Effects of floor space on the welfare of group housed sows 1C-105

Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

By

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March 2015

Established and supported under the Australian Government's Cooperative Research Centres Program

Executive Summary

There appears to be increasing concern with society's treatment of animals. Confinement housing of livestock, in particular housing of gestating sows, appears to be at the forefront of these concerns, which in turn has led to legislative, consumer, and retailer pressure to increase the use of group housing of gestating sows. However, international industry experience indicates that the opportunity for group housing to improve sow welfare may be limited by high levels of aggression that is commonly observed in newly formed groups of sows after mixing.

Sow aggression, especially if intense and prolonged, has obvious welfare implications particularly for subordinate sows because of injuries and stress and their probable links to pain and fear. Aggression is a basic feature of the formation of a dominance hierarchy in groups of sows, but once established, the hierarchy functions to reduce the need for aggression. However, although this may reduce fighting-induced injuries and any associated pain in subordinate sows, these sows might nevertheless remain fearful. Thus, aggression, injuries and stress should be understood to imply their negative affective consequences, including pain and fear. To ensure sow welfare, group housing design must, at the very least, ensure unimpeded access to necessary resources, opportunity to avoid or escape from potential aggressors, and avoidance of chronic physiological stress.

Floor space is an important determinant of aggression and stress in group-housed sows and therefore this experiment examined the effects of floor space allowance in the range of 1.45 to 2.9 m^2/sow on the aggression and stress of sows housed in groups after insemination. Previous research has shown no evidence of group size effects, for pens having between 10 and 80 sows, or appreciable interactions between space and group size on aggression, stress and reproduction. Thus the effect of space allowance was examined by varying group size: equal-sized pens but with varying groups sizes (10-20 sows) in 4 separate blocks of 3 contiguous pens within each of 9 time replicates (180 sows per replicate) were used to examine 6 space allowances (1.45, 1.61, 1.81, 2.07, 2.42 and 2.9 m^2/sow) where space treatments were randomised to pens.

There was a consistent linear effect of floor space on aggression at feeding on day 2 and plasma cortisol concentrations on day 2, with aggression and cortisol concentrations reducing with increasing space from 1.45 to 2.9 m^2/sow. There was no indication of space effects on aggression or plasma cortisol concentrations on day 26, or on subsequent farrowing rate, litter size (total or alive) or sows removed for non-reproductive reasons.

The current research and the previous research by Hemsworth et al. (2013) show that reducing floor space for sows within the range of 1.4 to 3.0 m^2/sow increases aggression and stress in the immediate period after mixing, as assessed by aggressive behaviour at feeding and plasma cortisol concentrations, and can reduce reproductive performance (Hemsworth et al 2013). These results together with previous results on gilts and sows, particularly those on aggression and stress and reproduction, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing. The current recommended minimum floor space allowance for group-housed gestating sows in the *Australian Model Code of Practice for the Welfare of Animals – Pigs* (Primary Industries Ministerial Council, 2007) is 1.4m^2 per sow and clearly this recommended minimum space allowance in the immediate post-mixing period needs to be reviewed.

Since there is evidence that sows may adapt to reduced floor space, albeit with risks to reproductive performance (Hemsworth et al., 2013), staged-gestation penning to provide increased floor space for recently-inseminated sows for the first week or so after mixing may be a practical solution to reduce aggression and stress. Providing more floor space at the top end of the range 1.4 to 3.0 m^2/sow should allow the dominance hierarchy in the group to be established quickly with minimum aggression and stress, and thus minimum risk to reproduction. Further modification to the pen by the use of visual barriers, feeding stalls, and straw or bedding may also assist in reducing aggression amongst newly mixed sows. There is then the opportunity in the remainder of gestation to reduce floor space to levels in excess of 1.8 m^2/sow. Indeed staged-gestation penning to provide increased space for recently-inseminated sows is one of the common features often recommended in a dedicated mixing pen.

These results and those by Hemsworth et al. (2013) highlight the need to reduce aggression and stress in the immediate post-mixing period. Interpreting the welfare implications, particularly early after mixing, is problematic. The strategy of staged-gestation penning, with more space immediately after insemination and less space later in gestation, may address both animal welfare and economic considerations. Ultimately, questions on acceptable animal use practices are ethical ones in which animal welfare implications are considered as well as other wider societal interests such as human health, economic, environmental and social implications. Science thus should provide the facts, but what society, groups or individuals do with these facts is a philosophical decision.

Table of Contents

1. Introduction

Housing gestating sows in stalls is being phased out in Europe (EU Commission, 2007) and will be voluntarily phased out by the Australian pork industry by 2017 (press release by the Australian Pork Limited, 17 November 2010). Concerns about the viability and logistics of group housing by the Australian pork industry has led to the Cooperative Centre for High Integrity Australian Pork investing a major research effort studying sow group housing. Furthermore, the *Australian Model Code of Practice for the Welfare of Animals – Pigs* (Primary Industries Ministerial Council, 2007) is due for review by 2018. The current recommended minimum floor space allowance for group-housed gestating sows in the *Australian Model Code of Practice for the Welfare of Animals – Pigs* (Primary Industries Ministerial Council, 2007) is 1.4m^2 per sow. This recommended minimum space allowance will come under scrutiny in the proposed review of the code of practice since international (e.g., Weng et al., 1998; Remience et al., 2008) and recent Australian (Hemsworth et al., 2013) research has shown that a space allowance of 1.4m^2 per sow is insufficient on the basis of aggression and stress after mixing. However, this recent research by Hemsworth et al. (2013) also indicates that recently-inseminated sows may adapt to less space within a week or so after mixing.

It is generally agreed that animal welfare relates to experienced sensations (Hemsworth et al., 2015). Scientists have basically utilized three conceptual frameworks to assess animal welfare, namely, biological functioning, affective state and natural living (Fraser, 2008). The rationale underpinning the biological functioning concept is that is that difficult or inadequate adaptation will generate welfare problems for animals (Broom, 1986, 2000). This conceptual framework is based on the fact that animals use a range of behavioral and physiological responses to assist them to cope with challenges. How well an animal is coping with the challenges it faces will be reflected in the normality of its biological functioning and fitness, with severe risks to welfare associated with the most extreme coping attempts (Hemsworth and Coleman 2011). The rationale underpinning the affective state concept is that the welfare of an animal derives from its capacity for affective experiences (Duncan and Fraser 1997). Two approaches utilized in assessing affective experiences include measures of the strength of the preference for a chosen environmental option or the motivation to perform a type of behaviour (Fraser and Nicol 2001). Other approaches include assessing changes in behaviour and physiology, particularly those indicative negative affective experiences, and testing cognitive bias (Boissy et al. 2007). The rationale underpinning the natural living concept, is that good welfare is determined by the ability of the animal to lead a kind of life for which it is adapted (Fraser, 2008). There is a need to define natural behaviours that are desirable or undesirable in terms of animal welfare and to clarify the rationale for their inclusion or exclusion (Barnett and Hemsworth 2009) and more recently there has been a focus on those behaviours that animals are highly motivated to perform as behaviours that are highly desirable. The majority of studies of the welfare of group-housed sows have employed the biological functioning framework to infer compromised sow welfare, on the basis that suboptimal biological functioning accompanies negative affective states such as sow hunger, pain, fear, helplessness, frustration and anger.

High levels of aggression are commonly observed in newly formed groups of sows after mixing (Velarde 2007; Bench *et al.* 2013a). This aggression, especially if intense and prolonged, has obvious welfare implications because of injuries and stress (Mendl *et al.* 1992; Nicholson *et al.* 1993; Verdon *et al.* 2013) and their probable links to affective consequences, such as pain and fear. Aggression is a basic feature of the formation of a dominance hierarchy in groups of sows, but once established, the hierarchy functions to reduce the need for aggression (Lindberg 2001). Arey (1999) found that skin lesion scores in sows fell rapidly 3 days after mixing and remained constant after 1 week, however the establishment of the dominance hierarchy and thus the rate of decline of aggression are likely to be affected by access to resources, such as floor space, feed and water. Nevertheless, there are few rigorous recommendations, particularly recently, in the scientific literature for minimising aggression and stress in sows (Barnett et al., 2001; Spoodler et al., 2009, Petherick and Blackshaw, 1987; Arey and Edwards, 1998), which are needed for the industry to successfully manage welfare and reproduction in group housed sows. Although the problem of pig aggression has received considerable attention, there is a lack of detailed studies on large numbers of sows under commercial conditions.

Floor space is an important determinant of aggression and stress in group-housed sows. Reducing floor space for gilts and sows within the range of 1.0 to 3.0 m^2/animal increases aggression and stress, as assessed by aggressive behaviour and plasma cortisol concentrations, and reduces both immune competence (in some studies), as reflected in cell-mediated responses, and reproductive performance. In gilts, for example, aggression at times was higher at a space allowance of 1.0 than at 3.0 m^2/gilt (Barnett *et al.* 1992; Barnett 1997) and stress was higher at 1.0 than at 1.4, 2.0 or 3.0 m^2/gilt (Hemsworth *et al.* 1986; Barnett *et al.* 1992; Barnett 1997). In sows, aggression was generally higher at 2.0 than at 2.4, 3.6 or 4.8 m^2/sow (Weng *et al.* 1998) and at 2.25 than at 3.0 m^2/sow (Remience *et al.* 2008), and within the range of 1.4 to 3.0 m^2/sow, significant negative relationships were shown between space allowance and aggression, stress and farrowing rate (Hemsworth *et al.* 2013). Effects of space on skin injuries have been observed in some of these studies (Weng et al., 1998; Salak-Johnson *et al.* 2007; Remience *et al.,* 2008) but not in others (Barnett *et al.* 1992; Barnett 1997; Hemsworth *et al.* 2013). These observations on space, particularly those on aggression and stress, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing . Furthermore, the effects of space on aggression and stress in sows are most pronounced soon after mixing (Hemsworth *et al.* 2013), that is both aggression and stress were affected by space at day 2 after mixing but not by days 8 or 9.

