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

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10  
11 **Abstract**

12  
13 Piglet survival relies on interactive influences of the sow, her piglets and their environment. There  
14 are a number of design challenges in a loose-housed farrowing and lactation system to optimise this  
15 dynamic, including achieving farrowing in the desired location (i.e. a protected nest area) and  
16 minimising crushings. The PigSAFE (Piglet and Sow Alternative Farrowing Environment) pen was  
17 developed with these challenges in mind. It has different areas to fulfil different biological and  
18 managerial needs, including a solid-floored nest area with piglet protection features (sloped walls,  
19 heated creep) intended for farrowing. Two hypotheses regarding pen design features to optimise  
20 farrowing location and improve piglet survival were tested: i) greater space would improve maternal  
21 behaviour; and ii) a heated nest-site would be more attractive to the farrowing sow. PigSAFE was  
22 adapted to give a LARGE treatment, 9.7m<sup>2</sup> in total with a nest area of 4.0m<sup>2</sup>, and a SMALL treatment,  
23 same design but 7.9m<sup>2</sup> in total with a nest area of 3.3m<sup>2</sup>. The nest floor was heated to either 30°C  
24 (T30) or 20°C (T20) from 48h before until 24h after farrowing. A 2x2 factorial design saw 88 Large  
25 White x Landrace sows randomly assigned to space and temperature treatments. Generalized linear  
26 mixed models were used to analyse performance data. Farrowing location analysis involved dividing  
27 the pen into seven areas (L1-L7); L1 deemed the safest location for the piglets to be born (in the  
28 nest, furthest from dunging area, closest to creep) and L7 the least protected (in the dunging area).  
29 Of all the piglets born 97% were born in the nest area. The majority of sows started farrowing in L1  
30 (56%), with 39% of remaining piglets being born in this location. There was a significant Space x  
31 Temperature interaction for farrowing location ( $P=0.011$ ) with SMALL\_T20 achieving the most L1  
32 births. Temperature had no significant influence on piglet survival (Total mortality  $P=0.401$ ; Live-  
33 born mortality  $P=0.826$ ). However space influenced mortality, with significantly greater live-born  
34 mortality when sows were afforded a larger farrowing space (LARGE=18.1% vs. SMALL=10.9%

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

40

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

42

### 43 1. Introduction

44

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

60

61 The PigSAFE (Piglet and Sow Alternative Farrowing Environment) project aimed to tackle this  
62 challenge and developed pen design criteria (based on those summarised in a review by Baxter et  
63 al., 2011a) that should provide the correct stimuli required to achieve the desirable outcomes. Since  
64 sows show clear preferences for a feeding area separate to both the dunging and nesting areas  
65 (Andersen and Pedersen, 2011), the pen incorporates different functional areas: a nest-site with a  
66 separate heated corner creep for the piglets, a dunging area and a lockable feeding stall. The nest-  
67 site provides enclosure on three sides, an entrance providing a view into the adjacent pen and a  
68 solid floor so that substrate can be provided for nest-building. These criteria were based on sow

69 preference experiments demonstrating the importance of such features (e.g. Cronin et al., 1998;  
70 Hunt and Petchey, 1987). Under-floor heating was also installed in the nest-site to offer the  
71 possibility of additional thermal support for the newborn piglets and provide a greater temperature  
72 differential from the dunging area which might attract sows into the nest for farrowing (Philips et al.,  
73 2000; Pedersen et al., 2007). The dunging area was separate and fully slatted to satisfy the sow's  
74 preference to dung away from the nest-site (Wiepkema, 1986; Damm and Pedersen, 2000) as well as  
75 fulfilling hygiene criteria for the stockworker.

