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The Effects of Group Housing during Gestation on Sow Welfare and Reproduction

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The University of Melbourne
Animal Welfare Science Centre
Prof Paul Hemsworth
Parkville Vic 3010

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Section

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Investigators

Professor Paul Hemsworth, University of Melbourne
Dr Rebecca Morrison, Rivalea Australia
Dr Peter Cakebread, University of Melbourne
Professor Alan Tilbrook, Monash University
Marcus Karlen, University of Melbourne
Maxine Rice, University of Melbourne
Judy Nash, University of Melbourne
Kym Butler, Department of Primary Industries
Dr Khageswor Giri, Department of Primary Industries

Executive Summary

Recent changes in the Australian Model Code of Practice for the Welfare of Animals – Pigs recommend restricting the duration of housing gestating sows in stalls to the first six weeks of gestation and very recently, the Australian pork industry voted to pursue the voluntary phasing out of gestation stalls by 2017. However, international industry experience indicates that the opportunity for group housing to improve sow welfare is presently limited by the high levels of aggression that are commonly observed in newly formed groups of sows after mixing. Thus a better understanding of the effects of floor space allowance, group size, time of mixing and provision of feeding stalls may assist in developing strategies to reliably reduce aggression and stress in group-housed sows. Furthermore, this research is necessary to inform animal welfare standards for sows mixed in groups after mating.

Two experiments were conducted in this project. The first experiment examined the effects of floor space allowance and group size on the welfare of sows grouped after mating. One of the most consistent effects found in this experiment was the effects of space on aggression at feeding, stress on the basis of plasma cortisol concentrations in the short term (day 2 of treatment) and farrowing rate (percent of inseminated sows that farrowed). There was a general decline in both aggression and cortisol concentrations with increasing space from 1.4 m^2/sow to 3 m^2/sow, while there was general increase in farrowing rate with increasing space. Surprisingly, there was no evidence that space affected skin injuries.

While there were no detectable replicate effects for most of the variables studied, examination of the results for farrowing rate and, in particular, how the response differs with replicate, indicates that the response of farrowing rate to space differs with replicate. One replicate, which appeared to experience 'seasonal infertility', showed the largest response, with farrowing rate increasing markedly as floor space increased from 1.4 m^2/sow to 3 m^2/sow.

The other consistent effect was that of group size (10, 20 and 80 sows per group) on injuries. While aggression was not affected by group size, the incidence of skin injuries was affected by group size. Groups of 10 had consistently low injuries throughout the experiment.

In conclusion, these results indicate that space affects aggression, stress physiology and reproduction in sows. Based on these effects of space, it is credible to judge that, within the range of sow densities and the feeding system used in this study, sow welfare improves as floor space allowance increases. However, it is difficult to determine what is an adequate space allowance for sows from the present results. Although the results are in accord with a linear decline in cortisol concentrations early post-mixing from 1.4 m^2/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

It should also be recognized that the effects of space are most pronounced early after grouping. Indeed, it appears that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the importance of sufficient space in order 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.

Therefore, further research is recommended to examine the effects of space allowance in the range of 1.8 to 2.4m^2/sow in more detail. Particular attention should be given to the effects of space and time of mixing relative to mating (days 1 to 4 post-mixing), since this is the period when aggression and stress are likely to be most pronounced and the adverse effects on reproductive performance are likely. This research should also include an examination of the effects of pen features such as feeding stalls and feeding systems, since these are likely to affect aggression and stress.

The second experiment in this project examined the effects of both feeding stalls in groups and time of mixing in groups on the welfare of sows. Plasma cortisol concentrations at days 2 and 50 after mating were higher in sows housed in groups with shoulder feeding stalls throughout gestation than sows housed in gestation stalls and those initially housed in gestation stalls and then housed in groups with shoulder feeding stalls from 36-38 days after mating. Furthermore, sows housed in group pens with shoulder feeding stalls at the time of injury assessment (days 2, 36 and 50 days after mating) had a higher incidence of injuries. However there were no effects of treatment on the farrowing rate, litter size and live weight and P2 back fat change of sows.

Therefore, while, injuries were higher in sows recently mixed in groups with shoulder feeding stalls and stress was higher in sows mixed in groups with shoulder feeding stalls after mating, these effects were not severe enough to adversely affect reproductive performance or growth characteristics during pregnancy. From a welfare perspective, attention should be given to the design aspects of these group pens, such as the design of the stalls in the group pens and the pen space available in these group pens, in order to reduce stress and injuries in sows mixed in groups shortly after mating.

Non-Technical Summary Report

Aims of the Research

There were two main aims in this project. In the first experiment, the effects of floor space allowance and group size on the welfare of sows grouped after insemination were examined. The sows were mixed at 1-7 days post-insemination. Welfare was assessed by measuring stress, immunology, aggressive behaviour, injuries, live weight and backfat changes and reproductive success of the sows.

In the second experiment, the effects of both feeding stalls in groups and time of mixing in groups on the welfare of sows were examined. Time of mixing was examined by studying mixing in groups with feeding stalls at 1 or 35 days post-insemination. Welfare was assessed by measuring stress, injuries, live weight and backfat changes and reproductive success of the sows.

Implicit in this research is the objective of providing scientific data to inform animal welfare standards for sows mixed in groups post-insemination.

Rationale for the Research

There appears to be increasing community concern with society's treatment of animals (Fraser, 2008). Confinement housing of livestock, such as those housing systems common in modern pig and poultry production, appears to be at the forefront of these concerns. In relation to pig housing, the most contentious animal welfare issue is housing of dry (non-lactating) sows. Increasing community concern about confinement housing has led nationally and internationally to legislation, consumer and retailer pressure to increase the use of group housing for gestating sows. Housing sows in stalls is being phased out in the European Union by 2013 (Council Directive 2001/88/EC, 2001). Recent changes in the Australian Model Code of Practice for the Welfare of Animals – Pigs recommend restricting the duration of housing gestating sows in stalls to early gestation (PISC (Primary Industries Ministerial Council), 2007) and very recently, the Australian pork industry voted to pursue the voluntary phasing out of gestation stalls by 2017 (press release by the Australian Pork Limited, 17 November 2010).

However, international industry experience indicates that the opportunity for group housing to improve sow welfare is presently limited by the high levels of aggression that are commonly observed in newly formed groups of sows after mixing (Velarde, 2007): this aggression, especially if intense and prolonged, may lead to injuries and stress. Nevertheless, there are few rigorous recommendations in the scientific literature on the design features of sow group housing that reduce aggression (Petherick and Blackshaw, 1987; Arey and Edwards, 1998; Barnett et al., 2001; Spoodler et al., 2009). While the problem of pig aggression has received considerable attention, detailed studies of aggressive behaviour have generally used staged paired encounters or small group sizes. These research settings are very different from commercial settings.

There is limited evidence that space, group size, time of mixing and provision of feeding stalls may reduce aggression and stress in group-housed sows. Competition for limited resources clearly leads to aggression and thus when sows are mixed, eliminating competition for resources, such as food and space, should assist in reducing aggression. There is limited evidence that floor space may affect injuries, stress and reproductive performance in grouped gilts and sows (Hemsworth et al. 1986; Barnett, 1997; Barnett et al. 1992; Weng et al., 1998; Salak-Johnson et al., 2007). Olsson et al. (1994) reported increased injuries as group size increased, while Taylor et al. (1997) found that varying group sizes of 5, 10, 20 and 40 sows with a space allowance of 2.0 m^2/sow, had no effects on skin lesions or reproductive performance (farrowing rate and litter size). Hemsworth et al. (2006) found that mixing in large groups on deep litter at 35 days after mating rather than immediately after mating reduced both aggression and plasma cortisol concentrations at the time of mixing. Furthermore, altering pen design may be a simple and effective way of reducing aggression. Provision of barriers between feeding animals and between pen areas, behind which animals may escape, may have beneficial effects. The provision of feeding stalls, either partial or full length stalls, in groups of gestating gilts has been shown to reduce aggression around feeding, reduce basal cortisol concentrations and improve immunology (Barnett et al., 2001).

Thus a better a understanding of the effects of floor space allowance, group size, time of mixing and provision of feeding stalls may reliably reduce aggression and stress in group-housed sows,

Brief Methodology

While there is some controversy within science over the assessment of animal welfare (Fraser, 2008; Barnett and Hemsworth, 2009), a common approach has been to judge animal welfare on the basis that difficult or inadequate adaptation will generate welfare problems for animals (Broom and Johnson, 1993; Barnett and Hemsworth, 2003) and thus a broad examination of the behavioural, physiological, health and fitness responses of sows was undertaken in this project to assess biological functioning of the animals. Basically this involved assessing the risks to the welfare of an animal at two levels (1) the magnitude of the behavioural and physiological responses to the stressor and (2) the biological cost of these responses. These behavioural and physiological responses include abnormal behaviours, such as stereotypies and redirected behaviours, and the stress response, respectively, while the biological cost includes adverse effects on the animal's ability to grow, reproduce and remain healthy and injury-free.

This broad examination of the behavioural, physiological, health and fitness responses of sows was used in this project to examine firstly the effects of floor space allowance and group size and secondly the effects of feeding stalls in groups and time of mixing on the welfare of post-mated sows.

Major Research Findings

Experiment 1

One of the most consistent effects found in this experiment was the effects of space on aggression at feeding, stress on the basis of cortisol concentrations in the short term (day 2 of treatment) and farrowing rate (percent of inseminated sows that farrowed). There was a general decline in aggression and cortisol concentrations with increasing space, while there was general increase in farrowing rate with increasing space. Surprisingly, there was no evidence that space affected skin injuries.

While there were no detectable replicate effects for most of the variables studied, examination of the results for farrowing rate and, in particular, how the response differs with replicate, indicates that the response of farrowing rate to space differs with replicate. One replicate, which appeared to experience 'seasonal infertility', showed the largest response, with farrowing rate increasing markedly as floor space increased from 1.4 m^2/sow to 3 m^2/sow. A weaker, but still positive, response occurred in another replicate studied in spring. On the other hand, there was no farrowing rate response to space allowance in the other two replicates studied in autumn and spring.

The other consistent effect was that of group size on injuries. While aggression was not affected by group size, the incidence of skin injuries was affected by group size. Groups of 10 had consistently low injuries throughout the experiment.

There were also relationships between the treatments and live weight and backfat gain. Live weight gain was highest in groups of 10 and backfat gain was highest in a floor space of 1.4 m^2.

Experiment 2

In relation to stress, cortisol concentrations at days 2 and 50 after mating were higher in sows housed in groups with shoulder feeding stalls throughout gestation than sows housed in gestation stalls and those initially housed in gestation stalls and then housed in groups with shoulder feeding stalls from 36-38 days after mating. Furthermore, sows housed in group pens with shoulder feeding stalls at the time of injury assessment (days 2, 36 and 50 days after mating) had a higher incidence of injuries.

However there were no effects of treatment on the farrowing rate, litter size and live weight and P2 back fat change of sows.

Conclusions

In conclusion, the results from Experiment 1 indicate that space affects aggression, stress physiology and reproduction in sows. While the effects of space on stress physiology were found early in treatment, the effects of space on farrowing rate highlight that stress might be biologically important in the period shortly after the formation of a static group of sows that have been recently inseminated. Furthermore, the results indicate that the effects of space are most pronounced early after grouping. Indeed, it appears that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the importance of sufficient space in order 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.

While these effects of space early after grouping have sow productivity implications, interpreting the welfare implications is problematic. When relying on behavioural, physiological and fitness measures to determine welfare risks, a judgement is made about what degree of change in these indicators is likely to indicate that a sow's welfare is compromised. Based on the effects of space on aggressive behaviour, cortisol concentrations and farrowing rate, it is credible to judge that, within the range of sow densities and the feeding system used in this study, sow welfare improves as floor space allowance increases. This judgement is supported by the results of previous research.

However, it is difficult to determine adequate space allowance from the present experiment. Although the results are in accord with a linear decline in cortisol concentrations early post-mixing from 1.4 m^2/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

Furthermore, these results indicate that in summer anything less than 3 m^2/sow may compromise reproductive productivity. In conditions in which the other replicates were studied, farrowing rate might not be compromised even at a space allowance of 1.4 m^2/sow. These results suggests that the effects of seasonal infertility may be alleviated in groups of sows by ensuring floor space allowances up to and possibly exceeding 3 m^2/sow.

While there were no effects of group size on aggression, cortisol concentration or reproduction, sows in groups of 10 generally had less injuries throughout the study and, although difficult to explain, is an outcome that is desirable from a welfare perspective.

The results of Experiment 2 indicate that while injuries were higher in sows recently mixed in groups and stress was higher in sows mixed in groups after mating, these effects were not severe enough to adversely affect reproductive performance or growth characteristics during pregnancy.

From a welfare perspective, attention should be given to the design aspects of these group pens, such as the design of the stalls in the group pens and the pen space available in these group pens, in order to reduce stress and injuries in sows mixed in groups shortly after mating.

Background to the Research

Animal welfare is an increasingly contributing perspective in society, strongly influencing the acceptability of various farm animal management options. Science has a critical role in underpinning decisions on animal welfare standards. Failure to assure key stakeholders, particularly the consumer and the general public, that the welfare standards for farm animals are underpinned by sound science has the potential to adversely influence the profitability and viability of animal industries, such as the pork industry, by affecting specific practices such as current as well as new housing and husbandry.

The housing of dry (non-lactating) sows, particularly individual housing, has become one of the most controversial animal welfare issues in livestock production. The main welfare concerns raised are the general lack of social contact, the inability to exercise and the restricted choice of stimuli for interaction, such as other pigs and additional features of the physical environment (Barnett *et al*., 2001). Housing in stalls is being phased out in Europe by 2013 (see EU Directive 2001/88/EC. Recent changes in the Australian Model Code of Practice for the Welfare of Animals – Pigs recommend restricting the duration of housing gestating sows in stalls to early gestation (PISC (Primary Industries Ministerial Council), 2007) and very recently, the Australian pork industry voted to pursue the voluntary phasing out of gestation stalls by 2017 (press release by the Australian Pork Limited, 17 November 2010). The Australian pork industry has and is considering several group housing options to replace gestation stalls.

Aggression among recently-grouped unfamiliar gilts and sows has both production and welfare implications. Indeed in spite of the research to date on minimising aggression when grouping unfamiliar pigs, there are few rigorous recommendations (Barnett et al., 2001; Spoodler et al., 2009) and this clearly subject needs further research to allow industry to successfully manage group housing of sows, and thus minimise risks to welfare and reproduction. In particular, the effects of, and interactions between, factors such as floor space allowance and group size on pig welfare require thorough investigation. Furthermore, time of mixing and provision of feeding stalls in group pens require thorough investigation.

There has been some research conducted on the effects of floor space allowance and group size (eg Kuhlers et al., 1985; Barnett et al., 1986, 1992; Hemsworth et al., 1986; Barnett, 1997). There is evidence of a chronic stress response and reduced reproductive performance if space allowance is insufficient. Hemsworth et al. (1986) examined the effects of floor space on the sexual behaviour and stress physiology of 34 non-pregnant gilts. The sexual behaviour of gilts in the 1.0 m^2 treatment was reduced in comparison to that of the gilts in the 2.0 or 3.0 m^2 treatments. After 9-11 days of treatment, plasma total and free cortisol concentrations were higher in the 1.0 m^2 treatment than the 3.0 m^2 treatment. In one of two replicates, plasma total and free cortisol concentrations were higher in the 2.0 m^2 treatment than the 3.0 m^2 treatment. Similar treatment effects on plasma total and free cortisol concentrations were apparent at 12 weeks of gestation. In a factorial experiment examining the effects of space and feeding stalls on 96 gestating gilts, Barnett et al. (1992) found that plasma cortisol concentrations, both total and free, at 28-29 and 49-51 days of treatment were elevated, immunological responsiveness, assessed on the basis of a cell-mediated response (skin-fold thickness) to a mitogen injection, at the 50-57 days of treatment was reduced and aggression around feeding was increased in gilts housed in groups of four at a floor space of 0.98 m^2 than 1.97 m^2. Number of lesions was no affected by floor space. In another factorial experiment examining the effects of space and feeding stalls on 180 gestating gilts, Barnett (1997) found that plasma cortisol concentrations, both total and free, at 36 and 53 days of treatment were higher in gestating gilts housed in groups of five with a floor space of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt. Cortisol response to ACTH and aggression around feeding were also higher in the floor space of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt.