The recent Australian research by Hemsworth et al. (2013) is the most substantial research on this topic, involving 3,120 mated sows. These results show effects of space on aggressive behaviour, cortisol concentrations and farrowing rate within the range of floor space from 1.4 to 3 m^2/sow, which as indicated previously is supported by other research. However, the space allowance at which aggressive behaviour and cortisol concentrations are optimal (i.e., unaffected by increasing space) could not be determined by the results of Hemsworth et al. (2013). Although the results were in accord with a linear decline in cortisol and aggression at day 2 after mixing from 1.4 to 3 m^2/sow, the results are also in accord with a decline in cortisol and aggression from 1.4 to 1.8 m^2/sow, and no further decline above 1.8 m^2/sow. The size of this experiment turned out to be insufficient to determine which of these scenarios is more biologically correct. Thus, in terms of aggressive behaviour, cortisol concentrations and injuries post-mixing, it is impossible to provide guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely too small early after mixing.

Clearly more comprehensive research is required to inform welfare policy on space requirements of group-housed gestating sows. The general prevailing European view is that sows require at least 2.25 m^2/sow. Indeed, some authors suggest a minimum space of between 2.4 and 3.6 m^2/sow may be necessary to promote good welfare (Weng et al., 1998).

Examination of the sources of variation in the experiment by Hemsworth et al. (2013) showed that there was a considerable amount of spatial variability across and along the research facility in both aggression and stress, which led to insufficient precision to determine the optimal space allowance. The present experiment was conducted in the same facility used in the previous experiment, but in order for the effects of space allowance to be examined with more precision, the contribution of spatial variability to experimental error was reduced by reducing the spatial area taken up by each pen block. This was achieved by only using pens of 10-20 sows and using an incomplete block design that had 4 separate blocks of 3 contiguous pens within each time replicate. To avoid any confounding with group size, each space allowance treatment would need pens of different sizes. Consequently, in a randomised design, there is the practical problem of having to frequently modify the size of pens in order to achieve randomisation of space treatments to pens. Therefore, space allowance in the present experiment was altered by varying group size from 10-20 sows. While it may be argued that space allowance is confounded with group size in this design, in the previous experiment (Hemsworth et al., 2013) there was no evidence of group size effects, for pens having between 10 and 80 sows, or appreciable interactions between space and group size on aggression, stress and reproduction. This finding provides confidence that the effect of space allowance in pens varying from 10 to 20 sows can be examined without appreciable confounding due to group size. In the previous experiment there was often an appreciable effect of group size on skin injuries and thus the effect of space allowance on skin injuries in pens with different number of sows cannot be examined without an expectation of confounding between group size and space allowance.

This experiment examined the effects of floor space in the range of 1.45 to 2.9 m^2/sow on the aggression, stress and reproduction of sows housed in groups after insemination.

2. Methodology

2.1 Animals, housing and experimental design

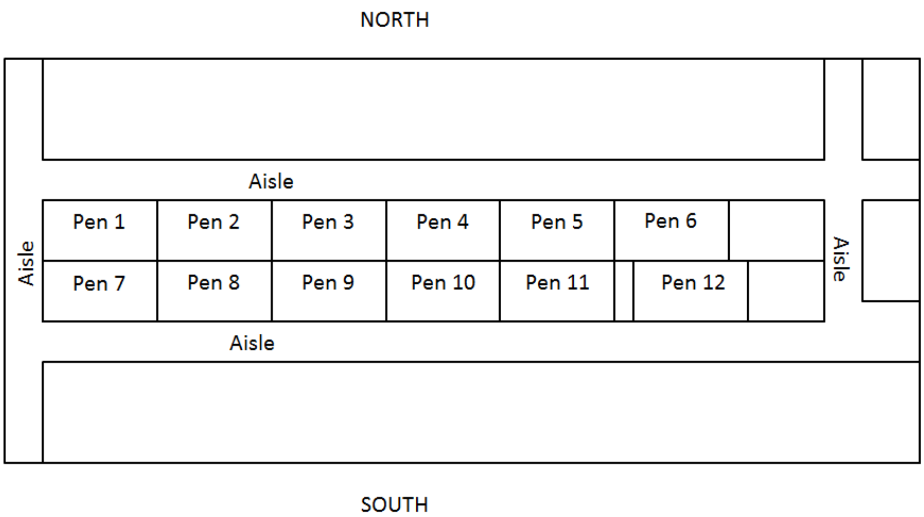
This experiment was conducted between January 2013 and May 2014 in a gestation unit of a large commercial piggery in southern New South Wales, Australia, specifically renovated for this experiment. The 61- by 19-m building was equipped with adjustable blinds and overhead water sprinklers, covering the 50% slatted floor area of the pens, that were activated (3 min on and 15 min off) when the internal temperature exceeded 26°C.

All animal procedures were conducted with prior institutional ethical approval under the requirements of the NSW Prevention of Cruelty to Animals Act 1985, in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organization/Australian Animal Commission *Code of Practice for the Care and Use of Animals for Scientific Purposes*.

A total of 1,620 Landrace × Large White sows were studied in 9 time replicates (i.e., 180 sows per replicate) in an experiment of 74-weeks duration. The sows of mixed parity (2 and older) were of good health at the beginning of the experiment, and were introduced to the post-insemination housing treatments within 4 days of insemination.

The sows were housed in two central blocks of 6 pens (total of 12 pens) within the shed, each with a floor area of 29m^2 each (9.6m long x 3.02m wide- see Fig. 1).

Figure 1 - Pen layout.



The floor space treatments imposed post-insemination were:

1. Floor space allowance of 1.45 m^2/sow (20 sows in a group)
2. Floor space allowance of 1.61 m^2/sow (18 sows in a group)
3. Floor space allowance of 1.81 m^2/sow (16 sows in a group)
4. Floor space allowance of 2.07 m^2/sow (14 sows in a group)
5. Floor space allowance of 2.42 m^2/sow (12 sows in a group)
6. Floor space allowance of 2.9 m^2/sow (10 sows in a group)

The pre-randomised design is presented in Fig. 2. The 12 pens are divided into 4 groups of 3 pens defined by 2 rows and 2 columns, with each column being the width of 3 west to east pens. Thus there are 3 pens in each row by column combination. The design is constructed so that every possible combination of 3 treatments occurs exactly twice within a time by row by column combination, with the exceptions of the 1.45, 1.81 and 2.42 combination and the 1.61, 2.97 and 2.9 combination. These two combinations never occur together in a time by row by column combination.

The space allowance to pens from this design were then randomised by time replicate, by row within a time replicate, by column within a time replicate and by pen within each row by column by time replicate combination. Introduction to the allocated housing treatment was considered day 1 of treatment.

Figure 2 - Layout of pens prior to randomisation process. Within each time replicate, north is to the top of diagram.

Time Replicate 1

	West Column			East Column		
Row 1	1.45	1.61	1.81	2.07	2.42	2.9
Row 2	2.07	2.42	2.9	1.45	1.61	1.81

Time Replicate 2

	West Column			East Column		
Row 1	1.45	1.61	2.07	1.81	2.42	2.9
Row 2	1.81	2.42	2.9	1.45	1.61	2.07

Time Replicate 3

	West Column			East Column		
Row 1	1.45	1.61	2.42	1.81	2.07	2.9
Row 2	1.81	2.07	2.9	1.45	1.61	2.42

Time Replicate 4

	West Column			East Column		
Row 1	1.45	1.61	2.9	1.81	2.07	2.42
Row 2	1.81	2.07	2.42	1.45	1.61	2.9

Time Replicate 5

	West Column			East Column		
Row 1	1.45	1.81	2.07	1.61	2.42	2.9
Row 2	1.61	2.42	2.9	1.45	1.81	2.07

Time Replicate 6

	West Column			East Column		
Row 1	1.45	1.81	2.9	1.61	2.07	2.42
Row 2	1.61	2.07	2.42	1.45	1.81	2.9

Time Replicate 7

	West Column			East Column		
Row 1	1.45	2.07	2.42	1.61	1.81	2.9
Row 2	1.61	1.81	2.9	1.45	2.07	2.42

Time Replicate 8

	West Column			East Column		
Row 1	1.45	2.07	2.9	1.61	1.81	2.42
Row 2	1.61	1.81	2.42	1.45	2.07	2.9

Time Replicate 9

	West Column			East Column		
Row 1	1.45	2.42	2.9	1.61	1.81	2.07
Row 2	1.61	1.81	2.07	1.45	2.42	2.9

Each time replicate was introduced into the experiment over a 2-wk period as follows. Within each time replicate on each of two successive Wednesdays, 90 sows that had been inseminated within 4 days prior were assigned to a (sub-replicate) block. Sows were housed in stalls post-weaning and twice inseminated in a morning/afternoon insemination routine, before being firstly selected for study and then allocated to treatment (6 group sizes).