76

77 The objective of this experiment was to investigate the sows' use of the designated functional areas  
78 in this new pen design, and to address two questions regarding design criteria – namely how much  
79 space does the sow require to achieve good performance and whether thermal enhancement of the  
80 nest area encourages correct farrowing location and improves piglet survival. It was hypothesised  
81 that (i) more space would result in better separation of functional areas and facilitate nest-building  
82 behaviour which, since feed-back from the unconstrained performance of nest-building behaviour  
83 can affect neuro-endocrine regulation of maternal behaviour (Castrén et al., 1993; Damm et al.,  
84 2003; Pedersen et al., 2003; Algers and Uvnäs-Moberg, 2007), would improve subsequent maternal  
85 behaviour and piglet survival (Arey et al., 1991; Jensen, 1993; Damm et al., 2003; Pedersen et al.,  
86 2003; Yun et al. 2013); and (ii) that a warmer nest floor would be more attractive to farrowing sows  
87 and reduce piglet mortality predisposed by perinatal hypothermia (Pedersen et al., 2007).

88

## 89 **2. Materials and methods**

90

### 91 **2.1 Ethical statement**

92

93 This study was reviewed and approved by the SRUC Ethical Review Committee (approval ID: ED AE  
94 5/2009). All animal management procedures were adhered to by trained staff.

95

### 96 **2.2 Animals and Housing**

97

98 Eighty-eight Landrace x Large White (Pig Improvement Company, Kingston, Oxfordshire, UK) sows  
99 and gilts (hereafter sows; average parity 2.42 ( $\pm$ sem 0.15)) were randomly selected to take part in  
100 this experiment. All animals were housed at the research farm of Scotland's Rural College (SRUC) in  
101 Midlothian, Scotland. During gestation sows were housed in groups no larger than six per pen. The  
102 pens were 3.60m x 6.25m, consisting of an enclosed straw-bedded area at the rear (3.60m x 2.50m),

103 a central dunging passage (3.60m x 1.95m), and an access passageway plus six individual feeding  
104 stalls side by side at the front (each 0.5m wide, 1.8m long). Sows were fed a standard pregnancy  
105 diet, once a day (two kg containing 12.74% CP, 13.32 MJ DE.kg<sup>-1</sup>). After farrowing, lactation diet  
106 (17% CP, 13.75 MJ DE.kg<sup>-1</sup>) was offered at a rate of three kg per day followed by 0.5 kg increments  
107 each day until seven kg and then followed by one kg increments each day up to a maximum of 12 kg  
108 until weaning. Throughout, all animals had ad libitum access to water. Approximately five days  
109 before their expected due date, sows were weighed, condition scored and had their back-fat  
110 thickness measured at the P2 position before being moved into farrowing accommodation (PigSAFE  
111 pens). Average pre-farrowing weight, condition score (0-5 scale) and P2 measurements for sows  
112 were 258.1 ±3.53kg, 3.30 ±0.07 score and 20.91 ±0.39mm respectively.

113  
114 PigSAFE (Piglet and Sow Alternative Farrowing Environment) pens had a basic nest area, with solid  
115 and insulated concrete flooring to allow provision of nesting material. For nesting, 2kg of long-  
116 stemmed straw was maintained by daily replenishment (not cumulative) from day -5. This level was  
117 maintained until day +7 and then it was reduced to 1kg of straw daily until weaning. The nest was  
118 equipped with sloping walls against which the sow can slide more slowly to ground level for suckling,  
119 which had a gap between their base and the floor to lower the risk of piglets being trapped and  
120 killed. A heated, corner creep area (0.75m<sup>2</sup>) with easy access from the nest was bedded with a thin  
121 layer of sawdust. The solid nest area was equipped with under-floor heating which could be adjusted  
122 on a pen by pen basis (see section 2.3 Experimental Design for temperature settings). A separate  
123 slatted dunging area (Triband metal 9mm void) was bounded by walls with barred panels to adjacent  
124 pens to discourage farrowing outside the nest and allow visual and oral-nasal contact between  
125 neighbouring sows. A feeding stall for the sow (0.50m wide, bounded by solid sides) was included at  
126 one side of the pen, where the sow could be locked in to allow safe inspection or treatment of the  
127 piglets. This basic prototype pen design was adapted to determine the influence of space and  
128 temperature on farrowing location, maternal behaviour and piglet survival (Figure 1a and b).

