.2 and 26.8%. Such high percentages of sows above normal for RESP suggests that the reference values used might not be suitable for late pregnancy status sows. However, the difference between farms in RESP might also reflect farm differences in respiratory disease status or differences in ambient temperatures. The percentages of sow with HB below 87 (considered borderline anaemic - National Research Council, 1998) were 10.7% and 5.81%. Low HB of sows has been reported previously for sows from different farms (Hermesch *et al.*, 2012).

Table 4. Characteristics of continuous variables by farm, along with the significance of the difference between farms (p-val)

Variable	N	Farm	Normal	Mean (SD)	CV (%)	Min - Max	p-val
RECT (^{0}C)	525	A	38.6	38.0 (0.44)	1	36.7-39.8	
	542	B		37.7 (0.47)	1	36.0-39.1	<0.0001
RESP (/min)	525	A	13-18	32.5 (19.4)	60	10-122	
	542	B		18.5 (4.81)	52	8-86	<0.0001
TEATF	557	A		3.74 (3.82)	102	0-14	
	545	B		13.6 (1.96)	14	0-16	<0.0001
TEATI	557	A		0.69 (1.06)	153	0-8	
	545	B		0.72 (1.09)	151	0-9	ns
CAL	553	A		13.5 (2.43)	18	5-21	
	545	B		15.3 (2.59)	17	6-22	<0.0001
HB (g/L)	433	A	>100	102 (13.5)	13	40-167	
	531	B	>100	109 (14.8)	14	67-167	<0.0001

Normal rectal temperature and respiration rate based on Ramirez *et al.* (2012); Normal HB based on National Research Council (1998)

While urinalysis procedures using test strips are straight forward, the collection of morning urine samples in commercial settings can be relatively difficult, as shown by the relatively low number of observations for urinalysis variables from Farm A, where project sows were dispersed amongst non-project sows and across farrowing sheds. Therefore, for urinalysis to be routinely applied a simpler sampling procedure is required. Nevertheless, the incidence of urinary tract infections inferred from urinalysis results alone is shown in Table 5, and based on UTI1 or UTI3, appears to be around 6% of sows affected in Farm A, with a lower percentage affected in Farm B. These results suggest that both farms might have a proportion of sows affected by undiagnosed UTI, but that the incidence and severity was likely higher at Farm A. Inferred UTI were not confirmed with laboratory testing of urine samples, since other studies have previously shown high concordance between urinalysis and laboratory culture (Mazutti *et al.*, 2013). Along with potential management changes, elimination of UTI with antibiotics requires culture of the pathogens and testing for antibiotic resistance (Piassa, M. *et al.*, 2015).

Based on urinalysis over both farms, only 19.7% (137/694) of sows sampled had completely normal urine samples when compared to reference values (Combiscreen VET 11): no odour, low turbidity, and negative for ketones, glucose, protein, blood, nitrite or leukocytes. The urinalysis parameters with the highest percentage of sows affected were the presence of protein (19.8 and 43.9% of sows had more than a trace of protein) and turbidity (16 and 33% positive), while nitrite and leukocytes were at higher levels in Farm A (15.4 and 12.7% positive) than in Farm B (6.8 and 0.7% positive). Farm B had very few sows (N≤3) which tested positive for either glucose or protein, and this might have reflected the lower feeding levels during gestation. The presence of protein in late pregnancy can indicate kidney dysfunction, stress, and/or the presence of inflammation (Duncan, 1994). Elevated protein level in urine can also indicate proteinuria (Petersen, 1983), potentially causing fatal pre-eclampsia. The significance of high turbidity for health generally is not established. Elevated nitrite and leucocytes were used as diagnostics for urinary tract infections.

Table 5. Prevalence of urinary tract infections by farm, based on urinalysis results only, along with the significance of the difference between farms (Chi-sq)

Variable	N sows	Farm	Absent (0)	Present (1)	Chi-sq
UTI 1	253	A	238 (94.1%)	15 (5.9%)	
	440	B	437 (99.3%)	3 (0.7%)	<0.0001
UTI 2	253	A	214 (84.6%)	39 (15.4%)	
	440	B	410 (93.2%)	30 (6.8%)	<0.001
UTI 3	253	A	236 (93.3%)	17 (6.7%)	
	440	B	425 (96.6%)	15 (3.4%)	ns

UTI1: samples +ve for leucocytes + blood; UTI2: samples +ve for nitrite only; UTI3: samples +ve for nitrite + pH>6 only

An overall picture provided by the monitoring variables included in this study, in comparison to the accompanying medication records from gestation, would suggest that the percentage of sows which enter the farrowing house with unobserved potential health and welfare issues was higher than the percentage of sows which had been previously observed and treated for health issues during gestation. This highlights the difficulty of close observation of sows for health and welfare issues in group gestation housing, and also the implications of more interactions amongst females enabled by group housing, as illustrated by locomotion problems and injuries. Recording of medication events post-entry to the farrowing house also suggests that without data from the additional monitoring variables included in this study, some conditions remained unobserved and/or untreated in the farrowing house, but were reflected by poorer individual outcomes (shown later in this report).

The failure to identify all unhealthy sows, particularly when symptoms might be sub-clinical, is likely due to the high demands on staff at this time, leaving less time for close inspection of individual sows for initiation of treatment. Underlying issues which remain unidentified potentially contribute to the undesired outcomes for these sows. However, sows which were treated in the farrowing house also had higher removal rates post-treatment, suggesting that identification and treatment regimens for obviously unhealthy sows was not entirely successful. Late detection of health issues (ie only after they become serious) could have reduced the successfulness of these interventions. Earlier detection of health issues combined with successful treatment is required to generate improvements in welfare and outcomes for sows.

3.2 Identifying pre-farrowing predictors for poor outcomes

Predictors from multi-variate analyses

In commercial practice it is not necessary or desirable to record all of the monitoring variables considered in this project. However, all predictors used in this study were significantly associated with one or more outcome traits, but differed in importance between traits and farms. For brevity, the grouping of pre-farrowing predictors is presented in the Table 6. For all variables, levels with too few (e.g. <10) sows were generally combined with the adjacent level.

The distribution of sows across factor levels by farm is provided in Appendix 2. Broad groupings of significant ($p<0.05$) predictors or those approaching significance ($p<0.10$) from the final multi-variate logistic regression models only, by farm and for the combined data, are summarised in Table 7. Several predictors were farm specific, while several were common to both farms and consistent in effect, becoming more significant in the combined data analysis.

Breed group and/or line were significant for outcomes in the reproductive sow, as expected, whereby sows from terminal lines had higher incidence of FFAIL and LFAIL, but lower incidence of SBFAIL and forced removals than maternal line sows (not tabulated). Since commercial sows are derived from their purebred maternal line counterparts, this result highlights that sows with higher genetic potential for litter size need careful management to reduce the incidence of still births and sow wastage. In contrast, gilts and their piglets were more likely to experience adverse outcomes during farrowing (SBFAIL: 16.3 vs 10.9% in combined data) and during lactation (LFAIL: 11.5 vs 6.23%) than sows despite lower litter size on average. Therefore, optimising management of gilts in the farrowing house should be considered separate to the implications of litter size generally. These factors are generally well known from other studies.

Other less-studied predictors (Table 8) which affected numerous performance outcomes, including ultimately forced removals, and which were most consistent across farms included variables with related to the timing of transfer relative to the impending farrowing (M2E/E2F/TTF), the fit of the sow into the crate and/or teat accessibility (CFIT/TACC) - more so than parity group, along with locomotion problems and injuries to legs (LOCO and INJURL). In addition, feed refusal observed before farrowing (FRFB) was an indicator for FFAIL and removals over all time periods. Some outcomes for the farrowing sow were also compromised by suboptimal CAL and low HB. Risks to piglets born to project sows were elevated by low Haemoglobin and poor udder development of the sow at transfer. Sows with injuries, high rectal temperatures at entry or bloodshot eyes were also more likely to become forced removals. Solutions for these variables which are consistent across farms are shown in Table 8.

Table 6: Grouping of pre-farrowing predictors (a detailed description of predictors is provided in Appendix 1)

Predictors				Factor levels			
Levels	0	1	2	3	4	5	11
BGRP		M	T				
BGRP:Farm		MA	MB	TA	TB		
GS		Gilt	Sow				
LOCO	0	1	2-3				
INJURY	No	Yes					
INJURV	0	1	2-3				
INJURL	0	1	2-3				
INJURS	0	1-3					
FIGHT	0	1	2-3				
DIRTY	No	Yes					
DIRTU	No	Yes					
DIRTV	No	Yes					
CAL		<11	11-12	13-14	15-16	>16	
EYE	No	Yes					
VSCORE	0	1	2				
CFIT		1	2	3			
TACC		1	2	3			
TEATI	0	1	2	>2			
TEATF		≤12	>12				
USCORE	0	1	2				
Mastitis	No	Yes					
RESP		<21	21-39	>39			
RECT	<38.7	≥38.7					NR
HB		<88	88-94	95-101	102-109	>109	NR
M2E		<106	106-108	109-111	>111		
GEST		<115	115-116	117-118	>118		
E2F		<5	5-7	8-10	>10		
TTF		≤4	5-6	7-8	>8		
		≤3	4-5	6-7	>7		
TREATBF	No	Yes					
Feed		Dry	Liquid				
FRBF	0	1-25%	>25-50%	>50%			NR

BGRP (breed group): maternal (M) or terminal (T); GS: sow is a Gilt or a later (Sow) parity; LOCO: locomotion score; INJURY: indicates if any injury is present (Yes/No), scored by severity for the vulva (INJURV), legs (INJURL) or shoulder (INJURS); FIGHT: fight lesion score; DIRTY: sow is dirty (YES/NO) prior to washing, on udder (DIRTU) or vulva (DIRTV); CAL: caliper reading (increments); EYE: bloodshot eye present or absent; VSCORE: vulva score; CFIT: score for sow fit in crate; TACC: score for accessibility of teats to piglets; TEATI: count of number of injured teats; TEATF: count of well-developed glands; USCORE: udder development score; Mastitis: score for hard, lumpy udder (Yes/No); RESP: respiration rate (/ min); RECT: rectal temperature; HB: haemoglobin level; M2E: interval from mating to entry (i.e. gestational age at entry); GEST: gestation length; E2F: interval from entry to farrowing (i.e. confinement pre-farrowing); TTF: expected days to farrowing after entry (GEST=116) for Farm A (1st row) and Farm B (2nd row); TREATBF: medicated (Yes/No) before farrowing; Feed: feed type (Liquid or Dry, Farm A only); FRBT: the percent of feeds with evidence of refusals, before farrowing; NR: sow not recorded (when many of these => group =11)

Table 7: Groups of pre-farrowing predictors found to be significant (p<0.05; p<0.10 in italics) within or across farms, by outcome

Predictor	Outcome traits affected		
	Farm A	Farm B	Combined data
BGRP	FFAIL/SBFAIL LFAIL REMW/REM60/REM142	*LFAIL* REMW/REM60/REM142	FFAIL/SBLIT/SBFAIL LFAIL REMW/REM60/REM142
GiltSow	SBFAIL PMORT	LFAIL	*SBFAIL* LFAIL *REM60/* REM142
M2E/E2F/TTF	FFAIL LFAIL REM60/REM142	FFAIL/SBLIT *REMW*/REM60	SBLIT LFAIL *REMW*/REM60/REM142
CFIT/TACC	FFAIL/SBLIT/*SBFAIL* PMORT/LFAIL	FFAIL/SBLIT/SBFAIL	FFAIL/SBLIT/SBFAIL PMORT/LFAIL
GEST		REMW/*REM60*	*REMW*/REM142
LOCO	SBFAIL PMORT/LFAIL	FFAIL LFAIL REMW	FFAIL/SBFAIL *PMORT*/LFAIL REMW
DIRTY	*SBLIT* *REM142*	*SBLIT*	
DIRTV	FFAIL		
INJURIES	FFAIL/*SBFAIL*		*REMW*
INJURV	FFAIL/SBFAIL	SBFAIL	*LFAIL*
INJURL	REMW/REM60	PMORT REM60/REM142	REM60/REM142
TEATI	LFAIL		
FIGHT		SBFAIL LFAIL	
RESP		FFAIL/SBFAIL	FFAIL/SBFAIL
FRBF	SBLIT REMW	FFAIL/SBFAIL REMW/REM60/REM142	FFAIL REMW/*REM60*/REM142
Mastitus	SBLIT/*SBFAIL*	SBLIT *REMW*	
USCORE		PMORT	*PMORT/LFAIL*
RECT		*REMW*	REMW
TREATBF	*SBFAIL*		
EYE			REM60/*REM142*
CAL	*SBFAIL* REM60/*REM142*	LFAIL	REM60
HB	*PMORT*	*FFAIL/SBFAIL* *PMORT*/LFAIL	PMORT
Feed type	SBFAIL LFAIL		

Table 8: Association of pre-farrowing predictors with outcomes from combined farm data, from multivariate analyses only

Predictor	Trait	P value	0	1	2	3	4	5	Unobserved
M2E	SBLIT	<0.05		51.5 (8.50)^{ab}	38.3 (4.36)^{ab}	47.6 (1.83)^{b}	33.7 (5.02)^{a}		
E2F	LFAIL	<0.05		13.6 (2.90)^{a}	6.57 (1.00)^{b}	7.87 (1.72)^{ab}	15.1 (4.97)^{a}		
	REMW	<0.10		1.64 (0.85)^{a}	4.41 (0.88)^{a}	4.20 (1.34)^{a}	1.34 (1.04)^{a}		
	REM60	<0.01		3.82 (1.43)^{a}	9.72 (1.23)^{b}	10.8 (2.03)^{b}	4.33 (2.08)^{ab}		
	REM142	<0.05		7.14 (2.11)^{a}	14.5 (1.51)^{b}	14.8 (2.56)^{b}	5.45 (2.61)^{a}		
GEST	REMW	<0.10		5.27 (2.25)^{ab}	2.88 (0.73)^{a}	3.56 (0.91)^{a}	12.0 (5.28)^{b}		
	REM142	<0.05		24.3 (5.15)^{b}	11.2 (1.46)^{a}	11.4 (1.65)^{a}	16.2 (5.41)^{ab}		
CFIT	FFAIL	<0.0001		13.6 (1.69)^{a}	11.6 (1.81)^{a}	26.6 (3.49)^{b}			
	SBLIT	<0.0001		41.1 (2.40)^{a}	43.0 (2.81)^{a}	59.7 (3.64)^{b}			
	SBFAIL	<0.0001		11.0 (1.54)^{a}	9.97 (1.70)^{a}	26.0 (3.51)^{b}			
	PMORT	<0.01		39.3 (2.94)^{a}	37.7 (3.56)^{a}	57.6 (5.17)^{b}			
TACC	LFAIL	<0.05		7.70 (1.21)^{a}	5.60 (1.38)^{a}	13.1 (2.58)^{b}			
LOCO	FFAIL	<0.05	14.4 (1.18)^{a}	15.2 (3.84)^{ab}	31.9 (8.41)^{b}				
	SBFAIL	<0.01	12.3 (1.10)^{a}	11.0 (3.29)^{a}	35.5 (8.64)^{b}				
	PMORT	<0.10	40.0 (2.00)^{a}	56.3 (7.43)^{b}	51.6 (10.3)^{ab}				
	LFAIL	<0.001	7.09 (0.86)^{a}	17.3 (4.13)^{b}	24.6 (7.71)^{b}				
	REMW	<0.05	3.24 (0.60)^{a}	6.99 (2.61)^{ab}	12.3 (5.47)^{b}				
INJURL	REM60	<0.01	7.26 (0.95)^{a}	10.9 (2.21)^{a}	20.4 (4.88)^{b}				
	REM142	<0.001	11.4 (1.15)^{a}	13.5 (2.45)^{a}	29.1 (5.62)^{b}				
INJUR	REMW	<0.10	2.68 (0.67)^{a}	4.81 (0.97)^{b}					
INJURV	LFAIL	<0.10	6.74 (0.97)^{a}	10.2 (2.03)^{ab}	13.0 (3.30)^{b}				
FRFB	FFAIL	<0.05	13.2 (1.52)^{a}	13.5 (2.06)^{a}	15.3 (2.77)^{ab}	22.2 (3.94)^{bc}			38.5 (12.7)^{c}
	REMW	<0.001	2.67 (0.69)^{a}	2.31 (0.81)^{a}	6.58 (1.90)^{b}	11.2 (3.07)^{b}			11.4 (6.86)^{b}
	REM60	<0.10	6.98 (1.13)^{a}	7.57 91.54)^{a}	10.8 (2.43)^{ab}	15.4 (3.52)^{b}			13.7 (6.95)^{ab}
	REM142	<0.05	10.4 (1.35)^{a}	12.1 (1.98)^{ab}	16.5 (2.92)^{bc}	20.4 (3.93)^{c}			18.1 (7.88)^{abc}
HB	PMORT	<0.05		45.8 (6.89)^{abc}	50.8 (6.57)^{bc}	33.5 (4.48)^{a}	35.5 (4.13)^{a}	40.3 (3.45)^{ab}	54.5 (5.37)^{c}
USCORE	PMORT	<0.10	45.7 (4.86)^{ab}	44.3 (2.74)^{a}	34.8 (3.51)^{b}				
	LFAIL	<0.10	7.92 (2.39)^{ab}	9.84 (1.35)^{b}	5.98 (1.23)^{a}				

RESP	FFAIL	<0.001		20.1 (1.88)^{a}	10.5 (1.65)^{b}	12.3 (2.69)^{b}			5.54 (3.65)^{b}
	SBFAIL	<0.05		16.4 (1.71)^{b}	8.63 (1.49)^{a}	12.0 (2.65)^{ab}			9.77 (5.47)^{ab}
RECT	REMW	<0.05	3.43 (0.62)^{a}	13.4 (5.83)^{b}					2.85 (2.33)^{ab}
EYE	REM60	<0.05	8.09 (0.91)^{a}	15.4 (4.20)^{b}					
	REM142	<0.10	12.2 (1.07)^{a}	19.5 (4.71)^{a}					
CAL	REM60	<0.05		17.9 (4.68)^{a}	9.61 (2.18)^{ab}	8.88 (1.58)^{b}	5.55 (1.34)^{b}	9.09 (1.94)^{ab}	

Values in rows with different superscripts were significantly different ($p<0.05$) from pairwise comparisons

Predictors from urinalysis

Predictors of outcomes from urinalysis results are presented separately due to the difficulty of obtaining data routinely for all sows for this variable (Table 9). Sampling ease was improved in the situation where all sows were located together (as with Farm B), but nevertheless this variable was more difficult and time consuming to obtain with the procedures used. The low number of observations for Farm A hindered identification of significant predictors from urinalysis, despite higher incidence of inferred UTI based on urinalysis results. However, the combined data analysis including data from both farms supported outcomes from Farm B, where urinalysis results were more complete but the incidence of UTI was lower.

Inferred presence of a urinary tract infection (UTI3, based on nitrite and pH) was associated with a doubling in the FFAIL outcome and more than double SBFAIL or removals post-weaning. These results would suggest that undiagnosed and therefore untreated UTI contributed to stillbirths occurring in these populations. This result is consistent with previous publications (A de Quatrebarbes *et al.*, 2014). In addition, sows with high levels of ketones were more likely to have litters affected by stillbirth (SBLIT: 44.0 vs 63.5%) and higher rates of lactation failure (LFAIL: 9.02 vs 31.5%), while dark (typically yellow) urine colour was associated with decreased PMORT (Table 9). This latter result could be because vitamin C increases the intensity of urine colour.

The absence of any ascorbic acid in the urine at testing was associated with excessive stillbirths (SBFAIL). Vitamin C is only excreted in urine when in excess to requirements. Lynch *et al.* (1981) have previously demonstrated that Vitamin C supplementation for sows reduced stillbirths, while other studies have demonstrated benefits for piglets (see https://www.dsm.com/markets/anh/en_US/Compendium/swine/vitamin_C.html). Energy restriction can reduce endogenous Vitamin C synthesis, and inclusion levels for the restricted diets fed to sows in this study should potentially be re-examined. Results observed here would suggest that deficiency of Vitamin C during gestation should be avoided, although lack of excretion may not be a perfect indicator of deficiency *per se*. Vitamin C deficiency during gestation also has implications for haemoglobin levels and piglet development *in-utero*. Low haemoglobin was also associated with an increase in PMORT in this study data (Table 8), and haemoglobin levels for sows were low on average (Table 4), based on reference values and a target of >100 g/L for sows (cited by Hermesch and Tickle, 2012).

