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Achieving optimum performance in a loose-housed farrowing system for sows: the effects of space and temperature

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Abstract

Piglet survival relies on interactive influences of the sow, her piglets and their environment. There are a number of design challenges in a loose-housed farrowing and lactation system to optimise this dynamic, including achieving farrowing in the desired location (i.e. a protected nest area) and minimising crushings. The PigSAFE (Piglet and Sow Alternative Farrowing Environment) pen was developed with these challenges in mind. It has different areas to fulfil different biological and managerial needs, including a solid-floored nest area with piglet protection features (sloped walls, heated creep) intended for farrowing. Two hypotheses regarding pen design features to optimise farrowing location and improve piglet survival were tested: i) greater space would improve maternal behaviour; and ii) a heated nest-site would be more attractive to the farrowing sow. PigSAFE was adapted to give a LARGE treatment, 9.7m^2 in total with a nest area of 4.0m^2, and a SMALL treatment, same design but 7.9m^2 in total with a nest area of 3.3m^2. The nest floor was heated to either 30°C (T30) or 20°C (T20) from 48h before until 24h after farrowing. A 2x2 factorial design saw 88 Large White x Landrace sows randomly assigned to space and temperature treatments. Generalized linear mixed models were used to analyse performance data. Farrowing location analysis involved dividing the pen into seven areas (L1-L7); L1 deemed the safest location for the piglets to be born (in the nest, furthest from dunging area, closest to creep) and L7 the least protected (in the dunging area). Of all the piglets born 97% were born in the nest area. The majority of sows started farrowing in L1 (56%), with 39% of remaining piglets being born in this location. There was a significant Space x Temperature interaction for farrowing location (*P=0.011*) with SMALL_T20 achieving the most L1 births. Temperature had no significant influence on piglet survival (Total mortality *P=0.401*; Live-born mortality *P=0.826*). However space influenced mortality, with significantly greater live-born mortality when sows were afforded a larger farrowing space (LARGE=18.1% vs. SMALL=10.9%

P=0.028). There were no significant interactions between space and temperature for either total mortality (*P=0.394*) or live-born mortality (*P=0.685*). The overall design successfully promoted farrowing in the nest location, irrespective of nest size and floor temperature. The higher piglet mortality in the LARGE treatment suggests that the larger nest size was less protective for the piglets and thus a smaller nest would be recommended.

Keywords: free farrowing, space, temperature, piglet survival, maternal behaviour

1. Introduction

Confinement of the sow during farrowing and lactation is a welfare issue which is a continuing focus for public concern and debate. At the present time, the majority of sows farrow in conventional farrowing crates (approximately 60% of sows farrow indoors in the UK with 96% of these in crates – Guy et al., 2012; 95% in EU and 83% in USA – EFSA, 2007; NAHMS, 2000), many with partly or fully slatted flooring for manure management as slurry. This places limitations on the freedom of movement of the sow and some practical constraints on the types of substrate which can be used to allow expression of nest building behaviour. There has been significant research into developing alternatives to the farrowing crate (for reviews see Baxter et al., 2012; Edwards and Fraser, 1997) but as yet there is no large-scale commercial up-take of a non-crate indoor farrowing system other than in countries where the crate has been prohibited (Sweden, Switzerland and Norway). Constraints preventing voluntary uptake in countries where farrowing crates are permitted include valid farmer concerns about the ability for a loose-housed system to deliver high piglet survival rates, acceptable capital, running and labour costs, efficient labour routines and operator safety (Baxter et al., 2012). There is consequently a need for new alternatives to the farrowing crate that provide maximal sow and piglet welfare whilst addressing these concerns.

The PigSAFE (Piglet and Sow Alternative Farrowing Environment) project aimed to tackle this challenge and developed pen design criteria (based on those summarised in a review by Baxter et al., 2011a) that should provide the correct stimuli required to achieve the desirable outcomes. Since sows show clear preferences for a feeding area separate to both the dunging and nesting areas (Andersen and Pedersen, 2011), the pen incorporates different functional areas: a nest-site with a separate heated corner creep for the piglets, a dunging area and a lockable feeding stall. The nest-site provides enclosure on three sides, an entrance providing a view into the adjacent pen and a solid floor so that substrate can be provided for nest-building. These criteria were based on sow preference experiments demonstrating the importance of such features (e.g. Cronin et al., 1998; Hunt and Petchey, 1987). Under-floor heating was also installed in the nest-site to offer the possibility of additional thermal support for the newborn piglets and provide a greater temperature differential from the dunging area which might attract sows into the nest for farrowing (Philips et al., 2000; Pedersen et al., 2007). The dunging area was separate and fully slatted to satisfy the sow's preference to dung away from the nest-site (Wiepkema, 1986; Damm and Pedersen, 2000) as well as fulfilling hygiene criteria for the stockworker.