Weng et al. (1998) reported increased aggression and injuries with decreasing space allowance and recommended a space allowance between 2.4 and 3.6 m^2/sow for groups of 6 pregnant sows. Salak-Johnson et al. (2007) studied the effects of floor space allowance (groups of five with 1.4, 2.3 or 3.3. m^2/sow or gestation stalls) on multiparous sows over two parities. Sows were introduced to their treatments at 25 days post-insemination. Grouped sows in pens at 1.4 m^2/sow generally had lower condition score, body weight and backfat throughout gestation than those in pens at 2.3 or 3.3 m^2/sow. Furthermore, sows in pens of 1.4 m^2/sow had consistently higher lesion scores. However, the reproductive performance of the sows and the productive of their piglets were similar regardless of the treatment during gestation. There is likely to be continued interest in the spatial requirements of grouped sows particularly in the light of the results of Hemsworth et al. (1986), Barnett (1997),Weng et al. (1998) and Salak-Johnson et al. (2007). Thus an important question that will confront the Australian and international pork industry as it moves towards group housing is “what is the optimum floor space allowance for group-housed sows during gestation?”.

There is also limited evidence of effects of group size on sow welfare and reproduction. Barnett et al. (1984, 1986) found that housing sexually mature gilts in pairs resulted in a chronic stress response compared to housing in groups of 4-8 with a similar space allowance. Both large group size (24 vs. 8 gilts) and small group size (3 vs. 9, 17 or 27 gilts) may reduce the expression of oestrus (Christenson and Ford 1979; Christenson and Hruska 1984), while increasing group size and concomitantly decreasing space allowance may also reduce the expression of oestrus in gilts (Cronin et al. 1983). Broom et al. (1995) compared sows in groups of 5 fed in stalls and a group of 38 sows with an electronic feeding station and, while there was increased aggression in the larger group, particularly after initial mixing, any differences in aggression and stereotypies had disappeared by the fourth parity. Olsson et al. (1994) reported increased injuries as group size increased, while Taylor et al. (1997) reported that varying group sizes of 5, 10, 20 and 40 sows with a space allowance of 2.0 m^2/sow, had no effects on reproductive performance (farrowing rate and litter size). Although aggression immediately after mixing increased as group size increased, the number of lesions during gestation was similar across treatments. In the same study, reducing space allowance for groups of 10 sows from 2.0 to 1.2 m^2/sow increased aggression. Clearly research is further required to determine the optimum space allowance and group size for pregnant pigs. There are no data on space allowance/group size interactions for adult female pigs. Thus a second important question that will confront the Australian and international pork industry as it moves towards group housing is "how does the optimum floor space allowance for group-housed sows during gestation vary with group size?"

Even less consideration has been given to other factors that may affect sow welfare. The use of deep-litter in housing systems for pigs is considered by some authors to improve pig welfare (Newberry, 1995). Leg problems and lameness are important causes for culling sows (Paterson et al., 1997) and pig consultants in Europe often recommend housing loose-housed sows on straw bedding. Andersen and Boe (1999) found a lower incidence of leg problems in sows in small groups (less than 20) on straw bedding than in sows in small groups on concrete. While Whittaker et al. (1999) reported that the provision of straw may increase aggression in sows, Durrell et al. (1997) reported that enriching pens with mushroom compost in a rack above the floor reduced aggressive behaviour and injuries

There is evidence that aggression and stress physiology may be affected by the provision of feeding stalls in pens for group-housed sows. In a factorial experiment examining the effects of space and feeding stalls on 96 gestating gilts, Barnett et al. (1992) found that full body length feeding stalls reduced plasma free cortisol concentrations, but not total cortisol concentrations, and improved immunological responsiveness, assessed on the basis of a cell-mediated response (skin-fold thickness) to a mitogen injection, in gestating gilts housed in groups of four at floor space allowances of 0.98 m^2 to 1.97 m^2. While aggression around feeding was reduced, feeding stalls did not affect skin lesions. In another factorial experiment examining the effects of space and feeding stalls on 180 gestating gilts, Barnett (1997) found that feeding stalls, particularly full body stalls rather than shoulder stalls, reduced aggression around feeding over 30 d of treatment and plasma total (but not free) cortisol concentrations at 36 and 53 days of treatment in gestating gilts housed in groups of five with a floor space of 1.0 to 2.0 m^2.

Research by Hemsworth et al. (2006) provided evidence that the practice of housing sows in stalls immediately after mating and delaying mixing in large groups on deep litter until pregnancy is confirmed, by reducing aggression at mixing, may provide some distinct welfare advantages over housing sows either in stalls or in large groups on deep litter for the entire gestation. For example, mixing in groups at 35 days post-insemination rather than mixing at day 1 post-insemination resulted in less aggression. Sows housed in stalls post-insemination had a higher neutrophil count and a lower lymphocyte count at 55 and 104 days of gestation than those in the two group treatments. However, sows in stalls had lower salivary cortisol concentrations than those mixed in groups either day 1 or day 35 post-insemination. The implications of these results for sows which are housed in smaller groups on concrete, are unknown. In particular, the effects of increased floor space, increased group size, provision of bedding and a central feeding station separated from the accommodation pen in the study by Hemsworth et al. (2006) are unknown. Similar results were reported by Strawford et al. (2008) in which sows introduced to groups with electronic sow feeding (ESF) systems at 37-46 days post-insemination initiated more aggressive interactions than those introduced to groups with ESF systems at 2-9 days post-insemination. In contrast, the former sows had higher salivary cortisol concentrations throughout treatment, however, this comparison is confounded by stage of gestation as cortisol concentrations increase throughout gestation (Barnett et al., 1985; Hay et al., 2000). A recent study by Jansen et al. (2007) examined the effects of relocating sows from stalls to either stalls or groups at about 10 weeks of gestation. Group-housed sows were involved in more aggressive encounters than stall-housed sows for the 2 days following relocation. Furthermore, lesions scores and salivary cortisol concentrations were higher in grouped sows during the day following relocation. Thus other important questions that will confront the Australian and international pork industry as it moves towards group housing are "what are the effects of time of mixing relative to mating and feeding system on the welfare of group-housed sows during gestation?" and "how can existing sheds of gestation stalls be converted to group housing with a feasible feeding system?"

In their review of the literature, Barnett et al. (2001) concluded that aggression at the time of mixing can be reduced in a number of ways. For example, modifying pen size and shape on the basis that pigs require a minimum space in which to fight, modifying pen design on the basis that the provision of escape areas reduces aggression, grouping after dark on the basis that it is the 'normal' sleeping time, providing feed *ad libitum* on the basis that restrictively fed pigs may prefer to feed than fight or using masking odours on the basis that anosmic pigs show reduced aggression. However, most of these mixing methods may only be effective in postponing aggression rather than reducing it.

Clearly there is a lack of understanding of the principles for mixing and housing breeding sows in groups to minimise aggression. Inadequate mixing strategies may lead to unacceptable levels of aggression amongst sows, with serious consequences for injury and reproductive failure and, in turn, reduce unplanned culling. Furthermore, increased aggression is clearly a welfare concern. It is useful to briefly review these consequences of high levels of aggression in group-housed breeding sows.

High levels of aggression in grouped sows may lead to injury and stress, to the extent where the reproductive performance of the herd is limited. Injury is responsible for a large number of early culls and deaths in breeding sows and thus injury increases the cost of production by increasing replacement rates. For example, it has been reported that an average of 9% of sows, with a maximum of 19% of sows, die on Australian farms (Australian Pig Annual, 2003), with many sows having injuries severe enough to result in early culling. In addition, research has shown that stress can adversely affect pregnancy rates and increase embryo loss and in turn reduce the number of piglets per mated sow per year (see Barnett et al., 2001).

In spite of the research to date on minimising aggression when grouping unfamiliar pigs, there are few rigorous recommendations for breeding sows in conventional group housing, that is small groups on concrete. This subject clearly needs further research to identify principles and thus strategies to reduce aggression in sows in small groups on concrete. In particular, the effects of key factors of space allowance, group size, time of mixing and feeding system on aggression, injury and stress require thorough investigation. There is likely to be continued interest in these aspects by both industry as well as animal welfare groups and the general public and clearly there is an important need to develop and defend science-based recommendations on group housing of sows during gestation.

This project examined the effects of space allowance, group size, feeding stalls in groups and time of mixing in groups on aggression, stress, injury and reproduction in sows housed in groups during gestation. The effects of floor space allowance and group size on the welfare of group-housed post-mated sows were examined in Experiment 1 and the effects of feeding stalls in groups and time of mixing in groups on the welfare of post-mated sows were examined in Experiment 2. An additional objective of Experiment 2 was to examine the practicality of converting existing gestation stalls to group pens using existing gestation stalls as shoulder feeding stalls and the back aisle space as pen space.

To assess sow welfare in this project, a broad examination of the behavioural, physiological, health and fitness responses of sows was undertaken to assess biological functioning of the animals. While there is some controversy within science over the assessment of animal welfare (Fraser, 2008; Barnett and Hemsworth, 2009), a common approach has been to judge animal welfare on the basis that difficult or inadequate adaptation will generate welfare problems for animals (Broom and Johnson, 1993; Barnett and Hemsworth, 2003) and thus a broad examination of the biological responses was undertaken. Basically this involves assessing the risks to the welfare of an animal at two levels (1) the magnitude of the behavioural and physiological responses to the stressor and (2) the biological cost of these responses. These behavioural and physiological responses include the abnormal behaviours, such as stereotypies and redirected behaviours, and the stress response, respectively, while the biological cost includes adverse effects on the animal's ability to grow, reproduce and remain healthy and injury-free.

In this research project the following biological responses were used to assess sow welfare. The stress response commences once the central nervous system firstly perceives a potential challenge (stressor) to homeostasis and one of the key general biological defence responses is that of the neuroendocrine system with the activation of the hypothalamic-pituitary-adrenal (HPA) axis and the release of corticosteroids (Barnett and Hemsworth, 2009). Thus cortisol concentrations were measured in this research project to determine activation of the HPA axis. Both total and free plasma cortisol concentrations were measured since cortisol is partitioned in the blood in three ways, bound to albumin, bound to transcortin or corticosteroid binding globulin and free in the blood (Westphal, 1971), and it is the free cortisol that is the biologically active component. The distribution of white blood cells were measured, as the effects of stress on the immune system can be characterised by a redistribution of white blood cells involved in the defence and immunological response against antigens, specifically an increase in neutrophils and a decrease in lymphocytes (Gross and Siegel, 1983). Extensive behavioural observations were conducted to study aggression, while skin injuries were also assessed (Karlen et al., 2007). The activation of the HPA axis may come at a physiological cost to the animal, such as a decreased metabolic efficiency, impaired immunity and reduced reproductive performance (Barnett and Hemsworth, 2009) and thus live weight and reproductive performance of the sows were also monitored.

Objectives of the Research Project

The specific objectives of this project were to:

1. Based on aggression, stress, injury and reproduction, identify the optimal space allowance and group size of multiparous sows mixed at 1-7 days post-insemination.
2. In comparison to sows housed in gestation stalls, determine whether stress, injury and reproduction are affected by (a) mixing in groups with shoulder feeding stalls and (b) mixing in groups with feeding stalls at 1-3 days or 36-38 days post-insemination.

By determining the effects of floor space allowance, group size, feeding stalls in groups and time of mixing on the welfare of sows grouped after insemination, the implicit objective of this research was to provide objective scientific evidence, along with published information, to support the development of appropriate standards for sows mixed in groups post-insemination.

Research Methodology, Detailed Results & Discussion of Results

Experiment 1: Effects of Group Size and Floor Space Allowance

Aims

The aim of this experiment was to determine the effects of group size and floor space allowance on aggressive behaviour, stress, immunology, injuries, live weight and backfat changes and reproductive success of sows housed in groups during gestation.

Materials and Methods

Facilities

This experiment was conducted in a modified breeding and gestation unit in a large commercial piggery in Corowa, NSW, Australia, and commenced in September 2008 and concluded in December 2009. The accommodation building was 61 m long and 19 m wide, with a galvanized roof and adjustable blinds on the sides and overhead water sprinklers that were activated for 3 minutes on and 15 minutes off when the internal temperature exceeded 26°C.

All procedures were conducted with the approval of the Rivalea animal ethics committee.

Animals and Treatments

A total of 3,120 mated sows, in four time replicates (780 sows per replicate) over 13 months were studied. The sows were crossbred (Landrace x Large White) of mixed parity and of good health at the beginning of the study. Sows were inseminated twice and were introduced to the post-mating housing treatments within 1-7 days of insemination.

A 3x6 factorial design was used to examine two main effects imposed post-mating:

1. Group size at 3 levels, 10, 30, 80 sows per pen.
2. Floor space allowance at 6 levels, 1.4m^2, 1.8m^2, 2.0m^2, 2.2m^2, 2.4m^2, 3.0m^2 per sow.

In each of the four time replicates there were 24 groups with 18 treatments as follows: 10 sows @ 1.4m^2/sow-2 groups; 10 sows @ 1.8m^2/sow-2 groups; 10 sows @ 2.0m2/sow-2 groups; 10 sows @ 2.2m2/sow -2 groups; 10 sows @ 2.4m^2/sow -2 groups; 10 sows @ 3.0m^2/sow-2 groups; 30 sows @ 1.4m^2/sow; 30 sows @ 1.8m^2/sow; 30 sows @ 2.0m^2/sow; 30 sows @ 2.2m^2/sow; 30 sows @ 2.4m^2/sow; 30 sows @ 3.0m^2/sow; 80 sows @ 1.4m^2/sow; 80 sows @ 1.8m^2/sow; 80 sows @ 2.0m^2/sow; 80 sows @ 2.2m^2/sow; 80 sows @ 2.4m^2/sow; and 80 sows @ 3.0m^2/sow. Two groups of 10 sows were included in each of the treatments for the group size of 10 in each time replicate in order to sample sufficient animals for the physiological and injury variables in each treatment and to obtain similar variance in the treatments in each time replicate (that is, to allow 20 sows were sampled in each treatment). Thus there were 24 pens in total within the facility, one pen of each space allowance for the group sizes of 30 and 80 and 2 pens of each space allowance for the group size of 10.

The 24 experimental pens were located within the same area of the accommodation building (see Figure 1). The three group sizes were located down the length of the building, but because of construction limitations, the groups of 80 were located in the two outside rows of pens and the groups of 10 and 30 were located in the two inner rows of pens. The length of the building was divided into 3 sub-replicates so that, within a sub-replicate, the outer and inner rows each contained an 80 group size treatment and each of the 2 inner rows contained both a 10 group size (2 pens) and a 30 group size treatment. The inner and outer row pens were 5.47 and 5.96 m deep and the width of the pens were varied to provide the space allowances of 1.4m^2, 1.8m^2, 2.0m^2, 2.2m^2, 2.4m^2 and 3.0m^2 per sow. Each pen had concrete floors with 50% slatted at the rear of the pens. Drop feeders evenly suspended across the width of each pen (2 drop feeders per 10 animals) were used to deliver the feed, which was delivered four times per day (hourly from 0700 h) providing a total of 2.5 kg/sow/day of a commercial diet (13.1 MJ/kg DM, and12.8% crude protein). Water was provided *ad libitum* via nipple drinkers attached to the back wall over the slatted flooring.