Table 9. Least squares means for urinalysis predictors from combined farm data, from multivariate analyses only

TRAIT	Predictor	p-val	0	1	2	3	4
FFAIL	BGRP:Farm	0.19		14.1 (2.45)^{a}	16.9 (2.06)^{a}	26.1 (6.26)^{b}	20.3 (3.97)^{a}
	GS	0.74		15.9 (2.61)^{a}	17.5 (1.74)^{a}		
	UTI3	<0.05	16.4 (1.45)^{a}	35.0 (8.62)^{b}			
SBLIT	BGRP:Farm	0.15		51.3 (3.54)^{a}	42.5 (2.72)^{a}	45.4 (7.11)^{a}	39.5 (4.83)^{a}
	GS	<0.05		37.9 (3.43)^{a}	47.8 (2.27)^{b}		
	Ketones	<0.05	44.0 (1.94)^{a}	63.5 (9.35)^{b}			
SBFAIL	BGRP:Farm	0.46		13.6 (2.49)^{a}	12.5 (1.85)^{a}	20.9 (5.95)^{a}	15.9 (3.61)^{a}
	GS	0.87		14.2 (2.49)^{a}	13.7 (1.59)^{a}		
	Vitamin C	<0.05	20.7 (3.24)^{a}	12.8 (1.78)^{b}	10.4 (2.43)^{b}		
	UTI3	<0.01	13.2 (1.34)^{a}	34.0 (8.59)^{b}			
PMORT	BGRP:Farm	0.68		44.9 (3.96)^{a}	37.9 (4.21)^{a}	43.4 (7.06)^{a}	42.3 (5.99)^{a}
	GS	0.55		40.1 (4.02)^{a}	43.1 (3.09)^{a}		
	Colour	<0.05		44.7 (5.51)^{ab}	45.4 (3.17)^{b}	30.3 (5.02)^{a}	
LFAIL	BGRP:Farm	0.30		10.2 (2.12)^{a}	7.91 (1.48)^{a}	16.1 (5.26)^{a}	11.6 (3.18)^{a}
	GS	<0.10		13.0 (2.37)^{a}	8.35 (1.26)^{a}		
	Ketones	<0.01	9.02 (1.13)^{a}	31.5 (9.21)^{b}			
REM60	BGRP:Farm	<0.05		9.99 (2.10)^{a}	8.27 (1.51)^{a}	23.2 (5.97)^{b}	14.5 (3.48)^{a}
	GS	<0.10		13.8 (2.46)^{a}	9.11 (1.32)^{a}		
	UTI3	<0.05	9.88 (1.19)^{a}	23.2 (7.81)^{b}			
REM142	BGRP:Farm	<0.05		12.7 (2.33)^{a}	12.1 (1.79)^{a}	25.3 (6.16)^{b}	20.4 (3.99)^{b}
	GS	<0.10		18.1 (2.76)^{a}	12.6 (1.53)^{a}		
	UTI3	<0.01	13.4 (1.36)^{a}	33.6 (8.70)^{b}			

Values in rows with different superscripts were significantly different (p<0.05) from pairwise comparisons

Prediction of imminent farrowing

Predicting the expected timing of farrowing would enable more targeted observation of sows. Currently sows are not sorted into farrowing crates based on either their relative size or the expected timing of their farrowing. The best prediction of the time to actual farrowing was the predicted TTF (Table 10), assuming 116 days gestation, as expected. In addition to TTF, sows with a very well developed udder at transfer farrowed more than 1 day earlier, and sows from selection lines with a higher litter size farrowed 0.8 days earlier. Feed refusals were also informative; sows closer to farrowing had a higher percentage feed refusal. Approximately 34.8% (379/1089 sows) of sows refused feed on the day of farrowing. Vulva score was significant in all three data sets for uni-variate models, but not in multi-variate models including TTF. From univariate results, as vulva score increased from 0 to 2, days until farrowing reduced by approximately 1.41 (1.27) days on Farm A (Farm B) after accounting for breed and parity. The accuracy of predicting the time until farrowing is high and could be further improved with knowledge of previous gestation lengths for individual sows.

Table 10. Significant predictors for the number of days until farrowing from combined data set

Predictors	p - val	Predictor level 0	1	2	3	4	NR
BGRP:Farm	<0.01		6.54 (0.14)^{b}	6.19 (0.14)^{b}	7.31 (0.29)^{a}	6.31 (0.23)^{b}	
GS	<0.05		6.19 (0.14)^{a}	6.55 (0.10)^{b}			
TTF	<0.0001		3.98 (0.25)^{a}	5.49 (0.14)^{b}	6.78 (0.12)^{c}	9.24 (0.28)^{d}	
USCORE	<0.0001	7.37 (0.24)^{a}	6.56 (0.11)^{b}	5.97 (0.13)^{c}			
FRBF	0.10	6.46 (0.11)^{ab}	6.71 (0.16)^{b}	6.19 (0.19)^{a}	6.06 (0.23)a		6.81 (0.55)^{ab}

3.3 Identifying post-farrowing predictors for poor outcomes

Characteristics of sow and piglet attributes after farrowing

Recording sow attributes after farrowing offers another opportunity to identify potential health issues resulting in undesirable outcomes. Despite significant differences between farms in udder development score observed at entry to the farrowing house (Table 3), there was no significant difference between farms in the percentages of sows observed (a subset) for the presence of accessible colostrum at farrowing (Table 11). However, colostrum (COLOS) was not easily extracted from 28 and 31% of sows at farrowing, 13.9 and 17.1% of sows were scored with mastitis on Day 2 (not clinically confirmed), and an undesirable discharge (DISCH5) was evident for approximately 8 and 12% of sows on day 5 (Table 9). These observations suggest that the production of colostrum and initiation of milk production in lactation were potentially suboptimal for a percentage of sows, and that some sows exhibited a discharge consistent with past-partum infection on Day 5. However, since colostrum was only extracted from the middle two teats, this procedure might have underestimated the total accessibility of colostrum to piglets.

Table 11. Distribution of scores for post-farrowing attributes of sows

Variable	N	Farm	0	1	2	3	Chi-sq
COLOS	141	A	7 (5%)	37 (26%)	37 (26%)	60 (43%)	
	133	B	6 (5%)	31 (23%)	33 (25%)	63 (47%)	ns
Mastitus2	520	A	448 (86.1%)	72 (13.9%)	na	na	
	539	B	447 (82.9%)	92 (17.1%)	na	na	ns
DISCH5	527	A	392 (74.2%)	92 (17.4%)	38 (7.4%)	5 (1.0%)	
	533	B	345 (64.7%)	116 (21.8%)	63(11.8%)	9 (1.7%)	<0.05

Comparison of distinct glands pre-farrowing (Table 4) vs functional teats (Table 12) observed on day 2 after farrowing demonstrates that on average the number of well-developed glands observed pre-farrowing was consistent with the number of functional teats observed on day 2 post-farrowing on Farm B, but that teat injuries and un-suckled teats could reduce effective teat numbers for nursing sows (Table 12). In contrast, the pre-farrowing assessment on Farm A was not consistent with the count of functional teats on day 2, largely due to generalised swelling which made individual glands less distinct at entry, despite clear udder distension. The cause of this phenomenon was unknown. Un-suckled teats rapidly regress in pigs (Kim *et al.*, 2001). Therefore, a higher number of un-suckled teats on day 2 would be expected to be associated with increased piglet mortality. The percentage of sows with abnormally high rectal temperatures at entry or on days 2 and at 5 days post-farrowing were 5.5, 4.4 and 2.8% at Farm A, increasing to 9.9% at weaning, or 1.7, 4.8 and 8.4%, increasing to 10.2% at weaning on Farm B.

Table 12: The number of functional (TEATF2), injured (TEATI2) or un-suckled teats (TEATU2) observed on day2, along with rectal temperature and respiration rate recorded on day 2 (RECT2, RESP2) or day 5 (RECT5, RESP5) post-farrowing

Variable	N	Farm	Mean(SD)	CV (%)	Min-Max	p-val
TEATF2 (N)	520	A	13.7 (1.30)	10	7-17	
	539	B	13.9 (1.03)	7	10-17	<0.05
TEATI2 (N)	520	A	0.90 (1.11)	123	0-5	
	539	B	0.42 (0.76)	181	0-5	<0.0001
TEATU2 (N)	520	A	1.42 (1.46)	103	0-15	
	539	B	1.11 (1.16)	105	0-6	<0.001
RECT2 (ºC)	526	A	38.8 (0.53)	1	36.8-41.1	
	538	B	39.0 (0.47)	1	37.6-41.0	<0.0001
RECT5 (ºC)	527	A	38.6 (0.57)	2	36.4-40.9	
	533	B	39.1 (0.48)	1	37.5-40.7	<0.0001
RESP2 (/min)	491	A	26.3 (13.8)	53	10-96	
	534	B	21.4 (10.2)	47	8-90	<0.0001
RESP5 (/min)	447	A	28.4 (15.3)	54	10-120	
	526	B	27.8 (15.5)	56	10-98	ns

The number of high quality piglets (shown by NVITAL) shortly after the completion of farrowing was higher on Farm B than Farm A, in contrast to reverse ranking for TB and therefore TOTP (Table 13). The percentage of high quality piglets/litter (NVITAL/TOTP) after farrowing varied from 75% (Farm A) to 85% (Farm B), on average (not shown). The number of thin piglets was relatively high on a percentage basis (>20%), whereas the average percentage of severely compromised (unthrifty) piglets at birth was very low (2-4%). Very pale piglets ranged from 11 to 6% of the litter affected, on average, and 8% (Farm A) or 17% (Farm B) of piglets were observed to be shivering. As the number of pale piglets increased, least squares means for haemoglobin significantly (p<0.05) declined from 107±0.44 (0 pale piglets) to 103±1.30 (>3 pale piglets in litter), supporting an association between litter size, haemoglobin depletion of the sow and sufficiency for the piglet(s). Shivering is a good proxy for environmental quality, insufficient birth weight, piglet compromise due to farrowing difficulties and low colostrum ingestion (Alonso-Spilsbury *et al.*, 2007). Meconium staining of 8 and 13% of piglets/litter would suggest a relatively high percentage of piglets were affected on both farms by farrowing difficulties (Mota-Rojas *et al.*, 2002; Mota-Rojas *et al.*, 2012).

Data recorded at weaning illustrated an overall decrease in caliper score on average (Table 4 vs 14), an increase in the number of injured teats (Table 10 vs Table 14) and a substantial number of regressed teats, particularly for Farm A. In contrast to expectation, average caliper score at Farm B slightly increased between entry to the farrowing house and weaning for both gilts and sows.

Table 13: Piglet vitality observed post-farrowing, prior to processing

Variable	N	Farm	Mean(SD)	CV (%)	Min-Max	p-val
TOTP	527	A	11.4 (3.27)	29	0 - 19	
	545	B	10.8 (2.97)	28	2 - 20	<0.0001
NVITAL	527	A	8.53 (2.94)	35	0 - 15	
	545	B	9.13 (2.66)	35	0 - 17	<0.001
NUNTH	527	A	0.38 (0.82)	210	0 - 6	
	545	B	0.20 (0.66)	330	0 - 10	<0.0001
NTHIN	527	A	2.94 (2.66)	90	0 - 17	
	545	B	2.47 (2.59)	105	0 - 14	<0.001
NSHIV	527	A	0.92 (1.99)	217	0 - 14	
	545	B	1.87 (3.42)	183	0 - 16	ns
NPALE	527	A	1.21 (1.70)	141	0 - 14	
	545	B	0.67 (1.42)	212	0 - 11	<0.0001
NMEC	527	A	0.94 (1.33)	142	0 - 7	
	545	B	1.42 (1.73)	122	0 - 8	<0.0001

TOTP: total observed; NVITAL: percent of high quality piglets; numbers of unthrifty (NUNTH), thin (NTHIN), shivering (NSHIV), pale (NPALE) or meconium stained (NMEC) piglets

Table 14: Sow attributes recorded at weaning

Variable	N	Farm	Mean (SD)	CV (%)	Min-Max	p-val
RECTW (^{0}C)	535	A	38.6 (0.59)	2	36.8 - 41.3	
	518	B	38.8 (0.47)	1	37.4 - 40.7	<0.0001
CALW (Unit)	535	A	12.8 (3.19)	25	2 - 22	
	518	B	16.9 (2.28)	14	6 - 23	<0.0001
TEATIW(N)	535	A	1.42 (1.99)	140	0 - 11	
	518	B	0.53 (0.96)	181	0 - 7	<0.0001
TEATR(N)	535	A	4.29 (2.55)	59	0 - 14	
	518	B	2.34 (2.09)	89	0 - 10	<0.0001

RECTW: rectal temperature; CAL: caliper measurement; the number of injured (TEATIW) or regressed (TEATRW) teats

Grouping of post-farrowing attributes

The grouping of post-farrowing predictors is shown in Table 15. For all variables, levels with too few (eg <10) sows were generally combined with the adjacent level. The distribution of sows across groups can be found in Appendix 3. Of interest, <10% of sows had ≥13 vital piglets at farrowing, even though both farms had >30% sows with NBA≥13. Therefore, attrition in piglet quality at birth was relatively high for these higher litter size.

Table 15: Grouping of post-farrowing predictors

Predictors	Factor levels							
	0	1	2	3	4	5	6	11
BGRP		M	T					
BGRP:Farm		MA	MB	TA	TB			
Farm		A	B					
GS		Gilt	Sow					
NPALE	0	1	2	3	≥4			na
NTHIN	0	1	2	3-4	≥5			na
NSHIV	0	1	2	3	≥4			na
NMEC	0	1	2	3	≥4			na
NUNTH	0	1	≥2					na
NVITAL		≤5	6-8	9-12	≥13			na
NBA		≤5	6-8	9-12	13-15	≥16		
SB	0	1	2	3	≥ 4			
TB		≤6	7-9	10-13	14-16	≥17		
Mastitis2	No	Yes						
TEATI2	0	1	2	≥3				na
TEATF2		≤11	>12					na
TEATU2	0	1	2	≥3				na
RECT2	≤39.7	≥39.8						na
RESP2		≤20	21-40	>40				na
RECT5	≤39.7	≥39.8						na
RESP5		≤20	21-40	>40				na
VULV5	0	1	2-3					na
FRAF	0	1-25%	>25-50%	>50%				na
NWEAN		≤6	7-8	9-10	11-12	≥13		
TEATRW		≤2	3-5	≥6				na
CALW*		≤10	11-12	13-14	15-17	≥18		na
		≤14	15-16	17-18	19-20	≥21		
SHOULDW	No	Yes						na
MastitusW	No	Yes						na
TEATIW	0	1	2	3	>3			na
RECTW	≤39.3	≥39.4						na
E2W		≤21	22-25	26-28	29-34	35-39	>40	
LACT*		≤22	23-28	29-32	33-34	≥35		
		≤17	18-19	20-21	22-23	≥24		
TREATE2W	No	Yes						

*Farm A first row; Farm B second row

Post farrowing predictors for outcome traits

Additional variables recorded during or after farrowing have potential to contribute to more accurate predictions for PMORT, LFAIL and subsequent sow removal traits. As for pre-farrowing predictors, post-farrowing predictors varied in significance by farm, but some were consistent across farms (Table 16). Litter size and piglet quality attributes were significant for all outcome traits, along with feed refusals after farrowing. The condition of the udder on day 2 post-farrowing was associated with LFAIL, PMORT and long term removals. The most consistent predictors for removals included attributes at weaning, such as NWEAN, LACT and TEATWI, which are criteria which would also be frequently used for voluntary culling of sows. In addition, pharmaceutical treatment and high rectal temperature were also predictors for future removals. Sows unrecorded on Day 2 after farrowing or at weaning had a high incidence of removal, reflecting serious health issues generally.

Table 16: Groups of post-farrowing predictors found to be significant ($p<0.05$; $p<0.10$ in italics) within or across farms, by outcome, after accounting for sow breed and parity group

Predictor	Farm A	Farm B	Combined data
NBA	*LFAIL* REMW	LFAIL REM142	LFAIL REM142
SB		PMORT	REMW
NPALE		PMORT	PMORT
NTHIN		PMORT LFAIL REM142	LFAIL
NUNTH	PMORT		PMORT
FRAF	*LFAIL* REMW/REM60/REM142	*PMORT*	LFAIL REM142
TEATF2	*PMORT*	REM142	
Mastitis2	LFAIL		LFAIL
E2W	REM60		REM142
LACT		REM60/REM142	REM60
TEATIW	REM60		REM142
RECTW			REM60
NWEAN	REM60/REM142	REM142	REM60
TREATM2W	REMW/REM60/REM142	REM142	
TREATE2W		REMW/REM60	REMW/REM60

Lactation failure occurred more frequently for sows with very low NBA, high SB, and as the number of thin piglets increased (Table 17). Sows which showed signs of mastitis on Day 2 post-farrowing or evidence of feed refusal (or inadequate appetite) after farrowing, were also at increased risk for LFAIL. PMORT was elevated proportionally in litters by each unthrifty piglet observed at farrowing (ie close to 100% mortality of unthrifty piglets at birth). Sows with both low and high numbers weaned were more likely to be removed. Sow with injured teats (typically from piglet trauma), short lactation or with elevated rectal temperature at weaning were also more likely to be removed.

Table 17: Association of post-farrowing predictors with outcomes from combined farm data, from multivariate analyses only

Predictor	Trait	p val	0	1	2	3	4	5	Unknown
BGRP:Farm	PMORT	0.50		41.9 (2.84)[a]	36.8 (3.96)[a]	45.7 (5.62)[a]	44.8 (5.41)[a]		
	LFAIL	0.16		6.67 (1.21)[a]	6.20 (1.18)[a]	13.6 (3.99)[b]	8.55 (2.35)[a]		
	REMW	<0.05		4.05 (0.90)[a]	3.20 (0.85)[a]	9.75 (3.10)[b]	7.71 (2.33)[b]		
	REM60	<0.05		8.00 (1.31)[a]	4.25 (0.98)[a]	13.8 (3.64)[a]	10.6 (2.78)[b]		
	REM142	<0.0001		21.2 (3.47)[a]	4.13 (1.05)[a]	27.8 (6.79)[a]	7.50 92.19)[b]		
GS	PMORT	0.61		42.9 (3.23)[a]	40.8 (2.40)[a]				
	LFAIL	0.10		9.19 (1.70)[a]	6.36 (0.94)[a]				
	REMW	0.53		4.91 (1.18)[a]	4.10 (0.73)[a]				
	REM60	0.27		8.16 (1.54)[a]	6.38 (0.95)[a]				
	REM142	0.62		11.5 (1.83)[a]	10.5 (1.19)[a]				
NBA	LFAIL	<0.01		21.6 (6.91)[c]	11.4 (2.90)[bc]	6.40 (1.16)[ab]	5.15 (1.19)[a]	8.60 (2.72)[abc]	
	REM142	<0.01		24.7 (6.00)[b]	13.0 (2.96)[ab]	12.0 (1.58)[a]	8.31 (1.57)[a]	6.68 92.56)[a]	
NTHIN	LFAIL	<0.0001	3.37 (0.99)[a]	6.16 (1.88)[ab]	6.28 (1.78)[ab]	7.73 (1.83)[b]	19.2 (3.10)[c]		
NUNTH	PMORT	<0.0001	35.9 (2.07)[a]	59.5 (5.00)[b]	71.0 (6.75)[b]				
NPALE	PMORT	<0.05	43.7 (2.71)[bc]	34.0 (4.50)[ab]	49.1 (5.66)[c]	27.0 (6.20)[a]	50.0 (8.35)[bc]		
SB	REMW	<0.01		4.43 (0.85)[a]	2.90 (0.96)[a]	5.82 (2.07)[a]	2.74 (1.98)[a]	17.8 (5.40)[b]	
Mastitus2	LFAIL	<0.0001	5.79 (0.83)[a]	14.4 (2.89)[b]					28.5 (9.21)[b]
TREATE2W	REMW	<0.0001	4.04 (0.63)[a]	22.7 (6.85)[b]					
	REM60	<0.001	6.54 (0.85)[a]	23.4 (7.14)[b]					
FRAF	LFAIL	<0.05	7.17 (1.20)[b]	2.14 (1.15)[a]	7.95 (1.85)[b]	11.1 (2.03)[b]			3.87 (0.84)[ab]
	REM142	<0.05	9.21 (1.37)[a]	7.99 (2.59)[a]	11.8 (2.29)[ab]	16.4 (2.50)[b]			5.35 (3.05)[a]
E2W	REM142	<0.001	36.6 (16.0)[b]	23.4 (4.71)[b]	23.3 (3.99)[b]	4.49 (1.32)[a]	5.76 (1.72)[a]	3.47 (1.11)[a]	
LACT	REM60	<0.01		16.9 (4.13)[c]	4.81 (1.10)[a]	9.10 (1.50)[b]	4.57 (1.65)[ab]	4.73 (2.48)[ab]	
NWEAN	REM60	<0.05		12.5 (3.45)[b]	8.99 (2.25)[ab]	5.13 (1.09)[a]	6.30 (1.29)[a]	14.8 (5.33)[b]	
RECTW	REM60	<0.0001	5.67 (0.80)[a]	16.2 (3.74)[b]					32.8 (8.47)[c]
TEATIW	REM142	<0.0001	8.05 (1.15)[a]	11.1 (2.24)[a]	10.1 (2.86)[a]	13.7 (4.49)[ab]	28.6 (6.32)[bc]		44.7 (12.3)[c]

Table 18. Association of predictors with outcomes for NWEAN from combined farm data, from multivariate analyses only