The objective of this experiment was to investigate the sows' use of the designated functional areas in this new pen design, and to address two questions regarding design criteria – namely how much space does the sow require to achieve good performance and whether thermal enhancement of the nest area encourages correct farrowing location and improves piglet survival. It was hypothesised that (i) more space would result in better separation of functional areas and facilitate nest-building behaviour which, since feed-back from the unconstrained performance of nest-building behaviour can affect neuro-endocrine regulation of maternal behaviour (Castrén et al., 1993; Damm et al., 2003; Pedersen et al., 2003; Algers and Uvnäs-Moberg, 2007), would improve subsequent maternal behaviour and piglet survival (Arey et al., 1991; Jensen, 1993; Damm et al., 2003; Pedersen et al., 2003; Yun et al. 2013); and (ii) that a warmer nest floor would be more attractive to farrowing sows and reduce piglet mortality predisposed by perinatal hypothermia (Pedersen et al., 2007).

2. Materials and methods

2.1 Ethical statement

This study was reviewed and approved by the SRUC Ethical Review Committee (approval ID: ED AE 5/2009). All animal management procedures were adhered to by trained staff.

2.2 Animals and Housing

Eighty-eight Landrace x Large White (Pig Improvement Company, Kingston, Oxfordshire, UK) sows and gilts (hereafter sows; average parity 2.42 (±sem 0.15)) were randomly selected to take part in this experiment. All animals were housed at the research farm of Scotland's Rural College (SRUC) in Midlothian, Scotland. During gestation sows were housed in groups no larger than six per pen. The pens were 3.60m x 6.25m, consisting of an enclosed straw-bedded area at the rear (3.60m x 2.50m), a central dunging passage (3.60m x 1.95m), and an access passageway plus six individual feeding stalls side by side at the front (each 0.5m wide, 1.8m long). Sows were fed a standard pregnancy diet, once a day (two kg containing 12.74% CP, 13.32 MJ DE.kg^{-1}). After farrowing, lactation diet (17% CP, 13.75 MJ DE.kg^{-1}) was offered at a rate of three kg per day followed by 0.5 kg increments each day until seven kg and then followed by one kg increments each day up to a maximum of 12 kg until weaning. Throughout, all animals had ad libitum access to water. Approximately five days before their expected due date, sows were weighed, condition scored and had their back-fat thickness measured at the P2 position before being moved into farrowing accommodation (PigSAFE pens). Average pre-farrowing weight, condition score (0-5 scale) and P2 measurements for sows were 258.1 ±3.53kg, 3.30 ±0.07 score and 20.91 ±0.39mm respectively.

PigSAFE (Piglet and Sow Alternative Farrowing Environment) pens had a basic nest area, with solid and insulated concrete flooring to allow provision of nesting material. For nesting, 2kg of long-stemmed straw was maintained by daily replenishment (not cumulative) from day -5. This level was maintained until day +7 and then it was reduced to 1kg of straw daily until weaning. The nest was equipped with sloping walls against which the sow can slide more slowly to ground level for suckling, which had a gap between their base and the floor to lower the risk of piglets being trapped and killed. A heated, corner creep area (0.75m^2) with easy access from the nest was bedded with a thin layer of sawdust. The solid nest area was equipped with under-floor heating which could be adjusted on a pen by pen basis (see section 2.3 Experimental Design for temperature settings). A separate slatted dunging area (Triband metal 9mm void) was bounded by walls with barred panels to adjacent pens to discourage farrowing outside the nest and allow visual and oral-nasal contact between neighbouring sows. A feeding stall for the sow (0.50m wide, bounded by solid sides) was included at one side of the pen, where the sow could be locked in to allow safe inspection or treatment of the piglets. This basic prototype pen design was adapted to determine the influence of space and temperature on farrowing location, maternal behaviour and piglet survival (Figure 1a and b).

2.3 Experimental design

The sows were randomly assigned to treatment groups in a 2x2 factorial design to test the influence of space and nest floor temperature on farrowing location and maternal behaviour. The sows were either assigned to the LARGE space treatment (9.7m^2 in total; dunging passage = 2.20m x 1.60m, nest-site = 1.30m x 2.80m) or the SMALL space treatment (7.9m^2 in total; dunging passage = 2.20m x 1.23m, nest-site = 0.90m x 2.38m). The nest-site floor was heated to either 20°C (T20) or 30°C (T30) from 48h before until 24h after farrowing. Figure 1 illustrates the experimental pens side-by-side. The overall farrowing room temperature was set at 18°C for the first week during and after farrowing, before being reduced to approximately 16°C for the remainder of lactation. Creep temperatures were set at 30°C for farrowing and the first week post-farrowing before being set on a curve gradually reducing the temperature to approximately 25°C for the remainder of lactation.