Within each replicate on each of the three alternate Mondays in a 6-week period, a sample of 260 sows was assigned to a sub-replicate, mated during the previous week. Within a sub-replicate sows were randomly allocated to treatments within that sub-replicate (Figure 1). Sows were housed post-weaning and inseminated in a morning/afternoon insemination routine in stalls, before being firstly, randomly selected for study and then randomly allocated to treatment. Within 1 week of insemination, sows were moved to their allocated housing treatment and, unless culled for reproductive failure, injuries or health, remained in their treatment pens for 105 days, after which they were relocated to a farrowing house for the remaining few days of gestation. Introduction to the allocated housing treatment was considered day 1 of treatment.

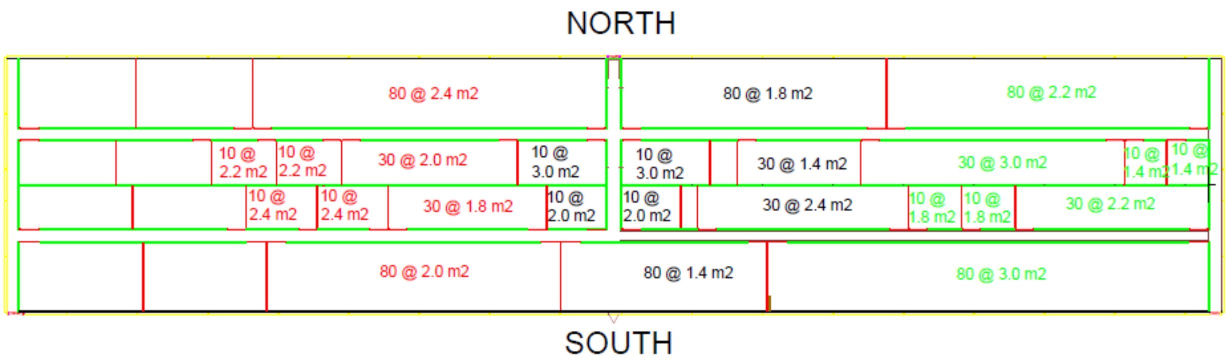

Figure 1: Layout of experimental pens in the accommodation building.

Sows commenced treatment (within 1-7 days of insemination) in replicate 1 from the 22nd September to 20th October 2008 (spring season in southern hemisphere, in replicate 2 from 5th

January to 2nd February 2009 (summer), in replicate 3 from 20th March to 18th May 2009 (autumn) and in replicate 4 from 3rd August to 31th August 2009 (winter).

Regular oestrus checks for returns to service were conducted as well as a pregnancy test using ultrasonography 5 weeks after mating. All sows that returned to oestrus, those that tested negative at the pregnancy test and those that were culled for injury or poor health were recorded and removed from treatment pens. Sows removed from treatment due to reproductive failure or injury were not replaced in the groups by other sows.

Measurements

Aggressive Behaviour at Feeding

As indicated earlier, feed was delivered to each pen four times per day (hourly from 0700 h) using overhead drop feeders evenly spaced across the width of each pen at a ratio of one drop feeder per five pigs. In order to observe aggressive behaviour at feeding, 3.6 mm infra red CCTV cameras were installed overhead to record behaviour at the time that feed was distributed on the solid floor across the width of each pen. The focal range of each camera matched the dimensions of the smallest pen size (i.e. 1.4 m^2/sow) and thus each camera covered a floor area of 1.4 m^2 allowing a constant floor area to be recorded at each feed drop. The cameras continuous recorded from 0600-1700 h for 3 days commencing at days 2, 8, 23, and 51.

From the digital video records, continuous observations were conducted to measure the number of bouts of aggressive behaviour in the 30 min following each feed drop only on day 2. 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. Behaviours recorded as aggressive behaviours were slashes, butts/pushes and bites and these aggressive behaviours were distinguished from other tactile interactions with pigs (e.g. licking) on the basis that they were associated with avoidance shown by one pig as a consequence of the interaction. Only aggressive interactions in which the head of the pig (defined as extending from the snout to the ears) displaying the aggressive behaviour was clearly visible were recorded. The location of the body (i.e. vulva or other parts of the body) in which the aggressive behaviour was targeted was also noted. The identity of each sow was not recorded since aggression at the level of the group was the main focus.

In order to compare aggressive behaviour between treatments, aggressive behaviour per pig observed in the field of view of each camera for 30 min after each feed drop was calculated as follows. The average number of pigs 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 pigs 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 pigs in each scan (thus providing an estimate of the average number of pigs in the field of view during each 5 minute block of the observation period). The number of pigs in the field of view was recorded at the point at which the feed dropped and every 30 s after during the 30 mins observation period after each feed drop. Thus using this estimate of the average number of pigs in the field of view over each 5-minute segment, the frequency of bouts of aggression after each feed drop was calculated on a "per pig in field of view" basis for each 5-min block observed. The average frequency of aggression during the four feed drops on day 2 was collated and analyzed.

Observations on aggressive behaviour are reported here only on day 2 of treatment. As shown in Appendix 1, Table 1.1, measurement of aggressive behaviour of individual sows on any of the first three days post-mixing provides a good estimate of aggression of individual sows over the first three days post-mixing.

Skin Injuries

Twenty sows in each treatment were randomly chosen and assessed (all sows in each group of 10 sows) on days 2, 9, 23 and 51. A modification of the assessment described by de Koning (1993) was used to describe skin lesions in both treatments. The assessment was simplified for the present experiment by reducing the number of areas in which the body of the sow was divided for injury data collection. Lesions were categorized into five categories: four of these categories were fresh lesions which included; (a) scratches; (b) abrasions; (c) cuts; and (d) abscesses, and the fifth category (e) included partially healed or old lesions. Each side of the sow's body was divided into 21 areas as shown in Figure 2 and described as follows: face (1), ear (2), neck (3), throat (4), processi scapulae (5), elbow (6), carpus (7), fetlock (8), coronary edge of the foreleg (9), hoof of the foreleg (10), sole of the foreleg (11), accessory digits of the foreleg (12), back and flank (13), tail and vulva (14), stifle (15), hock (16), coronary edge of the back leg (17), hoof of the back leg (18), sole of the back leg (19), accessory digits of the back leg (20) and udder (21). The number and the type of skin lesions were recorded on days 2, 9, 23, and 51 of treatment and from these records, the number of both fresh (lesions categorized as (a) to (d)) and total injuries (fresh lesions (lesions categorized as (a) to (d)) and old lesions ((lesions categorized as (e)) were collated for each sows at each observation day.

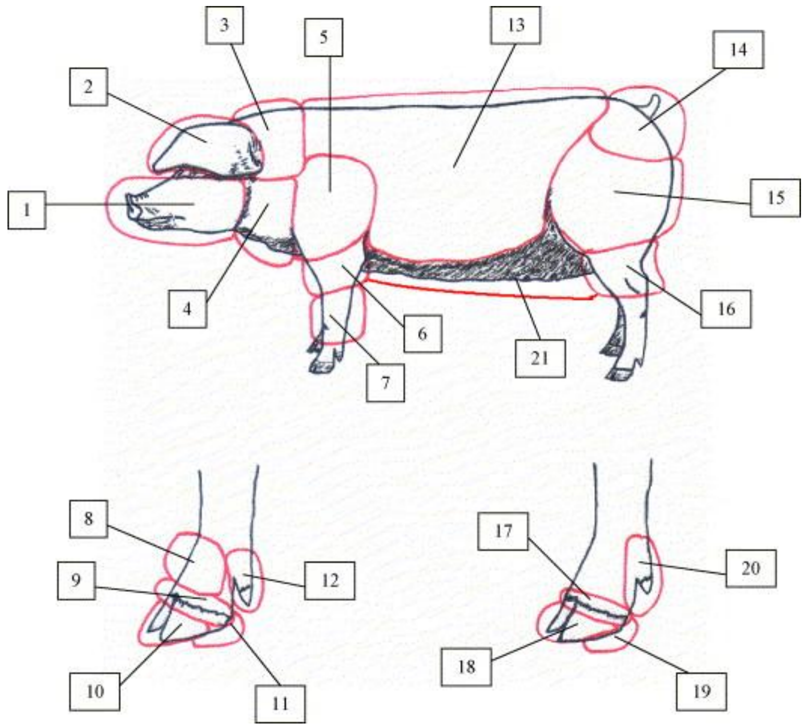

Figure 2: Divisions of the surface of the sow where injures were assessed.

Physiology

Blood samples were collected via venipuncture from the jugular vein from sows restrained with a snout snare. In this type of restraint, a rope (snout snare) was hooked behind the canine teeth (to prevent slippage) and over the bridge of the sow's nose. This procedure reduces movement in the animal and thus minimises injuries to both pig (associated with needle prick and abrasions with pen fittings) and operator. The blood sampling was performed by trained personnel in order to minimise the length of time that the animal was restrained. The sows were blood sampled within 2 minutes of snaring to avoid an acute stress response to handling influencing the basal levels of cortisol in the blood (i.e. to avoid handling confounding basal measures). Twenty sows from each treatment were chosen at random for sampling (all sows and in each group of 10 sows) sampling occurred on days 2, 9/10 and 51/52. Note that on days 9/10 and 51/52 to make the task easier, sampling was conducted over 2 days with 10 sows from each treatment sampled on each day after day 2 and for convenience these two sets of samples are referred to in this report as being collected on days 9 and 51, respectively.

Two blood samples of approximately 10 ml each were taken from each sample sow at each sample point for subsequent analyses of plasma cortisol and white blood cell count.

The samples for cortisol were collected in heparinised tubes (BD Vacutainer® BD, Belliver Industrial estate, Plymouth, UK), and centrifuged with the plasma drawn off into individual micro tubes and frozen. The samples were assayed for total and free cortisol in the physiology laboratory at Monash University (Clayton, Victoria). Samples from each pen were pooled using 200 µL aliquots from each individual sample. Plasma concentrations of total cortisol from the pooled samples were determined in duplicate 100-µL aliquots using an extracted radioimmunoassay according to the protocol developed by Bocking and Harding (1986) and validated for pig plasma using hydrocortisone H-4001 (Sigma Chemical Co., St Louis, MO) as standard. Free cortisol concentrations were determined using an ultrafiltration/ligand binding method as described in Ho et al. (2006). The sensitivity for assays ranged from 0.44 to 0.49 ng/ml.

Blood samples collected for haematology were transported on ice to IDEXX laboratories (Brisbane, QLD) and the absolute numbers of neutrophil and lymphocyte cells were measured in an autoanalyser CellDyn 3700 (Abbott Diagnostic Division, Abbott Park, IL, USA) and cell ratios at days 2, 9/10 and 51/52 (neutrophil to lymphocyte ratios) were calculated.

Live Weight and Backfat

All sows were weighed just prior to entry to treatment, and before entering the farrowing accommodation (day 110 and only sows that remained in treatment were weighed at this point). P2 backfat measurements were also taken immediately prior to weighing at both weigh points.

Reproductive Performance

All the sows farrowed in a common farrowing environment. The reproductive performance data collected allowed the following aspects to be calculated: Farrowing rate, litter size (total born, born alive, stillborn, mummified piglets) and litter weight (litter weight at birth, average piglet weight at birth, litter weight at weaning and average piglet weight at weaning). Data on returns to oestrus, NIPs ("not-in-pig sows", that is, sows confirmed pregnant but failed to farrow) and abortions were also collected as well as sows culled for injury.

Statistics

Each measurement was analysed using a series of restricted maximum likelihood (REML) mixed model analyses that, as well as treatment effect combinations being examined, a priori included a fixed effect for replicate and random effects for row within replicate, sub-replicate within replicate and the interaction between row and sub-replicate within replicate. In all REML analyses, the experimental unit was all sows being measured in a pen within a replicate. To improve precision, the live weight change analyses also included a covariate fixed effect of pre-experimental live weight. To reduce skewness of the residuals, prior to the REML analyses, several measurements were either square root or logarithmically transformed (Table 1). One extreme outlying pen was deleted from the analyses for each of fresh injuries at day 23, total injuries at day 23 and farrowing rate. The free cortisol readings at day 2 were extremely large for two samples. Thus for two pens the measurement of free cortisol at day 2 was calculated from a single sample, rather than the average of two samples. For measurements that were calculated using all sows, rather than just focus animals, a dot histogram of residuals from a saturated treatment model was drawn for each group size, so that the possibility of different amounts of random variation with group size could be examined. In no case was there any large change in the amount of residual variation with group size.

For each measurement four REML models were fitted with different treatment effects included, namely (1) no treatment effects at all, (2) additive effects of group size and a linear response to the amount of space per sow, (3) additive effects of group size and a quadratic response to the amount of space per sow, and (4) a saturated treatment model of all combinations of group size and space per sow. From these models Wald F tests were calculated for (1) group size after adjusting for an additive quadratic response to space per sow, (2) a linear response to space for sow adjusted for an additive effect of group size, (3) a quadratic response to space for sow adjusted for an additive effect of group size, and (4) any effect of group size and space per sow combinations in addition to additive effects of group size and the quadratic response to space per sow. These tests allowed a parsimonious treatment model to be selected for each measurement. Wald chi-square tests were occasionally substituted for the Wald F tests, when the Wald F tests could not be numerically calculated (Table 1).

Predicted values from these models are graphed, with the values back transformed when necessary, as a function of space per sow. In these graphs the predicted means of each group size by space per sow combination in the experiment are presented as individual points, after back transformation when necessary, using the saturated model of treatment effects.

Results

A total of 30 sows (0.95%) were removed from the study prior to day 9 of treatment due to injury or escaping from their pens (Table 1) and these animals were removed from the analyses.

Table 1: Details of the number of sows (%) that were removed from the study prior to day 9 of treatment due to injury or escaping from their pens.

Treatments		**Number of sows (%)**
Group size	10	2.5
	30	0.4
	60	0.8
Space (m^2/sow)	1.4	1.3
	1.8	1.3
	2.0	1.2
	2.2	1.0
	2.4	0.8
	3.0	0.2

The four REML models fitted with different treatment effects for each measurement and the most parsimonious REML models that were selected are presented in Table 1. The predicted values from these models are presented graphically as a function of space per sow in Figures a-b and these results are discussed for each measurement.

Table 2: P values of tests for choosing parsimonious models, of treatment effects, for each measurement

Effect	Group Size (GS)	Linear response to sow space (SpaceVar)	Quadratic response to sow space (SpaceVarSq)	Any further treatment effect	Treatment effects selected
Terms adjusted for	SpaceVar + SpaceVarSq	GS	GS +SpaceVar	Effects in previous 3 columns	
Aggressive behaviour at feeding					
Aggression[1]	0.48	**0.029**	0.34	0.29	**SpaceVar**
Physiology					
Total cortisol, day2	0.48	**0.0089**	0.052	0.13	**SpaceVar**
Total cortisol, day 9	0.35	0.23	0.47	**0.013**	None
Total cortisol, day 51	0.27	0.12	0.19	0.90	None
Free cortisol, day2[2]	0.41	**0.036**	0.080	0.13	**Space**
Free cortisol, day 9[2]	0.45	0.085	0.57	**0.0010**	**None**
Free cortisol, day 51[2]	0.94	0.76	0.14	0.78	**None**
Neutrophil-lymphocyte ratio, day 2[2]	**0.0092**	0.99	0.85	0.48	**GS**
Neutrophil-lymphocyte ratio, day 9[2]	0.18	0.94	**0.0080**	0.80	**SpaceVar + SpaceVarSq**
Neutrophil- lymphocyte ratio, day51[2]	**0.027**	0.063	0.28	0.76	**GS**

Injuries					
Fresh injuries, day 2[1]	057	0.59	0.19	0.70	None[4]
Fresh injuries, day 9[1]	**0.045**	0.099	0.91	0.12	**GS**
Fresh injuries, day 23[1]	0.40	0.37	0.99	0.14	None
Fresh injuries, day 51[1]	0.56	0.62	**0.031**	0.69	None
Total injuries, day 2[1]	0.50	0.39	0.32	0.41	None
Total injuries, day 9[1]	**0.0017**	0.36	0.44	0.17	**GS**
Total injuries, day 23[1]	**0.0046**	0.67	0.81	**$3.3*10^{-5}$**	**GS**
Total injuries, day 51[1]	**0.00059**[5]	0.17[5]	0.020[5]	0.94[3]	**GS**
Reproductive performance					
Born alive	0.66	0.13	0.71	0.15	None
Still born	0.56	0.94	0.22	0.97	None
Farrowing rate	0.77	**0.012**	0.37	0.74	**SpaceVar**
Live weight and backfat					
Change in backfat P2	0.12	**0.028**	**0.012**	0.56	**SpaceVar + SpaceVarSq**
Change in live weight	**0.013**	0.80	0.15	0.63	**GS**

[1]: Data transformed square root prior to statistical analysis; and [2]:Data log10 transformed prior to statistical analysis.