Predictor	P value	0	1	2	3	4	5	11
		Pre-farrowing predictors						
BGRP:Farm	<0.001		9.87 (0.16)^{a}	9.37 (0.16)^{b}	9.30 (0.36)^{b}	8.60 (0.26)^{c}		
GS	<0.05		9.10 (0.18)^{a}	9.64 (0.12)^{b}				
LOCO	<0.001	9.59 (0.10)^{a}	8.93 (0.33)^{b}	7.62 (0.48)^{b}				
TACC	<0.001		9.64 (0.14)^{a}	9.73 (0.19)^{a}	8.73 (0.21)^{b}			
FIGHT	<0.05	9.00 (0.19)^{a}	9.57 (0.16)^{b}	9.72 (0.17)^{b}				
HB	<0.10		8.64 (0.34)^{a}	9.23 (0.29)^{ab}	9.59 (0.22)^{b}	9.85 (0.22)^{b}	9.48 (0.17)^{b}	9.40 (0.28)^{ab}
TEATI	<0.05	9.56 (0.12)^{a}	9.55 (0.19)^{a}	9.48 (0.28)^{a}	8.45 (0.35)^{b}			
GEST	<0.05		8.70 (0.27)^{a}	9.48 (0.14)^{b}	9.73 (0.16)^{b}	9.23 (0.41)^{ab}		
		Post-farrowing predictors						
BGRP:Farm	<0.001		9.92 (0.15)^{a}	9.38 (0.15)^{a}	8.88 (0.32)^{b}	8.74 (0.26)^{b}		
GS	0.33		9.34 (0.17)^{a}	9.54 (0.11)^{a}				
NTHIN	<0.0001	10.1 (0.19)^{c}	9.58 (0.25)^{bc}	9.55 (0.23)^{bc}	9.39 (0.20)^{b}	8.72 (0.20)^{a}		
NVITAL	<0.01		8.62 (0.26)^{a}	9.44 (0.18)^{b}	9.70 (0.13)^{b}	9.70 (0.33)^{b}		
MAST2	<0.01	9.62 (0.10)^{a}	9.03 (0.24)^{b}					8.34 (0.46)^{c}
TREATE2W	<0.10	9.51 (0.10)^{a}	8.67 (0.46)^{a}					
		Urinalysis predictors						
BGRP:Farm	0.11		9.59 (0.22)^{a}	9.46 (0.17)^{a}	8.74 (0.42)^{a}	8.89 (0.29)^{a}		
GS	<0.05		9.00 (0.21)^{a}	9.51 (0.14)^{b}				
KETONES	<0.05	9.41 (0.12)^{a}	8.10 (0.55)^{b}					

Prediction of number weaned

Low NWEAN is frequently a criterion for culling of sows. However, the number of piglets weaned by a sow was also associated with pre- and post-farrowing predictors. Therefore, including NWEAN in a prediction model directly will mask sources of variation common to NWEAN and outcome traits. Across farms, substantial piglet losses occurred for sows with poor locomotion, restrictive teat access, very low sow haemoglobin and short gestation length (Table 18). Perhaps unexpectedly, sows with fight lesions evident at entry had higher NWEAN. Based on post-farrowing data, NWEAN decreased with the number of thin piglets at farrowing, when mastitus was present on day 2 and to a lesser extent for medicated sows. For the much smaller subset of sows with urinalysis data, high ketones were associated with a decrease in the number weaned (https://www.pig333.com/articles/ketosis-syndrome-in-sows_3860/).

3.4 Accuracy of prediction from multi-variate analyses

The final multi-variate models by trait and farm for pre-farrowing predictors only included:

Farm A

FFAIL = BGRP + TACC + INJUR + INJURV + DIRTV + TTF
SBLIT = CFIT + DIRT + Mastitis + FRBF
SBFAIL = BGRP + GS + CFIT + INJUR + INJURV + LOCO + CAL + Mastitis + TREATBF + Feed
PMORT = GS + HB + CFIT + LOCO
LFAIL = BGRP + TACC + LOCO + TEATI + M2E + Feed
REMW = BGRP + INJURL + FRBF + TTF
REM60 = BGRP + INJURL + CAL + TTF
REM142= BGRP + DIRTY + CAL + TTF

Farm B

FFAIL = CFIT + LOCO + HB + RESP + E2F + FRBF
SBLIT = CFIT + DIRTY + Mastitis + M2E
SBFAIL = CFIT + INJURV + FIGHT + HB + RESP + FRBF
PMORT = INJURL + USCORE + HB
LFAIL = BGRP + GS + LOCO + FIGHT + CAL + HB
REMW= BGRP + LOCO + RECT + FRBF + Mastitis + GEST
REM60 = BGRP + INJURL + E2F + GEST + FRBF
REM142 = BGRP + INJURL + FRBF

The best models varied by farm, depending on the prevailing conditions. For example, caliper score was a predictor of sow removals in Farm A, where sows were leaner, but was less useful in Farm B. Predictors which varied more on one farm compared to the other(eg M2E), or which were recorded more completely on Farm B, were also more evident as significant predictors in farm specific analyses. For brevity, we demonstrate alternative model formulations for all predictors (excluding urinalysis) for the combined data only below.

Combined data (see accompanying ROC curves)

Alternative model formulations can include predictors from pre-farrowing (Pre-), post-farrowing (Post) or both (Both-) time periods, and can also exclude variables known to contribute to voluntary culling decisions (NoVC-). Exclusion of voluntary culling variables (in red) leads to inclusion of additional variables (in purple).

Pre- FFAIL = BGRP:Farm + GS + CFIT + LOCO + RESP + FRBF
Pre- SBLIT = BGRP:Farm + GS + CFIT + M2E
Pre- SBFAIL = BGRP:Farm + GS + LOCO + RESP

Pre- PMORT = BGRP:Farm + GS + CFIT + LOCO + HB + USCORE
Post- PMORT~BGRP:Farm + GS + NPALE + NUNTH
Both- PMORT~BGRP: Farm + GS + CFIT + HB + NPALE + NUNTH

Pre- LFAIL = BGRP:Farm + GS + TACC + INJURV + LOCO + USCORE + E2F
Post- LFAIL~ BGRP:Farm + GS + NBA + NTHIN + MAST2 + FRAF
Both- LFAIL~ BGRP: Farm + GS + INJURV + LOCO + E2F + NBA + NTHIN + Mastitis
NoVC- LFAIL~ BGRP: Farm + GS + LOCO + TACC + E2F + NTHIN + NUNTH + FRAF + TEATF2 + MAST2

Pre- REMW = BGRP:Farm + INJUR + LOCO + RECT + E2F + GEST + FRBF
Post- REMW~ BGRP:Farm + GS + SB + TREATE2W
Both- REMW~ BGRP: Farm + GS + LOCO + FRBF + SB + TREATE2W

Pre- REM60 = BGRP:Farm + GS + INJURL + EYE + CAL + E2F + FRBF
Post- REM60~ BGRP:Farm + GS + LACT + NWEAN + RECTW + TREATE2W
Both- REM60~ BGRP: Farm + GS + INJURL + E2F + LACT + NWEAN + RECTW + TREATE2W
NoVC- REM60~ BGRP: Farm + GS + INJURL + E2F + RECTW + TREATM2W + NMEC + HB + TEATI

Pre- REM142 = BGRP:Farm + GS + INJURL + EYE + GEST + E2F + FRBF
Post- REM142~ BGRP:Farm + GS + NBA + FRAF + E2W + TEATIW
Both- REM142~ BGRP: Farm+GS + INJURL + E2F + NBA + FRAF + TEATIW + TREATM2W
NoVC- REM142~ BGRP: Farm + GS + INJURL + NTHIN + NVITAL + TREATE2W + E2W + TEATIW

Generally, TTF (the predicted time until farrowing) can replace E2F (the observed time from entry to farrowing), simplifying the prediction process in practice. However, where E2F was included in the models above, it was a better predictor than TTF because it reflected that the actual timing of farrowing events was more important than the predicted timing. Moreover, on both farms, outcomes frequently used for voluntary culling (eg poor number weaned, or short lactation) reduced the number of other predictors in the model for outcome traits, because these are affected by common causes. Therefore, models which excluded voluntary culling criteria, such as NBA, NWEAN or LACT, revealed significant predictors in their stead (in purple).

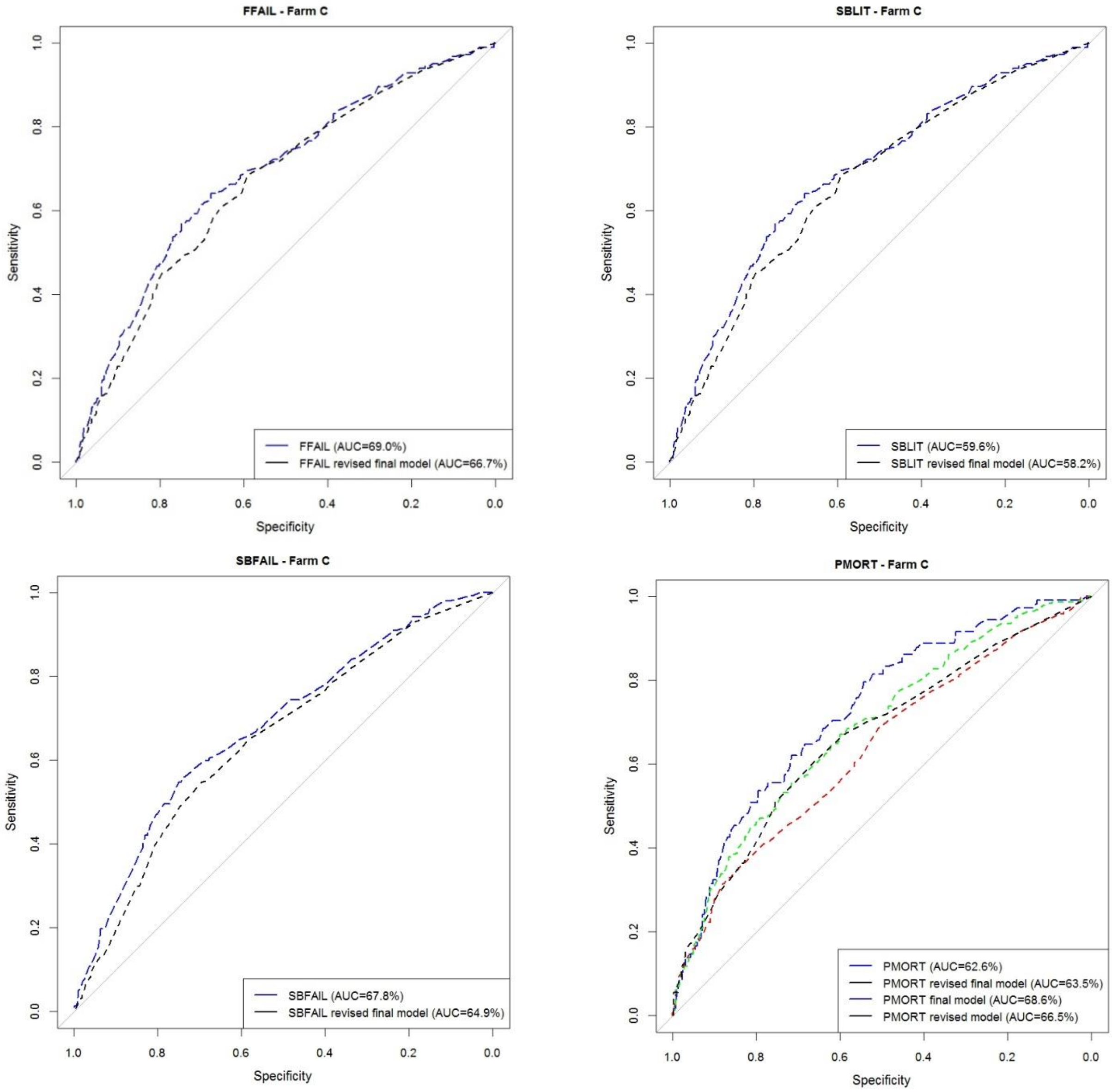
Plots of the ROC curves for predicted outcomes from a range of models are presented for the combined data (Figures 1a and 1b). The ROC curve is a plot of the true positive rate (Y-axis) against the false positive rate (X-axis). Accuracy of prediction is then based on the area under the ROC curve (AUC), which is typically described as: 0.90-1.0 = excellent; 0.80-

0.90 = good; 0.70-0.80 = fair; 0.60-0.70 = poor, and 0.50-0.60 = fail (see http://gim.unmc.edu/dxtests/RoC3.htm).

Based on this description, the ability to predict undesirable outcomes from pre-farrowing predictors only in the combined data (excluding urinalysis predictors), based on relatively small data sets, varied from failure (eg SBLIT) to relatively poor (PMORT, REM142, FFAIL, SBFAIL) or fair predictions (LFAIL, REMW, REM60). However, farm specific predictors could improve the accuracy of prediction within farm. Larger data sets may also provide more power to predict outcomes for individual sows, since some improvements in predictive capacity were observed using the combined data in analyses to more accurately estimate the magnitude of effects. Compared to within farm accuracies, the accuracy of predicting LFAIL and sow removal outcomes were improved in the combined farm analysis due to strengthening the information provided by important but low incidence predictors. However, revision of the predictive model based on solutions for each effect (termed revised final model in Figure 1a) tended to decrease the AUC for most outcomes, except PMORT.

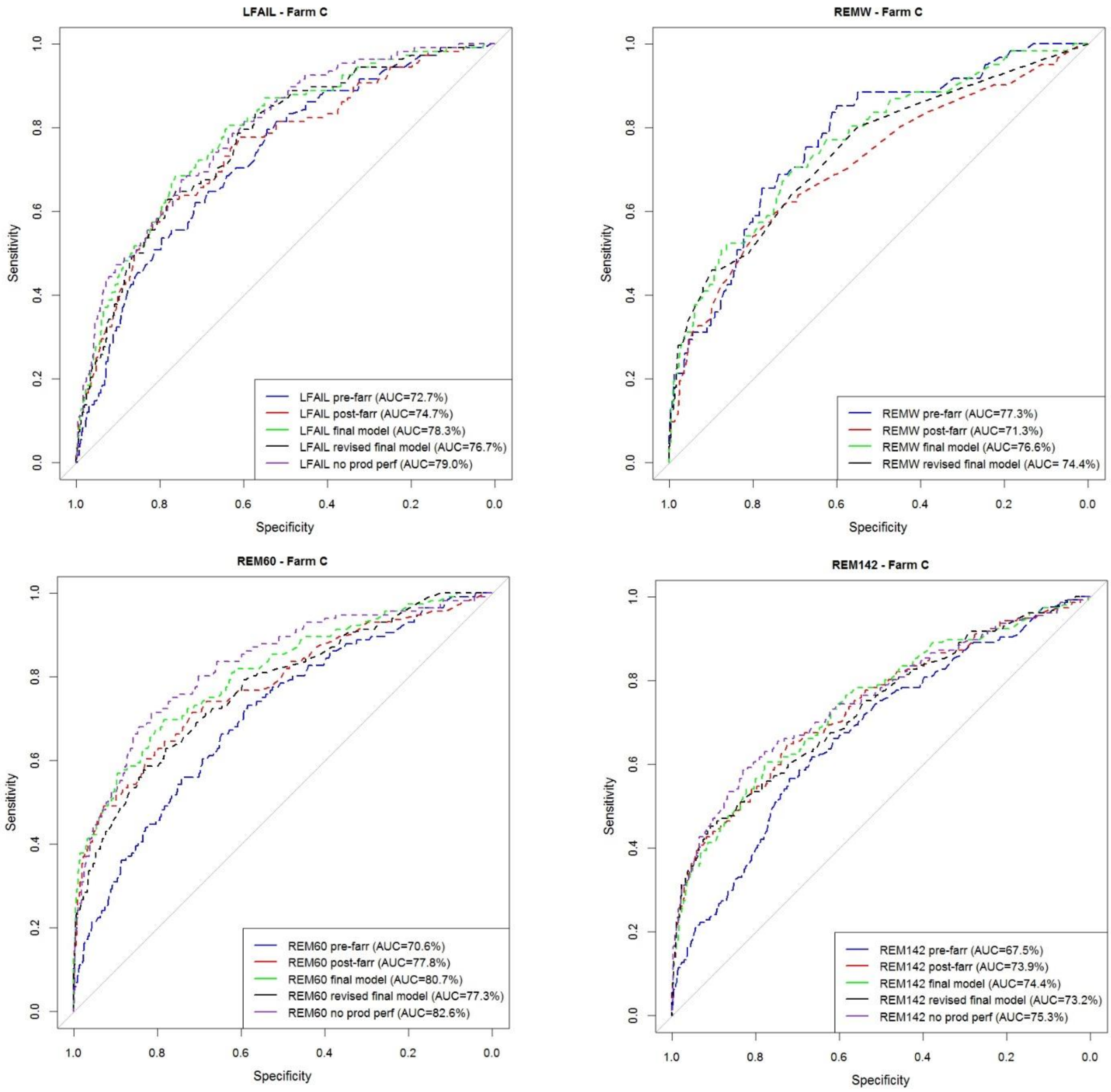
In contrast, the addition of post-farrowing predictors to final models for PMORT, LFAIL and the removal traits generally increased their accuracy of prediction, demonstrating that post-farrowing attributes had strong implications for later outcomes and culling decisions (Figure 1b). The most accurately predicted outcome was REM60, which combined removals which occurred during lactation and the rebreeding interval. The most accurate prediction equation for REM60 excluded variables which can be used for voluntary culling, such as NWEAN. This is because a voluntary culling criterion, like NWEAN, was itself associated with the predictors included in these data (Table 18). The addition of post-farrowing predictors to models for REM60 and REM142 had a substantial impact on the accuracy of predicting forced removals, suggesting that post-farrowing health and welfare related data could be used for better decision making to either cull or alter management of sows at weaning.

Figure 1a. ROC curves* for prediction of outcomes using pre-farrowing (SBLIT, SBFAIL, FFAIL) and/or post-farrowing predictors (PMORT)



*First line represents final multivariate model for predictors measured pre-farrowing, second line represents final multivariate model for re-grouped predictors (FFAIL, SBLIT, SBFAIL) or final multivariate model for predictors measured post-farrowing (PMORT), third line (PMORT) represents final model that includes all pre- and post-farrowing predictors and fourth line (PMORT) represents final multivariate model for re-grouped predictors.

Figure 1b. ROC curves* for prediction of outcomes using pre-farrowing and/or post-farrowing predictors



*First line represents final multivariate model for predictors measured pre-farrowing, second line represents final multivariate model for predictors measured post-farrowing, third line represents final model that includes all pre- and post-farrowing predictors, fourth line (PMORT) represents final multivariate model for re-grouped predictors and fifth line represents final multivariate model where production performances are not included in model (LFAIL, REM60, REM142).

3.5 Heritability estimates for sow outcomes and predictor traits

For all traits, the basic model used to estimate heritabilities accounted for breed group (nested within farm) and parity group fitted across farms.

Outcome traits

Farm-breed group and parity group explained relatively little variation for all outcome traits (all R^2<3%, Table 19), suggesting that the way outcome traits have been defined are not highly farm, breed or parity specific.

Outcome traits reflecting the farrowing process (FFAIL, SBLIT and SBFAIL), progeny survival (PMORT) and lactation quality (LFAIL) were lowly to moderately (FFAIL) heritable in one or both farms. Assuming that these types of failures should also contribute to culling decisions, this result implies that there are genetic components which contribute to sow removals, supporting previous low estimates of heritability for sow longevity which reflects removal decisions (eg. (Lewis *et al.*, 2011)). In contrast, sow removals (which are due to multi-factorial causes) in this study were not heritable, likely due to the relatively small data set (Table 19).

Table 19: Heritability estimates (h^2), phenotypic variance (σ^2p) and the coefficient of determination (R^2) for outcome traits

	Farm A			Farm B			Combined		
	h^2	σ^2p	R^2	h^2	σ^2p	R^2	h^2	σ^2p	R^2
FFAIL	0.06±0.11	0.13	2.26	0.19±0.09	0.14	0.01	0.16±0.07	0.14	0.67
SBLIT	0.04±0.08	0.24	2.51	0.10±0.08	0.24	0.63	0.08±0.06	0.24	1.88
SBFAIL	0.00±0.00	0.12	2.64	0.10±0.07	0.12	0.31	0.09±0.06	0.12	1.20
PMORT	0.09±0.10	0.25	0.08	0.05±0.11	0.24	0.21	0.06±0.07	0.24	0.32
LFAIL	0.07±0.11	0.09	0.29	0.00±0.00	0.09	3.11	0.07±0.06	0.09	0.51
REMW	0.00±0.00	0.06	0.54	0.00±0.00	0.05	1.18	0.00±0.00	0.05	0.70
REM60	0.03±0.10	0.11	0.56	0.00±0.05	0.08	1.19	0.01±0.05	0.09	1.27
REM142	0.00±0.00	0.13	0.68	0.00±0.00	0.12	1.20	0.00±0.00	0.12	1.08

Pre-farrowing predictors

Breed and parity group effects explained the most variation for CFIT, TACC, FIGHT and CAL and relatively less (<10%) for the remaining traits within farm (Table 20). VSCORE and USCORE were slightly more heritable when the interval to farrowing was included in the model, supporting the importance of a consistent timing of scoring. A larger R^2 for the combined data typically occurred for traits exhibiting a large difference between farms.