Parity 2-6 sows were randomly assigned to treatments whilst still in their stalls. Within 4 days of insemination, sows were moved to their allocated treatment pen following receiving their daily feed allocation, where they remained until checked for pregnancy at about 27 days post-insemination. Following pregnancy check, sows were rehoused in pens of up to 10 familiar sows with a floor space at least 1.8 m^2/sow.

The 12 experimental pens had concrete floors with 50% slatted at the rear of the pens. Feed was delivered using automated drop feeders that were evenly suspended across the width of each pen. Feed was delivered 4 times per day (hourly from 0700 h) to provide a total of 2.5 kg/sow/day of a commercial diet (13.1 MJ/kg DM, and 12.8% crude protein). Feeders were adjusted according to treatment (number of sows in the pen) the afternoon prior to mixing and one full drop of feed was on the floor in each pen at the time of mixing. Feeders were also adjusted according to the number of sows remaining in the pen at day 23 of treatment (prior to the day 26 physiology measurements). Water was provided *ad libitum* via 3 nipple drinkers per pen attached to the back wall of each pen, and over the slatted flooring.

2.2 Measurements

Aggression

In order to observe aggressive behaviour at feeding, 3.6 mm infra-red CCTV cameras were installed overhead, near one feeder, to record aggressive behaviour at the time that feed was distributed on the solid floor below the drop feeder. The focal range of each camera allowed a floor area of 14 m^2 to be viewed. From the digital video recordings, continuous observations were conducted to measure the number of bouts of aggressive behaviour in the 30 min following each of the four feed drops on each of days 2 and the first feed drop on Day 26. Aggressive behaviour on day 26 was only measured following the first feed drop because of the substantial time required to conduct these measurements.

A bout criterion interval of 5 s was chosen to separate one bout of aggressive behaviour from another bout of the same behaviour by an individual sow (Martin and Bateson, 2007). Aggressive behaviours recorded were slashes, butts, pushes, and bites, and these were distinguished from other tactile interactions with sows on the basis that the former were associated with avoidance or retaliation by one sow as a consequence of the interaction. Only aggressive interactions in which the head of the sow (defined as extending from the snout to the ears) displaying the aggressive behaviour was clearly visible were recorded. The identity of each sow was not recorded because aggression at the level of the group was the main focus.

The average number of sows in the field of view was recorded at regular intervals so that the number of bouts of aggression could be expressed on the basis of the average number of sows in the field of view during the observations. Point or instantaneous scans at 30-s intervals during each 5-min block of footage were used to count the number of sows in each scan, providing an estimate of the average number of sows in the field of view during each 5-min block of the observation period. Thus, the frequency of bouts of aggression after each feed drop was calculated on a “per sow in field of view” basis. The frequency of aggression per sow during the 4 30-min periods following the feed drops on days 2 and 26 was collated and analyzed for each pen. Since aggressive behaviour on day 26 was only measured following the first feed drop, aggressive behaviour following the first feed drop and following feed drops 2-4 on day 2 were also collated.

Stress

Blood samples were collected via jugular venipuncture (10-mL lithium-heparinized tubes; BD Vacutainer BD, Belliver Industrial Estate, Plymouth, UK) of sows restrained with a snout snare. Sampling by three technicians commenced at 1300 h and 10 sows from each pen (all sows in each pair of pens with 10 sows, and 10 sows pens containing 12 or more sows) on days 2 and 26. Sows sampled were selected once a technician was ready on the basis of the first sow alternatively sighted in the central and peripheral areas of pens. Blood samples were collected within 2 min of snaring to avoid an acute stress response to handling influencing the basal plasma cortisol concentrations (Broom and Johnson, 1993) and all batches of 10 sows took less than 10 min to collect. Karlen et al. (2007) reported that repeated sampling of different sows within three groups of 85 over 30 min did not affect salivary cortisol concentrations. Two 10-mL blood samples were collected from each sow for subsequent analyses of plasma cortisol.

The blood samples for cortisol were centrifuged for 10 min at 1,912 × *g* at 4°C, with the plasma drawn off into individual micro tubes and frozen. Samples from each pen were pooled using 200-μL aliquots from each individual sample and assayed for total and free cortisol concentrations. Plasma cortisol was measured with an extracted RIA (Bocking et al., 1986), using hydrocortisone (H-4001; Sigma Chemical Co., St Louis, MO) as the standard. The assay utilized [3H]-cortisol (Amersham Pharmacia Biotech, UK, Buckinghamshire HP, England) as tracer and a dichloromethane extraction procedure with a mean (±SEM) recovery of 93.2 ± 2.8%. The sensitivity for the 6 assays ranged from 0.15 to 0.47 ng/mL, with a mean of 0.33ng/mL and the intra- and interassay CV were 7.81 and the 12.06%, respectively.

Reproductive performance

Sows were routinely checked for return of oestrus throughout the study. All returns were removed from treatment immediately upon detection. The remaining sows were checked for pregnancy using ultrasound detection at about 27 days post-mixing. Once confirmed pregnant, sows in their treatment groups were moved to a different housing facility and housed with a minimum of $1.8m^2$ per sow. All the sows farrowed in a common farrowing environment and data collected included farrowing rate and litter size (number of piglets born alive, stillborn, and mummified). Stillborn piglets were judged on the basis that they were fully formed at farrowing, covered in fetal membrane, had fully-formed eponychia on their hooves and were located behind the sow. Data on sows confirmed pregnant but failed to farrow, and abortions were also collected, as well as sows culled for injury.

2.3. Statistical analyses

The unit of analysis was always a pen of animals. Each measurement was analysed using restricted maximum likelihood (REML) models with random effects for cohort, row within cohort, column within cohort and row-column combinations within cohort. These random effects reflect the randomisation of space allowances, in the pre-randomised design (Fig. 2), to the design actually used. As the design is orthogonal to cohort, row within cohort and column within cohort, but not row-column combinations within cohort, this analysis can be described as an analysis with recovery of information from row-column combinations. Prior to analyses, average aggression on day 2, drop 1 aggression on day 2 and cortisol on day 2 were logarithmically transformed, average of drops 2 to 4 aggression on day 2 was log(y + 1) transformed, cortisol on day 26 was transformed using the negative reciprocal (-1/y) transformation, drop 1 aggression at day 26, number of still born and number of mummified piglets were square root transformed and farrowing rate was transformed using a log(1.1 – y) transformation, so that the residual variation was homogeneous between replicates and space allowances. The analyses for number of piglets born alive, number of still born piglets, number of mummified piglets and total number of piglets born were weighted by the number of sows farrowing in each plot, because the residual variance appeared inversely proportional to the number of sows farrowing in a plot. To mimic the standard approach used in multi-strata analyses of variance, when a residual variance component was estimated to be negative this was allowed to stand. Only two outliers were deleted from analyses, a low value for cortisol at day 2 and a low value for cortisol at day 26.

Tests for a linear response to space allowance, on the transformed scale, were calculated by comparing a model with a fixed linear response to space allowance to a model with no fixed effects, using a Wald F test (has 1 numerator degrees of freedom). Tests for any additional response to space allowance were calculated by comparing a model with a fixed 6 level factor for space allowance to a model with a fixed linear response to space allowance, using a Wald F test (has 4 numerator degrees of freedom).

Response curves to space allowance, on the transformed scale, were estimated by fitting a model with a fixed linear response to space allowance (space per sow). Predicted values, for each of the 6 space allowances, were fitted with a fixed 6 level factor for space allowance. Response curves and predicted values were calculated on the transformed scale, back-transformed to the original scale and then presented graphically. All statistical analyses were carried out using the GenStat 17 statistical package. (Payne 2014).

3. Outcomes

There was a consistent linear effect of floor space on average aggression after the four feed drops on day 2 (P=0.001, Table 1 and Fig. 3). There were similar relationships between floor space and average aggression after feed drops 2-4 (P=0.001, Table 1 and Fig. 4) and aggression after the first feed drop on day 2 (P=0.001, Table 1 and Fig. 5). In contrast, there was no relationship between floor space and aggression after the first feed drop on day 26 (P=0.14, Table 1 and Fig. 6).

There was also a consistent linear effect of floor space on plasma cortisol concentrations on day 2 (P=0.001, Table 1 and Fig. 7). However, as seen with aggression, there was no relationship found between floor space and plasma cortisol concentrations on day 26 (P=0.79,Table 1 and Fig. 8).

As shown in Table 1 and Fig. 9 to 12, there was no indication of a space effect on farrowing rate (P=0.29), litter size (born alive, P=0.96), stillborn (P=0.73), Mummies (P=0.090) and litter size (total born, P=0.78). There was no indication of a space effect on sows removed for injury (Table 2 and Fig. 13)

Table 1 - Tests for effects of space on output measurements (Predicted means presented in Appendix).