[3] The random main effect for row was fixed to be 0, so as to achieve numerical convergence.

[4]:Model chosen is a constant value irrespective of group size and space per sow

[5] Used Wald χ^2 test because the calculation of F test numerically failed.

Aggressive Behaviour at Feeding

The most parsimonious model that predicted aggression at feeding on day 2 included a linear response to space (Table 2). As shown in Figure 3 in which this relationship is depicted, a general decline in aggression occurred with increasing space.

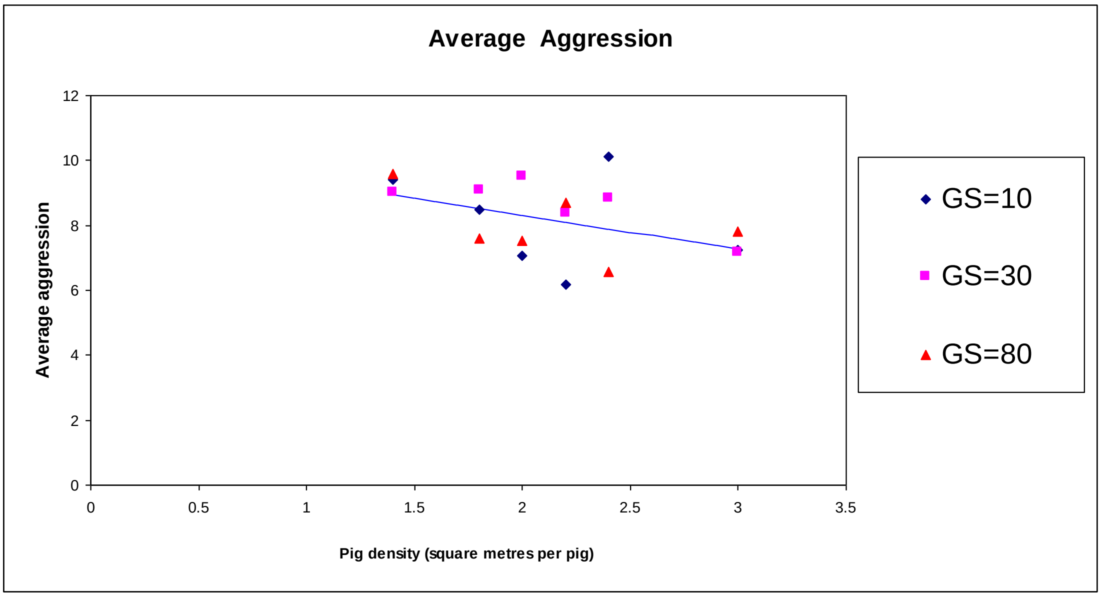

Figure 3: Predicted values of aggression at day 2 as a function of space per sow.

Physiology

The most parsimonious model that predicted plasma total and free cortisol concentrations at day 2 included a linear response to space (Table 2). As shown in Figures 4 and 5 in which this relationship between space and cortisol concentration is depicted, a general decline in both total and free cortisol concentrations occurred with increasing space.

As indicated in Table 2 and Figures 6, 7, 8 and 9, there were no relationships found between group size and space and total and free cortisol concentrations at days 9 and 51.

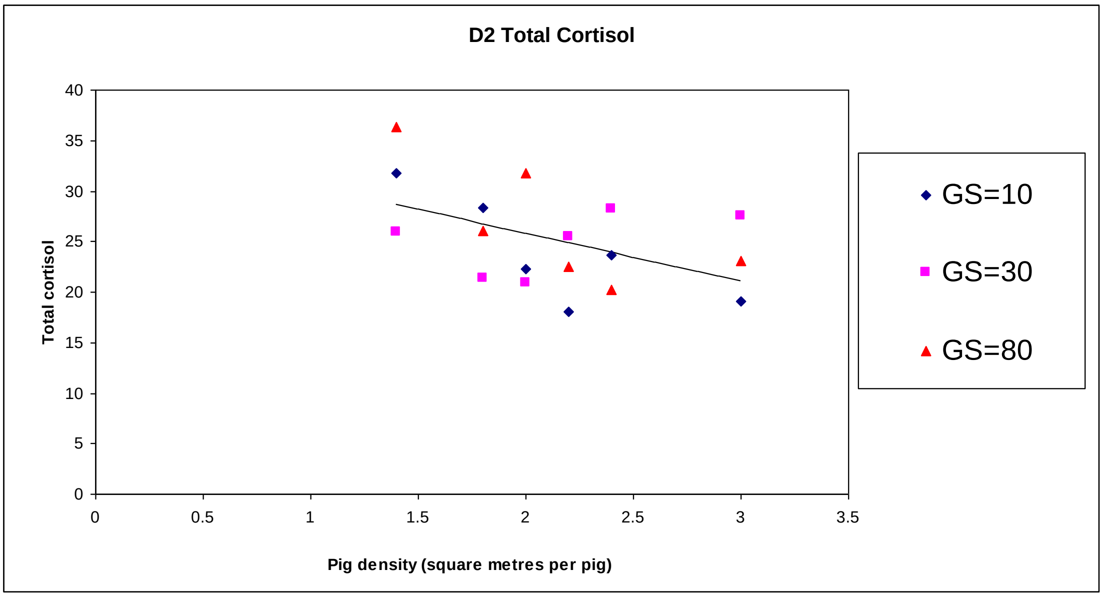

Figure 4: Predicted values of total cortisol concentrations at day 2 as a function of space per sow

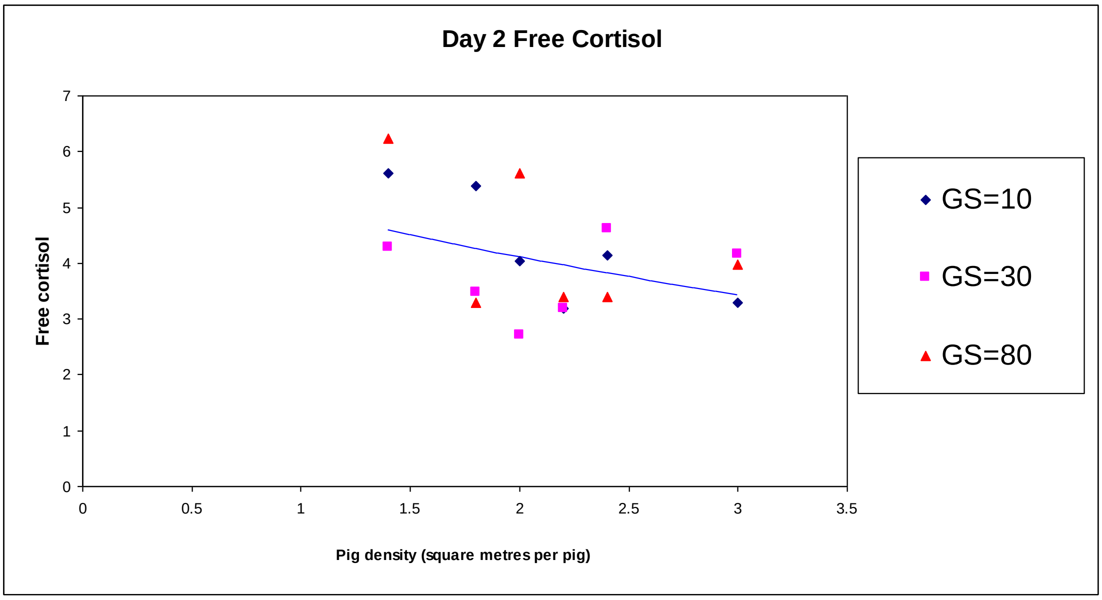

Figure 5: Predicted values of free cortisol concentrations at day 2 as a function of space per sow

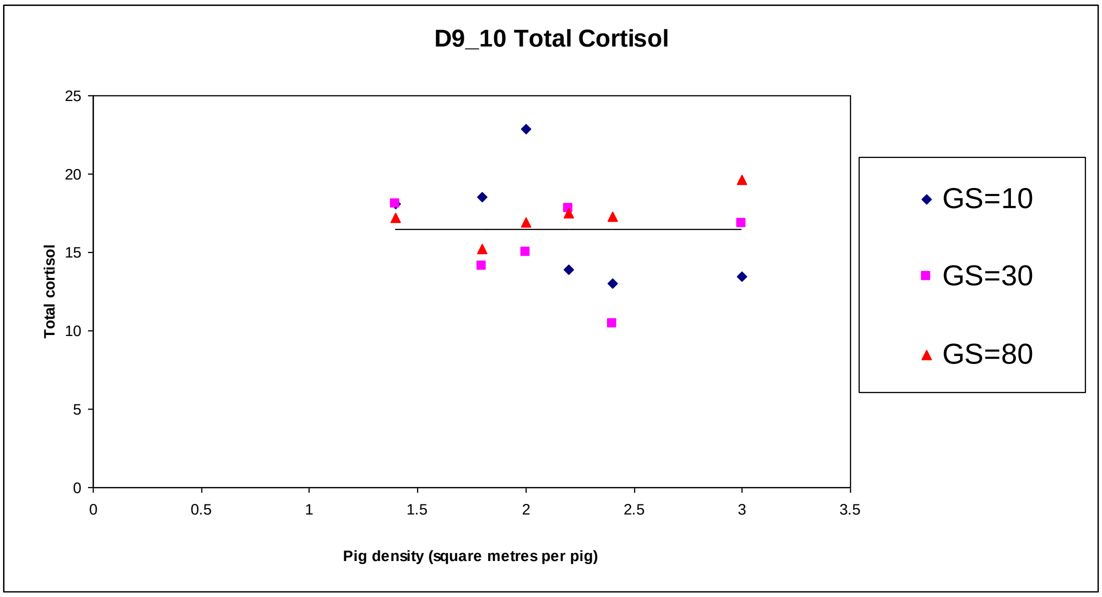

Figure 6: Predicted values of total cortisol concentrations at day 9 as a function of space per sow

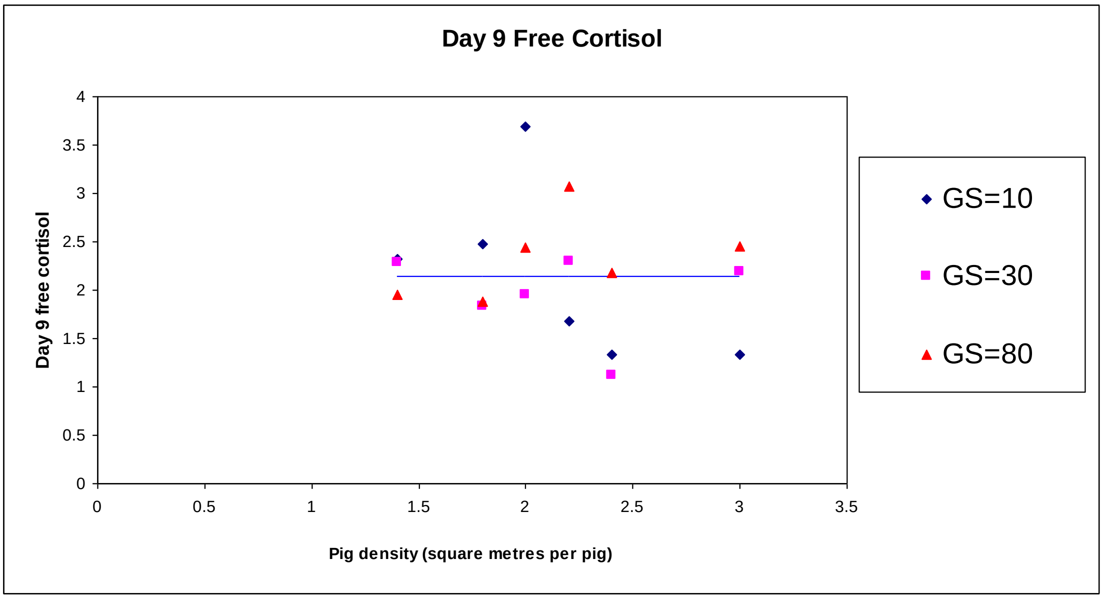

Figure 7: Predicted values of free cortisol concentrations at day 9 as a function of space per sow

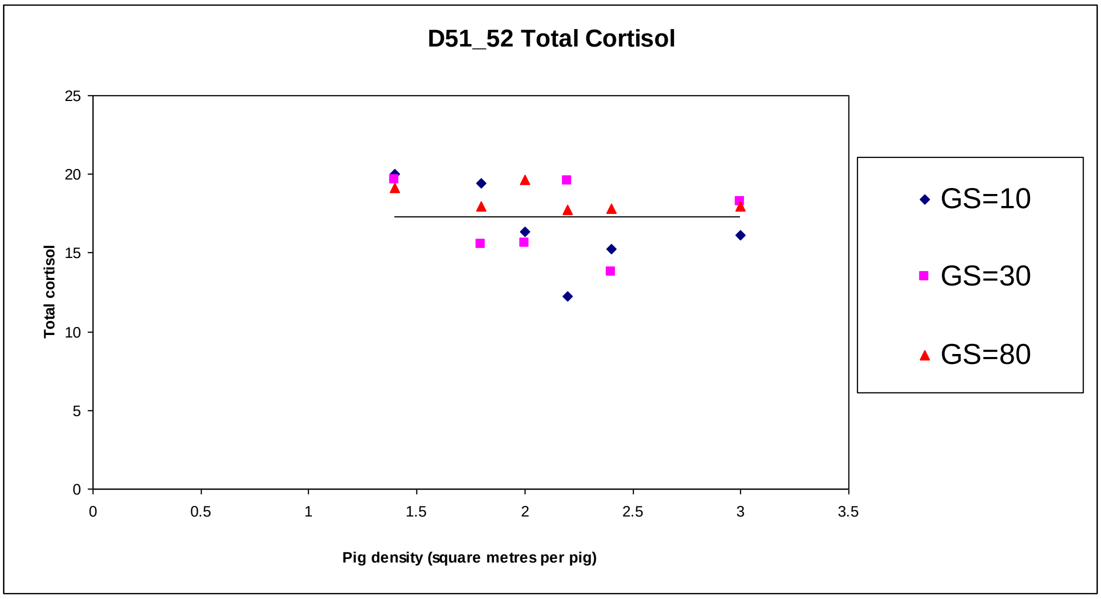

Figure 8: Predicted values of total cortisol concentrations at day 51 as a function of space per sow

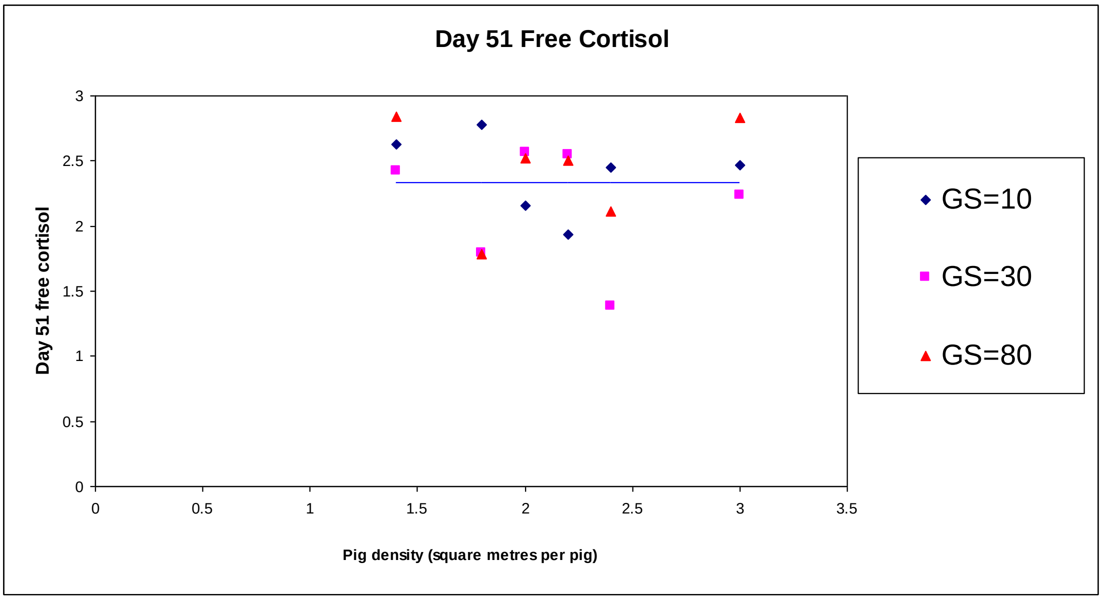

Figure 9: Predicted values of free cortisol concentrations at day 51 as a function of space per sow

As shown in Table 2, there were relationships between group size and space and the neutrophil to lymphocyte ratios at days 2, 9 and 51. The most parsimonious model predicting this ratio at days 2 and 51 included a group size effect in which a low neutrophil to lymphocyte ratio was associated with a group size of 10 (Figures 10 and 12). The most parsimonious model predicting the ratio at day 9 included a quadratic response to space whereby a high neutrophil to lymphocyte ratio was associated 1.4 m^2 and 3.0 m^2 of floor space (Figure 11).