Heritability estimates for pre-farrowing predictors were consistently zero or negligible on both farms for traits reflecting cleanliness pre-farrowing (DIRTY, DIRTV), the presence of some injuries (INJURS, TEATI), pre-farrowing locomotion scores (LOCO) or medication (TREATBF) and some physiological variables (EYE)(Table 20). That means that the variation amongst individuals for these attributes is not due to genetic variation. In contrast, moderate to high heritabilities were evident for fight lesions (FIGHT), caliper score (CAL) and associated traits like CFIT and TACC. There was also heritable variation in M2E and E2F, probably due to the high heritability of gestation length, which can be used to better assign sows to transfer dates. Characteristics of sow development in preparation for farrowing (VSCORE, USCORE) were also moderately heritable traits, along with most of the other physiological parameters (MASTITUS, RESP, RECT, HB) and the propensity for feed refusal pre-farrowing (FRBF). Therefore, individual variation in these traits was not at random, reflecting the presence of genetic variation for these traits.

Heritability estimates from urinalysis results varied by parameter and by farm (Table 21). Heritabilities for glucose and leukocytes could not be estimated using Farm B data due to the very low number of sows (N<=3) which had non-negative results for these parameters. Estimates of heritabilities ranged from low (Turbidity, Ketones) to moderate (the rest) to high (Bilirubin, Specific gravity) either on one or both farms, with the exceptions of BLOOD and UTI1, which were not heritable. This suggests that genetic differences amongst sows affected some urinalysis parameters, including those reflecting metabolic processes (eg. vitamin C, glucose, Hb), confirming results from other studies, and potentially health related issues (urine pH, UTI2 and UTI3).

Table 20. Heritability estimates (h^2), phenotypic variance (σ^2p) and the coefficient of determination (R^2) for pre-farrowing predictors

	Farm A			Farm B			Combined		
	h^2	σ^2p	R^2	h^2	σ^2p	R^2	h^2	σ^2p	R^2
INJUR	0.00±0.00	0.23	3.72	0.10±0.08	0.23	6.60	0.03±0.05	0.23	8.19
INJURV	0.00±0.00	0.38	5.59	0.19±0.10	0.68	3.99	0.12±0.06	0.53	10.3
INJURL	0.00±0.00	0.49	2.24	0.10±0.08	0.35	0.54	0.05±0.05	0.42	1.83
INJURS	0.00±0.00	0.19	1.30	0.00±0.00	0.02	0.04	0.00±0.00	0.11	3.25
FIGHT	0.13±0.09	0.63	11.7	0.39±0.10	0.71	18.0	0.31±0.07	0.68	25.8
LOCO	0.00±0.00	0.23	0	0.03±0.05	0.19	0	0.02±0.04	0.21	0
DIRTY	0.02±0.09	0.05	1.65	0.00±0.00	0.08	0.56	0.00±0.04	0.07	1.44
DIRTYU	0.00±0.00	0.03	1.40	0.10±0.09	0.04	0	0.06±0.06	0.04	0
DIRTV	0.05±0.09	0.01	0	0.01±0.05	0.03	0	0.01±0.04	0.02	0.80
CAL	0.41±0.12	4.95	16.0	0.21±0.10	6.38	4.89	0.34±0.08	5.91	16.3
EYE	0.00±0.00	0.08	4.19	0.00±0.00	0.04	0	0.00±0.00	0.06	3.63
VSCORE	0.34±0.12	0.29	1.22	0.01±0.05	0.15	0.28	0.24±0.08	0.23	26.3
VSCORE*	0.37±0.12	0.28	3.96	0.01±0.05	0.15	2.81	0.25±0.08	0.22	28.7
CFIT	0.31±0.12	0.28	46.4	0.20±0.09	0.38	39.4	0.22±0.07	0.33	43.4
TACC	0.13±0.11	0.39	30.0	0.22±0.10	0.43	32.1	0.18±0.07	0.41	34.8
TEATI	0.00±0.00	1.09	3.87	0.01±0.06	1.13	4.83	0.00±0.00	1.11	4.46
USCORE	0.08±0.11	0.39	19.6	0.34±0.11	0.27	4.25	0.26±0.08	0.34	28.8
USCORE*	0.12±0.11	0.35	27.1	0.35±0.12	0.26	9.16	0.26±0.08	0.31	35.2
MASTITIS	0.10±0.09	0.08	12.7	0.18±0.10	0.02	2.51	0.17±0.08	0.05	10.6
RESP	0.02±0.10	358	4.46	0.29±0.12	91.6	1.06	0.17±0.08	225	19.7
RECT	0.09±0.10	0.18	3.61	0.15±0.09	0.20	9.44	0.14±0.07	0.19	13.1
HB	0.12±0.13	176	3.15	0.14±0.08	204	6.73	0.13±0.06	193	8.52
TTF	0.11±0.11	4.39	2.73	0.28±0.12	0.79	0.83	0.26±0.09	2.69	11.5
E2F	0.00±0.00	6.10	5.04	0.48±0.13	2.23	2.23	0.29±0.09	4.40	4.64
M2E	0.11±0.11	4.39	2.73	0.28±0.12	0.79	0.83	0.26±0.09	2.69	11.5
TREATBF	0.00±0.00	0.04	0	0.00±0.00	0.02	1.08	0.00±0.00	0.03	0.23
FRBF	0.05±0.10	0.09	0.89	0.14±0.09	0.07	9.16	0.19±0.08	0.08	0.78

Table 21. Heritability estimates (h^2), phenotypic variance ($\sigma^2 p$) and the coefficient of determination (R^2) for urinalysis variables (all variables in mg/dL, except erythrocytes (Blood) and leucocytes: N/µL)

		Farm A (N=253)			Farm B (N=440)			Combined (N=693)		
		h^2	$\sigma^2 p$	R^2	h^2	$\sigma^2 p$	R^2	h^2	$\sigma^2 p$	R^2
BILIRUBIN	0,1,2,4	0.50±0.26	1.48	3.12	0.35±0.13	1.04	0.00	0.45±0.12	1.21	1.38
UROBILINOGEN	0,2,4	0.14±0.23	1.17	1.70	0.06±0.09	0.26	0.53	0.28±0.13	0.60	21.8
KETONES*	0,10,25,100	0.00±0.00	0.56	0.00	0.12±0.12	1.19	0.19	0.07±0.09	0.96	0.36
VITAMIN C	0,1,2	0.00±0.00	0.31	1.66	0.25±0.11	0.54	0.79	0.20±0.09	0.46	2.97
GLUCOSE*	0,2,5,14,28	0.29±0.28	0.67	0.69	nv					
PROTEIN*	0,15,30,100,500	0.38±0.24	15.0	1.37	0.12±0.10	9.23	0.00	0.27±0.12	11.4	8.83
BLOOD*	0,10,50,300	0.17±0.27	7.32	0.91	0.00±0.00	6.76	0.30	0.00±0.00	6.95	1.39
pH	5,6.0,6.5,7,8	0.13±0.23	0.35	0.00	0.17±0.11	0.49	0.00	0.15±0.09	0.44	0.00
NITRITE	0,1,2	0.00±0.00	0.29	1.55	0.30±0.12	0.12	0.00	0.31±0.12	0.18	1.39
LEUKOCYTES*	0,25,75,500	0.04±0.20	6.54	2.50	nv					
SPEC GRAVITY	1 - 1.030**	0.22±0.21	1.10	1.66	0.41±0.13	0.95	0.92	0.37±0.11	1.01	1.44
UTI1	0,1	0.00±0.00	0.06	0.61	0.00±0.00	0.01	0.02	0.00±0.00	0.02	3.24
UTI2	0,1	0.00±0.00	0.13	0.12	0.35±0.13	0.06	0.00	0.32±0.13	0.09	0.20
UTI3	0,1	0.00±0.00	0.06	0.75	0.24±0.12	0.03	0.00	0.19±0.11	0.04	0.26
ODOUR	0,1	0.36±0.23	0.24	4.45	0.10±0.10	0.12	0.10	0.29±0.12	0.16	13.2
COLOUR	1,2,3	0.25±0.20	0.35	4.54	0.23±0.11	0.40	0.28	0.23±0.09	0.38	1.70
TURBIDITY	0,1	0.00±0.00	0.17	3.39	0.08±0.09	0.14	0.00	0.05±0.08	0.15	1.56

*after square root transformation; **in 0.005 increments (x100)

Post-farrowing predictors

With the exception of NBA, RECT2 and RECT5 in Farm A, model R^2 were relatively low (<10%) for all traits analysed within farm. Heritability estimates for common reproductive traits (NBA, SB, MUM, TB, TBMUM) were generally consistent with expectation (Table 22). The corresponding number of vital piglets (NVITAL) was less heritable than NBA, as NMEC, NSHIV and NUNTH had negligible heritability estimates. In contrast, the numbers of thin and pale piglets were moderately heritable characteristics, consistent with the presence of genetic effects for the quality of in-utero piglet development, compared to characteristics influenced by outcomes from the farrowing process (NMEC, NSHIV and NUNTH). The number of thin piglets increased with litter size: litters with no thin piglets averaged 9.03 born alive pigs/litter, implying that sows gestating litters larger than this had thinner piglets on average. However, the heritability for NTHIN was more similar to estimates expected for average birth weight, which is a moderately heritable trait.

There was no evidence for genetic variation contributing to post-farrowing discharge (VULV5), teat injuries on Day 2 (TEATI2), mastitis at weaning (MASTITUSW) or post-farrowing treatments (TREATE2W,TREATM2W), suggesting these health issues and treatment regimes were individual specific. In contrast, the number of piglets weaned (NWEAN) along with TEATF2, TEATU2, TEATRW, and CALW were moderately to highly heritable in these diverse populations (i.e. containing multiple selection lines). These traits are known to be strongly associated with each other during lactation. The heritability of TEATIW increased relative to TEATI2 or TEATI (Table 22), perhaps reflecting increasing damage from piglets unable to obtain adequate milk during the lactation.

Table 22: Heritability estimates (h^2), phenotypic variance (σ^2p) and the coefficient of determination (R^2) for post-farrowing traits and predictors

	Farm A			Farm B			Combined		
Trait	h^2	σ^2p	R^2	h^2	σ^2p	R^2	h^2	σ^2p	R^2
NBA	0.07±0.10	9.32	17.3	0.11±0.08	9.07	6.08	0.11±0.07	9.23	11.9
SB	0.05±0.10	1.62	2.50	0.15±0.08	2.22	0.66	0.12±0.06	1.92	2.84
MUM	0.00±0.00	2.15	2.14	0.14±0.08	2.33	0.61	0.10±0.06	2.25	3.27
TB	0.14±0.11	9.54	20.7	0.06±0.08	10.3	6.00	0.11±0.07	9.98	13.4
TBMUM	0.12±0.11	9.95	20.4	0.05±0.08	10.4	5.91	0.10±0.07	10.2	13.8
NPALE	0.00±0.08	2.66	7.93	0.16±0.08	2.00	0.48	0.16±0.08	2.00	20.3
NTHIN	0.27±0.11	6.45	8.73	0.13±0.09	6.54	2.67	0.23±0.07	6.55	5.53
NMEC	0.00±0.00	1.75	0.37	0.08±0.08	2.99	0	0.04±0.05	2.38	2.34
NSHIV	0.00±0.00	3.95	0.38	0.05±0.07	11.8	0	0.02±0.04	7.93	2.45
NUNTH	0.05±0.09	0.66	0.64	0.00±0.00	0.44	0	0.00±0.00	0.55	1.69
NVITAL	0.06±0.09	8.01	7.53	0.10±0.08	6.67	5.67	0.08±0.06	7.35	7.50
Mastitis2	0.05±0.10	0.12	1.37	0.16±0.09	0.14	1.99	0.10±0.06	0.13	1.77
TEATI2	0.00±0.00	1.16	6.80	0.02±0.04	0.58	0.88	0.00±0.00	0.87	9.33
TEATF2	0.29±0.12	1.59	5.80	0.60±0.12	1.03	1.89	0.45±0.09	1.31	4.48
TEATU2	0.24±0.14	2.13	0.17	0.18±0.10	1.34	0.97	0.24±0.09	1.74	0.94
RECT2	0.14±0.12	0.24	12.5	0.27±0.11	0.21	5.68	0.23±0.08	0.23	10.4
RESP2	0.10±0.12	47.0	1.83	0.17±0.10	26.2	0	0.17±0.08	36.3	2.93
RECT5	0.00±0.00	0.28	15.0	0.26±0.11	0.21	7.87	0.15±0.07	0.24	24.1
RESP5	0.00±0.00	58.5	0.27	0.14±0.10	58.3	2.64	0.07±0.07	58.7	1.11
VULV5	0.00±0.00	0.42	1.44	0.01±0.05	0.58	0.91	0.00±0.04	0.50	2.05
FRAF	0.06±0.10	0.10	1.96	0.04±0.07	0.19	0.99	0.05±0.06	0.14	9.83
NWEAN	0.21±0.11	6.86	2.72	0.18±0.10	9.47	1.69	0.22±0.08	8.24	1.28
CALW	0.41±0.12	8.35	18.0	0.50±0.14	4.93	5.02	0.52±0.09	6.90	41.9
SHOULDW	0.07±0.10	0.06	0.25	0.13±0.09	0.08	3.02	0.12±0.06	0.07	3.79
MastitisW	0.00±0.00	0.10	0.20	0.00±0.00	0.06	0.40	0.00±0.06	0.08	1.85
TEATRW	0.27±0.12	5.99	8.24	0.26±0.11	4.27	1.93	0.35±0.09	5.27	18.2
TEATIW	0.04±0.08	3.84	2.69	0.14±0.09	0.91	0.50	0.07±0.06	2.41	6.48
RECTW	0.13±0.10	0.28	18.6	0.13±0.08	0.21	2.78	0.19±0.07	0.26	11.3
TTF	0.11±0.11	4.39	2.73	0.28±0.12	0.79	0.83	0.26±0.09	2.69	11.5
E2W	0.19±0.12	30.4	0.40	0.02±0.07	14.3	0.18	0.20±0.09	22.7	54.7
LACT	0.07±0.12	32.0	0.77	0.05±0.07	14.9	0	0.09±0.08	23.6	47.9
TREATE2W	0.00±0.00	0.05	0	0.00±0.00	0.02	0.07	0.00±0.00	0.04	0.40
TREATM2W	0.00±0.00	0.08	0	0.00±0.00	0.04	0.52	0.00±0.00	0.06	0.38

Overall, the low heritabilities for forced removals observed in this study are likely due to the relatively small data set, along with the multi-factorial nature of removal decisions (eg. some sows can be treated and retained instead of removed, despite previous poor performance). Nevertheless, specific detrimental outcomes were heritable (FFAIL, SBLIT, SBFAIL, PMORT and LFAIL), and might also have genetic correlations with some significant predictors. Potential predictors for poor outcomes varied from zero to high heritability estimates, providing the possibility of using indirect selection criteria to improve health and welfare outcomes for sows and their piglets. These opportunities will be investigated further.

3.6 Identifying at risk sows with ESF data recorded during gestation

Feed intake and feeding behaviours throughout gestation

Analysis of the ESF data from Farm A (large F1 population of pedigreed sows) demonstrated that daily feed intake was not a heritable trait, because of fixed delivery feeding curves, but that feeding behaviour traits were heritable (Vargovic et al, 2018; see Appendix 6). The feed delivery (allocation) and consumption (ADI) patterns throughout gestation are shown in Figure 2, along with the time spent feeding and the rate of feed consumption. The timing of eating activity throughout the day is illustrated in Figure 3.

Figure 2. Feed allocation and feed intake curves for gestating gilts and sows at Farm A (2015 data), along with the time spent in the feeder and the rate of feed intake (summarised from N=563756 daily feed intake records)

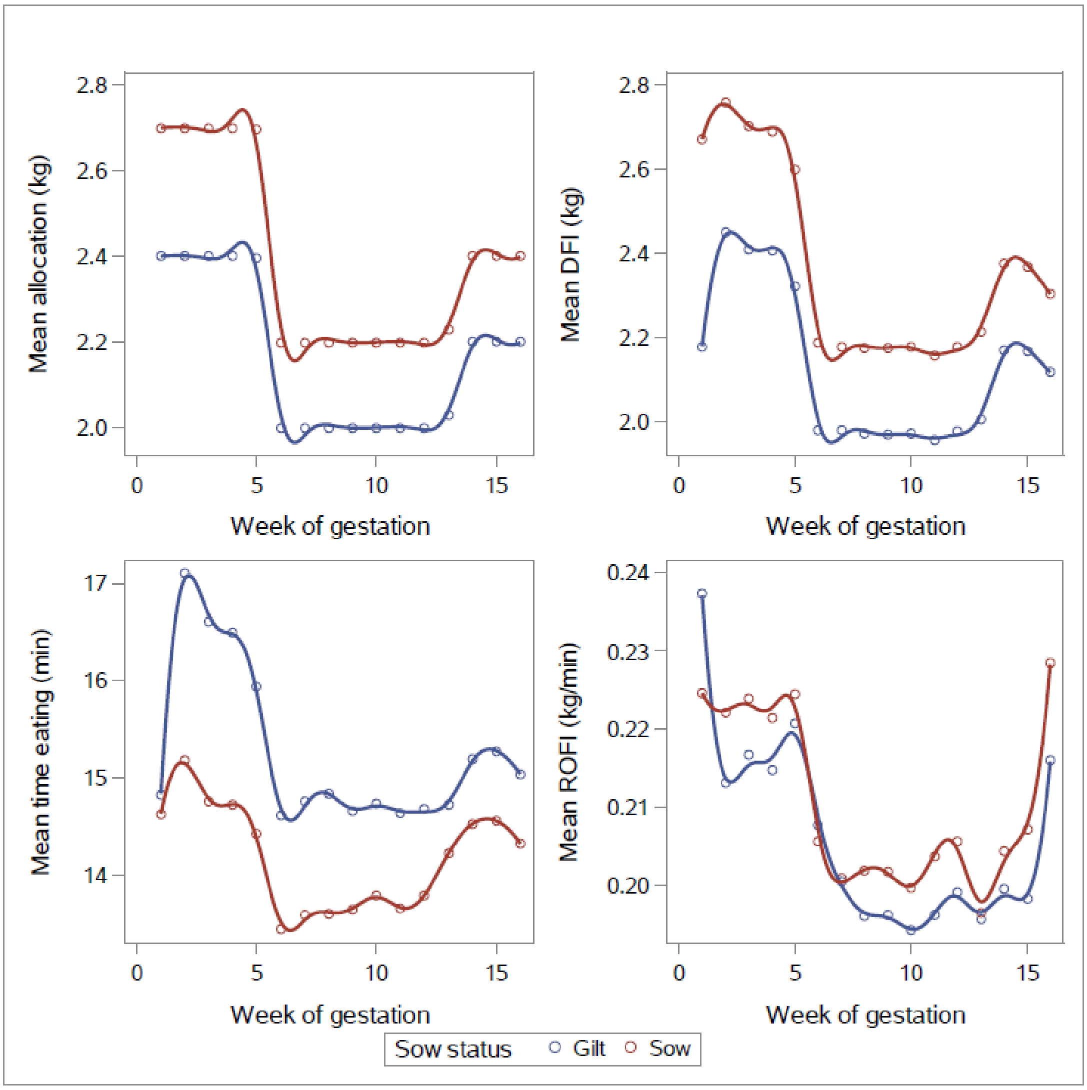
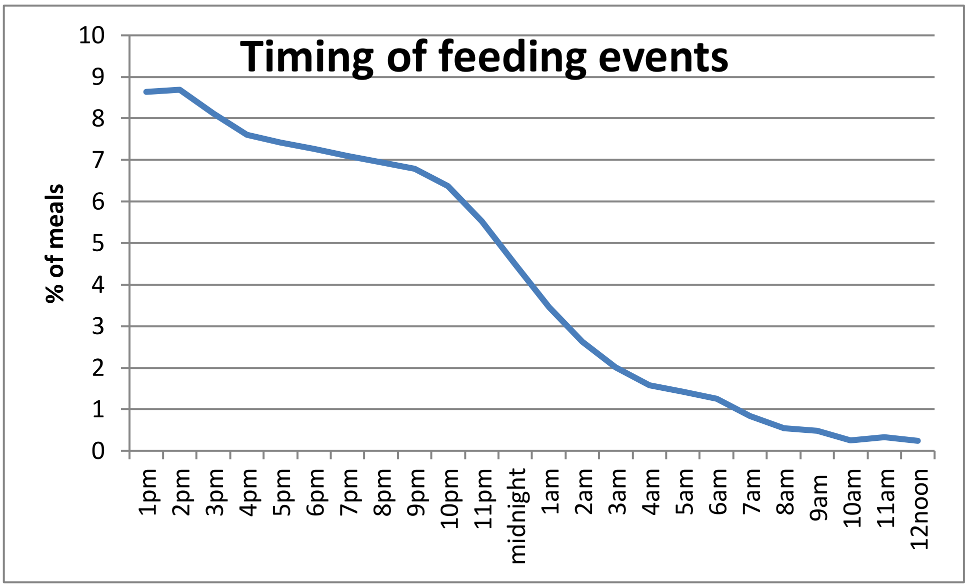