Measurement	Transformation	Weighting	P values	
			Linear response to space per sow	Any additional space effect
Aggression				
Day 2 Average of 4 drops	Logarithm	-	**0.0000089**	0.47
Day 2 Drop 1	Logarithm	-	**0.000070**	0.12
Day 2 Average of drops 2 to 4	Log(y+1)	-	**0.00072**	0.47
Day 26 Drop 1	Square root	-	0.14	0.60
Cortisol				
Day 2	Logarithm	-	**0.00030**	0.20
Day 26	Negative reciprocal (-1/y)	-	0.79	0.75
Reproduction				
Farrowing rate	-log(1.1 – y)	-	0.29	**0.028**
Born alive	-	Number of sows farrowing	0.96	0.72
Still born	Square root	Number of sows farrowing	0.73	0.15
Mummies	Square root	Number of sows farrowing	0.90	0.21
Total Born	-	Number of sows farrowing	0.78	0.77

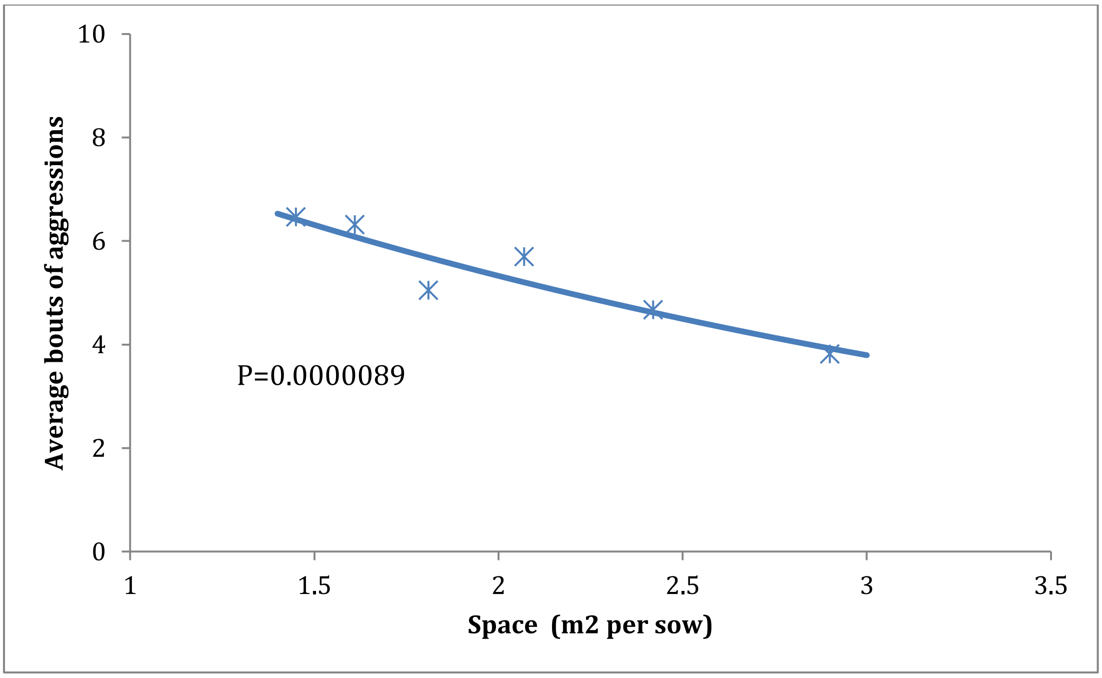


Figure 3 - Predicted values of aggression (frequency per sow) at day 2 as affected by floor space allowance. (Average across all four feed drops)

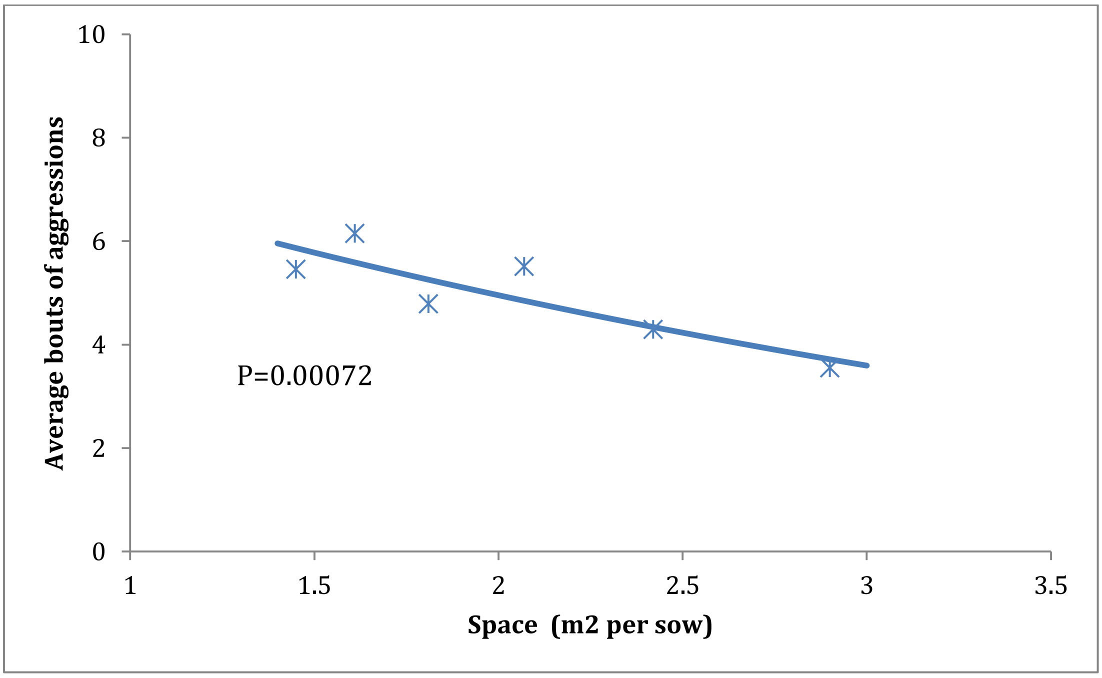


Figure 4 - Predicted values of aggression (frequency per sow) at day 2 as affected by floor space allowance. (Average of feed drops 2 to 4)

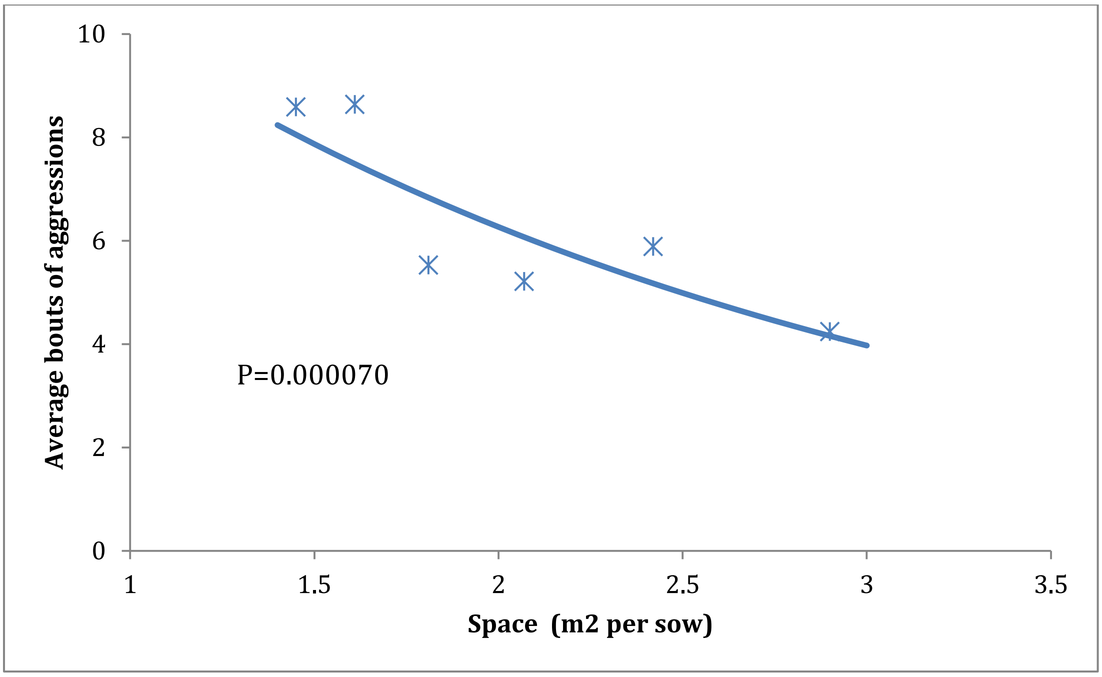


Figure 5 - Predicted values of aggression (frequency per sow) at day 2 as affected by floor space allowance. (1st feed drop only)

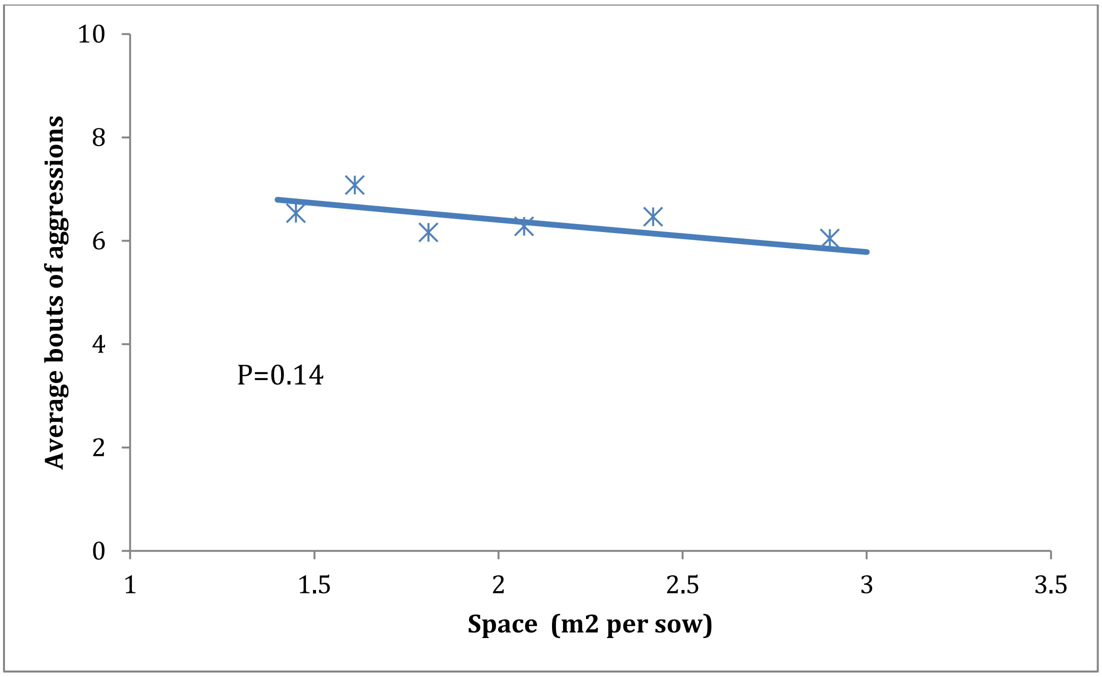


Figure 6 - Predicted values of aggression (frequency per sow) at day 26 as affected by floor space allowance. (1st feed drop only)