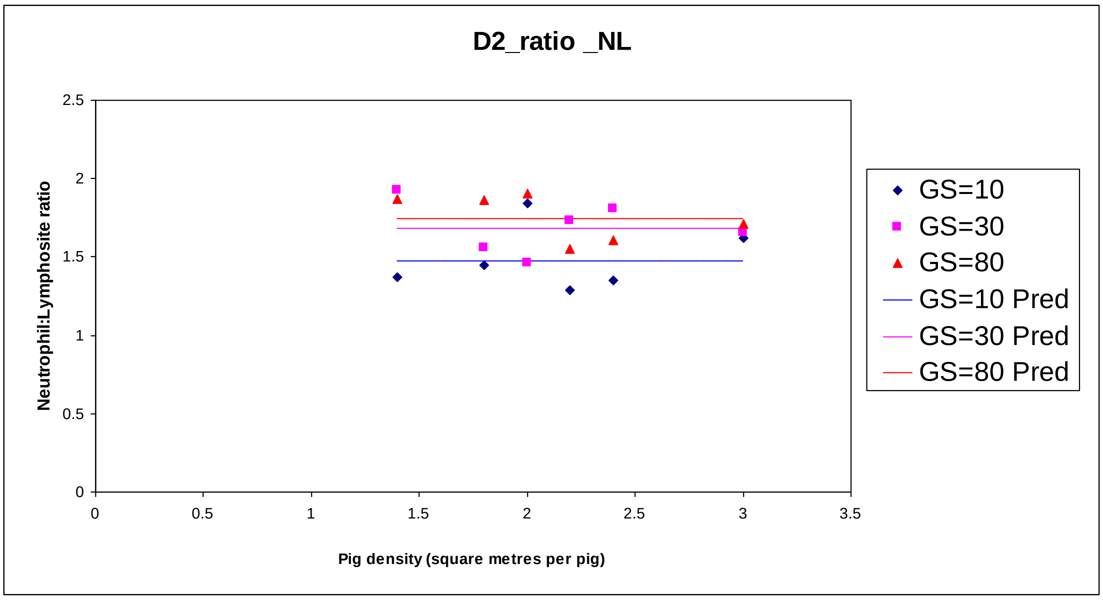

Figure 10: Predicted values of neutrophil to lymphocyte ratios at day 2 as a function of space per sow

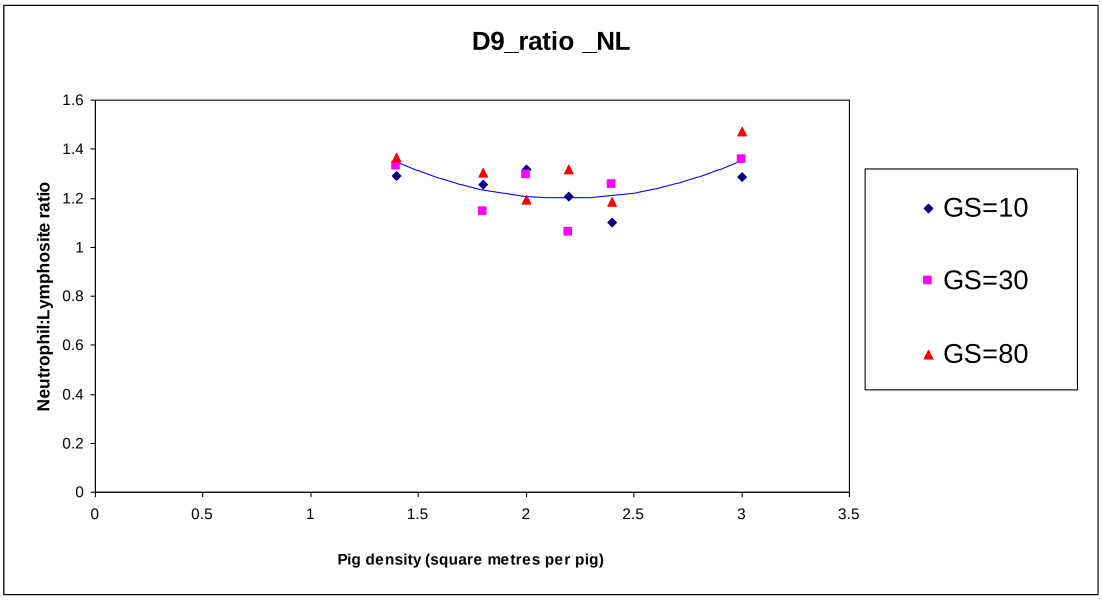

Figure 11: Predicted values of neutrophil to lymphocyte ratios at day 9 as a function of space per sow

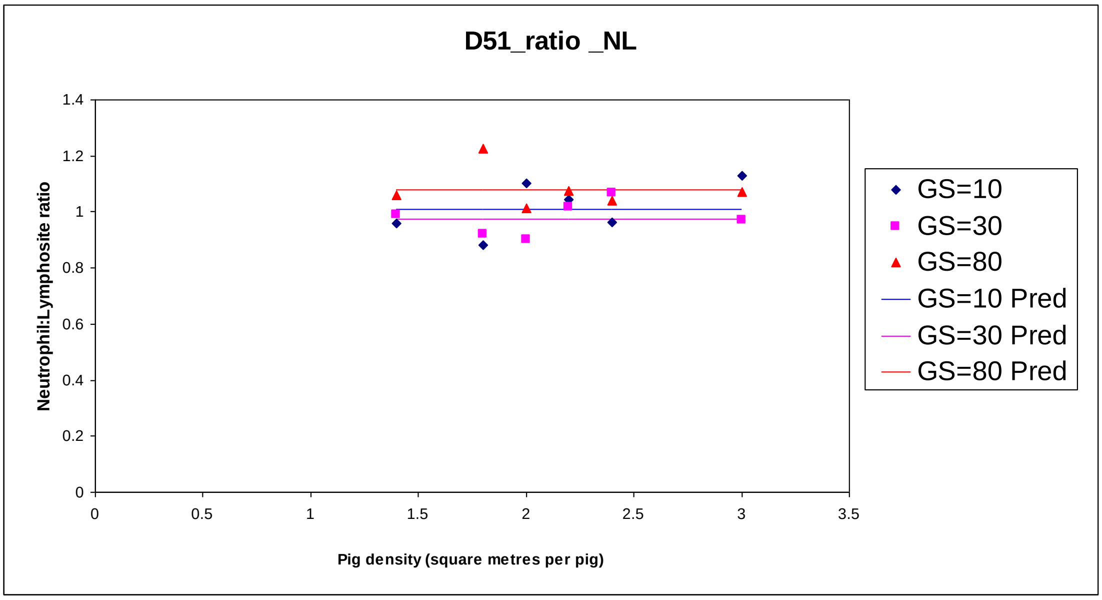

Figure 12: Predicted values of neutrophil to lymphocyte ratios at day 51 as a function of space per sow

Injuries

Over the study period there was a number of relationships between group size and injuries (Table 2 and Figures 13 to 18). The most consistent relationships were between group size and total injuries. The most parsimonious model predicting total injuries at days 9, 23 and 51 included a group size effect: total injuries were highest in groups of 30 at days 9 and 23 and highest in groups of 80 at day 51 (Figures 14 to 16). Groups of 10 had consistently low injuries from days 9 to 51. There was no relationship found between group size and space and injuries at day 2.

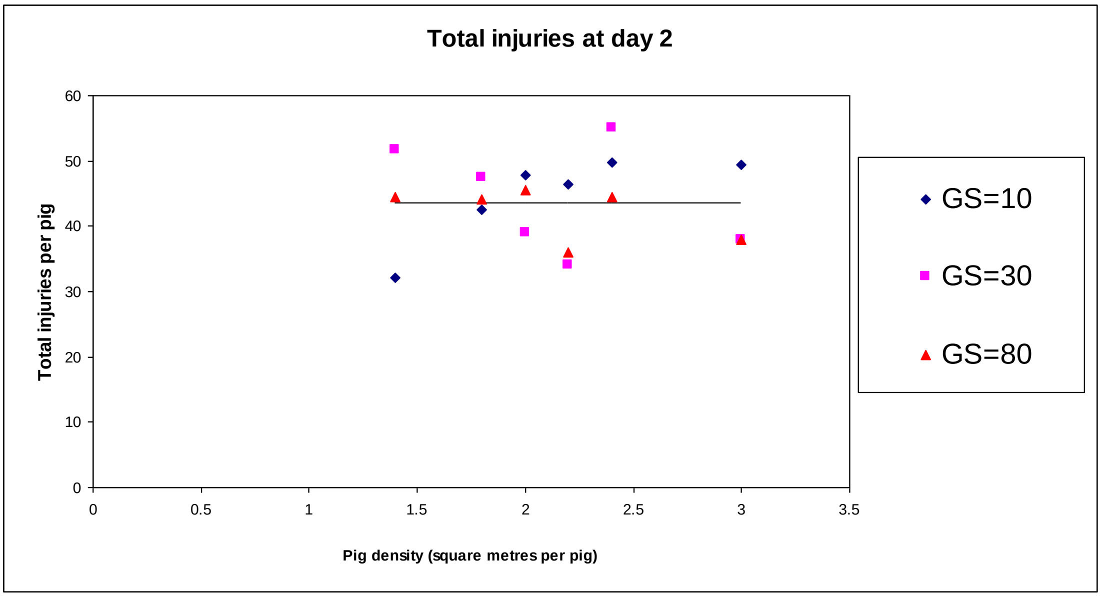

Figure 13: Predicted values of total injuries at day 2 as a function of space per sow

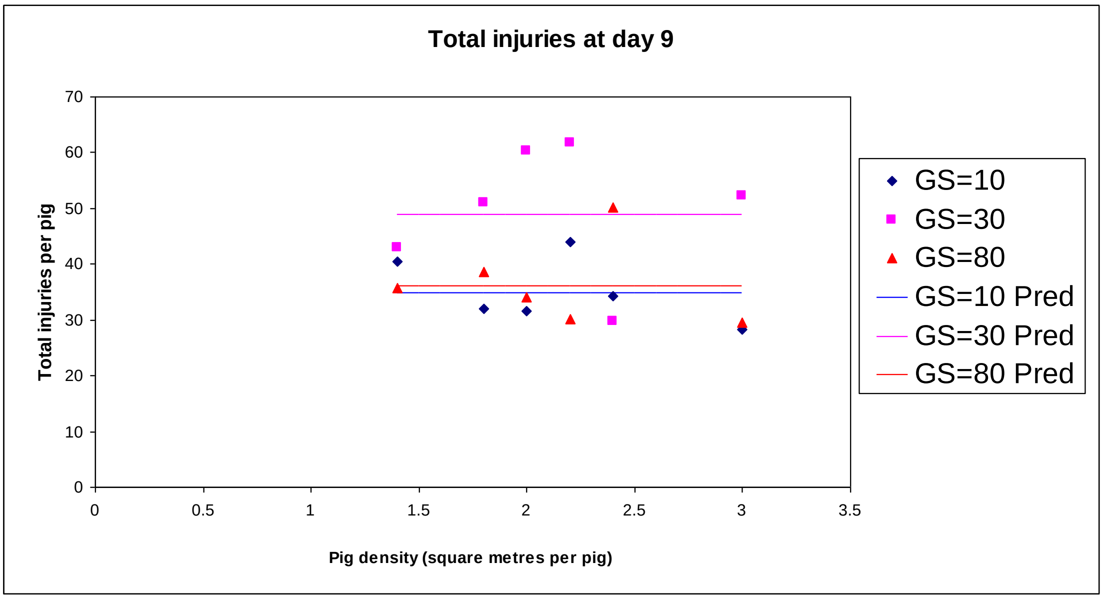

Figure 14: Predicted values of total injuries at day 9 as a function of space per sow

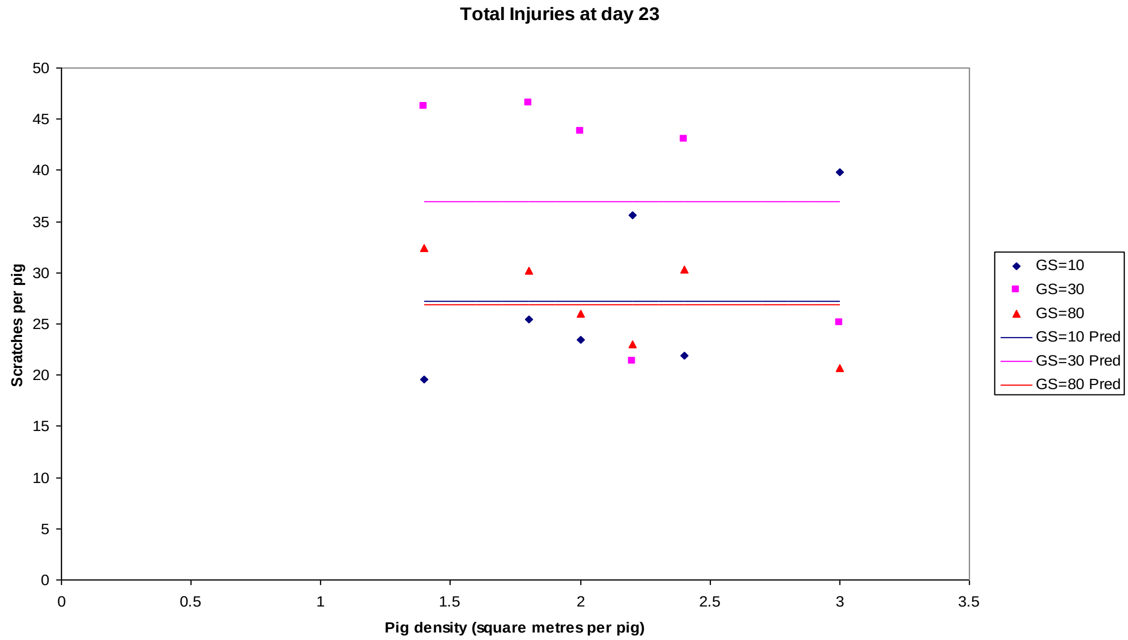

Figure 15: Predicted values of total injuries at day 23 as a function of space per sow