Figure 3. Percent of visits to ESRs throughout the day, averaged over all 2015 data (Farm A)

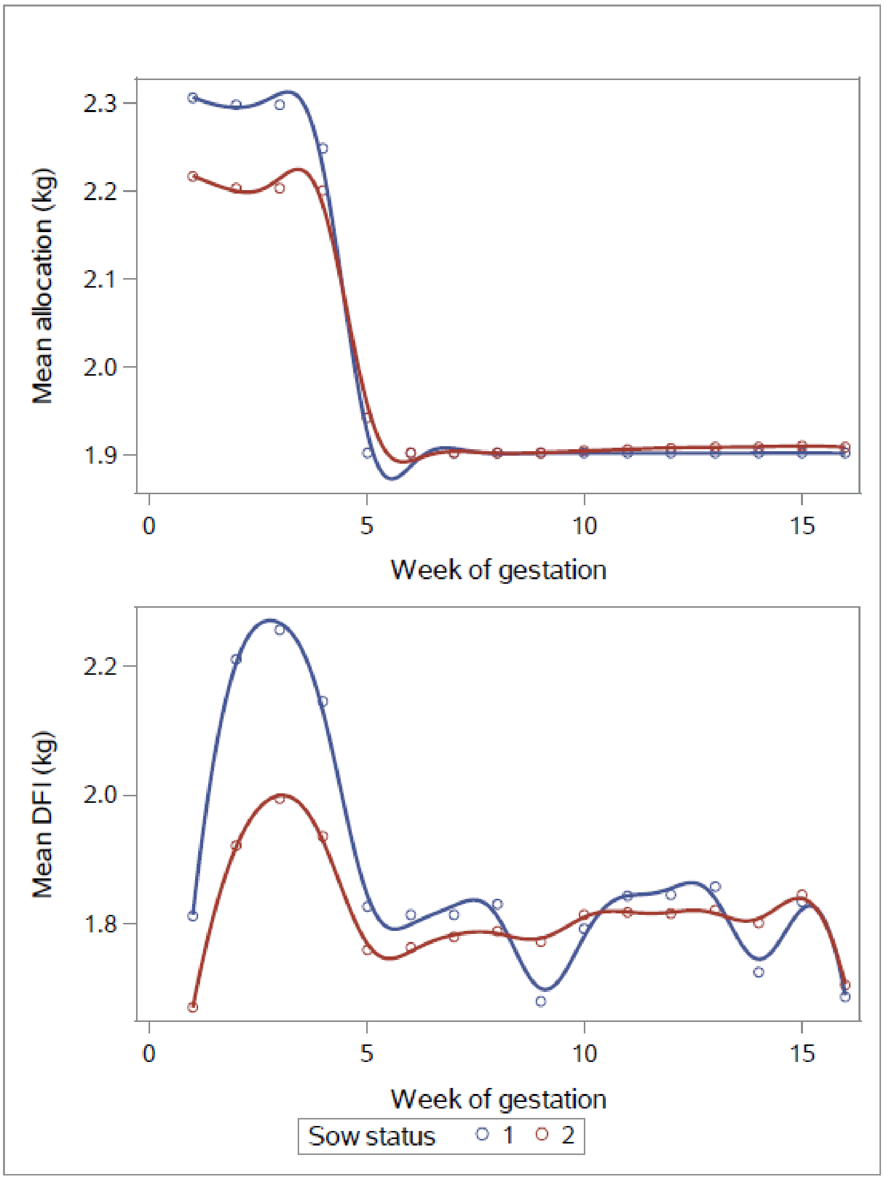


Feeding behaviour traits included time spent feeding (h^2 ~ 0.33) and therefore the rate of feed consumption, which was also moderately heritable (h^2 ~ 0.18). Both traits were highly repeatable (r > 0.60) pointing towards consistent eating behaviour exhibited by individual sows. In addition, the extent of missed feeding events or partial meals was lowly heritable (h2 ~0.1) and lowly repeatable, suggesting that observed feeding behaviours were more specific to each gestation. In contrast to results for daily feed intake, the heritability for feed requirement was also heritable (h^2 ~ 0.06, (Bunter *et al.*, 2018)), because feed requirement reflects both maintenance and performance requirements. Therefore, ESF data can provide useful information despite lack of heritability for individual feed intake.

In contrast to Farm A, average feed intake was a heritable trait (h2=0.19) on Farm B, but with relatively low variation. We propose that this result reflected characteristics of this type of ESF system. On Farm B, sows had 10 minutes only to consume their meal. Therefore, genetic variation in average feed intake reflected the ability of sows to consume their meal in the time allowed, or their rate of feed intake, which was known to be heritable from Farm A data. Heritability estimates for the number of missed and small meals varied between 0.06 and 0.17, similar to Farm A results.

The feed delivery (allocation) and consumption (ADI) patterns throughout gestation are shown for Farm B project sows in Figure 4. There was clear evidence for a disruption to feeding on weeks 9 and 14 of gestation. This was only partly confirmed to be potentially related to management activities for at least one time period (eg vaccination, drafting for pregnancy checking etc).

Figure 4. Feed allocation and feed intake curves for gestating gilts and sows at Farm B (2017-2018 data) (summarised from N=55518 daily records for 545 sows)



Both farms showed low average intakes in week one, due to a combination of a) sows being allocated meals in the ESF system before they enter the ESF system (which are therefore uneaten), and b) sows being fed elsewhere prior to transfer into the ESF system. Early sow removal at the end of gestation could also have contributed to the calculation of reduced average intake at the end of gestation but, since transfer date was known for Farm B sows, this effect was eliminated from the calculation. Therefore, these results suggest that heavily pregnant sows may have trouble in accessing and/or consuming all meals allocated in ESF systems for large sow groups towards the end of gestation.

Implications of feeding activity for outcomes of sows

Subsequently, it was demonstrated that the feeding regime at Farm A favoured the 'average' sow, with both over- and under-fed sows more likely to be culled at weaning (see Bunter *et al.* (2018), Appendix 5). Over fed sows were more likely to have a FFAIL outcome.

As the number of missed feeding events increased during gestation, sows were also less likely to farrow (-2%) and more likely to be removed by weaning (+5%). Iida *et al.* (2017) demonstrated a higher displacement hazard (ie removal due to health issues) associated with reduced daily intake, and a higher hazard of pregnancy loss associated with shorter time spent feeding, consistent with these results. Missed feeds potentially represent both out of feed events, known to cause ulcers in growing pigs (Brumm *et al.*, 2005), as well as be an indirect indicator of sows which returned to oestrus, and therefore are not pregnant (Cornou *et al.*, 2008). On Farm A, sows which spent more time eating, had a lower rate of feed consumption, and tended towards > 1 meal/day had lower FFAIL.

Considerably less ESF data was used for Farm B analyses, representing only data recorded on the project sows. However, only on Farm B could the associations between MISSF and other pre-farrowing predictors be further evaluated. As for Farm A, gilts on Farm B with low AFI and or with increasing MISSF or TMISS during gestation were more likely to have lactation failure and removal by weaning or day 60 after weaning (Table 23). A 2-5% reduction in feed intake below average allocation (restricted feed) was associated with lactation failure rates >30%, compared to LFAIL<10% when gilts ate close to their allocation. However, this pattern was not evident for sows, which already had both high caliper scores at entry and for which caliper score increased on average. An increasing number of missed feeds during gestation was also accompanied by increased incidence of lactation failure and removals.

Table 23. The influence of gestation feed intake traits on outcomes for first parity sows (Farm B)

		Predictor group				
Trait	p-val	1	2	3	4	5
		Average feed intake (kg/day)				
		<1.77	1.77-1.83	1.84-1.87	1.88-1.91	>1.91
LFAIL	<0.001	39.0 (15.0)[a]	40.3 (10.4)[a]	31.6 (9.20)[a]	3.10 (3.07)[b]	8.54 (3.76)[b]
		Number of missed feeding days				
		<6	6	7	8-9	>9
LFAIL	<0.05	7.49 (5.10)[a]	12.1 (6.70)[a]	13.0 (5.44)[a]	21.5 (7.80)[ab]	41.5 (9.57)[b]
REMW	<0.10	0.00 (0.00)[a]	6.83 (4.89)[a]	2.41 (2.40)[a]	10.3 (5.74)[a]	14.9 (6.96)[a]
		Number of missed and low intake days				
		<7	7-8	9-10	11-13	>13
LFAIL	<0.001	10.6 (5.12)[a]	6.00 (4.13)[a]	7.80 (5.32)[a]	39.1 (8.45)[b]	38.2 (12.3)[b]
REMW	<0.10	4.69 (3.34)[a]	0.00 (0.00)[a]	11.3 (6.28)[a]	5.86 (4.05)[a]	18.9 (9.97)[a]
REM60	<0.10	10.1 (4.96)[ab]	2.94 (2.91)[a]	15.5 (7.23)[ab]	8.92 (4.94)[ab]	31.9 (11.9)[b]

Based on Farm B data only, sows which missed meals during gestation were also recorded as abnormal for several other predictors (Tables 24 and 25), including low CAL and CALW, higher leg injury scores, lower HB, higher ketones, medication, and an increased probability of subsequent feed refusal in the farrowing house. Bunter *et al.* (2009) had previously observed a reduction in lactation feed intake for sows with a medication history, consistent with this study. With respect to performance at farrowing and after weaning, sows which missed more meals during gestation had increased SB, reduced lactation length and number weaned (Table 25). Sows which were unrecorded during lactation or at weaning due to early culling averaged 10 missed feeding events during gestation. Clearly, there is good evidence based on the above traits that monitoring of missed feeding events during gestation would be a useful tool for identifying numerous health and welfare related issues, and this information should be made available to staff in the farrowing house. Associations between missed meals and some other predictors were not as clear cut.

ESF systems routinely record feed intake of sows during the gestation period, but reporting functions tend to be limited to identifying sows that have missed a meal for real time remediation. Results from our study would suggest that sows with information regarding missed feeding events, or which fail to maintain intake when feeding levels are already restricted, should be identified in gestation and at transfer to farrowing for closer inspection regarding health and welfare issues. In addition, if the timing of missed feeding events coincides with the normal interval between adjacent oestrus, sows should be inspected for pregnancy as soon as possible to reduce late not in pig (NIP) identification, which also appears to be elevated in group housing systems. Therefore, changes to reporting options should be considered for ESF systems for better management of sows.

Publications from this project data can be found in Appendix 5 and Appendix 6.

Table 24. LSM for the number of missed meals recorded during the gestation period, by grouping for pre-farrowing predictors (Farm B)

Predictor	P value	0	1	2	3	4	5	11
BGRP	<0.05		8.04 (0.14)[a]	8.72 (0.26)[b]				
DIRTY	<0.01	8.09 (0.13)[a]	9.29 (0.44)[b]					
DIRTV	<0.05	8.15 (0.13)[a]	9.76 (0.74)[b]					
INJURL	<0.001	8.03 (0.14)[a]	8.32 (0.28)[a]	10.4 (0.65)[b]				
EYE	<0.001	8.11 (0.13)[a]	10.3 (0.69)[b]					
FIGHT	<0.001	8.80 (0.38)[a]	7.54 (0.20)[b]	8.50 (0.18)[a]				
CAL	<0.001		10.9 (0.77)[a]	8.31 (0.41)[b]	8.42 (0.26)[b]	7.97 (0.23)[b]	7.91 (0.21)[b]	
HB	<0.0001		8.48 (0.52)[bc]	9.73 (0.40)[c]	7.67 (0.30)[ab]	7.97 (0.28)[b]	8.18 (0.18)[b]	6.42 (0.65)[a]
E2F	<0.0001		9.58 (0.39)[a]	8.10 (0.15)[b]	7.60 (0.28)[b]			
GEST	<0.0001		10.4 (0.52)[a]	8.15 (0.18)[b]	7.92 (0.19)[b]	7.86 (0.55)[b]		
FRBF	<0.01	7.93 (0.17)[a]	7.84 (0.25)[a]	8.90 (0.31)[b]	9.24 (0.43)[b]			
TREATBF	<0.0001	8.11 (0.12)[a]	11.7 (0.98)[b]					
VSCORE	<0.01	6.90 (0.42)[a]	8.37 (0.13)[b]	7.54 (0.42)[ab]				
KETONES	<0.05	8.11 (0.14)[a]	10.0 (0.72)[b]					8.20 (0.28)[a]
PROTEIN	<0.001	8.07 (0.22)[b]	8.59 (0.21)[bc]	6.98 (0.33)[a]	9.44 (0.67)[c]			8.20 (0.21)[bc]
TURBIDITY	<0.01	8.36 (0.15)[a]	7.31 (0.32)[b]					

Table 25. LSM for the number of missed meals recorded during the gestation period, by grouping for post-farrowing predictors (Farm B)

Predictor	P value	0	1	2	3	4	5	11
BGRP	<0.05		8.04 (0.14)^{a}	8.72 (0.26)^{b}				
TB	<0.001		7.24 (0.47)^{a}	8.07 (0.32)^{a}	8.02 (0.18)^{a}	9.10 (0.26)^{b}	7.40 (0.41)^{a}	
NBA	<0.05		7.01 (0.50)^{a}	8.93 (0.35)^{c}	8.03 (0.18)^{ab}	8.39 (0.25)^{bc}	8.04 (0.46)^{abc}	
SB	<0.0001		8.14 (0.16)^{a}	7.72 (0.25)^{a}	8.56 (0.42)^{a}	7.58 (0.54)^{a}	10.8 (0.60)^{b}	
NTHIN	<0.10	8.58 (0.23)^{b}	7.68 (0.31)^{a}	7.82 (0.29)^{ab}	8.49 (0.28)^{ab}			
NSHIV	<0.001	8.11 (0.15)^{b}	10.4 (0.77)^{c}	6.55 (0.56)^{a}	9.14 (0.67)^{bc}	8.28 (0.27)^{b}		
RECT2	<0.0001	8.28 (0.13)^{b}	5.97 (0.48)^{a}					10.6 (1.24)^{c}
RESP5	<0.05		8.03 (0.19)^{ab}	8.49 (0.20)^{b}	7.70 (0.30)^{a}			9.20 (0.70)^{b}
TEATI2	<0.01	7.90 (0.15)^{a}	8.95 (0.28)^{b}	8.47 (0.43)^{ab}				10.6 (1.33)^{b}
TEATF2	<0.01		7.20 (0.40)^{a}	8.26 (0.13)^{b}				10.6 (1.33)^{c}
NWEAN	<0.0001		9.93 (0.44)^{b}	8.28 (0.28)^{a}	8.05 (0.19)^{a}	7.68 (0.23)^{a}	8.66 (0.72)^{ab}	
CALW	<0.0001		9.28 (0.37)^{c}	7.60 (0.23)^{a}	8.45 (0.22)^{b}	7.60 (0.29)^{a}	6.76 (0.49)^{a}	10.5 (0.63)^{c}
SHOULDW	<0.0001	7.95 (0.13)^{a}	9.28 (0.44)^{b}					10.5 (0.63)^{b}
E2W	<0.01		10.3 (0.64)^{a}	8.44 (0.25)^{b}	7.97 (0.15)^{b}	7.90 (0.49)^{b}		
LACT	<0.001		10.8 (0.69)^{a}	7.79 (0.26)^{b}	8.16 (0.15)^{b}	8.44 (0.62)^{b}		
MastitisW	<0.0001	8.15 (0.13)^{b}	7.08 (0.45)^{a}					10.5 (0.63)^{c}
TEATIW	<0.001	8.12 (0.15)^{a}	8.36 (0.28)^{a}	7.44 (0.48)^{a}	7.25 (0.53)^{a}			10.5 (0.63)^{b}
Treat M2W	<0.01	8.12 (0.13)^{a}	9.82 (0.65)^{b}					

3.7 *Implications of genetic merit for health and welfare, or other sow characteristics*

Because of the relatively low number(s) of sows per farm, not all of which have breeding values, the following results are considered preliminary only. All breeding values were deviated from the mean breeding by trait within line, and sows with unknown breeding values were assigned a breeding value of zero (ie equivalent to the assumption of average merit). All breeding values were predicted excluding the reproductive data collected during the project, but not excluding previous data of project sows. Breeding values for specific traits were available for all lines of sows, or within maternal or terminal lines only.

Breeding values for number born alive (Farm A) or total born (Farm B) were significantly associated with litter size of sows (Farm A, see Bunter *et al.* (2018)) and outcomes such as FFAIL, SBLIT or SBFAIL (Farm B). Higher EBVs for stillbirths (Farm B) were significantly ($p<0.05$) associated with increased FFAIL, SBLIT, SBFAIL and PMORT (Table 24), whereas higher EBVs for NBA were associated with reduced FFAIL. Therefore, low genetic merit for litter size or unfavourable EBVs for still births were predictors for poor reproductive outcomes for these sows in the project period, as expected. Breeding values for the number of teats were favourably associated with FFAIL, SBFAIL and LFAIL. Breeding values reflecting birth weights were not significant in this data. However, in a larger study, sows with high EBVs for piglet birth weights had decreased LFAIL, but were also more likely to be removed from the herd by weaning. It seems likely that these sows partition more energy towards piglet development, at the expense of their own fatness (Bunter et al, 2010) and health. Removals by weaning were not associated with genetic merit for any trait on Farm B, because these removals were excluded from our analyses. However, on Farm A, the association between sow removals and genetic merit for some traits remained after excluding sows annotated as removed for genetic merit. High genetic merit for NBA or low genetic merit number for teats increased REMW, whereas later removals (REM60/REM142) were unfavourably associated with the breeding value for the weaning to conception interval recorded at the completion of the first lactation.

In contrast, EBVs for other production traits (eg growth, backfat) were generally not significantly associated with undesirable outcomes in the farrowing house (Table 26), whereas mid-parent EBVs for back fat were significant for farrowing rate in the much larger data set of pedigreed F1 sows used to examine ESF data (see Bunter *et al.* (2018), Appendix 5). Both lack of statistical power in the Farm B data, and the high caliper score of project sows on this farm prior to farrowing, might have contributed to this result. In the project data, sows with higher genetic merit for ADG (expected to be larger) were more likely to have excessive stillbirths (Farm A) or lactation failure (Farm B).

Health and welfare related outcomes were not completely independent of genetic merit (Table 27). Urinary tract infection, inferred from urinalysis results, was more frequent for animals with higher genetic merit for production traits (ADG, BF or LD), and lower for animals with higher genetic merit for NBA or WCI. Sow haemoglobin was unfavourably associated with higher genetic merit for litter size in Farm A (which had a higher litter size overall), but favourably associated with genetic merit for other traits in Farm B. Ketones were lower for animals with higher genetic merit for ADG (Farm A) or TB and SB (Farm B). Caliper scores were positively associated with breeding values for back fat and loin muscle depth in Farm A, but not Farm B, while genetic merit for loin muscle depth was positively associated with glucose. Higher genetic merit for AFI and teats was associated with better locomotion score on Farm B only. Overall, the number of piglets weaned by a sow was positively associated with several traits (eg ADG, TB and TEATS) but unfavourably associated with BF, IGF and the wean to rebreeding interval

Variation between sows in genetic merit for a range of traits contributes to their variation in phenotypic performance, either directly (eg for the same trait) or indirectly (for related traits). However, also important is the trajectory of development for sow body composition, which is largely driven by the combination of feeding and management regimes, as well as genetic potential for performance levels.