129

### 130 **2.3 Experimental design**

131

132 The sows were randomly assigned to treatment groups in a 2x2 factorial design to test the influence  
133 of space and nest floor temperature on farrowing location and maternal behaviour. The sows were  
134 either assigned to the LARGE space treatment (9.7m<sup>2</sup> in total; dunging passage = 2.20m x 1.60m,  
135 nest-site = 1.30m x 2.80m) or the SMALL space treatment (7.9m<sup>2</sup> in total; dunging passage = 2.20m x  
136 1.23m, nest-site = 0.90m x 2.38m). The nest-site floor was heated to either 20°C (T20) or 30°C (T30)

137 from 48h before until 24h after farrowing. Figure 1 illustrates the experimental pens side-by-side.  
138 The overall farrowing room temperature was set at 18°C for the first week during and after  
139 farrowing, before being reduced to approximately 16°C for the remainder of lactation. Creep  
140 temperatures were set at 30°C for farrowing and the first week post-farrowing before being set on a  
141 curve gradually reducing the temperature to approximately 25°C for the remainder of lactation.

142

143 *Figure 1 recommended here*

144

#### 145 **2.4 Data collection**

146

147 Piglet mortality was recorded with post-mortem examination confirming cause of death. Video  
148 cameras (Low-lux B/W waterproof cameras: SK-2020XC/SO, RF Concepts Ltd, Belfast, Ireland)  
149 captured continuous data from all pens from day -5 until at least day +2 post farrowing. Farrowing  
150 kinetics (cumulative farrowing duration and average birth interval) were recorded. Of particular  
151 interest in this study was where in the pen sows chose to farrow and the quality of maternal  
152 behaviour in terms of posture changes during farrowing. These data were collected for 84 of the  
153 sows (camera failure resulted in four sows not being observed). A sub-set of animals (n=52) were  
154 followed for 24h after the birth of the first piglet to record crushing incidents (both injurious and  
155 non-injurious – see Table 1 for full ethogram). One sow and her litter had to be excluded from  
156 analysis of performance and behaviour at 24h post-partum because the piglets contracted  
157 alloimmune thrombocytopenia after ingestion of their mother’s colostrum. As the condition only  
158 manifested itself in the piglets post-farrowing, the sow’s farrowing location data were included for  
159 analysis. For farrowing location analysis, the pen was divided into seven areas (L1-L7). L1 was  
160 designated as the preferred farrowing location based on the fact that if sows farrowed in this  
161 location piglets would be born closest to the creep area and furthest from the dunging passage  
162 which was designated as L7. L7 was designated the least preferred farrowing location as it contained  
163 no piglet protection features or bedding and had no additional heating source for the piglets (Figure  
164 2).

165

166 *Table 1 recommended here*

167

#### 168 **2.5 Statistical analysis**

169

170 The number of sows in each treatment was unbalanced (SMALL\_T20 n = 21; SMALL\_T30 n = 23;  
171 LARGE\_T20 n = 22; LARGE\_T30 n = 22), thus Generalised Linear Mixed Models (GLMM) were fitted  
172 to the data (Genstat 14<sup>th</sup> edition) for analysis of mortality, farrowing location, farrowing kinetics, and  
173 number of posture changes during farrowing. A binomial distribution with a logit link function was  
174 fitted to a GLMM to analyse the influence of space and temperature (fitted as fixed effects) on  
175 mortality (i.e. piglets were either dead (1) or alive (0) for the binomial model) and the sows' location  
176 to farrow the first piglet in the litter. These location data were categorical (i.e. 1-7 possible  
177 locations), therefore the fixed estimate of binomial totals was set at 7. A Poisson distribution, with a  
178 logarithm link function was fitted to GLMMs to analyse the influence of space and temperature on  
179 the location where the remaining piglets were farrowed. In all models parity was fitted as a fixed  
180 effect and sow was fitted as a random factor. When necessary, cross-fostering was performed (only  
181 within the first 48h post-partum) and the subsequent mortality data were adjusted accordingly to  
182 reflect the fostered litter size.