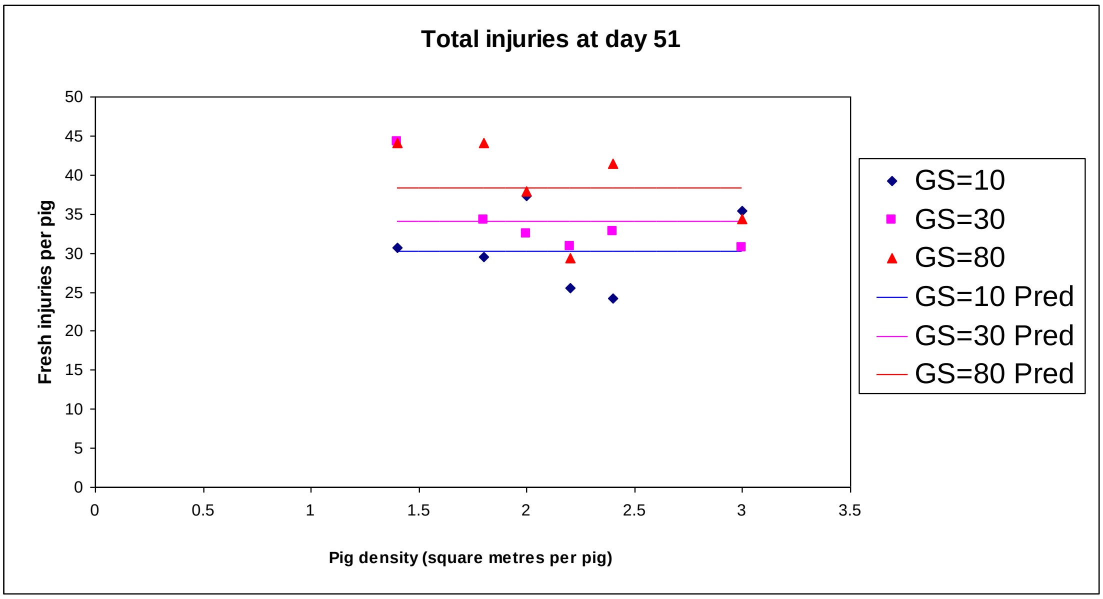

Figure 16: Predicted values of total injuries at day 51 as a function of space per sow

The only relationship found between group size and fresh injuries was at day 9 (Table 1), in which a low incidence of injuries was associated with a group size of 10 (Figure 18).

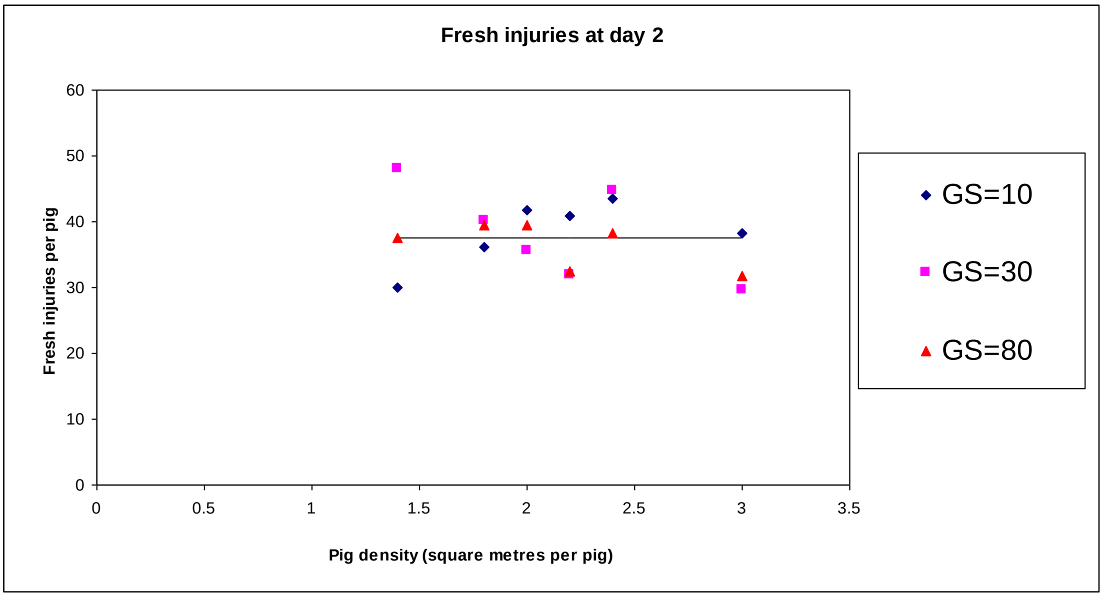

Figure 17: Predicted values of fresh injuries at day 2 as a function of space per sow

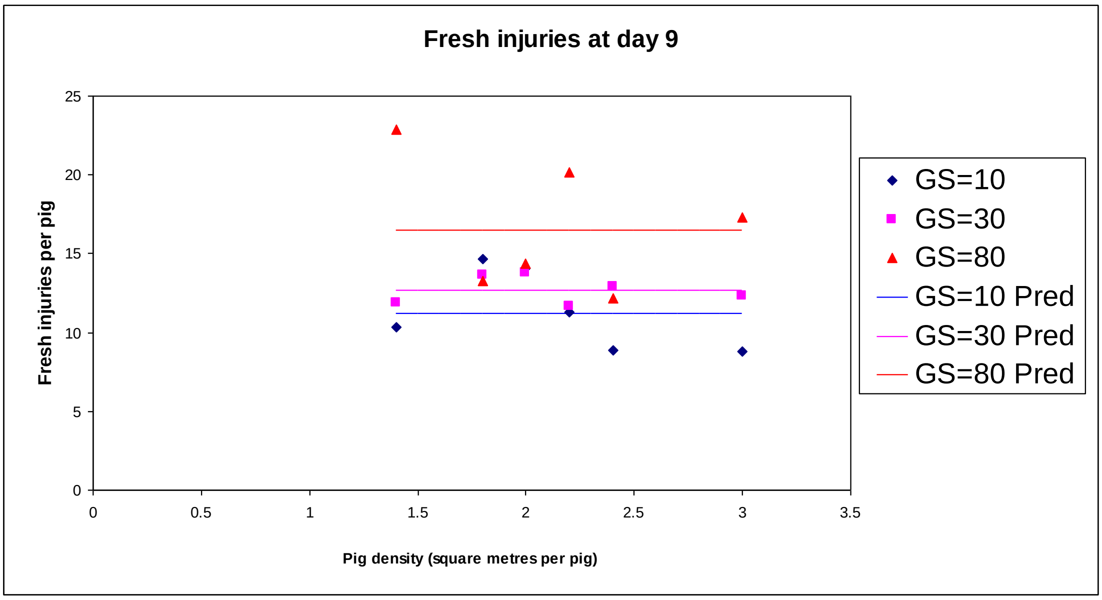

Figure 18: Predicted values of fresh injuries at day 9 as a function of space per sow

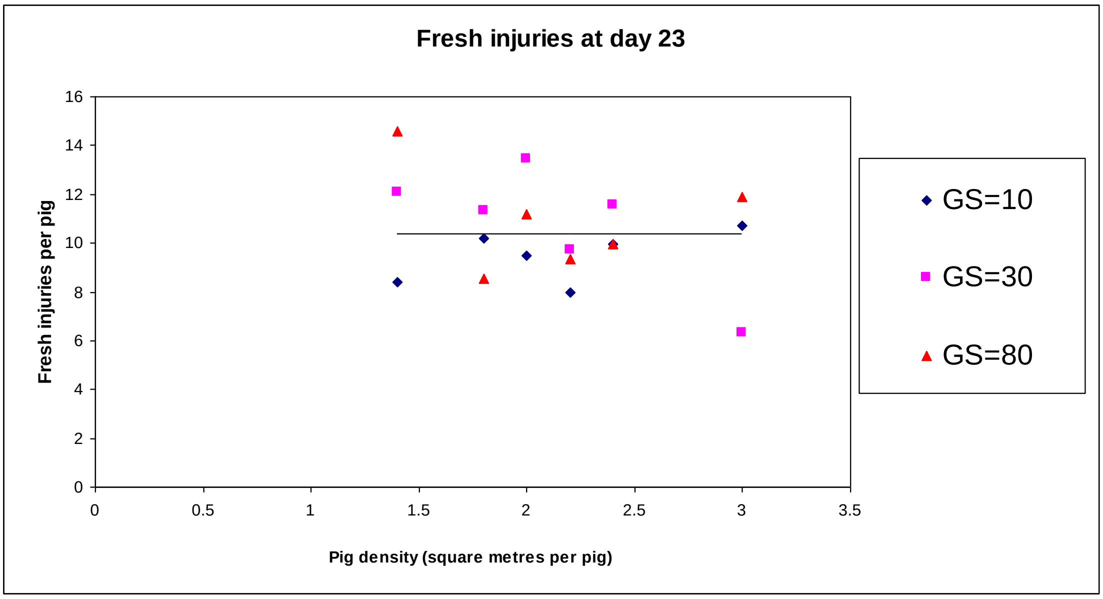

Figure 19: Predicted values of fresh injuries at day 23 as a function of space per sow

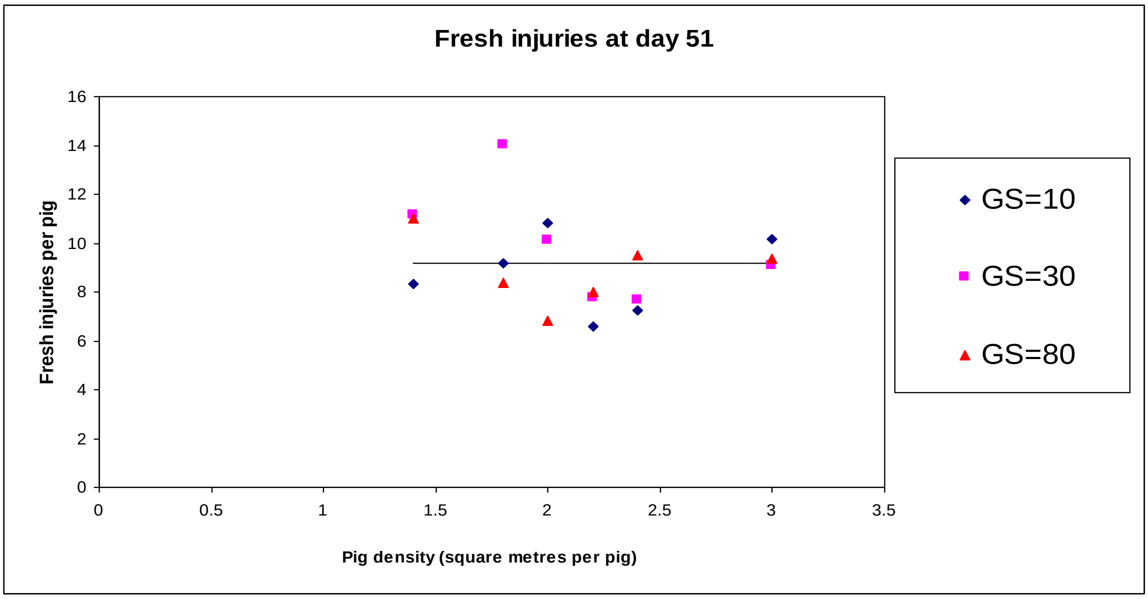

Figure 20: Predicted values of fresh injuries at day 51 as a function of space per sow

Reproductive Performance

There were no relationships found between the treatments of group size and space and litter size (born alive) and number of stillborns (Table 2 and Figures 21 and 22). However, there was a relationship found between the treatments of group size and space and farrowing rate (Table 2). The most parsimonious model predicting farrowing rate included a linear response to space: farrowing rate increased with increasing floor space (Figure 23).

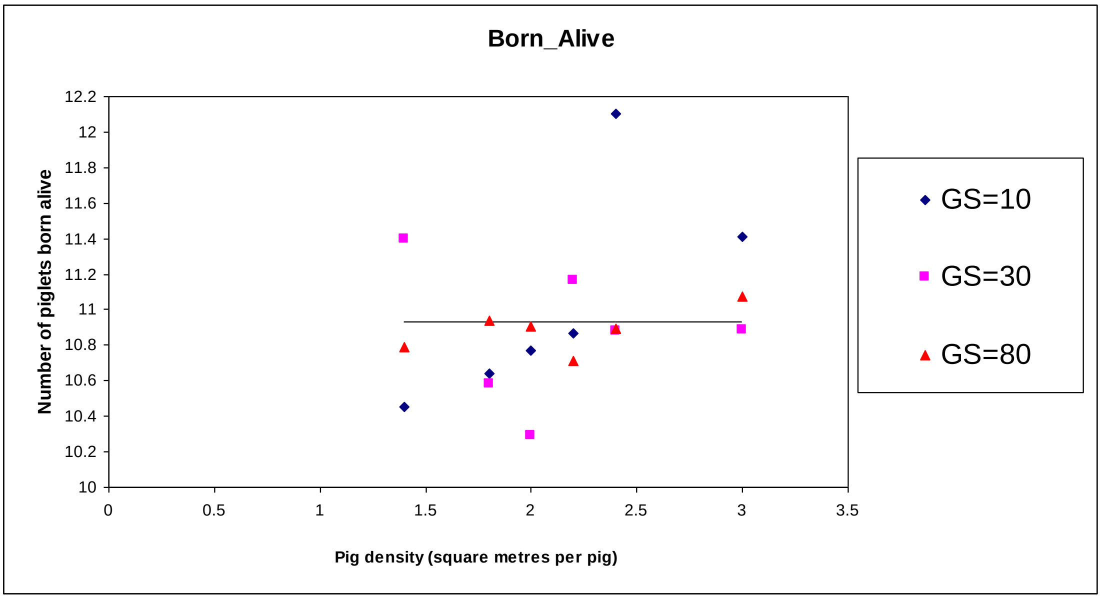

Figure 21: Predicted values of litter size (born alive) as a function of space per sow

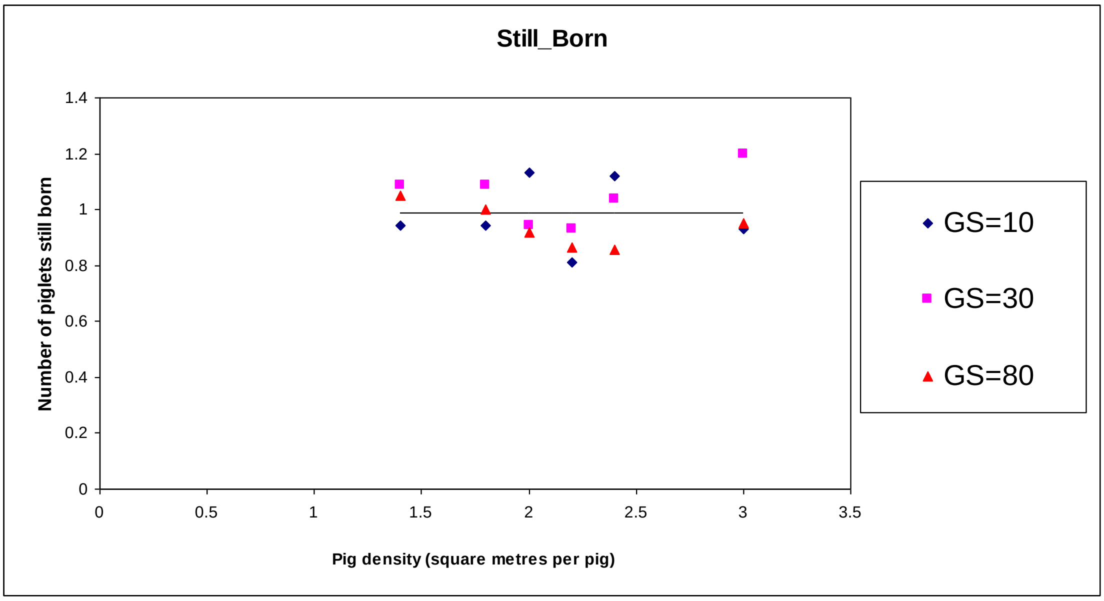

Figure 22: Predicted values of number of stillborns as a function of space per sow