Table 26. The significance of breeding values for outcome traits, using a stepwise analysis including model terms based on AIC (Breed group and gilt-sow fitted explicitly for all traits), fitting each trait EBV as a linear covariate

		Trait EBVs													
		All lines			Terminal		Maternal								Terminal
Trait	Farm	ADG	BF	LD	AFI	FCR	TB	SB	NBA	Teats	LWT	ABWT	WMI	WCI	IGF
FFAIL	A	ns	ns	ns	na	ns	na	na	<0.05	<0.10	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	<0.05	na	ns	ns	na	ns	na	na
SBLIT	A	ns	ns	ns	na	ns	na	na	<0.10	ns	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	<0.05	ns	na	ns	ns	na		na	na
SBFAIL	A	<0.10	ns	ns	na	ns	na	na	ns	<0.01	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	<0.05	na	ns	ns	na	ns	na	na
PMORT	A	ns	ns	ns	na	ns	na	na	ns	ns	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na
LFAIL	A	ns	ns	ns	na	ns	na	na	ns	<0.05	na	ns	na	ns	ns
	B	=0.10	ns	ns	ns	na	ns	<0.10	na	ns	ns	na	ns	na	na
REMW	A	ns	ns	ns	na	ns	na	na	<0.05	<0.10	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na
REM60	A	ns	ns	ns	na	ns	na	na	<0.10	ns	na	ns	na	<0.05	ns
	B	ns	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na
REM142	A	ns	ns	ns	na	ns	na	na	<0.10	ns	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na

ADG: average daily gain; BF: backfat depth; LD: loin depth

Table 27. The significance of breeding values for health and welfare related traits, using a stepwise analysis including model terms based on AIC (Breed group and gilt-sow fitted explicitly for all traits), fitting each trait EBV as a linear covariate

		Trait EBVs													
		All lines			Terminal		Maternal								Terminal
Trait	Farm	ADG	BF	LD	AFI	FCR	TB	SB	NBA	Teats	LWT	ABWT	WMI	WCI	IGF
UTI3	A	ns	<0.05	ns	na	ns	na	na	<0.10	ns	na	ns	na	<0.10	ns
	B	<0.05	ns	<0.01	ns	na	ns	ns	na	ns	ns	na	<0.05	na	na
HB	A	ns	ns	ns	ns	ns	ns	ns	<0.10	ns	ns	ns	ns	ns	ns
	B	ns	<0.0001	ns	ns	na	<0.05	ns	na	ns	ns	na	<0.10	na	na
VitC	A	ns	ns	ns	na	ns	na	na	ns	ns	na	ns	na	ns	ns
	B	<0.10	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na
KETONES*	A	=0.10	ns	ns	na	ns	na	na	ns	ns	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	<0.10	<0.05	na	ns	ns	na	ns	na	na
GLUCOSE	A	ns	ns	<0.05	na	ns	na	na	ns	ns	na	ns	na	ns	ns
CAL	A	ns	<0.10	<0.10	na	ns	na	na	ns	ns	na	ns	na	ns	ns
	B	ns	ns	ns	ns	na	ns	ns	na	ns	ns	na	ns	na	na
LOCO	A	ns	ns	ns	na	ns	na	na	ns	ns	na	ns	na	ns	ns
	B	ns	ns	ns	<0.10	na	ns	ns	na	<0.05	ns	na	ns	na	na
NWEAN	A	<0.10	<0.05	ns	na	ns	na	na	ns	=0.10	na	ns	na	ns	<0.10
	B	<0.10	ns	ns	ns	na	<0.0001	ns	na	ns	ns	na	<0.10	na	na

*SQRT trans

4. Application of Research

This work has demonstrated, through characterisation of health and welfare variables, that sow health upon entry to the farrowing house is less optimal than is suggested by the incidence of detection and treatment of sows during the gestation period. The extent of involuntary sow removals affects profit, and at least some of this sow wastage is associated with unidentified health and welfare issues. We therefore propose that addressing some of these issues could improve outcomes for sows and their piglets and reduce rates of involuntary culling.

Results from this study suggest that interpretation of data from ESF systems and targeted monitoring for identification and treatment of unhealthy or injured sows in both gestation housing and the farrowing house is likely an avenue for reducing poor outcomes for sows and subsequently sow wastage. Several possible causes for poor outcomes were identified, including physiological and/or nutritional (eg Vitamin C, HB), physical (crate dimensions), management (movement logistics, feed delivery) and health related (UTI, injuries, lameness) issues. In larger data sets and to a lesser extent amongst project sows, there was also evidence for the impact of genetic merit on feed requirements, various health measures and also contributing to risks for removal.

To make timely use of this information would require investment in additional staff and development of appropriate interventions for gestating sows. In addition, improving information delivery to staff (i.e. ESF reporting functions, or development of a farrowing house app) regarding issues for individual sows and to assist with activity management could also be beneficial.

5. Conclusion

This project identified a suite of additional data which can be used to identify risk factors for premature culling of sows, predominantly due to health and welfare related issues. Further work should be initiated regarding interpretation of ESF data and transfer of meaningful information to staff in the farrowing house as an approach to improving future outcomes.

6. Limitations/Risks

This study was conducted on two farms only to enable the majority of recording to be conducted by a single operator (Laura Vargovic) within short windows of recording. The resource data were also recorded in nucleus operations, with the exception of the ESF data and outcomes from Farm A, and sows were mostly observed in warmer months of the year. Nevertheless, the farms chosen enabled detailed recording across a range of data sources (ESF, medication, farrowing house performance, outcomes) and offered diversity in genetics, production and management environments. Common problems, along with farm specific and across farm predictors for undesirable outcomes were both identified. This is a good start to investigating the association between sow health and welfare indicators with sow wastage, but it is not exhaustive. Some additional benefits could be obtained from replicating recording for the more promising predictors elsewhere.

7. Recommendations

As a result of the outcomes in this study the following recommendations are made:

With respect to ESF systems

- ESF systems for group housed sows should be adapted to record non-feeding visits. In addition, reporting functions for ESF systems should be modified to identify and report on individual sows at transfer regarding the number of missed or low intake feeding events. ESF systems which are event based are superior to those which are not regarding information content, because they also enable derivation of feeding behaviour traits. Further investigation of data from these ESF systems is warranted.
- The ESF reporting systems should be used to provide information to staff which flag sows which require health checks during gestation, or to be followed up in the farrowing house. The health and welfare checks performed in this project have highlighted potential avenues for relevant assessments.
- At both sites it was observed that heavily pregnant sows in large dynamic group systems appeared to have trouble maintaining their feed intake after day 106 of gestation. It can be speculated that the ESFs are too confining, or that there is too much competition for access to feeders in large groups, and/or that locomotion is too difficult for sows to negotiate returning to feeders when they are unable to consume their complete meal in one session. Sows might benefit from ESF systems enabling a transition pen and a change to feeding arrangements towards the end of gestation. ESF on Farm B, which are time limited, might require modification of the maximum time limit as gestation progresses. Further investigation of possible causes of this phenomenon, and solutions, are required.
- Individual variation in feeding behaviour characteristics could result in sub-optimal intake where ESF systems do not protect sows for the full time period it takes for feed consumption of all sows (eg assuming a common fixed time interval per sow, which is less time than that required by the slowest eating sow).

With respect to the farrowing house

- Very early entry to the farrowing house, accompanied by restrictive feeding until farrowing, had detrimental effects for outcomes on Farm A. Late entry (eg < 4 days before farrowing) was also problematical.
- Reinvestigation of optimum organisation (ie allocation of sows within the farrowing house) and feeding strategies in the farrowing house could be warranted to avoid missed meals (eg. due to timing of transfer to the farrowing house), inconsistent feed delivery amongst individuals with different farrowing dates (eg restrict fed non-farrowed sows adjacent to ad-lib fed farrowed sows) and mismatching of sows to crates (due to size).

- It was observed that drinker location in farrowing crates can be problematical for sows with locomotion issues. Therefore, sows identified with locomotion issues should be placed in farrowing crates designed to avoid this problem.
- Sows do not arrive in the farrowing house with information regarding their previous health during gestation (sow cards typically contain only prior performance). Activities involved in sow transfer to farrowing accommodation are labour intensive, which typically allows staff limited time to evaluate individual sows. A possible solution is to develop a position with a specific role to identify and treat compromised sows at entry and to monitor farrowing sows more closely (ie a nurturing role, rather than to feed sows, tag piglets etc).
- SBLIT and SBFAIL both show a relatively high level for the group housed sows in this study, compared to lower levels previously observed when sows were housed in stalls. This phenomenon has been reported elsewhere and deserves further investigation.
- In addition, excessive loss of piglets is only observed when the mortality of individual piglets is monitored (PMORT) and was not evident if the outcome at weaning (LFAIL) was the performance indicator for nursing sows. That is, cross-fostering strongly masks true levels of piglet losses for some (typically more prolific) sows. These losses are associated with various pre- and post-farrowing predictors.
- The cost benefit of additional labour in the farrowing house for monitoring and assisting farrowing and nurturing sows and piglets should consider immediate benefits as well as implications for sow removals.

With respect to identifying poor outcomes, and the transfer of information for individual sows

- The need for staff to traverse several farrowing houses to attend sows, with no easy way to manage and prioritise their activities, makes for inefficient management of sows in large operations. Systems which better integrate targeted information across different zones (eg mating, gestation and farrowing) and data sources (eg previous performance, medication records, EBVs) to identify daily events required for individual sows in the farrowing house could be beneficial (eg a farrowing house app). These systems are currently absent, could potentially be used to locate sows into specific zones within the farrowing house and could assist staff with time limitations. Such systems may also better enable recording of additional data (eg farrowing duration) which currently remain unrecorded, despite the fact that a long farrowing duration is a known risk factor of poor outcomes for sows and piglets.
- Some variables related to poor outcomes are not routinely monitored. Examples of this were SBLIT, which reflects the proportion of sows affected by stillbirths, and PMORT, which reflects the proportion of birth piglets lost by biological dams (rather than sow performance as a nursing sow). Both of these traits are potentially better indicators of problems which occurred during gestation or at farrowing than the % stillbirths (unaltered even when the % of affected sows increases) or number weaned (affected by cross-fostering). SBLIT is an easy trait to monitor, while PMORT is not. Therefore, monitoring SBLIT in addition to % stillbirths is recommended for commercial sow herds.
- Based on the discrepancy between sows identified by staff for treatment in gestation vs sows identified with health issues at transfer, and the association of specific issues

with poor outcomes, the impact of an increased investment in sow observation (staff, labour) during gestation or in the farrowing house is warranted.
- Very different caliper score profiles between farms demonstrates that both genetics and environment (including feeding schedules and weaning age) have a strong influence on the development profile of each herd and individual sow condition pre and post-farrowing.

With respect to potentially useful predictors

- Feed intake below target, both during gestation and within the farrowing house pre- and post-farrowing, was identified as a risk factor for sows and their offspring. In addition, low feed intake was associated with locomotion problems, low caliper score and low haemoglobin levels.
- Injuries affecting mobility or enabling of infection were also accompanied by lowered feed intake and an increased risk for poor outcomes.
- Urinalysis parameters, such as high ketones, low vitamin C and inferred UTI also identified poor outcomes, but were harder to obtain in practice.
- Poor fit of sows into farrowing crates can be avoided by improved crate design and sorting of sows. Failing to alter adjustable crates to improve fit was observed, and appears counterproductive. The strategy of low gestation intake did not improve crate fit when accompanied by higher average caliper values and parity. The cost-benefit of replacing old infrastructure which is more limiting for higher parity sows should be considered, and might contribute to the higher percentage of sows with stillbirths.
- Farm specific predictors tended to be associated with particular management differences.

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9. Appendices

Appendix 1 – data recording

Sows were recorded for a range of attributes upon entry to the farrowing shed, at farrowing when possible, and at two and five days post-farrowing and at weaning (described below). All scores were subjective.

Data recorded prior to farrowing

- Locomotion (LOCO) was scored while sows were walking (at least 20 metres) from the gestation housing to the farrowing shed, on a subjective scale: 0 – good mobility (easy movement); 1 – restricted mobility (stiffness, slow movement); 2 – poor mobility (limping, reluctance, uneven slow movement); 3 – very limited mobility (inability to bear weight on one or more limbs) (Bunter, 2015b; Harris *et al.*, 2006; Tabuaciri, 2012). Lame sows will have difficulties in standing, eating, drinking water, and also reacting to avoid piglet crushing, and this has an impact on rearing ability (Anil *et al.*, 2008; Bonde *et al.*, 2004; Cornou *et al.*, 2008; Heinonen *et al.*, 2013).
- The degree of dirtiness (DIRTY) was scored at the same time as LOCO, but before washing (Farm A), and in the farrowing shed (Farm B) as follows: dirty udder (DIRTU), dirty around vulva (DIRTV), and dirty both around vulva and udder (DIRTVU). Cleanliness of the sow can be an indicator of hygiene, but is also an indirect indicator of health and welfare issues: for example, lame sows spend more time lying down (Zurbrigg *et al.*, 2006).
- The extent of fight lesions (FIGHT) was scored as 0 – no lesion observed; 1 – few lesions observed (1-5 lesions); 2 – several lesions observed (6-10 lesions); 3 – numerous lesions observed (10+ lesions) over the whole body (Bunter, 2015b) . Signs of fighting (skin lesions), which result from aggressive encounters, have been found detrimental for sow performance or lameness (Bunter, 2015a) and can indicate increased stress levels which affect immune response(Maes *et al.*, 2016).
- The presence of other injuries (excluding fight lesions) (INJUR) was scored on the subjective scale where 0 represents no injuries, and 1 represents injuries observed. Injuries or wounds were further scored based on their location and severity, with scores 1 to 3 representing increasing severity:
    - Shoulder lesions (INJURS) - mild, moderate, severe (Tabuaciri *et al.*, 2010)
    - Vulva lesions (INJURV) - mild, moderate, severe (Zurbrigg *et al.*, 2006)
    - Leg injuries (INJURL) - mild, moderate, severe (Harris *et al.*, 2006)
- Udder development (USCORE) was scored on a subjective scale: 0 – individual mammary glands not well defined; 1 – udder is well developed, but mammary glands are not clearly distinct; 2 – udder is well developed, with a clear distinction of mammary glands (Balzani, A. *et al.*, 2016 {Tabuaciri, 2012 #158; Tabuaciri, 2012). The count of distinct mammary glands (TEAT) was recorded at the same time. Udder development at transfer is potentially indicative of the time to farrowing (Balzani, A *et al.*, 2016; Tabuaciri, 2012) and also the presence of colostrum for piglets.
- Udder health was assessed based on indicators of previous infection, current swelling (localised or generalised) and the presence or absence of injuries (Martineau *et al.*, 2012), with possible implications for the lactation period. Pre-farrowing mastitis (Mastitus) was considered to be present for sows with a hard, swollen and firm udder. The count of injuries on n teats (TEATI) represents the number of teats with injuries.

- The vulva was scored (VSCORE) on a subjective scale to represent the extent of swelling: 0 - limited; 1 - moderate; 2 extensive, in order to establish if vulva score reliably related to the imminence of farrowing (http://www.thepigsite.com/pighealth/article/220/parturition-farrowing/) the example is also for lambing (http://gadi.agric.za/Agric/Vol15No1_2015/viljoen.php)
- The extent to which the eyes (EYE) were bloodshot or irritated was scored on a subjective scale: 0 - not bloodshot; 1 - mildly bloodshot; 2 - heavily bloodshot; T - tearing (Neary *et al.*, 2005; Tabuaciri, 2012). Blood shot eyes can indicate elevated body temperature, imminent farrowing (Peltoniemi *et al.*, 2015), infection of the eyes such as pig conjunctivitis (Done *et al.*, 2012) and/or irritation resulting from the environment, such as ammonia (Zulovich, 2012).
- Body condition score (CAL) was measured as caliper increments. The caliper was placed on the back of the sow after palpating the location of the last rib (Knauer *et al.*, 2015). The caliper quantifies the angularity from the spinous process to the transverse process of the sow's back (Knauer *et al.*, 2015). The number of increments represents an increase in body condition from "thin" to "fat" based on fat and muscle accumulation around the vertebrae (Knauer *et al.*, 2015).
- Crate dimensions relative to sow size (CFIT) was assessed when sows were recumbent, recorded on a subjective scale: where 1 - represents plenty of room and crate not filled; 2 - moderate room and overall crate filled; and 3 - represents limited room, crate filled, movement likely to be restricted (Tabuaciri, 2012).
- Teat access (TACC) was recorded when sows were recumbent, on a subjective scale where: 1 represents teat access unrestricted; 2 - interference to teat access, back and teats are close to crate bars; and 3 - represents teat access restricted, and teats in contact with lower bar of farrowing crates (Tabuaciri, 2012).
- Resting respiration rate (RESP) was recorded as the number of expirations per 30 seconds, when sows were recumbent. RESP was generally targeted to be recorded while sows were at rest after completing an early morning feeding, before mid-morning.
- Rectal temperature (RECT) was measured using thermometer "Liberty", model DT-KO1A (Farm A) and thermometer "Vicks" (Farm B). Rectal temperatures were taken with the thermometer in contact with the bowel wall, when sows were at rest (after RESP was recorded).
- Urinalysis: Urine was collected once per sow, before sows farrowed. Urine was collected in the early morning, before the first feeding event, into clean sterile cups and stored at 2-4 ºC, until testing with reagent strips within 4 hours from collection, according to kit instructions (CombiScreen®VET 11 PLUS). The test strips evaluated levels of bilirubin, urobilinogen, Ketones, ascorbic acid, glucose, protein, blood, pH, nitrite, leucocytes and specific gravity. In addition, colour, odour and turbidity of the urine samples were subjectively evaluated. Colour was scored on a scale of 1 to 3 (pale, normal, dark), while odour and turbidity were scored as present (1) or absent (0) (Mazutti *et al.*, 2013; Piassa, M. *et al.*, 2015). Urinary tract infection (UTI) was defined as absent or present (0/1), if leukocytes and blood were positive (UTI1), nitrite was positive (UTI2), or nitrite was positive and pH >=6 (UTI3). Sows with UTI have previously been shown to have poor reproduction performances (Almond, 2005) but UTIs can be difficult to routinely diagnose. Test strips provide an alternative (Mazutti *et al.*, 2013).
- Haemoglobin (HB): haemoglobin level was measured using the Hemocue H201+ (HemoCue AB, Angelholm, Sweden) using a single drop of a blood obtained from a skin prick on the sow's ear (Hermesch *et al.*, 2012). Sows which farrowed prior to the measurement or which appeared distressed during the procedure were excluded from

this measurement. On Farm B, all sows within a group were measured on the same day.

Data recorded during or post-farrowing

Sows were allowed to farrow naturally, with human intervention only when necessary, following each farm's protocols.

- The presence of colostrum (COLOS) was assessed immediately prior to or during parturition, using procedures modified from Balzani, A *et al.* (2016). Using manual pressure on 1-2 teats only, colostrum presence was scored as 0 – none extracted; 1 – colostrum extracted with repeated massage; 2 – colostrum extracted with simple massage; 3 – easy extraction with finger and thumb (no massage required).
- Vitality of piglets in the birth litter was assessed at processing, which occurred within 24 (12) hours of the completion of farrowing on both farms. Piglets were firstly scored for potentially negative indicators of vitality. These included the number of piglets which were observed to be unresponsive (unthrifty) during handling (NUNTH); stained with meconium (NMEC); shivering (NSHIV); thin (NTHIN) -backbone, pins and ribs clearly evident; or exceedingly pale (NPALE) piglets (Tabuaciri, 2012). Individual piglets could have more than 1 detrimental indicator observed (i.e. a piglet could be both pale and thin), but data were not recorded to individual piglets. The number of vital piglets (NVITAL) was also recorded to represent the total number of piglets that didn't have any of the detrimental indicators of poor health, along with the total number observed (TOTP). Aspects of piglet vitality were recorded in order to investigate the quality of piglets at birth, which can be affected by gestation length, uterine capacity and nutritional levels of sows during gestation, as well as the farrowing process (Baxter *et al.*, 2018; Edwards *et al.*, 2015).
- Resting respiration rate (RESP2, RESP5) and rectal temperatures (RECT2, RECT5) of sows were reassessed on days 2 and 5 post-farrowing, as above.
- Udder health and indicators of suckling load were assessed at day 2 after farrowing. Udder health included the presence or absence of mastitis, as described above, along with the count of teats with injuries (TEATI2). Suckling load indicators included the count of unsuckled (regressing) teats (TEATU2) and the count of functional (active milk gland) teats (TEATF2). Regression of individual un-suckled teats is relatively rapid for sows (Kim *et al.*, 2001).
- Evidence for the presence of post-farrowing infection was evaluated by inspecting sows for vulval discharge on day 5 after farrowing (DISCH5) subjective scores: 0 – not present; 1 – light discharge; 2 – moderate discharge; and 3 – heavy discharge (Anil *et al.*, 2008; Glock *et al.*, 2005; www.thepigsite.com)

Data recorded at weaning

- Udder health and suckling load were re-evaluated at weaning by recording the count of regressed (TEATR) and injured teats (WTEATI) at weaning.
- The incidence of shoulder lesions (SHOULDW) at weaning was scored as 0 - no shoulder lesions were present, and 1 - shoulder lesions are visible, regardless of the severity.

Feed refusals

- Feed refusals (FR) were recorded daily from the morning after sows entered the farrowing shed, until the start of *ad libitum* feeding post-farrowing, concurrently identifying whether sows were on a dry or a liquid type of feeding at Farm A. Feed refusals were scored 3 – 4 hours after the first morning feed was delivered, as 0 – all or almost all eaten; 1 - approximately half of the meal remained, and 2 - more than half of the meal remained. Data were subsequently presented as 0 - all or almost all eaten and 1 - more than half of the meal remained. Subjective scoring was feasible as both locations had a fixed volume of feed delivery at the first feeding event each morning. The feed was not weighed at delivery or at the time of scoring. Since sows were fed restrictively and pregnant sows eat relatively quickly (Vargovic *et al.*, 2018), feed refusals should have been absent for healthy sows.

Routine data available from companies

- Reproductive data for all sows included: mating date(s), parity (MATEP), farrowing date, number born alive (NBA), number of stillborn (SB) and mummified piglets (MUM), litter birth weight (not available for all sows), weaning date, number of weaned piglets (NWEAN), sow culling and removal dates, and removal reason (both for sows and piglets). For a subset of maternal line sows, individually identified piglets had individual birth weights (ABW) and mortality (PMORT) recorded.
- Medication data were recorded for all sows, as part of standard farm procedures. Sows were allocated into 4 treatment classes based on medication data: 1) sows were medicated during the gestation period only; 2) sows were medicated any time between mating until weaning; 3) sows were only medicated in the farrowing house; 4) un-medicated sows. The timing of treatment was considered in context of the medication used for separate health issues. Blanket medication events (i.e. medication applied to all sows) were not included in the above.