Figure 1 recommended here

2.4 Data collection

Piglet mortality was recorded with post-mortem examination confirming cause of death. Video cameras (Low-lux B/W waterproof cameras: SK-2020XC/SO, RF Concepts Ltd, Belfast, Ireland) captured continuous data from all pens from day -5 until at least day +2 post farrowing. Farrowing kinetics (cumulative farrowing duration and average birth interval) were recorded. Of particular interest in this study was where in the pen sows chose to farrow and the quality of maternal behaviour in terms of posture changes during farrowing. These data were collected for 84 of the sows (camera failure resulted in four sows not being observed). A sub-set of animals (n=52) were followed for 24h after the birth of the first piglet to record crushing incidents (both injurious and non-injurious – see Table 1 for full ethogram). One sow and her litter had to be excluded from analysis of performance and behaviour at 24h post-partum because the piglets contracted alloimmune thrombocytopenia after ingestion of their mother's colostrum. As the condition only manifested itself in the piglets post-farrowing, the sow's farrowing location data were included for analysis. For farrowing location analysis, the pen was divided into seven areas (L1-L7). L1 was designated as the preferred farrowing location based on the fact that if sows farrowed in this location piglets would be born closest to the creep area and furthest from the dunging passage which was designated as L7. L7 was designated the least preferred farrowing location as it contained no piglet protection features or bedding and had no additional heating source for the piglets (Figure 2).

Table 1 recommended here

2.5 Statistical analysis

The number of sows in each treatment was unbalanced (SMALL_T20 n = 21; SMALL_T30 n = 23; LARGE_T20 n = 22; LARGE_T30 n = 22), thus Generalised Linear Mixed Models (GLMM) were fitted to the data (Genstat 14th edition) for analysis of mortality, farrowing location, farrowing kinetics, and number of posture changes during farrowing. A binomial distribution with a logit link function was fitted to a GLMM to analyse the influence of space and temperature (fitted as fixed effects) on mortality (i.e. piglets were either dead (1) or alive (0) for the binomial model) and the sows' location to farrow the first piglet in the litter. These location data were categorical (i.e. 1-7 possible locations), therefore the fixed estimate of binomial totals was set at 7. A Poisson distribution, with a logarithm link function was fitted to GLMMs to analyse the influence of space and temperature on the location where the remaining piglets were farrowed. In all models parity was fitted as a fixed effect and sow was fitted as a random factor. When necessary, cross-fostering was performed (only within the first 48h post-partum) and the subsequent mortality data were adjusted accordingly to reflect the fostered litter size.

In order to analyse each separate location by treatment, non-parametric tests (Mann-Whitney U – Genstat 14th edition) had to be used as there were a large number of values returned as zero. The differences between treatments regarding type of crushing behaviour by the sow also returned a large number of zeros therefore were analysed using non-parametric tests (Chi-square and Mann-Whitney U).

3. Results

3.1 Farrowing location

The majority of sows commenced farrowing in the L1 position (56%). However sows changed position during farrowing, with only a further 39% of total piglets born in this location. Ninety-seven percent of total piglets were born in the nest with dunging passage farrowings very rare (Figure 2).

Figure 2 recommended here

Temperature and space treatments had no effect on where sows chose to start farrowing ($F_{1,80}$ = 0.00, *P=0.986* and $F_{1,80}$ = 0.52, *P=0.474* respectively) or where they chose to farrow the remainder of their litter ($F_{1,556}$=0.09, *P=0.763* and $F_{1,556}$=0.01, *P=0.941* respectively), however the small number of sows that farrowed in the dunging area (3%; four sows farrowed 13%, 20%, 86% and 100% of their litter respectively in L7; two of these sows started farrowing in L7) were from the SMALL_T20 treatment. Overall there were significant differences in percentage of piglets farrowed in each location ($F_{6,556}$=11.96, *P<0.001*) with a significant space x temperature interaction for farrowing location ($F_{6,556}$=2.80, *P=0.011*). Figure 3 summarises the interactive effects illustrating that the combination of the smaller space and the T20 temperature achieved the most L1 farrowing positions.

Figure 3 recommended here

Table 2 summarises differences at each location for the separate treatments and shows that significantly more piglets were born in L5 and L7 in the SMALL treatment compared with the LARGE (Table 2. L5: SMALL = 12.97% vs. LARGE = 2.37% *P=0.04* and L7: SMALL = 6.02% vs. LARGE = 0.00% *P<0.001*). The only significant difference within the temperature treatment came at L2 where more piglets were born in this location in the T30 temperature (Table 2. T20 = 15.25% vs. T30 = 35.79% *P=0.006*).

Table 2 recommended here

3.2 Performance

Eight-eight sows produced 1109 piglets; average litter size was 12.75 (±0.41), with 11.97 (±0.40) born alive and 0.78 (±0.14) born dead (intra-partum stillbirths).