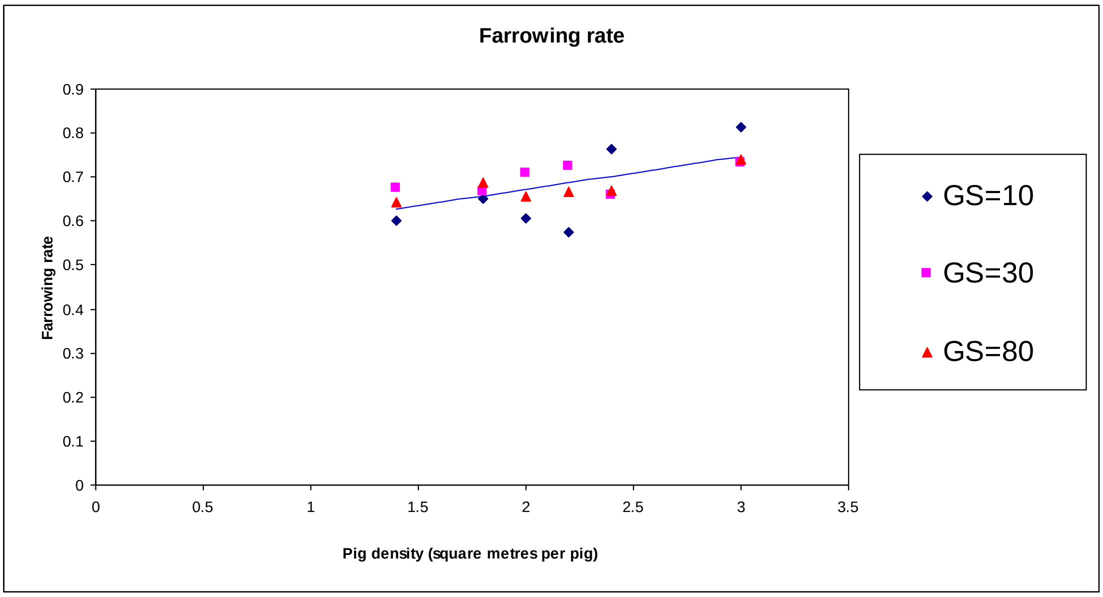

Figure 23: Predicted values of farrowing rate as a function of space per sow

Live Weight and Backfat

There were relationships found between the treatments and live weight and backfat gain (Table 2). The most parsimonious model predicting live weight included a group size effect: live weight gain was highest in groups of 10 (Figure 24). The most parsimonious model predicting backfat gain included a quadratic response to space: backfat gain was highest in a floor space of 1.4 m^2 (Figure 25).

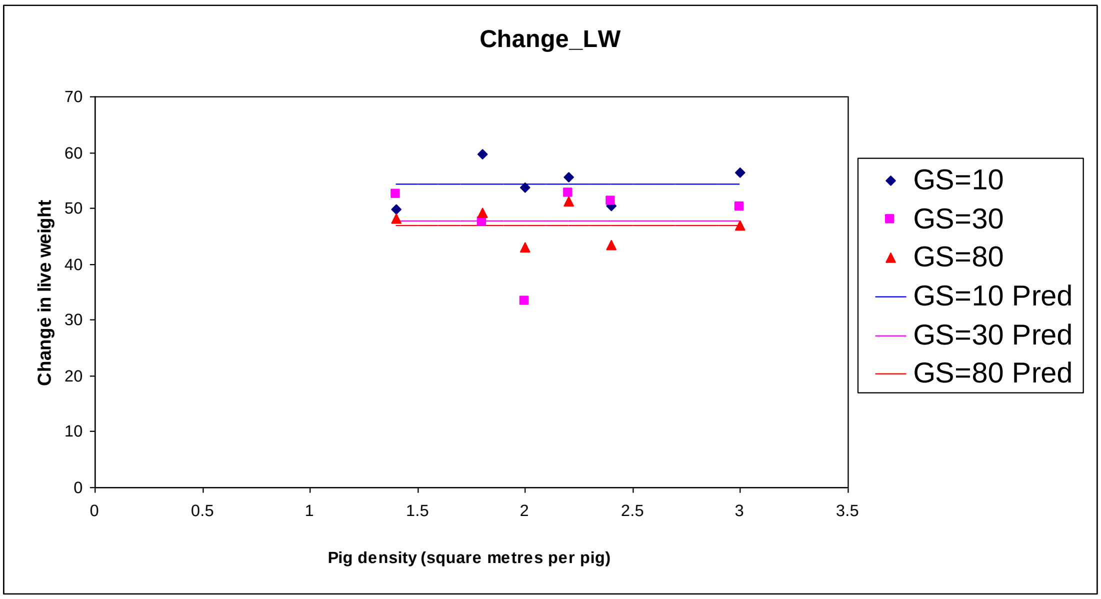

Figure 24: Predicted values of live weight change as a function of space per sow

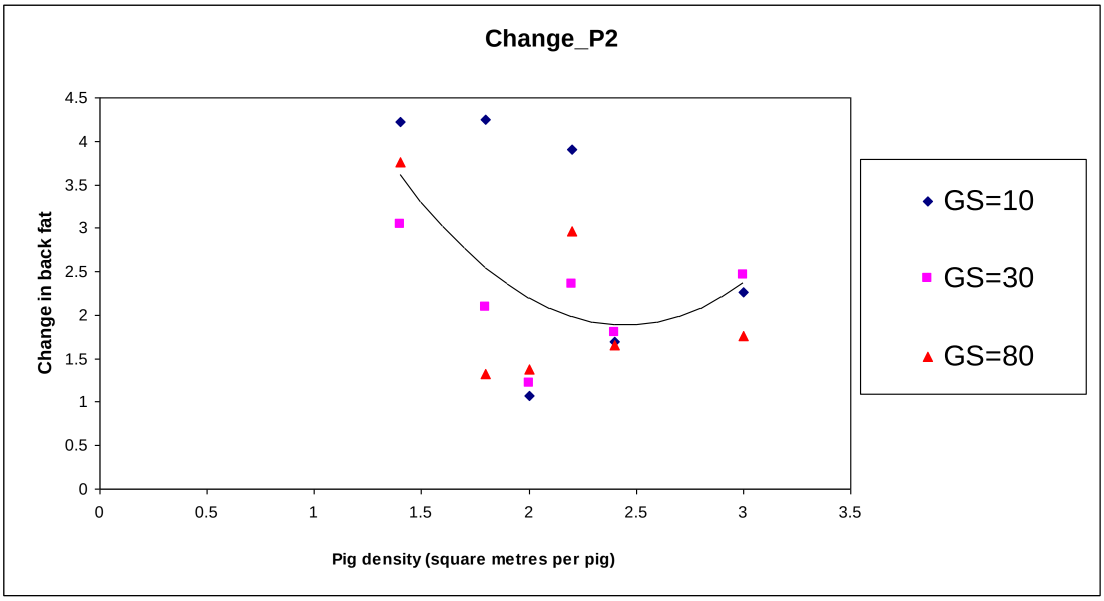

Figure 25: Predicted values of backfat (P2 measurement) change as a function of space per sow.

Discussion

Prior to discussing the results of the present experiment, it is necessary to comment on first, the use of static groups in this experiment and second, interpreting individual effects of group size and space allowance.

The use of static groups in which no additional sows are added, while limiting production flexibility, is often recommended on the basis of minimizing production losses associated with stress in the first 4 weeks after insemination (Levis, 2004; Gonyou, 2002; Stadler et al. 2007). Adding relatively small numbers of animals to established groups to maintain group size is likely to risk injury, stress and reproductive failure, particularly in the introduced sows. Thus, in this experiment, sows that suffered reproductive failure or injury or escaped from their pens were removed from the experiment and not replaced. It therefore should be recognized that the group size, and the nominal space allowance, only apply for a short period after sows are mixed. The treatments should thus be considered to mimic commercial outcomes when specific group sizes, and specific space allowances, are applied at the time sows were mixed in static groups after insemination.

There were few interactions, between group size and space allowance, observed in this experiment. In fact, there was no measurement in which the parsimonious model included both terms for group size. The important implication from this is that it is legitimate to discuss space allowance effects without the need to refer to group size effects, and it is legitimate to discuss group size effects without the need to refer to space allowance effects.

One of the most consistent effects found in the present experiment were those of floor space allowance on several parameters early in the treatment period. A key finding was the effects of space on aggression at feeding at day 2 of treatment, both total and free cortisol concentrations at day 2 of treatment and farrowing rate. For all four variables, there was a linear relationship with space: there was a general decline in aggression and both total and free cortisol concentrations with increasing space, while there was general increase in farrowing rate with increasing space. Aggression was not measured later in the treatment period, but there was no evidence that space affected total or free cortisol concentrations at days 9 and 51 of treatment. Surprisingly, there was no evidence that space affected fresh or total injuries at day 2 of treatment when there was evidence of space effects on aggression or subsequently at days 9, 23 and 51 of treatment.

These results on the effects of space on aggression and stress in grouped sows are generally supported by a number of previous experiments on gilts. Hemsworth et al. (1986) found that space allowance affected plasma cortisol concentrations in both non-pregnant and pregnant gilts. Both total and free cortisol concentrations at 9-11 days of treatment in non-pregnant gilts were higher at a space of 1.0 m^2 than the 3.0 m^2 per gilt. In one of two replicates, plasma total and free cortisol concentrations were higher at 2.0 m^2 than 3.0 m^2. Similar treatment effects on plasma total and free cortisol concentrations were apparent at 12 weeks of gestation. Barnett et al. (1992) found that plasma cortisol concentrations, both total and free, at 28-29 and 49-51 days of treatment were elevated and immunological responsiveness at the 50-57 days of treatment was reduced in gestating gilts housed at a space allowance of 1.0 m^2 than 2.0 m^2. Barnett et al. (1992) also found that aggression in gilts around feeding on day 2 of treatment was higher at a floor space of 1.0 m^2 than 2.0 m^2, however, there was no effect of space on skin lesions measured on day 10 of treatment. Similarly, Barnett (1997) found that plasma cortisol concentrations, both total and free, at 36 and 53 days of treatment were higher in gestating gilts housed with a space allowance of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt. Cortisol response to ACTH was also higher in the floor space of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt. Barnett (1997) also found that aggression around feeding measured frequently from days 2 to 54 of treatment was higher in gilts housed in groups of five with a space of 1.0 m^2 than 1.4 or 2.0 m^2, but there was no difference in aggression between the floor spaces of 1.4 or 2.0 m^2 per gilt. Therefore, in addition to the evidence that cortisol concentrations are elevated at 9-11 days of treatment at 1.0 m^2 than 2.0 or 3.0 m^2/gilt (Hemsworth et al., 1986), these experiments show that cortisol concentrations are elevated at (1) 12 weeks of treatment at a space allowance of 1.0 m^2 than 3.0 m^2 per gilt (Hemsworth et al., 1986); (2) at 28-29 and 49-51 days of treatment at a space allowance of 1.0 m^2 than 2.0 m^2 per gilt (Barnett et al., 1992); and (3) at 36 and 53 days of treatment at a space allowance of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt (Barnett, 1997). In contrast, the present experiment indicates a relationship between space and cortisol concentrations at day 2 of treatment but not days 9 and 51 of treatment.

There were no effects of space on fresh or total injuries at days 2, 9, 23 and 51 of treatment in the present experiment. As discussed above, while Barnett et al. (1992) found increases in both aggression and cortisol concentrations at a floor space of 0.98 m^2, there was no effect of space on skin lesions at day 10 of treatment. However there is evidence that space can affect injuries in sows. Weng et al. (1998) found that aggression in sows in groups of 6 on days 6 and 7 of treatment was higher at a space allowance of 2.0 m^2/sow than at 2.4 and 3.6 m^2/sow, which in turn was higher than at 4.8 m^2/sow. The total number of skin lesions measured on day 7 of treatment generally reflected the level of aggression: number of lesions was higher at 2.0 m^2/sow than 2.4 m^2/sow, which in turn was higher than in 3.6 and 4.8 m^2/sow. Salak-Johnson et al. (2007) found that sows in groups of 5 at a space allowance of 1.4 m^2/sow had consistently higher lesion scores than those at 2.3 or 3.3. m^2/sow. In the studies by Weng et al. (1998) and Salak-Johnson et al. (2007), sows were introduced to their treatments at 25 days post-insemination and 7-10 weeks post-insemination.

Therefore in summary, there are both similarities and differences in the results of the previous and present experiments. Hemsworth et al. (1986), Barnett et al. (1992) and Barnett (1997) found that cortisol concentrations were generally higher in both the short and long term at 1.0 m^2 than at 1.4, 2.0 or 3.0 m^2/gilt. In the present experiment, space affected cortisol concentrations in the short term but not the long term. Barnett et al. (1992) and Barnett (1997) found that while aggression in gilts was higher in both the short and long term at 1.0 m^2 than at 1.4 or 2.0 m^2/gilt, the incidence of skin lesions was not affected. In the present experiment, space also affected aggression in sows but not skin lesions. In contrast, Weng et al. (1998) found that aggression and skin lesions in sows were higher in the short term at 2.0 m^2/sow than at 2.4, 3.6 and 4.8 m^2/sow, while Salak-Johnson et al. (2007) found that skin lesions in sows were higher in the short and long term at 1.4 m^2/sow than at 2.3 or 3.3. m^2/sow. These results indicate that space can affect aggression, injuries and stress physiology, however the main areas of contention are the short term vs long term effects of space on stress physiology and the effects of space on injuries. These two areas of contention will be considered here to assist in interpreting the implications of the present results.

There are several explanations for the conflicting results on the effects of space on stress physiology in the long term. First, the experiments in which long term effects of space were found (Hemsworth et al., 1986; Barnett et al., 1992; Barnett, 1997) studied gilts, which because of smaller body sizes may have different space requirements than sows. Nevertheless, although the lowest space allowance studied in the present experiment was 1.4 m^2, long term elevations in cortisol were consistently found in these previous experiments at 1.0 m^2 rather than 1.4 m^2 or 2.0 m^2. Second, the cortisol data in the long term in the present experiment suggests that sows may adapt to low space allowances. There is evidence, particularly in rodents, that as gestation proceeds and during lactation there is a dampening of the HPA axis' response to stressors (Lightman et al., 2001). Third, since sows were removed from treatment if they suffered reproductive failure or injury or escaped from their pens, sufficient space may have been provided to reduce stress in pens with allocated low space allowances. However, only a small percentage of sows (0.95%) was removed from the study prior to day 9 of treatment, the time of the second cortisol sample. Furthermore, the predicted values from the REML models indicate no cortisol response at days 9 and 51 (Figures 6-9) as a function of increasing space from 1.4 through to 3.0 m^2.

There are also several explanations for the conflicting results on the effects of injuries. Weng et al. (1998) found short term effects of space on skin lesions. While established groups of sows were studied from mid to late gestation, the incidence of injuries generally appeared lower than in the present experiment. For example, treatment means for the number of skin lesions per sow varied from 9 to 22 at day 7 in the experiment by Weng et al. (1998) compared to 28 to 63 at day 9 in the present experiment. Furthermore, while aggression is likely to lead to skin lesions, contact with pen features associated with movement in the pen and avoidance of other animals as well as pen design and flooring, may also lead to injuries (Karlen et al., 2007). In contrast to these results, Salak-Johnson et al. (2007) found that skin lesions in sows were higher in the short and long term at 1.4 m^2/sow than at 2.3 or 3.3. m^2/sow.