Calculated variables

From the routine data obtained from each farm, additional variables were calculated. These included:

- Gestation length (GEST) - the interval between mating date and farrowing date. Gestation length for sows that did not farrow successfully was calculated as the interval between mating and the outcome date (n=3).
- Lactation length (LACT) - the interval between farrowing date and weaning date (including extended lactation if multiple litters were suckled).
- Days from mating to the entry into the farrowing shed (M2E).
- Expected interval from entry to farrowing (TTF), assuming a gestation length of 116 days.
- Days from entry to the farrowing shed until farrowing (E2F). This variable was as both a potential predictor for sow outcomes, and as the dependent variable to identify predictors which could indicate that farrowing was imminent.
- Days from mating/entry/farrowing to removal (M2Rem/E2Rem/F2Rem), removals or removal decision up to 60 days post-weaning, regardless of the reason for removal.
- Weaning to first mating interval (WMI).
- Mate parities were grouped (PGRP) as: parity 0 = group 1; parity 1 = group ; parities 2, 3, and 4 = group 3; and parity > 4 = group 4. An alternative grouping of parity (GS) was considered: where 0 represents gilts, and 1 represents sows.

Appendix 2

The distribution of sows (% in level) across factor levels for pre-farrowing predictors, by farm (Farm A: N=558; Farm B: N=545)

Predictors		Factor levels						
	Farm	0	1	2	3	4	5	11
BGRP	A		83.5	16.5				
	B		75.6	24.4				
GiltSow (GS)	A		34.4	65.6				
	B		26.1	73.9				
LOCO	A	89.2	7.3	3.5				
	B	89.2	8.3	2.5				
INJURY	A	60.0	40.0					
	B	40.9	59.1					
INJURV	A	80.8	13.4	5.8				
	B	52.7	30.6	16.7				
INJURL	A	74.4	17.0	8.6				
	B	74.7	20.7	4.6				
INJURS	A	91.0	9.0					
	B	98.2	1.8					
FIGHT	A	40.1	37.8	22.1				
	B	12.5	34.7	52.8				
DIRTY	A	94.8	5.2					
	B	90.9	9.2					
DIRTU	A	96.8	3.2					
	B	95.4	4.6					
DIRTV	A	99.5	0.5					
	B	96.5	3.5					
CALIPER	A		9.5	23.5	35.1	22.4	9.5	
	B		3.7	9.2	25.7	28.4	33.0	
EYE	A	91.2	8.8					
	B	96.0	4.0					
VSCORE	A	58.8	38.9	2.3				
	B	7.2	84.8	8.0				
CFIT	A	53.0	32.4	14.6				
	B	44.0	32.5	23.5				
TACC	A	67.2	17.4	15.4				
	B	40.0	34.7	25.3				
TEATI	A	59.5	22.0	12.2	6.3			
	B	57.1	25.1	11.0	6.8			
USCORE	A	28.0	51.4	20.6				
	B	1.7	44.2	54.1				
Mastitis	A	90.1	9.9					
	B	97.4	2.6					
RESP	A		29.8	41.2	23.1			5.9

	B		73.2	23.1	3.7			
RECT	A	88.9	5.2					5.9
	B	98.3	1.7					
HB	A		8.2	9.9	35.5	20.1	19.5	22.9
	B		5.7	11.0	16.0	18.5	46.0	2.8
M2E	A		6.8	25.0	60.0	8.2		
	B			2.2	89.0	8.8		
GEST	A		14.9	45.7	34.2	5.2		
	B		7.2	47.5	40.6	4.7		
E2F	A		13.3	48.2	26.9	11.6		
	B			12.8	69.8	17.4		
TTF			8.3	41.2	26.3	24.2		
			4.0	15.8	78.0	2.2		
TREATBF	A	95.3	4.7					
	B	97.6	2.4					
Feed	A		64.0	36.0				
	B		100.0					
FRBF	A	45.2	25.3	13.8	11.1			4.6
	B	49.2	24.0	17.2	9.6			

Appendix 3

The distribution of sows (% in level) across factor levels for post-farrowing predictors, by farm (Farm A: N=558; Farm B: N=545)

Predictors	Factor levels								
	Farm	0	1	2	3	4	5	6	11
NPALE	A	43.5	21.3	14.7	7.5	7.4			5.6
	B	72.8	9.9	6.4	6.1	4.8			0.0
NTHIN	A	19.0	12.9	17.2	23.5	21.8			5.6
	B	29.6	15.0	16.7	19.3	19.6			0.0
NSHIV	A	63.6	13.8	5.7	3.4	7.9			5.6
	B	68.6	3.3	3.9	3.7	20.6			0.0
NMEC	A	53.0	14.9	14.5	6.6	5.4			5.6
	B	47.3	11.4	16.5	12.1	12.7			0.0
NUNTH	A	71.5	14.1	8.8					5.6
	B	85.9	10.6	3.5					0.0
NVITAL	A		14.5	31.5	40.5	7.9			5.6
	B		11.0	24.8	56.0	8.2			0.0
SB	A	50.9	27.1	13.3	4.5	4.3			
	B	58.2	22.4	9.0	5.0	5.5			
TB	A		5.6	14.0	39.6	30.1	10.8		
	B		6.1	14.7	45.7	25.1	8.4		
NBA	A		6.3	11.5	37.8	34.4	10.0		
	B		5.1	13.8	47.0	26.8	7.3		
NWEAN	A		9.7	12.4	34.6	37.5	5.9		
	B		9.9	18.9	41.1	27.0	3.1		
Mastitis2	A	80.3	12.9						6.8
	B	82.0	16.9						1.1
MastitusW	A	84.8	11.1						4.1
	B	88.8	6.2						5.0
TEATI2	A	47.8	18.3	18.3	8.8				6.8
	B	69.0	21.3	8.6					1.1
TEATF2	A		15.9	77.2					6.8
	B		8.4	90.5					1.1
TEATU2	A		31.7	19.7	25.8	15.9			6.8
	B		40.7	20.4	28.6	9.2			1.1
TEATIW	A	45.9	15.9	14.3	7.0	12.7			4.1
	B	63.9	20.4	5.9	5.0				5.0
TEATRW	A		24.2	46.2	25.4				4.1
	B		58.5	27.0	9.5				5.0
RECT2	A	90.1	4.1						5.7
	B	93.9	4.8						1.3
RECT5	A	91.8	2.7						5.6
	B	89.5	8.3						2.2
RECTW	A	86.4	9.5						4.1
	B	85.3	9.7						5.0
RESP2	A		41.4	36.4	10.2				12.0
	B		62.9	29.5	5.5				2.0
RESP5	A		30.6	37.8	11.6				19.9
	B		41.5	39.3	15.8				3.5
VULV5	A	70.3	16.5	7.7					5.6
	B	63.3	21.3	13.2					2.2
FRAF	A	41.0	19.5	17.0	15.6				6.8
	B	34.9	0.0	21.3	43.8				

CALW	A		21.0	19.3	26.7	23.7	5.2		4.1
	B		12.8	27.0	33.6	16.5	5.1		5.0
SHOULDW	A	90.1	5.7						4.1
	B	85.9	9.2						5.0
E2W	A		0.0	4.1	3.8	30.6	27.4	34.1	
	B		4.8	25.5	63.7	6.1			
LACT	A		3.6	0.0	7.0	29.4	35.7	24.4	
	B		4.2	22.0	69.7	4.0			
TREATE2W	A	94.8	5.2						
	B	97.8	2.2						

Appendix 4

*The distribution of sows (% in level) across factor levels for urinalysis predictors across farms (*N=693, except for odour/colour/turbidity N=694*)*

	Factor levels									
Predictors	Unit	Normal values	0	1	2	3	4	5	6	7
Bilirubin	mg/dl	Neg	60.5	22.5	10.2	6.8				
Urobilinogen	mg/dl	NW	78.2	21.8						
Ketones	mg/dl	Neg	96.1	3.9						
Ascorbic Acid	mg/dl		24.5	53.0	22.5					
Glucose	mg/dl	Neg	92.1	7.9						
Protein	mg/dl	Neg	27.3	44.1	19.2	9.4				
Blood	Ery/ml		80.5	19.5						
pH		5.5-8.0		51.1	34.3	14.6				
Nitrite	µmol/l	Neg	90.0	10.0						
Leukocytes	Leuko/µl	Neg	94.9	5.1						
Specific gravity		1.00-1.040		4.6	14.1	15.6	11.0	7.9	15.6	31.2
Odour	NY		74.8	25.2						
Colour	Classes	PD		19.0	61.2	19.8				
Turbidity	NY	No	81.9	18.7						

Appendix 5

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The influence of feed delivery and feeding patterns during gestation on reproductive outcomes for sows

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Summary

Mid-parent breeding values and outcomes from 6126 mating (4998 farrowing) events and accompanying feed-related traits, derived from feeding events recorded during gestation, were used to investigate the associations between these factors with reproductive outcomes for commercial sows. Variability in genetic merit for piglet birth weight had undesirable consequences for premature sow removal (REM35). Sows in the highest quintile for missed feeding events (> 24 hours between meals) recorded over 90 days had both lower farrowing rate (97.2% vs 97.9 - 99.2%) and increased REM35 (12% vs 7 - 9.5%) compared to the rest. Results from the present study demonstrated that when feeding during gestation did not accommodate variation in litter size and body weight amongst sows, performance of the "average" sow with respect to litter size was favoured. While heritability of intake under restricted feed delivery was zero, variability in litter size alone created heritable variation ($h^2 \sim 0.05$) in actual feed requirement, and therefore the deviation in actual intake from requirement. Reproductive outcomes for commercial sows, and the retention of genetically superior sows for reproductive traits, might be better optimised if gestational feeding was better adapted to sow phenotypes.

Keywords: heritability, nutritional requirements, out-of-feed events, culling

Introduction

In commercial pig production, diets and feeding levels for gestating sows are typically based on requirements of the parity "average" sow, using assumed parameters for maintenance and maternal gain during gestation, along with expected litter size and piglet/conceptus weight. However, variation amongst sows occurs in nutritional requirements due to variation around these average values, due to both genetic and environmental effects. Feeding levels during gestation are also relatively restrictive, when compared to feed intakes observed in gestating sows allowed *ad-libitum* access to feed (van Barneveld *et al.* 2007). Therefore, sows cannot moderate their own intake upwards, even if required. Both over- and under-feeding of sows can contribute to poor outcomes in the farrowing house at the end of gestation (Kim 2010), but there are few reports of the full impact in a wider window around the farrowing period. Sows must have their nutritional needs during gestation met by diet, or their own body reserves, and/or the requirements of the developing litter, could become compromised. Changes in sow body composition and sow weight gain associated with litter size were previously illustrated by Bunter *et al.* (2010). We hypothesised that genetic variation amongst commercial sows combined with fixed feeding curves during gestation may have unintended consequences for sow performance, resulting in culling related to genetic merit combined with sub-optimal feeding level. In addition, we investigated whether feeding behaviours observed during gestation had any impact on outcomes.

Material and methods

Data

Data were obtained for all feeding events recorded at a single site, which housed large dynamic groups of commercial (predominantly F1) sows during gestation. Sows were fed with electronic sow feeders (ESFs: manufactured by Rivalea Australia Pty Ltd), capable of delivering individually specified feeding levels for group sizes of up to 300 sows. Two feed delivery curves were applied throughout gestation without seasonal adjustment. Gilts received allocations of 2.4 kg/day for days 1-35 of gestation, 2.0 kg/day for days 36-90 and 2.2 kg/day above 90 days of gestation; sows received corresponding allocations of 2.7, 2.2 and 2.4 kg/day. A small proportion of sows were allocated higher levels, based on body condition.

Groups of ~ 250 sows of variable parity and gestational age were initially constructed over a one week period in January 2015. Subsequently, new sows were introduced to gestation groups after mating. All sows had received prior training with ESFs and were conditioned to using the feeders. Daily feed allocations for individual sows were activated for each 24 hour period at midday every day. Each feeding event per sow was subsequently recorded to date, time of entry and exit from the feeder, diet (A vs B), and volume of feed delivered (kg). Sow visits to feeders which did not result in feed delivery were not recorded. Individual feeding event records (N > 1 million) were collapsed to become daily records per sow (N ~ 500K events), combining separate events recorded within a day. Days without a feeding event, spanned by adjacent days of intake (N = 21522), were allocated a zero feed delivery record.

Subsequently, daily event data were used to calculate a range of variables relating to feed intake and feeding behaviours recorded over N = 6126 mating events with outcomes known. These traits included averages of feed intake (ADI, kg/day), time spent in the feeder (AFT, minutes/day), the average number of feeding events per day (AFE) and the rate of feed consumption (AFR, g/minute), for sows with 90+ days recorded within a parity (N = 3926 records). An interval of 90 days allowed for multiple mating events and/or recording over the majority of the gestation period. In addition, the cumulative number of missed (MISS) or low intake (LOW, < 1 kg/day) feeding events per day was obtained for individual sows.

The required daily intake (RDI, kg/day) was calculated for sow i in parity j by accumulating MJ DE per day required to maintain assumed parity averages for weight at mating (WT_j) and the targeted maternal gain (MG_j), and obtain the expected average piglet birth weights (BWT_j) for (TB_{ij}) recorded at farrowing (equation 1), for a diet averaging 13.5 MJ DE/kg. The difference between actual and required intake (defined generally as AFI-RDI) was considered as an additional trait (DEVR).

$$RDI_{ij} = ((WT_j\text{^}0.75 \times 0.455) + MG_j + (TB_{ij} \times BWT_j))/13.5 \qquad \text{for sow } i \text{ in parity } j \quad (1)$$

Mid-parent averages of breeding values, estimated based on purebred data, were available for 91.7% of the commercial sows for the traits: average daily gain (mpADG), back fat (mpBF), along with number born alive (mpNBA) and piglet birth weight (mpBW1, mpBW2) in the first and later parities.

The outcomes from each mating event were known for 3785 sows. Sows with unknown outcomes included sows with lost identity, which can be a significant problem in large dynamic groups. Sows were firstly identified as farrowed or not (FARR) from each mating event. Returns to service and negative pregnancy test combined with "not in pig" were the primary alternative outcomes. Other unsatisfactory outcomes included: 1) FFAIL: farrowing failure (abortion, NBA<=5, farrowing difficulty, excessive still births or mummies), 2) LFAIL: lactation failure (lactation length<14 days or number weaned <6), 3) DD: death (including destruction) and 4) REM35: premature culling, within 35 days of farrowing, or removed between days 100 and 120 days post-mating.

Analyses

The significance of mid-parent breeding values for production and reproductive traits on outcomes for FARR, FFAIL, LFAIL, DD and REM35 was evaluated using PROC GLIMMIX (SAS Institute, Cary NC). Each breeding value was fitted separately as a linear regression within models which accounted for mating year-month (MYM: 16 levels) and sow parity group (4 levels). The significance of feed-related traits on outcomes for sows was evaluated by fitting terms for MYM, sow age group (gilt vs sow), quintile ranking for the feed-related trait of interest (defined separately within gilt and sow groups) and their interaction terms, when significant at $P<0.05$. Sows with less than 90 days of feed intake data recorded were allocated to a "6th quintile". Sow was fitted as a random effect in the model to accommodate observations from multiple mating events per sow.

Sows were progeny of 267 sires and 2403 dams, and the pedigree was extended back by 4 generations for parameter estimation. Estimates of heritability were obtained for all traits using models which accounted for mating year-month (16 levels), parity group (4 levels), diet (2 levels) and shed-pen (12 levels), where significant ($P<0.05$). Sow identity and sow permanent environmental effects were fitted to accommodate repeated records. All parameter estimates were obtained under an animal model using ASREML (Gilmour *et al.* 2009).

Results and Discussion

In total, 3785 sows had 6126 mating events with known outcomes, including 4998 farrowing events (81.6% of records). Sows which did not have a farrowing outcome from a mating event were re-mated (creating a new mating event), culled or dead. FFAIL was established using 5403 records, because FFAIL included sows with pregnancy loss, due to abortion or not-in-pig sows. Outcomes for LFAIL were confined to sows with a farrowing date, while REM35 also included sows which were removed from the herd between 100-150 days post-mating, or within 35 days of farrowing. These outcomes either represent forced removals or variables contributing to culling decisions for individual sows.

Data characteristics and heritability estimates

Consistent with results presented by Vargovic *et al.* (2018), who used the same resource data, AFI had negligible heritability, while AFT, AFR and MISS recorded over 90 days had moderate to high heritabilities (Table 1). Therefore, sows can express heritable feeding behaviours under restricted feeding, when time limits are not imposed at feeding. In contrast to zero heritability for AFI, both the estimated daily feed requirement (RFI) and DEVR were lowly heritable traits

(Table 1). This demonstrates that genetic variation which alters performance levels creates heritable phenotypes for nutritional requirements, and therefore heritable variation in whether sows will be over-or under-supplied with feed during gestation under fixed feeding curves. The magnitude of this heritability could represent, more generally, the nutritional limitation to optimising performance of all sows. This estimate might be conservative, given that other heritable traits also alter nutritional requirements. The heritability of an outcome from a single mating event was negligible, whereas significant sow effects (genetic or non-genetic) were present for sow removals, and to a lesser extent farrowing or lactation failures. With few records per sow and a single generation of data, partitioning between genetic and non-genetic effects was relatively inaccurate.

Table 1. Raw data characteristics (N, Mean(SD)), along with estimates of heritability (h^2±se), permanent environmental effects (pe^2±se) and phenotypic variance (σ^2_p)

Trait (units)		N	Mean (SD)	h^2	pe^2	σ^2_p
Feeding events (N/day)	AFE	3926	1.17 (0.105)	0.06±0.02	0.25±0.04	0.012
Intake (kg/day)	AFI	3926	2.27 (0.124)	0.01±0.01	0.14±0.03	0.002
Time eating (mins/day)	AFT	3926	14.8 (3.75)	0.33±0.05	0.37±0.05	13.1
Rate of intake (g/min)	AFR	3926	163 (41.4)	0.41±0.06	0.28±0.05	1401
Missed days (N)	MISS	3926	4.38 (3.61)	0.17±0.04	0.21±0.04	11.5
Required FI (kg/day)	RFI	3676	2.47 (0.238)	0.04±0.02	0.05±0.04	0.006
AFI-RFI	DEVR[1]	3676	0.0 (0.117)	0.06±0.03	0.08±0.04	0.002
Total born (pigs/litter)	TB	4997	12.4 (2.81)	0.17±0.03	0.08±0.03	7.40
Farrowed (or not)	FARR[3]	6126	81.6 (38.8)	0.01±0.01	B[2]	1381
Farrowing failure	FFAIL[3]	5403	4.71 (21.4)	0.01±0.01	0.05±0.03	443
Lactation failure	LFAIL[3]	4998	10.1 (30.1)	0.00±0.01	0.04±0.02	890
Removals	REM35[3]	5785	9.68 (29.6)	0.04±0.02	0.28±0.03	819

[1]centred around 0; [2]B: boundary estimate; [3]×100

Influence of breeding values on sow reproductive outcomes

Mid-parent breeding values of commercial gilts were variable for growth (SD: 16.1 g/day), litter size traits (SD: 0.45-0.54 pigs/litter), back fat (SD: 0.40mm) and piglet birth weight (SD: 59g) traits (not shown). Using linear regression, mpNBA predicted daughter litter sizes with regression coefficients >0.70 across parity groups and a model R^2 of 8-10%, demonstrating that EBVs for litter size based on purebred performance were predictive (with low accuracy, as expected) of realised litter size for F1 sows in a commercial setting. With respect to outcomes for sows, mpBF approached significance (P=0.07) for FARR, as higher mpBF significantly (P<0.0001) reduced returns, which increases farrowing rate. Positive associations between fatness and farrowing outcomes have been observed previously (Bunter *et al.* 2010; Farmer *et al.* 2017). Sows with higher mpBWT1 or mpBWT2 had significantly (P=0.01) decreased LFAIL, but sows with higher mpBWT1 were also more likely (P=0.04) to be removed prematurely around the farrowing event (REM35). A high birthweight EBV (adjusted for litter size) is consistent with a sow partitioning more resources towards piglet development, potentially to their own detriment with respect to fatness and longevity (Bunter *et al.* 2010). These results demonstrated that genetic variability present in F1 sow populations contributed to phenotypic variability, while unidentified variation amongst individual sows in genetic merit for specific traits was also associated with outcomes (both beneficial and detrimental) for sow performance.

The impact of feed-related traits on sow reproductive outcomes

Least squares means for FARR, FFAIL, LFAIL and REM35 by quintile are shown in Table 2 for effects which were significantly ($P<0.05$) associated with these outcomes. Increasing quintile rank reflects increasing value of the explanatory variables. There were no factors identified which were significantly associated with sow deaths, which occurred at a low frequency per mating event.