183

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

189

### 190 **3. Results**

191

#### 192 **3.1 Farrowing location**

193

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

197

198 *Figure 2 recommended here*

199

200 Temperature and space treatments had no effect on where sows chose to start farrowing ( $F_{1,80} =$   
201  $0.00, P=0.986$  and  $F_{1,80} = 0.52, P=0.474$  respectively) or where they chose to farrow the remainder of  
202 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  
203 sows that farrowed in the dunging area (3%; four sows farrowed 13%, 20%, 86% and 100% of their

204 litter respectively in L7; two of these sows started farrowing in L7) were from the SMALL\_T20  
205 treatment. Overall there were significant differences in percentage of piglets farrowed in each  
206 location ( $F_{6,556}=11.96$ ,  $P<0.001$ ) with a significant space x temperature interaction for farrowing  
207 location ( $F_{6,556}=2.80$ ,  $P=0.011$ ). Figure 3 summarises the interactive effects illustrating that the  
208 combination of the smaller space and the T20 temperature achieved the most L1 farrowing  
209 positions.

210

211 [Figure 3 recommended here](#)

212

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

219

220 [Table 2 recommended here](#)

221

### 222 3.2 Performance

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

225

226 The 2x2 structured comparison showed that the floor temperature at the time of farrowing had no  
227 significant influence on piglet survival (Total mortality: T20 = 19.01% ( $\pm \text{sem}2.41$ ) vs. T30 = 19.81%  
228 ( $\pm \text{sem}3.05$ )  $F_{1,86}=0.71$ ,  $P=0.401$ ; Live-born mortality: T20 = 13.07% ( $\pm \text{sem}2.30$ ) vs. T30 = 16.01%  
229 ( $\pm \text{sem}2.96$ )  $F_{1,86}=0.05$ ,  $P=0.826$ ). However the amount of space influenced live-born mortality, with  
230 significantly more piglets dying when sows were afforded a larger farrowing space (Live-born  
231 mortality: LARGE = 18.10% ( $\pm \text{sem}2.30$ ) vs. SMALL = 10.90% ( $\pm \text{sem}2.92$ )  $F_{1,86}=5.00$ ,  $P=0.028$ ). This was  
232 reflected in a tendency for greater total mortality when sows were afforded the larger space (Total-  
233 mortality: LARGE = 23.14% ( $\pm \text{sem}2.34$ ) vs. SMALL = 15.68% ( $\pm \text{sem}3.05$ )  $F_{1,86}=2.86$ ,  $P=0.095$ ). There  
234 were no significant interactions between space and temperature for either total mortality  
235 (SMALL\_T20 = 16.05% ( $\pm \text{sem}3.27$ ), SMALL\_T30 = 15.31% ( $\pm \text{sem}5.10$ ), LARGE\_T20 = 21.97%  
236 ( $\pm \text{sem}3.50$ ), LARGE\_T30 = 24.31% ( $\pm \text{sem}3.13$ )  $F_{1,86}=0.74$ ,  $P=0.394$ ) or live-born mortality (SMALL\_T20  
237 = 9.73% ( $\pm \text{sem}2.96$ ), SMALL\_T30 = 12.07% ( $\pm \text{sem}5.03$ ), LARGE\_T20 = 16.42% ( $\pm \text{sem}3.47$ ), LARGE\_T30



238 = 19.96% ( $\pm$ sem3.09)  $F_{1,86}=0.17$ ,  $P=0.685$ ). Crushing was the largest cause of mortality (42%);  
239 however there was a great deal of individual variation with some sows showing a high propensity to  
240 crush whilst others achieved 100% survival (Figure 4).