The 2x2 structured comparison showed that the floor temperature at the time of farrowing had no significant influence on piglet survival (Total mortality: T20 = 19.01% (±sem2.41) vs. T30 = 19.81% (±sem3.05) $F_{1,86}$=0.71, *P=0.401*; Live-born mortality: T20 = 13.07% (±sem2.30) vs. T30 = 16.01% (±sem2.96) $F_{1,86}$=0.05, *P=0.826*). However the amount of space influenced live-born mortality, with significantly more piglets dying when sows were afforded a larger farrowing space (Live-born mortality: LARGE = 18.10% (±sem2.30) vs. SMALL = 10.90% (±sem2.92) $F_{1,86}$=5.00, *P=0.028*). This was reflected in a tendency for greater total mortality when sows were afforded the larger space (Total-mortality: LARGE = 23.14% (±sem2.34) vs. SMALL = 15.68% (±sem3.05) $F_{1,86}$=2.86, *P=0.095*). There were no significant interactions between space and temperature for either total mortality (SMALL_T20 = 16.05% (±sem3.27), SMALL_T30 = 15.31% (±sem5.10), LARGE_T20 = 21.97% (±sem3.50), LARGE_T30 = 24.31% (±sem3.13) $F_{1,86}$=0.74, *P=0.394*) or live-born mortality (SMALL_T20 = 9.73% (±sem2.96), SMALL_T30 = 12.07% (±sem5.03), LARGE_T20 = 16.42% (±sem3.47), LARGE_T30

= 19.96% (±sem3.09) $F_{1,86}$=0.17, *P=0.685*). Crushing was the largest cause of mortality (42%); however there was a great deal of individual variation with some sows showing a high propensity to crush whilst others achieved 100% survival (Figure 4).

Figure 4 recommended here

3.3 Maternal behaviour

3.3.1 Farrowing kinetics and behaviour

There were no interactive effects of space and temperature on farrowing kinetics (cumulative farrowing duration (mins): SMALL_T20 = 199.9 (±15.95); SMALL_T30 = 279.6 (±25.86); LARGE_T20 = 302.2 (±73.27); LARGE_T30 = 279.0 (±45.79); $F_{1,86}$ =1.00, *P=0.320* and average birth interval (mins) SMALL_T20 = 19.02 (±2.03); SMALL_T30 = 24.19 (±2.34); LARGE_T20 = 23.80 (±5.34); LARGE_T30 = 25.85 (±4.16); $F_{1,86}$ =0.38, *P=0.451*). However the higher floor temperature resulted in longer average birth intervals ($F_{1,86}$ =4.09, *P=0.047*). There was no influence of treatment on the average number of posture changes sows performed during farrowing (SMALL_T20 = 25.87 (±4.37); SMALL_T30 = 28.91 (±4.47); LARGE_T20 = 25.27 (±3.28); LARGE_T30 = 27.66 (±6.80): $F_{1,86}$ =1.06, *P=0.306*).

3.3.2 Crushing behaviour

Of the sub-set of sows that were observed for 24h from the birth of the first piglet 53% (n=27) of them showed some type of crushing behaviour. Since there was no influence of temperature on mortality, only the influence of space on type of crush was analysed. There were significantly more crushing incidents when sows were afforded the larger space (X^2_6 = 35.85, *P<0.001*). This treatment yielded a greater total number of observed rolling, clamping and kicking (i.e. when the sow transitions from standing to walking) events (Table 3). Mann Whitney U tests revealed that a significant difference existed only for the kicking category, indicating that the numerical differences between space treatments regarding rolling and clamping events were attributable to a small number of sows within the treatments. Stand to sit crushing incidences were rare but were only observed in the SMALL space treatment (Table 3).

Table 3 recommended here

4. Discussion

4.1 Farrowing location

Sows showed a clear preference to farrow in the nest area regardless of the different space or temperature treatments. Heating the floor did not alter the attractiveness of the nest area for farrowing. It is likely that the design of the PigSAFE pen provided sufficient stimuli to encourage the sow to farrow in the nest area without the additional heat source. These stimuli included provision of enclosure by solid walls, sufficient substrate with which to satisfy nest-building behaviour and suitable flooring to maintain the nest. In early work looking at nest-site choice of sows, Hunt and Petchey (1987) demonstrated clear preferences for farrowing inside, or against a solid wall. Similar choices were shown by sows under natural and semi-natural conditions (Stolba and Wood-Gush, 1984) where 40% chose total enclosure and 89% chose partial enclosure. The nest opening in the PigSAFE pen permits sows the ability to see their neighbour's pen and this added motivation to face the nest entrance is likely to have further influenced the sow's decision to farrow in the L1 location within the nest, since sows in the wild select nest sites allowing them to maintain vigilance for approaching threats (Stolba and Wood-Gush, 1984). In the current study the majority of sows started farrowing in this position which is considered optimal in the PigSAFE pen because the birth site is furthest away from the cooler and unprotected slatted dunging area and the udder when lying laterally is immediately adjacent to the creep. Within minutes of being born piglets stand and perform teat seeking behaviours (Rohde and Gonyou, 1987). If sows are lying in the L1 position in the PigSAFE pen, piglets will walk in front or through the heated creep to access the udder, which could promote early use of this warmed and protected area. It is generally thought that piglets remain in close proximity to the udder within the first 2-3 days post-partum, although there is large variation between litters studied (Berg et al., 2006; Vasdal et al., 2010). Proximity to the udder brings warmth, develops teat fidelity for better colostrum and milk intake but also brings greater risk of crushing by the sow (Weary et al., 1996a). In a loose farrowing environment in particular, it is advantageous to attract the piglets into a protected area as quickly as possible (outwith the periods of suckling). Opposite the creep the nest wall is sloped with specific dimensions to protect piglets from being crushed when sows descend from standing to lying or roll against the pen side. The sloped wall also prevents piglets from being blocked when teat-seeking, providing a protected tunnel if they choose to walk around the sow. Sow preferences to use such supportive structures have been demonstrated in the past (Baxter, 1991; Damm et al., 2006; Marchant et al., 2001) and providing these structures in this pen design appears to have aided optimal farrowing position.