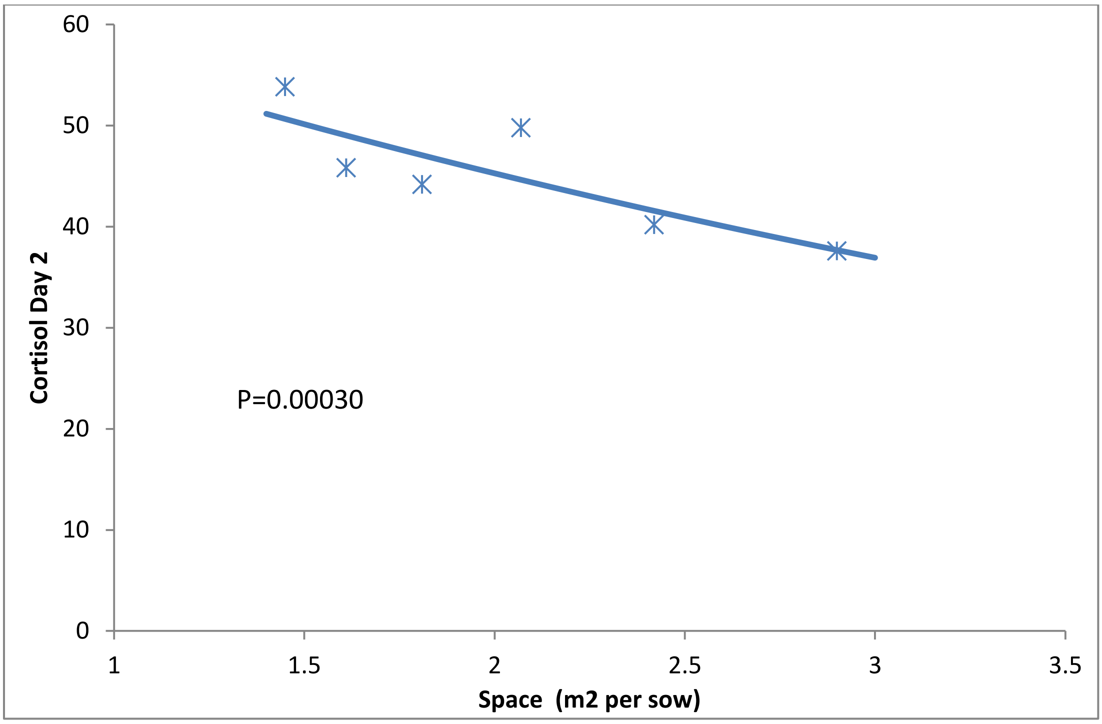


Figure 7 - Predicted values of cortisol (ng/ml) at day 2 as affected by floor space allowance.

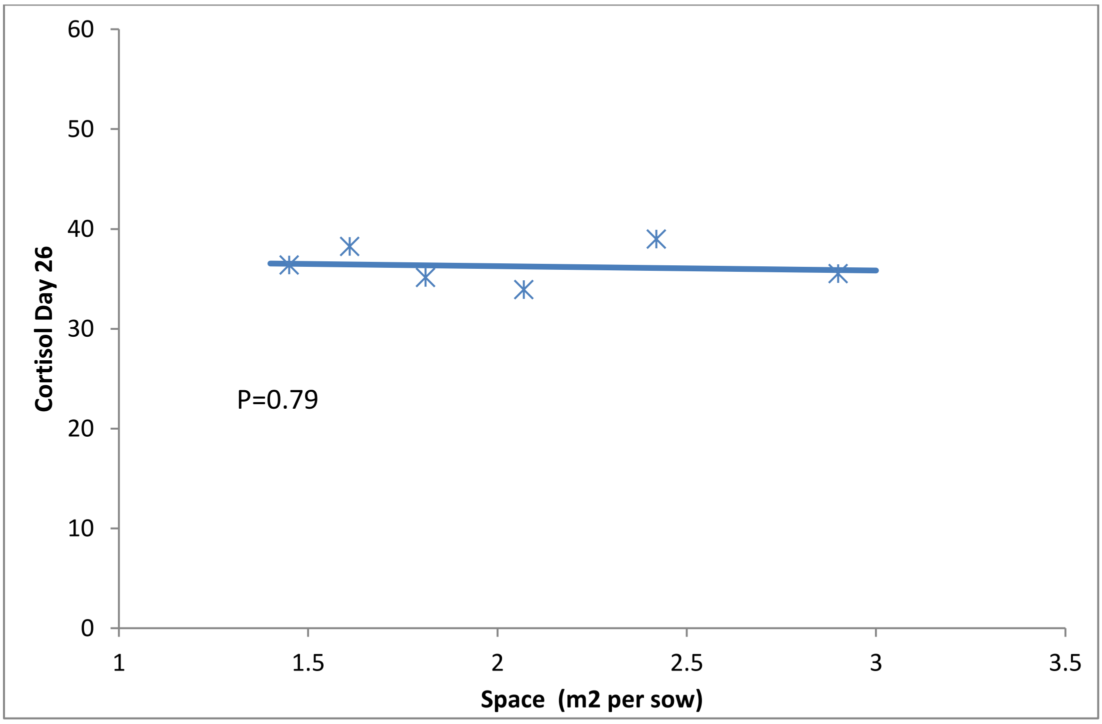


Figure 8 - Predicted values of cortisol (ng/ml) at day 26 as affected by floor space allowance.

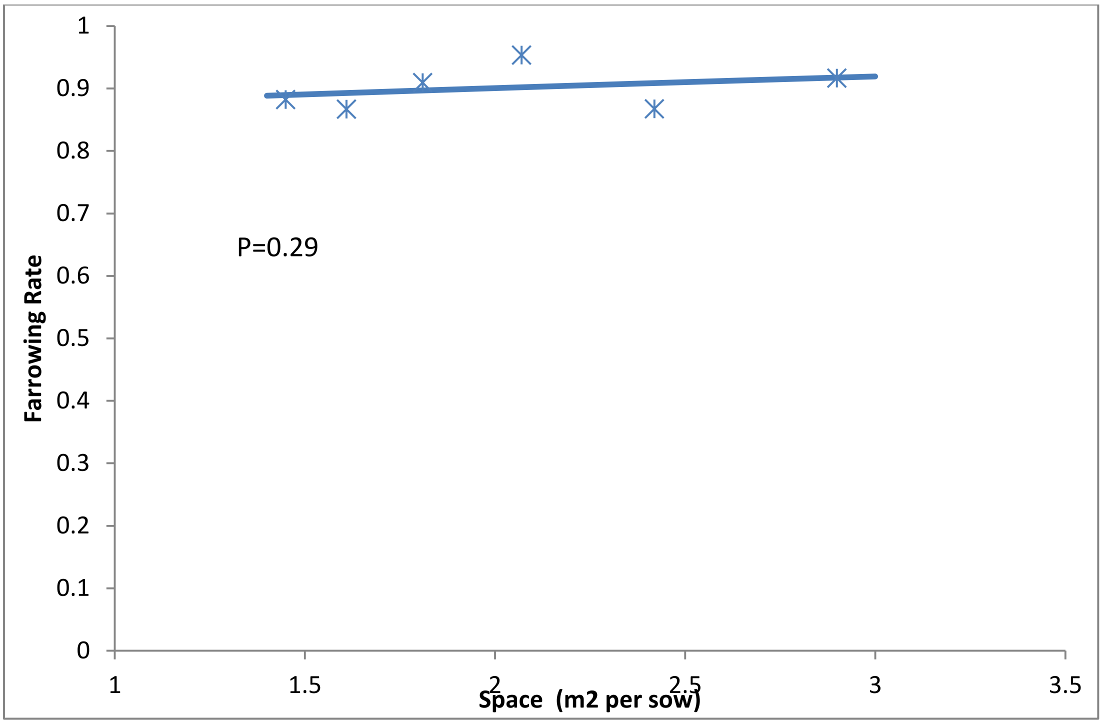


Figure 9 - Predicted values of farrowing rate as affected by floor space allowance.