241

242 *Figure 4 recommended here*

243

### 244 **3.3 Maternal behaviour**

245

#### 246 **3.3.1 Farrowing kinetics and behaviour**

247

248 There were no interactive effects of space and temperature on farrowing kinetics (cumulative  
249 farrowing duration (mins): SMALL\_T20 = 199.9 ( $\pm$ 15.95); SMALL\_T30 = 279.6 ( $\pm$ 25.86); LARGE\_T20 =  
250 302.2 ( $\pm$ 73.27); LARGE\_T30 = 279.0 ( $\pm$ 45.79);  $F_{1,86}=1.00$ ,  $P=0.320$  and average birth interval (mins)  
251 SMALL\_T20 = 19.02 ( $\pm$ 2.03); SMALL\_T30 = 24.19 ( $\pm$ 2.34); LARGE\_T20 = 23.80 ( $\pm$ 5.34); LARGE\_T30 =  
252 25.85 ( $\pm$ 4.16);  $F_{1,86}=0.38$ ,  $P=0.451$ ). However the higher floor temperature resulted in longer average  
253 birth intervals ( $F_{1,86}=4.09$ ,  $P=0.047$ ). There was no influence of treatment on the average number of  
254 posture changes sows performed during farrowing (SMALL\_T20 = 25.87 ( $\pm$ 4.37); SMALL\_T30 = 28.91  
255 ( $\pm$ 4.47); LARGE\_T20 = 25.27 ( $\pm$ 3.28); LARGE\_T30 = 27.66 ( $\pm$ 6.80);  $F_{1,86}=1.06$ ,  $P=0.306$ ).

256

#### 257 **3.3.2 Crushing behaviour**

258

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

269

270 *Table 3 recommended here*

271

## 272 4. Discussion

273

### 274 4.1 Farrowing location

275

276 Sows showed a clear preference to farrow in the nest area regardless of the different space or  
277 temperature treatments. Heating the floor did not alter the attractiveness of the nest area for  
278 farrowing. It is likely that the design of the PigSAFE pen provided sufficient stimuli to encourage the  
279 sow to farrow in the nest area without the additional heat source. These stimuli included provision  
280 of enclosure by solid walls, sufficient substrate with which to satisfy nest-building behaviour and  
281 suitable flooring to maintain the nest. In early work looking at nest-site choice of sows, Hunt and  
282 Petchey (1987) demonstrated clear preferences for farrowing inside, or against a solid wall. Similar  
283 choices were shown by sows under natural and semi-natural conditions (Stolba and Wood-Gush,  
284 1984) where 40% chose total enclosure and 89% chose partial enclosure. The nest opening in the  
285 PigSAFE pen permits sows the ability to see their neighbour's pen and this added motivation to face  
286 the nest entrance is likely to have further influenced the sow's decision to farrow in the L1 location  
287 within the nest, since sows in the wild select nest sites allowing them to maintain vigilance for  
288 approaching threats (Stolba and Wood-Gush, 1984). In the current study the majority of sows  
289 started farrowing in this position which is considered optimal in the PigSAFE pen because the birth  
290 site is furthest away from the cooler and unprotected slatted dunging area and the udder when lying  
291 laterally is immediately adjacent to the creep. Within minutes of being born piglets stand and  
292 perform teat seeking behaviours (Rohde and Gonyou, 1987). If sows are lying in the L1 position in  
293 the PigSAFE pen, piglets will walk in front or through the heated creep to access the udder, which  
294 could promote early use of this warmed and protected area. It is generally thought that piglets  
295 remain in close proximity to the udder within the first 2-3 days post-partum, although there is large  
296 variation between litters studied (Berg et al., 2006; Vasdal et al., 2010). Proximity to the udder brings  
297 warmth, develops teat fidelity for better colostrum and milk intake but also brings greater risk of  
298 crushing by the sow (Weary et al., 1996a). In a loose farrowing environment in particular, it is  
299 advantageous to attract the piglets into a protected area as quickly as possible (outwith the periods  
300 of suckling). Opposite the creep the nest wall is sloped with specific dimensions to protect piglets  
301 from being crushed when sows descend from standing to lying or roll against the pen side. The  
302 sloped wall also prevents piglets from being blocked when teat-seeking, providing a protected  
303 tunnel if they choose to walk around the sow. Sow preferences to use such supportive structures  
304 have been demonstrated in the past (Baxter, 1991; Damm et al., 2006; Marchant et al., 2001) and  
305 providing these structures in this pen design appears to have aided optimal farrowing position.