There were significant treatment effects on farrowing location, with the combination of the smaller space and the lower under-floor temperature of 20°C achieving the most L1 births. Although there is evidence that sows prefer warmer areas in which to farrow and certainly seek them post-partum (Pedersen et al., 2007; Phillips et al., 2000), the current study does not support this preference. However the nest-site may have provided adequate thermal stimuli in all treatments, since 2kg of long-stemmed straw (known to reduce heat loss - Mount, 1967) was provided on a solid, insulated concrete floor heated to a minimum of 20°C. It thus provided a microclimate with less thermal conductivity than the slatted dunging area, and the nest-site enclosure with a narrow nest entrance also reduced air movement.

Some sows did choose to vary their farrowing positions and there was greater variability evident in the smaller space. The greater number of L5 births in the smaller space seemed to reflect the fact that this position was often adopted for the second born in the litter, with sows starting the farrowing process in L1 then getting up and inspecting their piglet before lying back down facing their first piglet and continuing the farrowing process. Dunging passage farrowings were very rare; however the two sows that did commence farrowing at this location were both housed in the small space. Extra space in the large pen may create a much clearer distinction between the two areas for the sows.

4.2 Performance

The larger space resulted in higher piglet mortality, despite farrowings taking place in the nest and the nest having the same design features in both treatments. The sow was afforded greater unobstructed floor space in the larger nest and could lie down unsupported if she chose. In addition she could roll without contacting the supportive structures. Rolling from a ventral to a lateral lying position is a known risk factor for crushing in loose-housed systems (Weary et al., 1996b; Damm et al., 2005; Danholt et al., 2011) and the descriptive data for types of crush saw sows farrowing in the larger space showing greater total crushing incidents involving rolling, although these incidences were confined to only a few of the sows.

The other risk with a larger nest space is that piglets have a greater area in which to wander and become chilled when distant from heat sources. When sows have suitable floor-type and sufficient materials with which to build a nest, they will often dig a hollow depression, fill it with substrates like grasses, mosses and leaves and surround it with larger branches and twigs (reviewed in Wischner et al., 2009). The nest is thus an oval shape designed to keep the piglets close and offer thermal protection. Such nest construction is limited in a farm setting. There was a tendency for a greater number of farrowings in the L3 position in the larger space. Although this is still in the nest-site, piglets were born further away from the creep with closer proximity to the dunging area and therefore a greater risk of hypothermia. Cronin et al. (Cronin and Smith, 1992; Cronin et al., 1994), in their development of the Werribee Farrowing Pen, also demonstrated that too large a nest site increases mortality, especially in cooler ambient temperatures, suggesting that piglet thermal protection can interact with nest size. However, these authors also demonstrated the importance of providing a nest of sufficient width to allow performance of behaviours that influence piglet survival, notably nest-building and suckling (Cronin et al., 1998).

The current study has demonstrated the problems associated with affording too much space in the area to be shared by the piglets. The small space was sufficient to facilitate nest-building because it provided a greater planar width and length at the sow's shoulder height compared with the space provided at the floor level, making turning around easier, and provided a separate dunging area giving additional space for activity. The nest dimensions were proposed by Baxter et al. (2011a) after their review of space requirements for farrowing and lactation systems based on body dimensions of modern sows (Moustsen et al., 2011). However, experience during this study, where large sows were frequently observed with their udders compressed against the creep bars, would recommend an extra 20cm width to the pens, to accommodate unimpeded suckling for all litters.

4.3 Maternal behaviour

In this study higher floor temperatures resulted in longer piglet inter-birth intervals. A similar result was observed by Malmkvist et al. (2012), but was correlated with length of time the under-floor heating was on before farrowing. Neither these authors nor the current study found a negative relationship with survival, however prolonged farrowings and heat stress in sows do have the potential for negative outcomes for both sows and piglets (e.g. Prunier et al., 1997; Edwards, 2002), particularly in restrictive environments where the sows are unable to regulate their body temperature via behavioural adaptations (Malmkvist et al., 2012).

Regardless of space or temperature treatments, there was great variability between sows in piglet mortality and in crushing behaviour, with number of crushed piglets per litter ranging from 0-14.