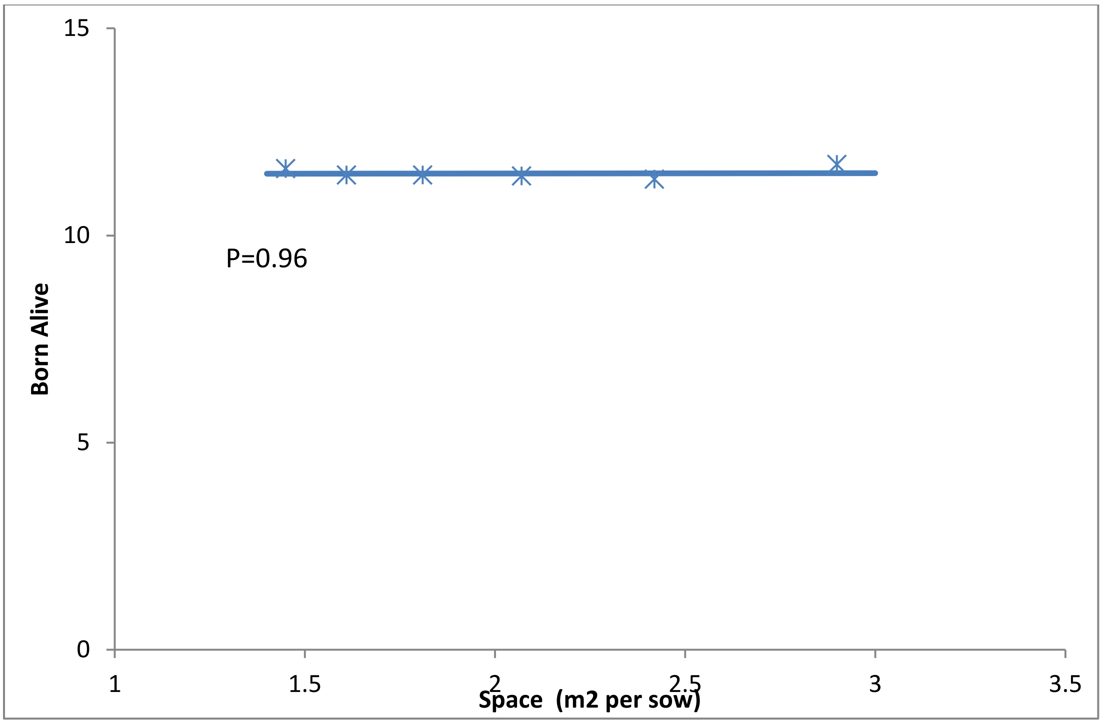


Figure 10 - Predicted values of litter size (born alive) as affected by floor space allowance.

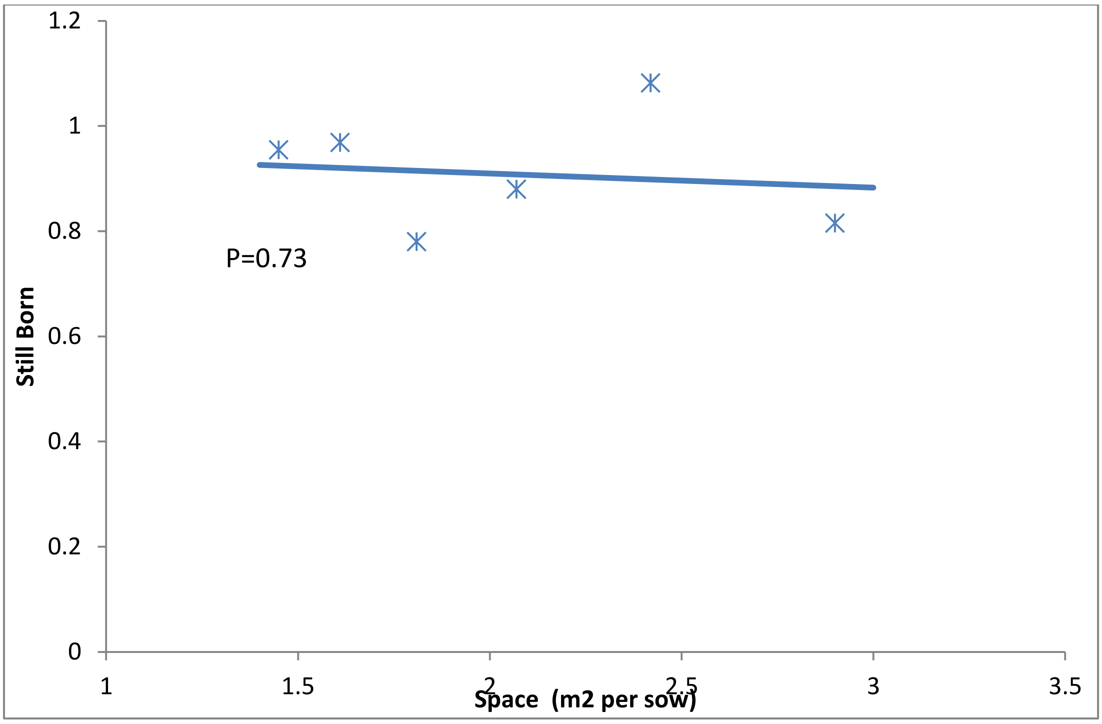


Figure 11 - Predicted values of stillborn (per litter) as affected by floor space allowance.

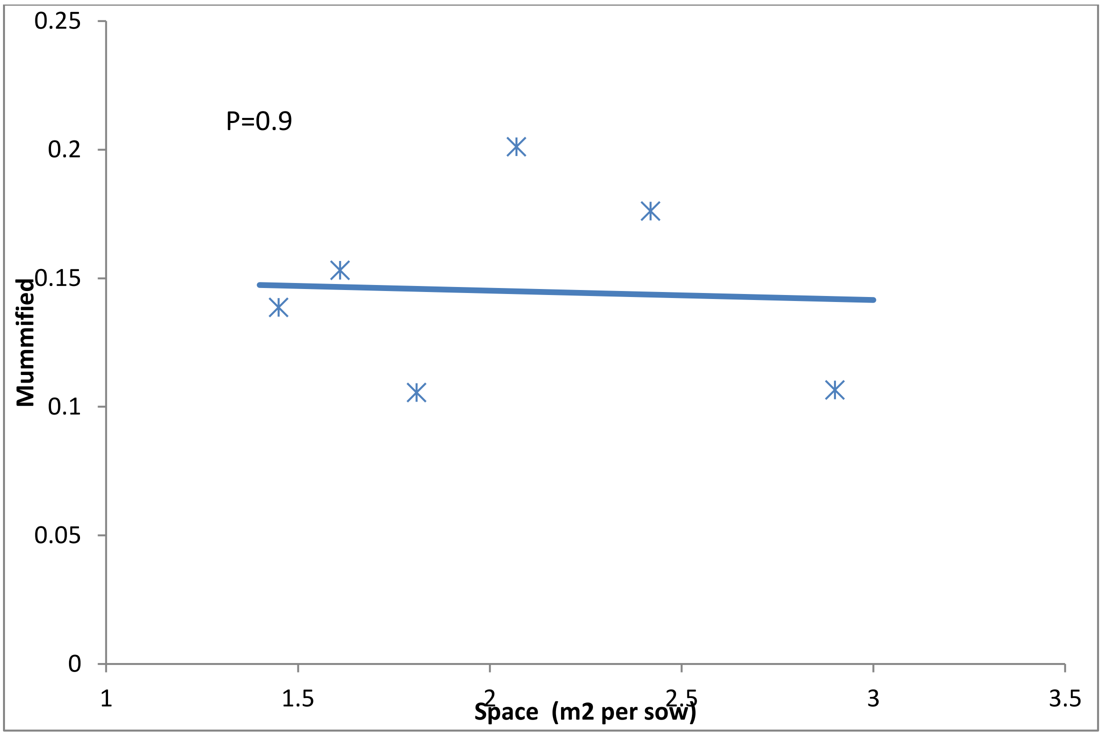


Figure 12 - Predicted values of mummified piglets (per litter) as affected by floor space allowance.

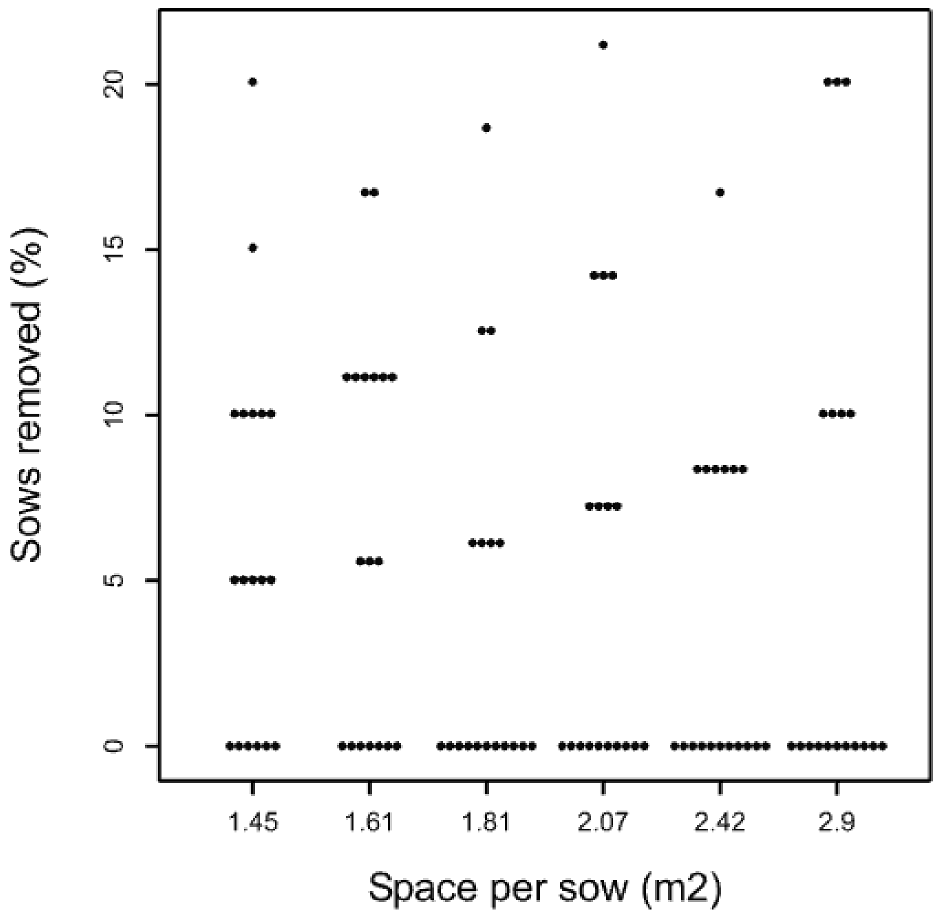


Figure 13 - Sows removed for injuries as a function of floor space allowance (each dot represents a group of sows).