306

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

316

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

325

#### 326 **4.2 Performance**

327

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

336

337 The other risk with a larger nest space is that piglets have a greater area in which to wander and  
338 become chilled when distant from heat sources. When sows have suitable floor-type and sufficient  
339 materials with which to build a nest, they will often dig a hollow depression, fill it with substrates like

340 grasses, mosses and leaves and surround it with larger branches and twigs (reviewed in Wischner et  
341 al., 2009). The nest is thus an oval shape designed to keep the piglets close and offer thermal  
342 protection. Such nest construction is limited in a farm setting. There was a tendency for a greater  
343 number of farrowings in the L3 position in the larger space. Although this is still in the nest-site,  
344 piglets were born further away from the creep with closer proximity to the dunging area and  
345 therefore a greater risk of hypothermia. Cronin et al. (Cronin and Smith, 1992; Cronin et al., 1994), in  
346 their development of the Werribee Farrowing Pen, also demonstrated that too large a nest site  
347 increases mortality, especially in cooler ambient temperatures, suggesting that piglet thermal  
348 protection can interact with nest size. However, these authors also demonstrated the importance of  
349 providing a nest of sufficient width to allow performance of behaviours that influence piglet survival,  
350 notably nest-building and suckling (Cronin et al., 1998).

351

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

361

#### 362 **4.3 Maternal behaviour**

363

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

371

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

374 Given the importance of maternal behaviour to piglet survival in loose-housed farrowing systems  
375 (Arey, 1997), this variability could be key in whether or not loose-farrowing accommodation  
376 becomes more commercially viable. Since maternal behaviour has been shown to have a genetic  
377 component (Grandinson et al., 2003; Gäde et al., 2008), investigating the consistency and possibility  
378 for change in important maternal behaviours such as carefulness (e.g. pre-lying behaviour, offspring  
379 communication and maternal responsiveness – Weschler and Hegglin, 1997; Valros et al., 2003;  
380 Illmann et al., 2008), aggression (e.g. offspring-directed – Chen et al., 2007; Baxter et al., 2011b, and  
381 stock-person directed– Marchant-Forde, 2002) and temperament (e.g. fearfulness – Thodberg et al.,  
382 2002) in the environment in which the animals will be kept is an area meriting further investigation.

383

#### 384 **4.4 Conclusions**

385

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

395

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397

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401

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- 524

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

527

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

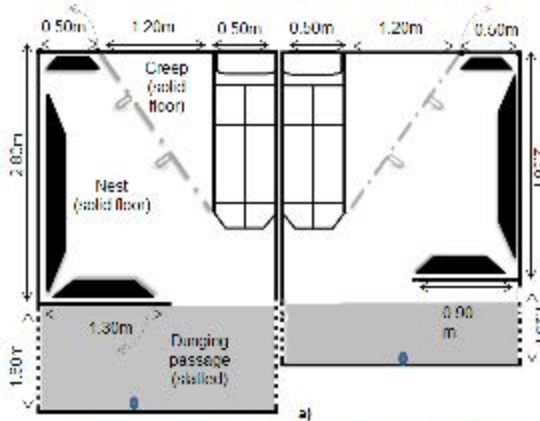
531

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

534

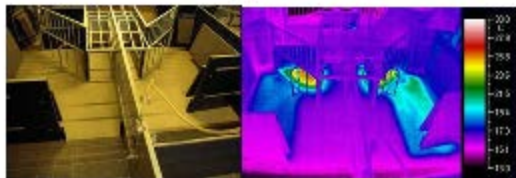
535 **Figure 4:** Differences in a) number of live-born deaths and b) crushes by individual sows in each  
536 treatment