Given the importance of maternal behaviour to piglet survival in loose-housed farrowing systems (Arey, 1997), this variability could be key in whether or not loose-farrowing accommodation becomes more commercially viable. Since maternal behaviour has been shown to have a genetic component (Grandinson et al., 2003; Gäde et al., 2008), investigating the consistency and possibility for change in important maternal behaviours such as carefulness (e.g. pre-lying behaviour, offspring communication and maternal responsiveness – Weschler and Hegglin, 1997; Valros et al., 2003; Illmann et al., 2008), aggression (e.g. offspring-directed – Chen et al., 2007; Baxter et al., 2011b, and stock-person directed– Marchant-Forde, 2002) and temperament (e.g. fearfulness – Thodberg et al., 2002) in the environment in which the animals will be kept is an area meriting further investigation.

4.4 Conclusions

Designing a farrowing environment that optimises both sow and piglet welfare involves providing adequate freedom of movement for the sow, in conjunction with the correct stimuli to promote good maternal behaviour (e.g. correct farrowing location) and suitable protection (thermal and physical) for piglets. This study has provided quantitative information on specific design criteria required in a loose farrowing and lactation system and demonstrated the importance of design detail such as dimensions of specific functional areas. Individual variation in maternal behaviour influences consistency of performance in loose-housed systems and their potential for further commercial adoption. Investigating the possibilities of selecting sows for specific loose-farrowing traits should be a target in this area of research.

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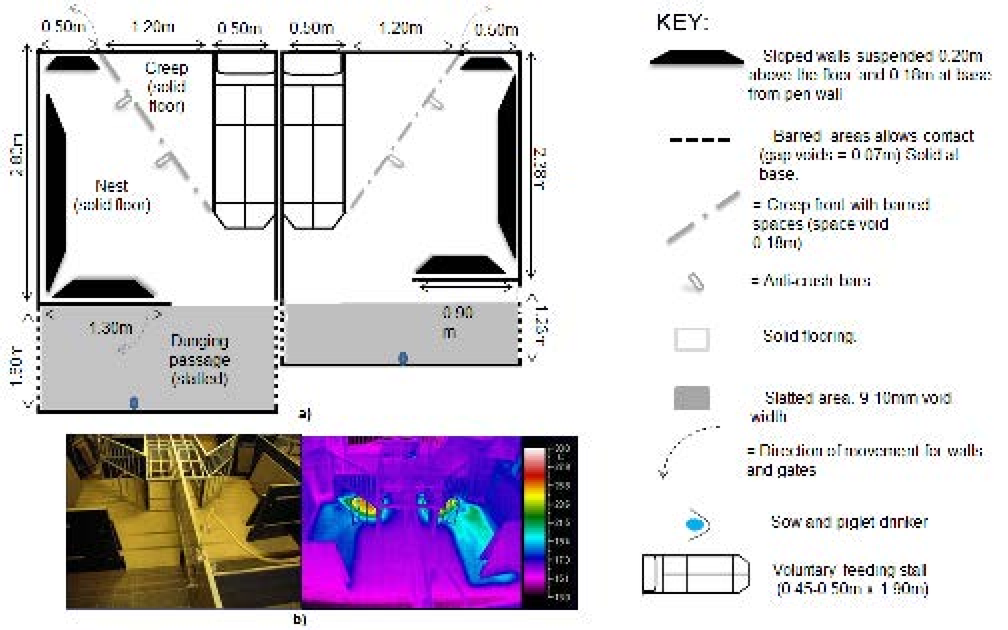
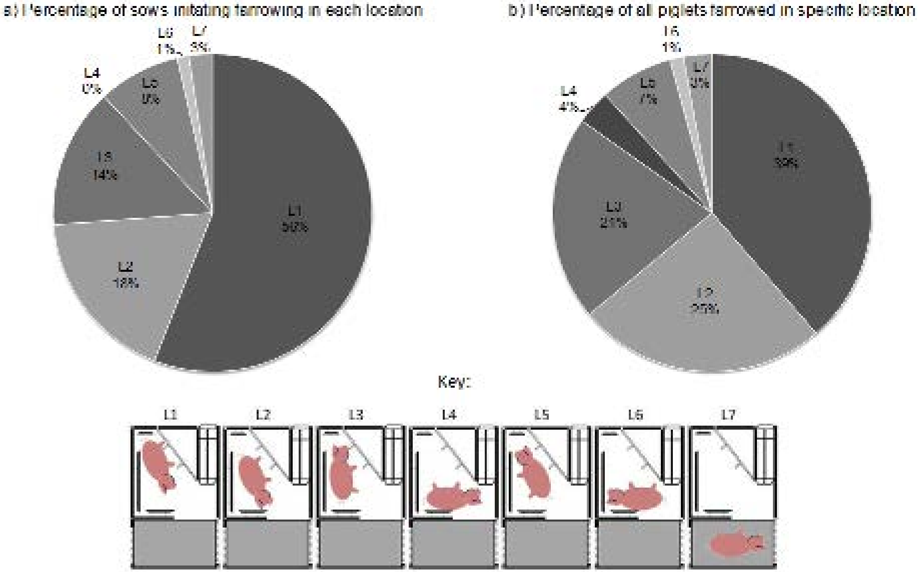
Figure 1. a) Prototype PigSAFE pens (not to scale) side-by-side showing the LARGE and SMALL space treatments and b) the under-floor heating treatments T20 (20°C) and T30 (30°C).