Since records reflected outcomes for each mating event, sows not recorded for 90 days or more had low farrowing rates (ie culled due to returns, etc) and also elevated rates of FFAIL (abortions included) and REM35, as expected. In addition, for sows with the majority of their gestational intake recorded, as MISS increased from quintiles 1 to 5, FARR declined from 99.2 to 97.2%, REM35 increased from 7.0 to 12.0%, and there was a gradual increase ($P>0.05$) in FFAIL. Sows in quintile 5 had 10 periods, on average, of > 24 hours between feeding events, although many consumed close to their feed allocation. MISS is equivalent to out-of-feed events, which has detrimental effects for growth and is a known contributor to ulcers in growing pigs (Brumm *et al.* 2005). As sows ate more of their feed allocation (higher AFI), FARR tended to increase but FFAIL and REM35 did not differ. Sows spending the most time eating (high AFT), with a lower rate of feed consumption (AFR) and a tendency towards more feeding events per day (AFE), had lower FFAIL. Therefore, even under restricted feeding levels during gestation, the pattern of feed intake was associated with outcomes.

When expressing feed intake as a deviation from feed requirement (based on parity and litter size only), quintile 1 represented underfed sows and quintile 5 represented sows overfed, relative to litter size only and assumed average body weights by parity. For comparison, results for TB itself are presented. Quintile 1 for TB (<9-10 pigs per litter) had the highest FFAIL, LFAIL and REM35 relative to larger litters. The corresponding pattern for DEVR was consistent with the impact of TB for FFAIL and LFAIL, but demonstrated that both over and under-fed gilts had increased REM35. Overfed gilts and sows (quintile 5) had significantly higher FFAIL, but both over- and under-fed sows had higher rates of REM35. Sows least likely to be removed were those closest to average litter size for their parity.

We hypothesised that sows whose nutritional requirements were not met during gestation could have undesirable outcomes as a consequence. Other species can adapt their intakes (eg through increased time spent grazing) or are fed more (eg better pasture or supplementary feed for twinning ewes) to better meet their nutritional requirements based on output. This will not occur when combining fixed feed delivery with variable but unknown animal phenotypes. In general, low accuracy of predicting individual phenotypes (eg for litter size or body weight) from breeding values hinders the ability to address this issue during gestation for commercial sows. However, knowledge of individual sow weights and gestating litter size could assist in the development of more suitable feeding schedules for higher risk sows. Evidence for missed feeding events during gestation will also assist in predicting at risk sows. These steps could lead to better retention of sows with superior litter size potential.

Conclusions

Results from this study imply that variation in both genetic potential and phenotypes, combined with feed delivery and feeding patterns during gestation, contributes to unintended detrimental outcomes for commercial sows. This suggests that genetic improvement distributed to commercial herds might not be fully exploited, due to premature removal of sows with higher nutritional requirements. More research is required to optimise outcomes for commercial sows.

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Table 2. Least squares means for quintile group of significant (P<0.05) explanatory variables[1] for a successful farrowing outcome (FARR), a farrowing (FFAIL) or lactation (LFAIL) failure[2], or premature removal (REM35) around the farrowing event[2] for gilts (G) and sows (S)

			Quintile (defined separately within gilt and sow group)					Variable not
Trait	Variable[1]	Age	1	2	3	4	5	recorded
FARR	AFI	GS	97.1±0.7^{a}	98.3±0.3^{ab}	98.6±0.2^{b}	98.8±0.2^{b}	98.1±0.3^{a}	32.4±1.9^{c}
(N=6126)	MISS	GS	99.2±0.2^{a}	98.6±0.2^{ab}	98.3±0.3^{b}	97.9±0.3^{b}	97.2±0.2^{c}	32.4±1.9^{d}
FFAIL	TB	GS	18.6±1.7^{a}	1.6±0.4^{b}	1.8±0.5^{b}	1.1±0.4^{b}	2.5±0.6^{b}	29.1±2.9^{c}
(N=5403)	AFI	GS	3.6±0.7^{a}	4.1±0.8^{a}	1.7±0.5^{a}	3.2±0.7^{a}	3.3±0.7^{a}	12.7±1.3^{b}
	AFT	G	5.0±1.3^{a}	2.8±0.9^{ab}	3.5±1.0^{ab}	4.8±1.2^{a}	1.8±0.7^{b}	10.8±1.6^{c}
	AFT	S	2.9±0.8^{a}	4.2±1.0^{a}	3.0±0.9^{a}	1.9±0.7^{c}	1.9±0.6^{c}	14.6±1.8^{b}
	AFR	G	1.8±0.7^{a}	5.1±1.2^{b}	3.2±1.0^{b}	3.1±1.0^{b}	4.7±1.2^{b}	10.8±1.6^{c}
	AFR	S	1.9±0.6^{a}	1.7±0.6^{a}	3.3±0.8^{ab}	4.4±1.0^{b}	2.7±0.8^{ab}	14.6±1.8^{b}
	MISS	GS	2.6±0.6^{a}	3.0±0.6^{a}	3.2±0.7^{a}	3.2±0.7^{a}	3.8±0.8^{a}	12.7±1.3^{b}
	DEVR	G	1.1±0.5^{a}	1.0±0.5^{a}	1.1±0.5^{a}	1.9±0.7^{a}	9.9±1.8^{b}	12.0±1.6^{b}
	DEVR	S	1.8±1.6^{a}	1.5±0.6^{a}	0.6±0.4^{a}	0.8±0.4^{a}	6.1±1.2^{b}	16.5±1.8^{c}
REM35	TB	GS	11.0±1.3^{a}	5.0±0.7^{b}	5.1±0.9^{b}	5.6±0.8^{b}	4.5±0.8^{b}	55.2±2.2^{c}
(N=5804)	AFI	GS	11.6±1.4^{a}	9.6±1.3^{a}	7.8±1.1^{a}	7.0±1.1^{a}	9.6±1.3^{a}	19.8±1.4^{b}
	AFE	GS	10.8±1.3^{a}	8.4±1.2^{a}	9.6±1.3^{a}	8.4±1.2^{a}	8.3±1.2^{a}	19.8±1.4^{b}
	MISS	GS	7.0±1.1^{a}	8.3±1.1^{a}	9.1±1.3^{a}	9.5±1.3^{a}	12.0±1.5^{b}	19.8±1.4^{c}
	DEVR	GS	3.1±0.6^{ac}	2.3±0.5^{ac}	2.1±0.5^{a}	2.4±0.5^{ac}	4.8±0.8^{c}	31.3±1.4^{b}
LFAIL	TB	GS	12.5±1.3^{a}	8.8±0.9^{b}	8.2±1.1^{b}	9.8±1.1^{b}	8.8±1.0^{b}	NE
(N=4998)	DEVR	G	11.5±2.4^{a}	6.8±1.7^{b}	10.1±2.2^{ab}	11.0±2.3^{a}	12.6±2.5^{a}	11.9±2.5^{a}
	DEVR	S	3.4±1.0^{a}	7.4±1.7^{ab}	8.6±1.9^{b}	6.7±1.6^{ab}	8.2±1.8^{ab}	11.0±2.2^{ab}

[1] TB: total born; AFI: average feed intake; AFE: average feeding events; AFT: average time spent feeding; AFR: average rate of feed intake; MISS: count of missed feeding events; DEVR: deviation of intake from requirement; NE: not estimable

[2] FARR: sow farrowed (1) or not (0); FFAIL=1 for abortion, low litter size, farrowing difficulty, excessive stillbirths or mummies (otherwise 0); REM35: sow removed from herd between within 35 days of farrowing, or between days 100 and 120 days post-mating (otherwise 0); LFAIL=1 for lactation length<14 days or small number weaned (otherwise 0)

Appendix 6

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Feeding behaviour traits recorded during gestation are heritable even though feed intake itself is restricted

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Summary

Data obtained from electronic sow feeders during the gestation period were used to investigate feed intake and feeding behaviour traits from 3785 predominantly (89.9%) F1 sows. Estimates of heritability, permanent environmental effect of the sow and phenotypic variance were obtained for seven distinct time periods during gestation for average feed intake (AFI), daily time spent eating (AFT), rate of feed consumption (AFR), the number of feeding events (AFE) and total born (TB) piglets. As expected, heritability estimates for feed intake traits such as AFI1-AFI7 were not different from zero, which can be explained by the restricted feed allocation (rather than *ad libitum* feeding). In the same time periods, heritabilities for the amount of time sows spent eating were low to moderate: lowest at the beginning (0.12±0.03) and at the end of gestation (0.16±0.04) and highest in the middle of gestation (range: 0.16 to 0.27). The same pattern was found for the rate of feed consumption. Further investigation of these feeding behaviour traits is warranted with respect to their associations with reproductive performance outcomes, given that they represent potential limitations to sows' ability to consistently meet their nutritional requirements over time.

Keywords: gestation, ESF, feed intake, feeding behaviour, sows, heritability

Introduction

Traits that reflect feeding behaviour patterns include the number of visits within a day, feed intake per visit or per day, time spent for each feeding event, total eating time per day as well as the rate of feed consumption (Cassady *et al.*; Labroue *et al.*, 1997). With the development of electronic sow feeders (ESF) in the 1980s, it became possible to record feed intake of sows on an individual level (Chapinal *et al.*, 2008). Recording and evaluating feed intake of sows, and possible deviations from a given feeding curve could, for example, be the first indicator on an individual level of compromised health status (Cornou *et al.*, 2008). In this study we examined genetic parameters for feed intake and feeding behaviour traits recorded during the gestation period for sows housed in a large dynamic groups fed using ESF.

Material and methods

The data were part of routine feed intake recording by Rivalea Australia Pty Ltd during the period of one year (January-December 2015) from a gestation housing system with large dynamic groups. Sows with feed intake records were predominantly (89.9%) F1 (Large White x Landrace, PrimeGro^{TM} Genetics, Corowa, NSW) females. The majority of sows (91.7%) had known parentage. In total, there were 3785 sows from 251 sires and 2268 dams recorded over 6132 mating events. Sow feed was delivered using ESF manufactured by Rivalea Australia. Sows were trained to use ESF as gilts prior to their first entry into the gestation groups. The amount of feed delivered to individual sows was based on standard feeding curves, which were constructed separately for first vs higher parity sows. These feeding curves were not altered seasonally, but the feeding curve could be adjusted for individual sows, if required. Intake for individual sows was controlled through recognition of individual sow identification tags using RFID by the ESF. Non-feed delivery events were not recorded by these feeders.

Data from all individual feeding events (about 1 million records) were used to construct a range of traits for individual sows. Preparation of the data included eliminating duplicates, combining adjacent events (within 60 seconds) into one feeding event, adding in missed events (a zero daily intake) if a one day gap occurred between two feeding events, and accumulating all daily feeding events into a single daily record per sow. From originally 4106 sows, 3785 sows with known outcomes from 6132 mating events were included in analysis (92% of sows). Sows with unknown outcomes were generally due to the loss of identification tag.

The gestation period was arbitrarily divided into seven groups, based on days of gestation: 1-7 (Group 1), 8-14 (Group 2), 15-35 (Group 3), 36-90 (Group 4), 91-100 (Group 5), 101-105 (Group 6) and more than 105 days of gestation (Group 7). Groups were arbitrarily constructed to align them with both specific periods of interest and changes to the feed delivery curve on days 35 and 90 of gestation. Data in this study included average daily feed intake recorded for each stage of gestation (AFI1-AFI7), time spent feeding (AFT1-AFT7), rate of feed consumption (FR1-FR7), calculated as AFI/AFT within each observed period, average feed intake for all of the observed sows per mating event (AFIALL), along with average feed intake (AFI), average feeding time (AFT), average number of feeding events per day (AFE) and average rate of feed consumption (AFR) for sows with more than 90 days of records. The counts of missed feeding events (MISSF), daily feeding intake below 1 kg (BELOW1), and feeding events above 30 minutes (ABOVE30) over all records, along with total born piglets (TB) were also obtained.

Data preparation and analysis were performed using R (R Core Team, 2016). F-tests were used to assess the significance of systematic effects and/or their interaction; effects that were significant at $P<0.05$ were retained in models for analyses. Systematic effects evaluated included sow line (5 levels), mating year-month (16 levels), parity group (4 levels), diet (2 levels) and shed-pen (12 levels). For all the feed related traits, significant systematic effects included parity group, diet, mating year-month and pen-shed. Sow line was added to this model for AFI4 and AFT3, MISSF, BELOW1, and AFIALL. Mating year-month, parity group and shed-pen were significant for TB. Random effect models were developed and parameter estimates were obtained using ASReml (Gilmour *et al.*, 2014). Estimates of variance components were performed under a linear mixed animal model by residual maximum likelihood procedures. Univariate analyses were performed for estimation of genetic parameters. Inclusion of the permanent environmental effect of the sow to accommodate repeated records per sow was tested using the likelihood ratio test (Mrode, 2005).

Results and discussion

Not all sows had complete intake data in all time periods during gestation because the data commenced with groups of mixed gestational age, or because sows were removed from the group if they were unsuited to the ESF system (i.e. failed to eat), or because sows could not complete their gestation within the time period examined.

Raw data characteristics

Overall means are presented in Tables 1 and 2. The average daily feed intake, amount of time sows spent eating and the rate of feed consumption were the highest at the beginning of gestation (2.63±0.27, 16.0±4.86 and 180±63.3), and the lowest in the middle of gestation (2.09±0.13, 14.1±3.95 and 158±42.1), mirroring changes in feeding curves. Feed intakes were lower than the allocated feeding curve predominantly in periods 1 (-0.13 kg/day) and 4 (-0.15 kg/day). The average number of feeding events over all sow-mating events was 1.16±0.13, reflecting that most sows ate only once per day. The average count of missing feeding events during the gestation period was 3.45±3.41. However, this did not always represent a reduction in feed intake below the sow's allocation because sows could eat twice in one calendar day (typically close to midnight), consuming allocations from 2 days within 1 day, resulting in them missing the following day.

Based on calculated coefficients of variation (CV), variability in average daily feed intake was lower than variability in time spent eating or the rate of feed consumption within all time periods. Variability in the time spent eating or rate of feed intake was the highest at the beginning and at the end of the gestation and lowest in mid-gestation (Table 1). High variability at the start of gestation probably reflects disruption in feeding activity due to group construction, while at the end of gestation could represent increasing variability between sows in their physical capacity to eat or access the feeders.

The model R^2 was the lowest for the amount of time sows spent eating per day, 3.0-9.5% (Table 1) and rate of feed consumption, showing a low accuracy of the model for predicting time spent eating. Model R^2 were also relatively low for the average number of feeding events (5.3%), missing feeding events (18.4%) or feeding events below 1 kg (24.2%) (Table 2). In contrast, the model almost perfectly explained average feed intakes for sows which had a lot of feed intake data (R^2 90.2%, Table 2), demonstrating that most sows eat their allocation of feed averaged over days.

Parameter estimates

Currently, there is limited literature regarding genetic parameters for feed intake and feed intake behaviour traits of group housed gestating sows. Heritability estimates for average daily feed intake under restricted feeding were negligible and not different to zero (Table 1). Heritability estimates of daily feed intake obtained for growing pigs, which typically express their appetite under *ad-libitum* feeding, are around 0.20 (Huisman & Van Arendonk, 2004; Shirali *et al.*, 2017). Heritabilities for the average time sows spent eating were moderate: lowest at the beginning (0.12±0.03) and at the end (0.16±0.04) of the gestation period, while in the middle estimates had a range from 0.16-0.27 (Table 1). These estimates were also lower than heritabilities previously reported for growing pigs, 0.36±0.05 (Labroue *et al.*, 1997). Heritabilities for the rate of feed consumption followed a similar pattern over the gestation, with an estimate of 0.18±0.03 for AFR (Table 1). For comparison, heritability of the rate of feed consumption for growing pigs was 0.49±0.05 (Labroue *et al.*, 1997) and 0.26 (Shirali *et al.*, 2017). Heritability for average number of feeding events observed was 0.03±0.02, which was much lower than for growing pigs (0.43±0.05) (Labroue *et al.*, 1997). This outcome might reflect the fact that visits without a feed delivery were not recorded by the feeders. Average feed intake for sows that had more than 90 days of records had heritability not different from zero. Heritability for total born piglets was 0.16±0.03, which is similar to the previous findings (Bunter *et al.*, 2009).

Conclusions

Results presented in this paper show that heritability for the traits connected with the daily amount of feed consumed is not different from zero, which was expected, as sows were restricted in the amount of feed delivered throughout gestation. However, sows were still able to express heritable variation in feeding behaviour traits, such as the time spent feeding, and the number of missed feeding events or small feeds. Further investigation of these feeding behaviour traits is warranted with respect to their associations with reproductive performance outcomes, given they represent potential limitations to a sow's ability to consistently meet their nutritional requirements during gestation.

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Table 1: The number (N) of sows recorded for average feed intake (AFI), time spent feeding (AFT) and rate of feed consumption (AFR) defined by gestation phase (1-7), with the raw mean (SD) and estimates of heritability (h^2), permanent environmental effect (pe^2) and the phenotypic variance (σ_p^2)

	Gestation phase (days)							
	1-7	8-14	15-35	36-90	91-100	101-105	>105	
N	5723	5750	5682	5269	4064	3849	3016	6132
	Feed intake (kg/day)							
Trait	AFI1	AFI2	AFI3	AFI4	AFI5	AFI6	AFI7	AFIALL
R^2	33.7	33.2	65.2	61.2	43.3	19.8	10.9	45.8
mean (SD)	2.46 (0.44)	2.63 (0.27)	2.55 (0.17)	2.09 (0.13)	2.28 (0.16)	2.28 (0.23)	2.22 (0.31)	2.31 (0.23)
h^2 (se)	0.02 (0.01)	0.01 (0.01)	0.01 (0.01)	NA	0.02 (0.02)	0.0003 (0.01)	0.02 (0.02)	0.007 (0.01)
pe^2 (se)	0.02 (0.02)	NA	0.02 (0.02)	NA	NA	NA	NA	0.06 (0.02)
σ_p^2	0.13	0.05	0.01	0.007	0.01	0.04	0.09	0.03
	Daily time (minutes/day)							
Trait	AFT1	AFT2	AFT3	AFT4	AFT5	AFT6	AFT7	
R^2	3.0	9.5	8.3	4.5	4.6	4.3	5.1	
mean (SD)	14.7 (4.56)	16.0 (4.86)	15.4 (4.23)	14.1 (3.95)	15.0 (4.87)	15.0 (5.43)	14.7 (5.89)	
h^2 (se)	0.12 (0.03)	0.16 (0.03)	0.19 (0.04)	0.27 (0.04)	0.22 (0.04)	0.17 (0.04)	0.16 (0.04)	
pe^2 (se)	0.19 (0.03)	0.21 (0.03)	0.32 (0.04)	0.31 (0.04)	0.33 (0.04)	0.34 (0.04)	0.33 (0.05)	
σ_p^2	20.2	21.4	16.4	14.9	22.6	28.3	32.9	
	Rate of feed consumption (grams/minute)							
Trait	FR1	FR2	FR3	FR4	FR5	FR6	FR7	AFR
R^2	7.2	14.0	16.6	13.0	9.5	8.1	6.9	9.7
mean (SD)	183 (70.2)	180 (63.3)	178 (50.2)	158 (42.1)	167 (52.2)	169 (55.9)	171 (62.8)	168 (51)
h^2 (se)	0.09 (0.02)	0.10 (0.03)	0.26 (0.04)	0.34 (0.05)	0.19 (0.04)	0.20 (0.04)	0.13 (0.04)	0.18 (0.03)
pe^2 (se)	0.11 (0.03)	0.16 (0.03)	0.23 (0.04)	0.24 (0.04)	0.18 (0.04)	0.18 (0.05)	0.32 (0.05)	0.43 (0.03)
σ_p^2	4568	3447	2100	1544	2468	2875	3668	2315

[1] NA. Non applicable based on likelihood ratio test

Table 2: The number of sows recorded (N) for average feeding events per day (AFE), missing feeding events (MISSF), feeding events below 1 kg (BELOW1), feeding events longer than 30 minutes (ABOVE30), along with average feed intake/day (AFI) and time spent feeding (AFT) for sows with more 90 days recorded, total born piglets with the raw mean (SD), and estimates of heritability (h^2), permanent environmental effects (pe^2) and the phenotypic variance (σ_p^2)

	Feeding behaviour traits						
Trait	AFE	MISSF	BELOW1	ABOVE30	AFI	AFT	TB
N	6132	6132	6132	6132	3926	3926	4997
R^2	5.3	18.4	24.2	11.4	90.2	5.9	6.3
mean (SD)	1.16 (0.13)	3.45 (3.41)	5.25 (4.18)	4.33 (7.44)	2.27 (0.13)	14.7 (3.73)	12.4 (2.81)
h^2 (se)	0.03 (0.02)	0.12 (0.03)	0.10 (0.02)	0.13 (0.03)	0.005 (0.01)	0.33 (0.05)	0.16 (0.03)
pe^2 (se)	0.28 (0.02)	0.11 (0.03)	0.09 (0.03)	0.26 (0.03)	0.14 (0.03)	0.37 (0.05)	0.08 (0.03)
σ_p^2	0.02	9.47	13.2	49.0	0.002	13.1	7.39