Table 2 - Percentage of sows removed for non-reproductive reasons.

	Space per sow (m^2)					
Space allowance	1.45	1.61	1.81	2.07	2.42	2.90
Sows removed (%)	6.1	6.5	3.8	5.2	3.7	5.6

4. Discussion

Scientists commonly assess animal welfare based on three conceptual frameworks, namely, biological functioning, affective state and natural living (Fraser, 2008: Hemsworth et al., 2015). Sow aggression, especially if intense and prolonged, has obvious welfare implications particularly for subordinate sows because of injuries and stress caused (Mendl *et al.* 1992; Nicholson *et al.* 1993; Verdon *et al.* 2013) and their probable links to pain and fear (Hemsworth et al., 2015). Aggression is a basic feature of the formation of a dominance hierarchy in groups of sows, but once established, the hierarchy functions to reduce the need for aggression (Lindberg 2001). However, although this may reduce fighting-induced injuries and any associated pain in subordinate sows, these sows might nevertheless remain fearful (Verdon *et al.* 2013). Thus, aggression, injuries and stress should be understood to imply their negative affective consequences, including pain and fear (Hemsworth et al., 2015).

The current research and the previous research by Hemsworth et al. (2013) are the most substantial on this topic. The results show that reducing floor space for sows within the range of 1.4 to 3.0 m^2/animal increases aggression and stress, as assessed by behaviour and concentrations of cortisol in plasma, and can reduce reproductive performance (Hemsworth et al., 2013).

Earlier studies have shown similar effects in gilts and sows. In gilts, for example, aggression was generally higher both early and later after mixing at a space allowance of 1.0 than at 3.0 m^2/gilt (Barnett *et al.* 1992; Barnett 1997) and stress was higher both early and later after mixing at 1.0 than at 1.4, 2.0 or 3.0 m^2/gilt (Hemsworth *et al.* 1986; Barnett *et al.* 1992; Barnett 1997). In sows, aggression was generally higher early after mixing at 2.0 than at 2.4, 3.6 or 4.8 m^2/sow (Weng *et al.* 1998) and at 2.25 than at 3.0 m^2/sow (Remience *et al.* 2008). In our previous research (Hemsworth et al., 2013), we have shown that increasing floor space for sows within the range of 1.4 to 3.0 m^2/animal reduces aggression and stress early after mixing and increases farrowing rates. Effects of floor space on skin injuries have been observed in some of these studies (Weng et al., 1998; Salak-Johnson *et al.* 2007; Remience *et al.*, 2008) but not in others (Barnett *et al.* 1992; Barnett 1997; Hemsworth *et al.* 2013). These observations on space, particularly those on aggression and stress early after mixing, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing and that significant improvements in these respects are likely to be achieved with space allowances for gilts and sows of 2.0 m^2/animal or more.

The effects of space on aggression and stress in the experiment by Hemsworth et al. (2013) and in the present experiment were most pronounced early after grouping, suggesting that sows in static groups may adapt over time to reduced space. Indeed adaptation may occur as the dominance hierarchy forms since it functions to reduce the need for aggression (Lindberg 2001). As Hemsworth et al. (2013) noted, there is evidence in rodents of a dampening of the hypothalamo-pituitary-adrenal axis' response to stressors as gestation proceeds and during lactation (Lightman et al., 2001). Moreover, increasing density (increasing animals/unit of space) increased plasma corticosterone concentrations in male mice at d 1 and 7, but not at d 14, after grouping (Peng et al., 1989). Although the development of the social hierarchy over time may assist in reducing aggression and stress with overcrowding, habituation to spatial restriction may also be implicated. Apart from a few studies similar to Peng et al. (1989), there is little evidence in the literature of habituation to spatial restriction in groups. Clearly, there is a need to examine the effects of reducing space during gestation because this effect may offer the opportunity for staged-gestation penning to provide increased space immediately after insemination. Nevertheless, these results highlight the importance of sufficient space to reduce aggression and stress at mixing, and that the sow's requirement for space appears to be less once the group is well established.

Due to considerable spatial variability across and along the research facility in both aggression and stress in the experiment by Hemsworth et al. (2013), there was insufficient precision to determine the optimal space allowance (that is, to determine whether there was a linear decline in both cortisol and aggression at day 2 after mixing from 1.4 to 3 m^2/sow or whether there was a decline in both cortisol and aggression from 1.4 to 1.8 m^2/sow, and no further decline above 1.8 m2/sow). In the present experiment in which the contribution of spatial variability to the experimental error was reduced by reducing the spatial area taken up by each pen block, the relationship between space and both aggression and cortisol on day 2 after mixing was linear, suggesting that both aggression and stress are likely to continue to decline as space is increased beyond 2.9 m^2/sow. It is perhaps not surprising that aggression and consequently stress on day 2 are likely to decline although only marginally as space is increased beyond 2.9 m^2/sow. For example, Edwards et al. (1986) observed that in a situation of unrestricted space in a straw yard, sows were pursued following aggressive interactions over distances that varied from 0 to 20 m. Indeed, irrespective of space, unfamiliar sows will attempt to establish the dominance hierarchy in the group and thus aggression and stress are likely to occur soon after mixing. Thus identifying the space allowance at which aggressive behaviour and cortisol concentrations are optimal (i.e., unaffected by increasing space) is an unrealistic objective. Since there is evidence sows may adapt to reduced space, albeit with risks to reproductive performance as shown by Hemsworth et al. (2013), the optimal strategy from both animal welfare and economic perspectives may be staged-gestation penning to provide increased space immediately after insemination. This increased space early after mixing should allow the dominance hierarchy in the group to be established quickly with minimum aggression and stress, and thus mimumum risk to reproduction, and then reduce space to levels in excess of 1.8 m^2/animal for the remainder of gestation. But obviously as discussed earlier, there is a need to examine the effects of reducing space in the remainder of gestation.

In contrast to the present experiment, Hemsworth *et al.* (2013) found a significant negative relationship between space allowance and farrowing rate. There is no obvious explanation for these conflicting results. Although there was no replicate effect on aggression and stress in this previous study, the fertility of sows in summer was more susceptible to reduced space than in other replicates (Hemsworth et al., 2011). Furthermore, while it is generally accepted that stress impairs reproduction, Turner et al. (2005) concluded that a proportion of female pigs appear to be resistant to the effects of prolonged stress or sustained increased cortisol. All sows in both experiments had prior experience of group housing during gestation, but older parity sows in the present experiment most likely had greater experience of group housing than those older sows in the previous experiment. Furthermore, management of sows in groups is likely to improve over time as stockpeople become more familiar and experienced with group housing. Thus differences in seasonal effects, experience of both pigs and stockpeople, and/or variation in the susceptibility of females to stress may be implicated in these conflicting findings.

Thus the results on gilts and sows, particularly those on aggression, stress and reproduction, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing and that significant improvements in these respects are likely to be achieved with space allowances for gilts and sows in excess of 1.8 m^2/animal. The results of Hemsworth et al. (2013) and those of the current experiment indicate a consistent linear effect of space on aggression at feeding and plasma cortisol concentrations early after mixing, but not at 1 and 4 weeks after mixing, respectively. These results highlight the need to reduce aggression and stress in the immediate post-mixing period. Although these effects of space early after grouping may have sow productivity implications, interpreting the welfare implications are problematic.

Since there is evidence that sows may adapt to reduced floor space, albeit with risks to reproductive performance (Hemsworth et al., 2013), staged-gestation penning to provide increased floor space for recently-inseminated sows immediately after mixing may be a practical solution to reduce aggression and stress. Providing more floor space at the top end of the range 1.4 to 3.0 m^2/sow should allow the dominance hierarchy in the group to be established quickly with minimum aggression and stress, and thus minimum risk to reproduction, with the opportunity to reduce for floor space for the remainder of gestation to levels in excess of 1.8 m^2/sow for the remainder of gestation. Indeed staged-gestation penning to provide increased space for recently-inseminated sows is one of the common features often recommended in a dedicated mixing pen (Edwards et al., 1993; Arey and Edwards, 1998). Increased floor space along with other features, such as visual barriers, feeding stalls, straw or bedding, and *ad libitum* feed, have been been advocated as ways of reducing aggression, stress and injuries early after mixing (Edwards et al., 1993; Arey and Edwards, 1998; Barnett et al., 2001). However, there has been little research on this topic, particularly the long-term effects when sows are subsequently placed in gestation group systems at lower space allowances.