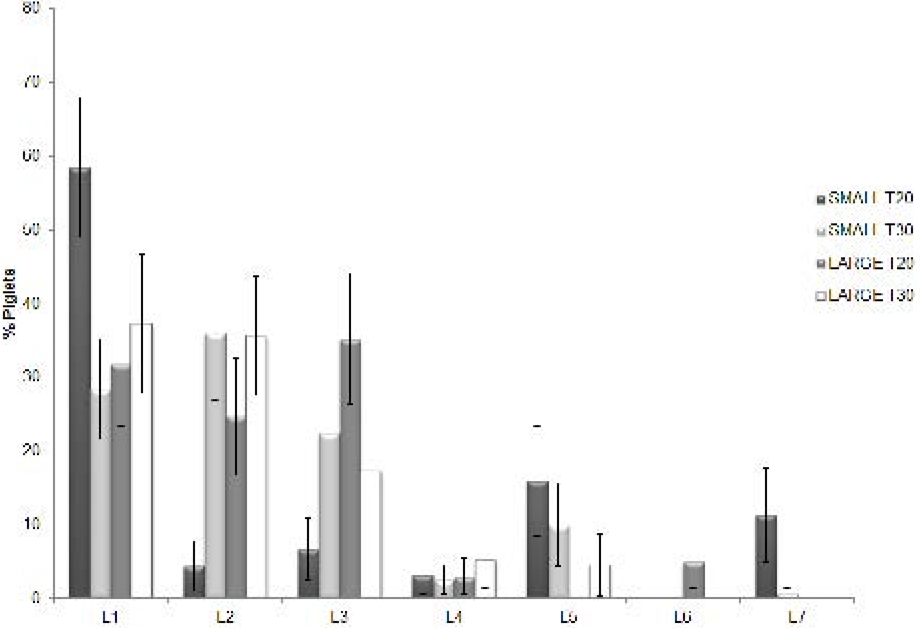
Figure 2: Farrowing location for a) percentage of all first born piglets and b) percentage of all piglet births. Possible farrowing locations in PigSAFE pens (not to scale) illustrated below pie-charts. L1 considered the optimum farrowing location for piglet survival.

Figure 3. Interactive effects of space and temperature on the areas where piglets were farrowed in PigSAFE pens.

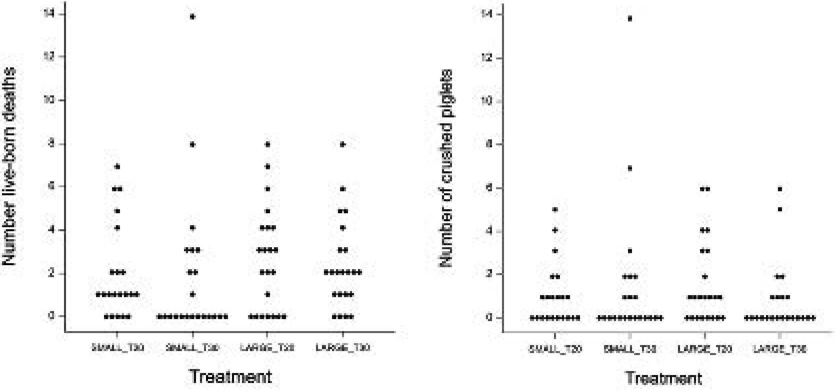
Figure 4: Differences in a) number of live-born deaths and b) crushes by individual sows in each treatment


0.50m
1.20m
0.50m
0.50m
1.20m
0.50m
Creep (solid floor)
Nest (solid floor)
1.30m
Dunging passage (slatted)
0.90 m
a)
b)
KEY:
Sloped walls suspended 0.20m above the floor and 0.10m at base from pen wall
Barred areas allows contact (gap voids = 0.07m) Solid at base.
= Creep front with barred spaces (space void 0.10m)
= Anti-crush bars
Solid flooring.
Slatted area. 9-10mm void width
= Direction of movement for walls and gates
Sow and piglet drinker
Voluntary feeding stall (0.45-0.50m x 1.90m)


a) Percentage of sows initiating farrowing in each location
L1
56%
L2
18%
L3
14%
L4
0%
L5
8%
L6
1%
L7
3%
b) Percentage of all piglets farrowed in specific location
L1
39%
L2
25%
L3
21%
L4
4%
L5
7%
L6
1%
L7
3%
Key:
L1
L2
L3
L4
L5
L6
L7



% Piglets
80
70
60
50
40
30
20
10
0
L1
L2
L3
L4
L5
L6
L7
SMALL T20
SMALL T30
LARGE T20
LARGE T30



Number live-born deaths
Treatment
Number of crushed piglets
Treatment
SMALL_T20
SMALL_T30
LARGE_T20
LARGE_T30

a) b)