537

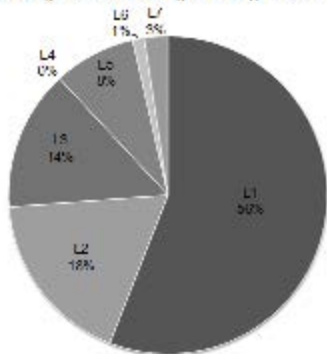


## KEY:

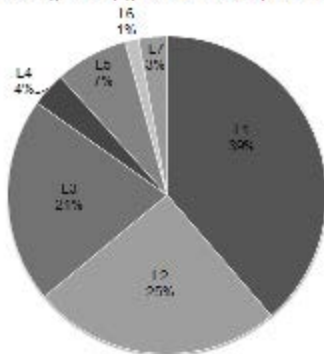
-  Sloped walls suspended 0.20m above the floor and 0.10m at base from pen wall
-  Barred areas allows contact (gap voids = 0.07m) Solid at base.
-  = Creep front with barred spaces (space void 0.10m)
-  = Anti-crush bars
-  Solid flooring.
-  Slatted area. 9-10mm void width
-  = Direction of movement for walls and gates
-  Sow and piglet drinker
-  Voluntary feeding stall (0.45-0.50m x 1.00m)



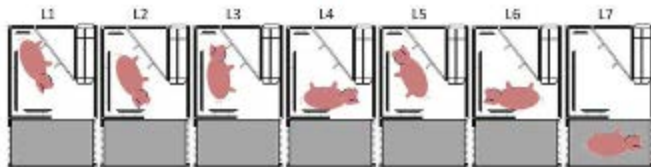
a) Percentage of sows initiating farrowing in each location

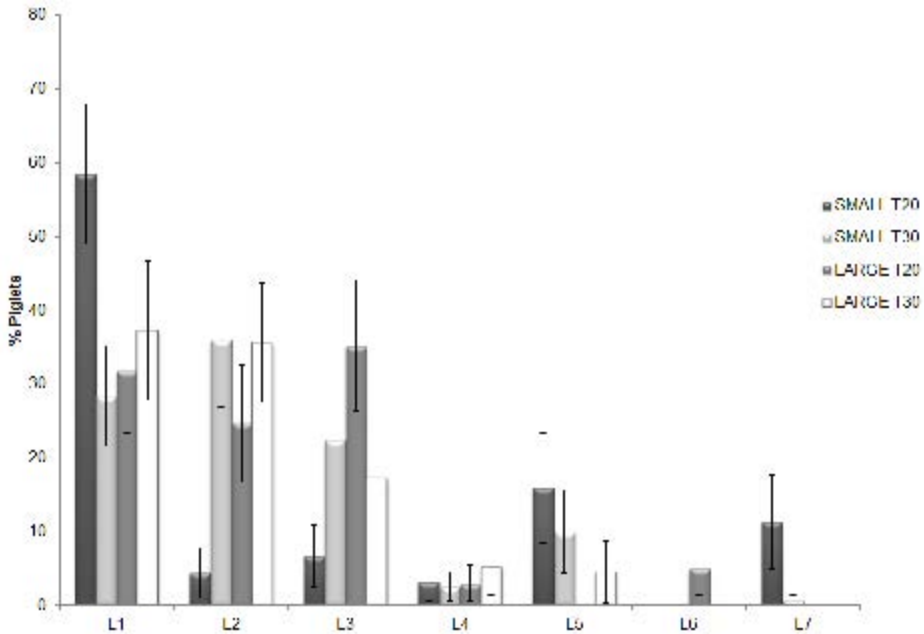


b) Percentage of all piglets farrowed in specific location



Key:







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

<b>Sow crush behaviour</b>	<b>Description</b>
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.

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

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

4 **Table 2:** Percentage of piglets per litter ( $\pm$  SEM) born in each location in SMALL (7.9m<sup>2</sup>) or LARGE (9.7m<sup>2</sup>) PigSAFE farrowing pens with T20 (20°C) or T30  
 5 (30°C) under-floor heating temperatures. Figures given as means ( $\pm$  sem) and medians to demonstrate descriptive data.

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

6

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