The strategy of staged-gestation penning, with more space immediately after insemination and less space later in gestation, may address both animal welfare and economic considerations. Questions on acceptable animal use practices are ethical ones in which animal welfare implications are considered as well as other wider societal interests such as human health, economic, environmental and social implications (Fisher and Mellor 2008; Mellor and Bayvel 2008). Indeed there will continue to be trade-offs between the attendant conditions, such as profitable animal production as well as human health and social implications, and compromises, such as moral and environmental costs with many farm animal uses and indeed other animal uses outside agriculture.

Acknowledgements

The authors thank the Rivalea R&D team, and the staff from Rivalea Module 3 for their help with conducting this project.

5. Application of Research

The interpretations from these findings are:

- The results of previous research by Hemsworth et al. (2013) show that reducing floor space for recently-inseminated sows in the first week or so after mixing within the range of 1.4 to 3.0 m^2/sow increases aggression and stress, as assessed by aggressive behaviour and plasma cortisol concentrations, and reduces reproductive performance, as assessed by farrowing rate. Earlier studies have shown similar effects in gilts and sows.
- The results of the current research show that reducing floor space for sows within the range of 1.4 to 3.0 m^2/sow also increases aggression and stress early after mixing, but had no effect on reproduction.
- The results of present experiment show that the relationship between space and both aggression and cortisol on day 2 after mixing was linear, suggesting that both aggression and stress on day 2 are likely to continue to decline although only marginally as space is increased beyond 2.9 m^2/sow.
- However, the effects of space on aggression and stress in the experiment by Hemsworth et al. (2013) and in the present experiment were most pronounced early after grouping, suggesting that sows in static groups may adapt over time to reduced space.
- These results highlight the need to reduce aggression and stress in the immediate post-mixing period. Furthermore, the strategy of staged-gestation penning, with more space immediately after insemination and less space later in gestation may address both animal welfare and economic considerations.

6. Conclusion

The current research and the previous research by Hemsworth et al. (2013) show that reducing floor space for sows within the range of 1.4 to 3.0 m^2/animal increases aggression and stress, as assessed by behaviour and concentrations of cortisol in plasma, and may reduce reproductive performance. These results together with previous results on gilts and sows, particularly those on aggression, stress and reproduction, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing.

There is evidence that sows may adapt to reduced space, albeit with risks to reproductive performance (Hemsworth et al., 2013). Therefore, the optimal strategy from both animal welfare and economic perspectives may be staged-gestation penning to provide increased space for recently-inseminated sows immediately after mixing, for example at the top end of the range 1.4 to 3.0 m^2/sow, and then reduce space possibly to levels in excess of 1.8 m^2/sow for the remainder of gestation.

7. Limitations/Risks

To ensure sow welfare, group housing design must, at the very least, ensure unimpeded access to necessary resources, opportunity to avoid or escape from potential aggressors, and avoidance of chronic physiological stress. Another consideration in relation to the adequacy of space is the expression of unmodified time budgets by the animals. Measurements on the time budgets of behaviour would provide valuable data on behavioural restriction with increasing space within the range of 1.4 to 3.0 m^2/animal.

An obvious question is the interaction of space with other factors on sow aggression and stress. While it may be argued that space allowance may be confounded with group size, in the previous experiment (Hemsworth et al., 2013) there was no evidence of group size effects, for pens having between 10 and 80 sows, or appreciable interactions between space and group size on aggression, stress and reproduction.

In addition to increased floor space, modifying pen design by providing escape areas allows subordinates to avoid dominant sows. The incorporation of barriers in pens has been shown to reduce aggression in pigs (see Gonyou 2001; Marchant-Forde and Marchant-Forde 2005). Furthermore, with competitive feeding, the incorporation of feeding stalls in pens has been shown to reduce aggression and stress in gilts. While floor feeding is competitive, accessing feeding stalls or electronic sow feeder stalls also leads to competition between group-housed sows. For instance, in non-gated stalls, aggression often occurs during feeding periods; and in electronic sow feeding systems, queuing and vulva biting occur in accessing feeding stalls (Bench et al., 2013).

There is very little research on possible space allowance and feeding system interactions on sow aggression, injuries and stress.There is only one reported experiment in the literature that examined the effects of both feeding system and floor space (excluding floor area occupied by the feeding system). In a factorial experiment, feeding system (no stall and fed on floor, trough and fed in trough, trough with shoulder stall and fed in trough, or trough with body stall and fed in trough) and floor space excluding trough or stall (3 allowances: 1.0, 1.4 or 2.0 m^2/gilt) were examined by Barnett (1997). In relation to the feeding system, body stalls, in comparison with floor feeding, reduced both aggression at feeding and cortisol concentrations, while in relation to floor space, 2.0 m^2/gilt, in comparison with 1.0 m^2/gilt, reduced both aggression at feeding and cortisol concentrations. Surprisingly, there were no interactions between feeding system and space on these variables. That is, in relation to aggression and stress, the presence of body stalls with reduced space outside the stall did not compensate for this spatial restriction. Conversely though, the presence of body stalls with increased space outside the stall area reduced aggression and stress. These results highlight the importance of both the provision of body stalls and floor space in the pen outside the area occupied by the feeding system. This experiment was comprehensive in terms of animal numbers and measurement, but it was conducted on gilts, that are generally less aggressive than sows (Li et al., 2912). Nevertheless, the design of pens with feeding stalls for sows should consider this principle that spatial restriction in the area outside the feeding system is unlikely to be compensated by provision of full length feeding stalls. Clearly further research is required on spatial requirements of sows in pens with body stalls.

These present results highlight the need to reduce aggression and stress in the immediate post-mixing period. Interpreting the welfare implications, particularly early after mixing, is problematic. The strategy of staged-gestation penning, with more space immediately after insemination and less space later in gestation may address both animal welfare and economic considerations. Ultimately, questions on acceptable animal use practices are ethical ones in which animal welfare implications are considered as well as other wider societal interests such as human health, economic, environmental and social implications. Science thus should provide the facts, but what society, groups or individuals do with these facts is a philosophical decision.

7. Recommendations

The following recommendations are made:

- These results and those of the previous research by Hemsworth et al. (2013) show that reducing floor space for recently-inseminated sows immediately after mixing within the range of 1.4 to 3.0 m^2/animal increases aggression and stress, as assessed by behaviour and concentrations of cortisol in plasma, and may reduce reproductive performance. These results together with previous results on gilts and sows, particularly those on aggression, stress and reproduction, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing.
- The effects of space on aggression and stress in the experiment by Hemsworth et al. (2013) and the effects of space on stress in the present experiment were most pronounced on recently-inseminated sows early after grouping, suggesting that sows in static groups may adapt over time to reduced space.
    - Therefore, close attention should be given to the period within the first week or so after after grouping to minimse aggression and stress and thus minimise risks to sow welfare and reproduction.
    - Furthermore, there is a clear need to examine the effects of reducing space, and its duration, during early gestation on sow welfare and reproduction because this effect may offer the opportunity for staged-gestation penning in which more space is provided for recently-inseminated sows immediately after mixing.
- These results together with previous results on gilts and sows indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small early after mixing. The current recommended minimum floor space allowance for group-housed gestating sows in the *Australian Model Code of Practice for the Welfare of Animals – Pigs* (Primary Industries Ministerial Council, 2007) is 1.4m^2 per sow. This recommended minimum space allowance needs to be reviewed.
- Thus the results from Hemsworth et al. (2013) and the present experiment indicate that both animal welfare and economic considerations can be addressed by providing sows within the first week or so after mixing with more floor space at the top end of the range 1.4 to 3.0 m^2/sow. The formation of the social hierarchy within this early period post-mixing provides the opportunity to then reduce floor space to levels in excess of 1.8 m^2/sow for the remainder of gestation. However, the effects of subsequently placing sows in gestation group systems at lower space allowances warrants investigation.

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Appendix - *Predicted means for the main variables*

Measurement	Transformation	Predicted mean#					
		1.45	1.61	1.81	2.07	2.42	2.90
Aggression							
Day 1 Average of 4 drops	Logarithm	6.46	6.32	5.05	5.69	4.67	3.81
Day 1 Drop 1	Logarithm	8.58	8.63	5.52	5.21	5.88	4.24
Day 1 Average of drops 2 to 4	Log(y+1)	5.46	6.15	4.79	5.51	4.29	3.55
Day 26 Drop 1	Square root	6.53	7.08	6.16	6.28	6.46	6.04
Cortisol							
Day 2	Logarithm	53.8	45.8	44.2	49.8	40.2	37.6
Day 26	Negative reciprocal (-1/y)	36.4	38.3	35.1	33.9	39.0	35.5
Reproduction							
Farrowing rate	-log(1.1 – y)	0.88	0.87	0.91	0.95	0.87	0.92
Born alive	-	11.6	11.5	11.5	11.4	11.4	11.7
Still born	Square root	0.95	0.97	0.78	0.88	1.08	0.82
Mummies	Square root	0.14	0.15	0.11	0.20	0.18	0.11
Total Born	-	12.7	12.5	12.4	12.5	12.7	12.7

#: for measurements transformed, back transformed predicted means presented.