Table 1. Ethogram describing the type of crushing behaviour displayed by sows

Sow crush behaviour	Description
Stand-to-Walk	Sow puts prolonged pressure (defined as more than 2 seconds) on the piglet by stepping or sow kicks the piglet whilst walking
Sit-to-Lie	Sow puts prolonged pressure on the piglet when moving from a sitting posture to lying down. Piglets can get trapped underneath the sow's sternum
Stand-to-Lie	Sow puts prolonged pressure when moving from a standing posture to lying down. Sow may kneel before dropping her flank either to the side into a lateral* lying posture or straight down into ventral*
Roll	Sow puts prolonged pressure on the piglet whilst rolling from a ventral lying posture to a lateral lying posture or sow is already lying laterally but stretches to fully expose her udder and traps a piglet
Stand-to-Sit	Sow puts prolonged pressure by moving from a standing to a sitting posture by lowering rear directly down without kneeling
Clamp	Sow puts prolonged pressure on a piglet by trapping it with her leg when lying in a fully lateral position. Piglets can get clamped between the two back legs or crushed between a leg and a pen fitting.

*Lateral lying description: Lying with the udder exposed and one shoulder completely on the ground

*Ventral lying description: Lying on the udder with neither shoulder touching the ground

Table 2: Percentage of piglets per litter (± SEM) born in each location in SMALL (7.9m^2) or LARGE (9.7m^2) PigSAFE farrowing pens with T20 (20°C) or T30 (30°C) under-floor heating temperatures. Figures given as means (± sem) and medians to demonstrate descriptive data.

Location	**Space (S)**						**Temperature (T)**					
	SMALL (n=40)		**LARGE (n=44)**		**U-stat[1]**	**P-value**	**T20 (n=42)**		**T30 (n=42)**		**U[1]-stat**	**P-value**
	Mean (±sem)	**Median (range)**	**Mean (±sem)**	**Median (range)**			**Mean (±sem)**	**Median (range)**	**Mean (±sem)**	**Median (range)**		
L1	43.44 (±6.24)	35.42 (0-100)	34.35 (± 6.20)	10.48 (0-100)	741	0.201	44.16 (± 6.53)	23.21 (0-100)	32.93 (± 5.82)	21.54 (0-100)	765	0.283
L2	20.17 (± 5.37)	0.00 (0-100)	29.93 (± 5.66)	7.69 (0-100)	738	0.165	15.25 (± 4.74)	0.00 (0-100)	35.79 (± 5.96)	24.04 (0-100)	601	*0.006*
L3	14.56 (± 4.57)	0.00 (0-100)	26.66 (± 5.76)	0.00 (0-100)	716	0.098	21.94 (± 5.54)	0.00 (0-100)	19.80 (± 5.11)	0.00 (0-100)	865	0.867
L4	2.84 (± 1.60)	0.00 (0-50)	4.08 (± 2.21)	0.00 (0-80)	864	0.682	3.08 (± 1.72)	0.00 (0-53.3)	3.92 (± 2.19)	0.00 (0-80)	863	0.867
L5	12.97 (± 4.65)	0.00 (0-100)	2.37 (± 2.00)	0.00 (0-87.5)	735	*0.040*	7.61 (± 3.65)	0.00 (0-100)	7.22 (± 3.46)	0.00 (0-87.5)	879	0.907
L6	0.00 (± 0.00)	0.00 (0-0)	2.61 (± 1.91)	0.00 (0-75)	840	0.543	2.67 (± 1.96)	0.00 (0-75)	0.00 (± 0.00)	0.00 (0-0)	840	0.494
L7	6.02 (± 3.27)	0.00 (0-100)	0.00 (± 0.00)	0.00 (0-0)	748	*<0.001*	5.27 (± 3.05)	0.00 (0-100)	0.35 (± 0.35)	0.00 (0-14.3)	798	0.114

[1] Mann-Whitney U tests carried out on raw percentage data and used to show whether there was a significant effect of space or temperature.

Table 3. Types of crushing incident in the SMALL and LARGE space treatments. Figures given as total and median number of incidents for sows that showed crushing behaviour, during 24h from the birth of the first piglet. Mann-Whitney U tests determine where differences lie.

	Total number		Medians			
	SMALL (n=11)	**LARGE (n=16)**	**SMALL (range)**	**LARGE (range)**	**U-stat**	**P-value**
Clamp	0	13	0 (0-0)	0 (0-9)	71.5	0.383
Stand-to-lie	20	17	2 (0-6)	1 (0-3)	67.0	0.284
Sit-to-lie	8	9	0 (0-2)	0 (0-2)	81.0	0.704
Stand-to-walk	0	17	0 (0-0)	0.5 (0-4)	44.0	*0.012*
Roll (ventral to lateral)	1	11	0 (0-1)	0 (0-7)	73.0	0.406
Lie-to-sit	1	4	0 (0-1)	0 (0-2)	79.0	0.734
Stand-to-sit	4	0	0 (0-2)	0 (0-0)	64.0	*<0.001*