With the effects of space on aggression and cortisol at day 2 of treatment found in the present experiment, the effects of space on farrowing are not unexpected since there is evidence that stress post-insemination can adversely affect reproductive performance of sows. While it is generally agreed that stress can impair reproduction, Turner et al. (2005) in a review of the literature concluded that reproduction in female pigs is resistant to the effects of acute or repeated acute stress or acute or repeated acute elevation of cortisol, even if these occur during the series of endocrine events that induce oestrus and ovulation. In contrast, the authors concluded that prolonged stress and sustained elevation of cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appears to be resistant to the effects of prolonged stress or sustained elevation of cortisol. For example, housing gilts in tether stalls, which results in sustained elevation of plasma concentrations of free cortisol (Barnett et al., 1985), reduced pregnancy rate compared to the housing of gilts in groups (Barnett and Hemsworth, 1991). In contrast to the present study, Salak-Johnson et al. (2007) found no effects of floor space allowance (1.4, 2.3 or 3.3. m^2/sow) on the reproductive performance of the sows. However, sows were introduced to their treatments at 25 days post-insemination, a period in which complete reproductive failure is less likely (Ashworth and Prickard, 1998).

The other consistent effect found in the present experiment was that of group size on injuries. While aggression at day 2 of treatment was not affected by group size, the incidence of total skin lesions was affected by group size. Groups of 10 had consistently low injuries from days 9 to 51, with the highest incidence of total injuries at days 9 and 23 in groups of 30 and at day 51 in groups of 80. In relation to fresh injuries, a low incidence of fresh injuries at day 9 was associated with a group size of 10. It should be recognized that fresh injuries provide information on injuries over a smaller timeframe than total injuries which include both fresh and old injuries.

There is little information in the literature on the effects of group size on injuries in sows. Edwards et al. (1993) reported that commercial experience has suggested that aggression is reduced when sows are mixed into larger groups. Most of the limited number of studies on the effects of group size are confounded by space allowance or feeding system. Research by Taylor et al. (1997) has shown that varying group sizes, of 5, 10 20 and 40 sows with a space allowance of 2.0 m^2/sow, while aggression, which was measured on days 1 and 2 of treatment, increased as group size increased, the number of lesions, measured on days 5 and 53 of treatment, were similar across treatments. Taylor et al. (1997) found no treatment effects on reproductive performance. While aggression is likely to lead to skin lesions (Turner et al., 2006), as suggested earlier other factors such pen design, feeding system and flooring may affect the incidence of injuries.

There was a number of other effects found in the present experiment that are difficult to interpret. In relation to the neutrophil to lymphocyte ratio, there were significant relationships between group size and this immune parameter at days 2 and 51, but not 9. At days 2 and 51, a low neutrophil to lymphocyte ratio was associated with a group size of 10. At day 9, there was a relationship between space and the neutrophil to lymphocyte ratio, with a low ratio associated with intermediate space allowances. Stressors can be deleterious to immune function and studies in a number of species have shown that increasing corticosteroid (endogenous or exogenous) concentrations result in a redistribution of white blood cells, such as an increase in neutrophils, a decrease in lymphocytes and thus a higher ratio of neutrophils to lymphocytes (Gross and Seigel, 1983; Roth, 1985; Brown-Borg et al., 1993; Dhabhar et al., 1995, 1996; Dee, 1999; Kehrli et al., 1999). While group size was related to the neutrophil to lymphocyte ratios at days 2 and 51, there were no effects of group size on cortisol concentrations. Injuries are unlikely to lead to marked or sustained changes in neutrophil and lymphyocte cell numbers in the plasma. "Physiologic neutrophilia", that is an increase in neutrophils within physiological ranges, is most common during fear, excitement or strenuous exercise (Smith, 2006) and thus increases in the neutrophil to lymphocyte ratio are mainly due to increases in neutrophils. Substantial injury that causes purulent tissue inflammation and tissue damage will increase in neutrophils, however scratches and minor cuts that commonly observed in group-housed sows are unlikely to affect neutrophils. Thus the relationship between group size and injuries does not explain the relationships between group size and neutrophil to lymphocyte ratio. Although there was a relationship between space and cortisol at day 2 of treatment but no relationship between space and the neutrophil to lymphocyte ratio at day 2, it is possible that the higher cortisol concentrations with reduced floor space at day 2 (which may have extended beyond day 2) may have led to a subsequent high neutrophil to lymphocyte ratio with reduced space at day 9. However this explanation is tenuous.

There were also relationships between the treatments and live weight and backfat gain. Live weight gain was highest in groups of 10 and backfat gain was highest in a floor space of 1.4 m^2. Again explanations for these relationships are not obvious. Sows in groups of 10 had consistently low injuries throughout the study and thus it is possible that these sows may have been more settled around feeding, allowing for less feed wastage and increased feed intake. The higher backfat gain in the groups with 1.4 m^2 is surprising, particularly since sows in these groups had higher cortisol concentrations early in the study. However, Sargent (2001) found that ACTH treated pigs had a higher feed intake, were fatter at the carcass P2 back fat and leg fat sites and had more visceral fat. Experiments conducted on broiler chickens, pheasants and rats (see Sargent, 2001) have shown that chronic treatment with corticosterone increased feed intake and fat deposition in the abdominal area. Forbes (1995) administered corticosteroids to sheep and cattle with the result of increased carcass fatness and feed intake. Sows with reduced space in the present study had elevated cortisol concentrations early in the study and perhaps stress at this stage of reproduction may have affected fat deposition during gestation. In contrast to these results, Salak-Johnson et al. (2007) found that sows grouped 25 days post-insemination in pens at 1.4 m^2/sow generally had lower condition score, body weight and backfat throughout gestation than those in pens at 2.3 or 3.3 m^2/sow.

The present results indicate that space affects aggression, stress physiology and reproduction in sows. While the effects of space on stress physiology were found early in treatment, the effects of space on farrowing rate highlight that stress might be biologically important in the period shortly after in the formation of a static group of sows that have been recently inseminated. Furthermore, the results indicate that the effects of space are most pronounced early after grouping. Indeed, it appears that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the need to reduce aggression and stress at mixing.

While these effects of space early after grouping have sow productivity implications, interpreting the welfare implications is problematic. When relying on behavioural, physiological and fitness measures to determine welfare risks, a judgement is made about what degree of change in these indicators is likely to indicate that a sow's welfare is compromised. Based on the effects of space on aggressive behaviour, cortisol concentrations and farrowing rate, it is credible to judge that, within the range of sow densities in this study, sow welfare improves as floor space allowance increases. This judgement is supported by the results of Hemsworth et al. (1986), Barnett (1997), Weng et al. (1998) and Salak-Johnson et al. (2007).

The space allowance at which sow welfare is acceptable is difficult to determine from the present results. Farrowing rate appears to be linearly related to space up to 3.0 m^2/sow (Figure 23). However, further examination of the results for farrowing rate and, in particular, how the response differs with replicate, indicates that the response of farrowing rate to space differs with replicate (Figure 26). By far the largest response, with farrowing rate increasing from about 0.3 at 1.4 m^2/sow to about 0.6 at 3 m^2 /sow, occurs in replicate 2. Sows in replicate 2 commenced treatment in the summer season (5th January to 2nd February 2009). A weaker, but still positive, response occurred in replicate 1 in which sows commenced treatment spring (22nd September to 20th October 2008). On the other hand, there was no farrowing rate response to space allowance in replicates 3 and 4 (autumn, 20th March to 18th May 2009 and spring, 3rd August to 31th August 2009). Sows studied in replicate 2 may have experienced what might be considered as 'seasonal infertility'. Seasonal infertility is a reduction in fertility and, at times, fecundity in breeding pigs at a particular period of the year, usually summer and early autumn (Hughes and van Wettere, 2010). Causes of seasonal infertility are not fully understood, although it is generally considered to be due to either long daylight hours and/or higher environmental temperatures. In an analysis of the reproductive records of 610,117 sows at 266 indoor farms in France, Auvigne et al. (2010) concluded that seasonal infertility, defined as the relative difference between the fertility rate in summer (inseminations in weeks 25–42) and winter (inseminations in weeks 1–18 of the same year), was related to photoperiod with heat stress having exacerbating effect.

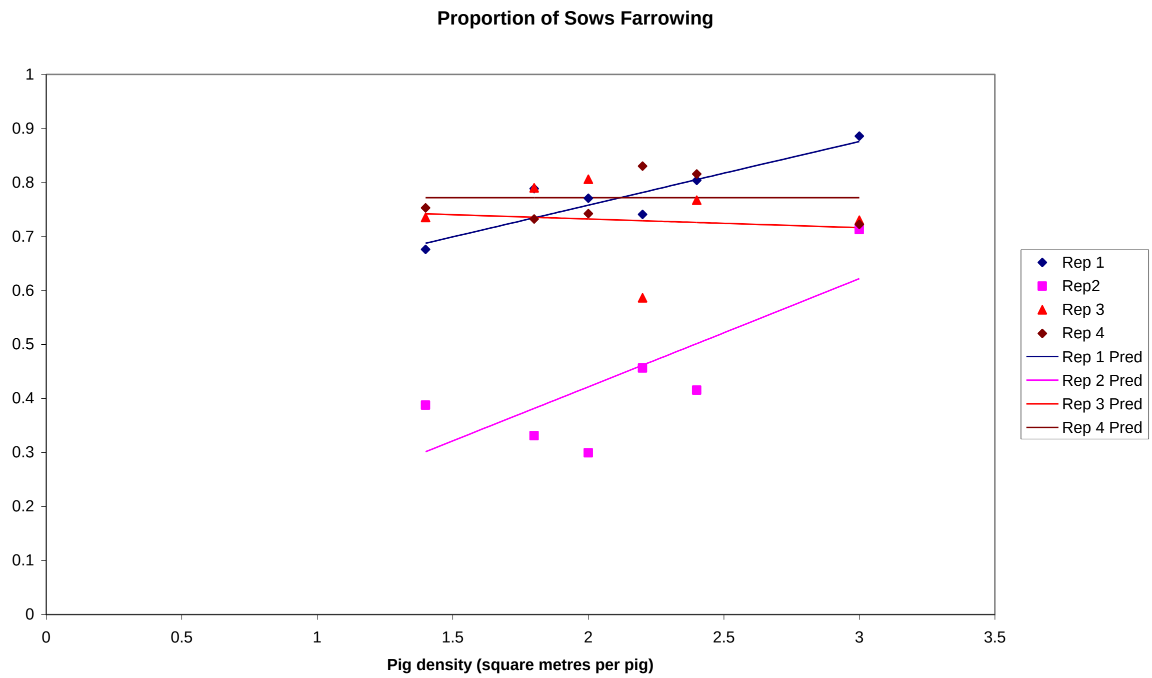

Figure 26: Predicted values of farrowing rate as a function of space per sow and replicate

The message from these results appears to be that in the conditions in which replicate 2 was studied, anything less than 3 m^2/sow will compromise reproductive productivity. In conditions in which the other replicates were studied, farrowing rate might not be compromised even at a space allowance of 1.4 m^2/sow. Furthermore, these results suggests that the effects of seasonal infertility may be alleviated in groups of sows by ensuring floor space allowances somewhere greater than 3 m^2/sow.

The results for total and free cortisol at day 2 are different, in that there is no detectable replicate effect. Although the results are in accord with a linear decline in day 2 cortisol from 1.4 m^2/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow (Figure 5). The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

In relation to seasonal infertility, the results also suggest that although there was no replicate effect on aggression and stress, the fertility of sows in replicate 2 was more susceptible to stress than in other replicates. This raises the question of whether an important feature of seasonal infertility in sows is an increased susceptibility to stress at this time of the year: while the cortisol response to space was not affected by replicate, the farrowing rate response to space was affected by replicate. This clearly requires further investigation because of the general practical implications of seasonal infertility. Furthermore in relation to the present topic, further research is clearly required because sows may require more space in summer to maintain their fertility.

While there were no effects of group size on aggression, cortisol concentration or reproduction, sows in groups of 10 generally had less injuries throughout the study and, although difficult to explain, is an outcome that is desirable from a welfare perspective.

Therefore, further research is required to examine the effects of space allowance in the range of 1.8 to 2.4m^2/sow in more detail. Particular attention should be given to the effects of space and time of mixing relative to insemination (days 1 to 4 post-mixing), since this is the period when aggression and stress are likely to be most pronounced. This research should also include an examination of the effects of pen features, such as feeding stalls and feeding systems, since these are likely to affect aggression and stress.

Experiment 2: Effects of Time of Mixing

Aims

This experiment examined the effects of housing sows in gestation stalls or in groups with shoulder feeding stalls from either 1 or 35 days post-insemination on stress, injuries, live weight and backfat changes and reproductive success.

Furthermore, this experiment also examined the feasibility of modifying existing gestation stalls to group pens with shoulder feeding stalls. The feasibility was assessed in terms of the practicality of the group housing system as well as the stress, injuries and reproductive success of the sows in the group housing system relative to those in gestation stalls.

The hypothesis tested in this experiment was that sows housed in group housing with shoulder feeding stalls and $1.5m^2$ per sow pen space from either 1 or 35 days post insemination have similar welfare and reproductive performance to those housed in stalls for their entire gestation.

Materials and Methods

Facilities

This experiment was conducted in a modified breeding and gestation unit in a large commercial piggery in Corowa, NSW, Australia, and commenced in September 2009 and concluded in September 2010. The accommodation facility had a galvanized roof and adjustable blinds on the sides and overhead water sprinklers that were activated for 3 minutes on and 15 minutes off when the internal temperature exceeded 26°C.

All procedures were conducted with the approval of the Rivalea animal ethics committee.

Animals

A total of 540 mated sows, in three time replicates (180 sows per replicate) over 12 months, were studied. The sows were Large White x Landrace of mixed parity and good health at the beginning of the experiment. The sows were artificially inseminated in individual mating stalls and within an average of 2 days after their second insemination, were randomly allocated to housing treatment (day 1 of treatment). All sows that returned to oestrus, or were deemed not pregnant during the pregnancy test, died or were culled/removed for welfare reasons were recorded and removed from the experiment.

Housing Treatments

The following three housing treatments were studied:

1. GESTATION STALL: Sows were housed in individual gestation stalls after their second insemination (day 1) for their entire gestation. The stalls were 0.6 m wide x 2.1 m in length including the feed trough.(Photograph 1).

2. GROUP: Sows were housed in groups of 10 after their second insemination (day 1) for their entire gestation. The pens were 4.9m long x 3m wide providing 1.5m^2 of floor space per sow. The pens contained 10 shoulder feeding stalls that were 0.8m long x 0.6m wide (see Photographs 2 and 3).
3. GESTATION STALL + GROUP: Sows were housed in individual gestation stalls after their second insemination from day 1 to day 35, and then mixed in groups of 10 in pens with 10 shoulder feeding stalls for the remainder of gestation. The gestation stalls and the group pens with shoulder feeding stalls were identical to those used in the first two treatments. (Photographs 2 and 3).

   At day 35, 'non-experimental' sows that were of the same stage of pregnancy and had been housed in gestation stalls were used to replace sows allocated to this treatment that were not pregnant in order to ensure group sizes of 10 at mixing. These non-experimental sows were not included in the data analysis.

In each of the three time replicates, 180 mated sows were randomly allocated to each of the three treatments (i.e. 6 'groups' or experimental units of 10 sows to each of three treatments, GESTATION STALL, GROUP and GESTATION STALL + GROUP). The sows were transferred to their respective treatments within three days of insemination. The housing treatments were located within the same area of the facility (Figure 22). In this experiment, day 1 denotes the first day of housing treatment.

Sows commenced treatment in the three replicates in September 2009, January 2010 and March 2010, respectively.

Feeding

All sows were fed once daily at approximately 0730 h with 2.5 kg/day of a commercial diet (13.1 MJ/kg DM and 12.8% crude protein). The feed was delivered by an automatic feed delivery system that delivered total daily feed into an individual feeding trough at the front of the gestation stall or shoulder feeding stall. Water was provided *ad libitum* via nipple drinkers attached to the back wall over the slatted flooring.

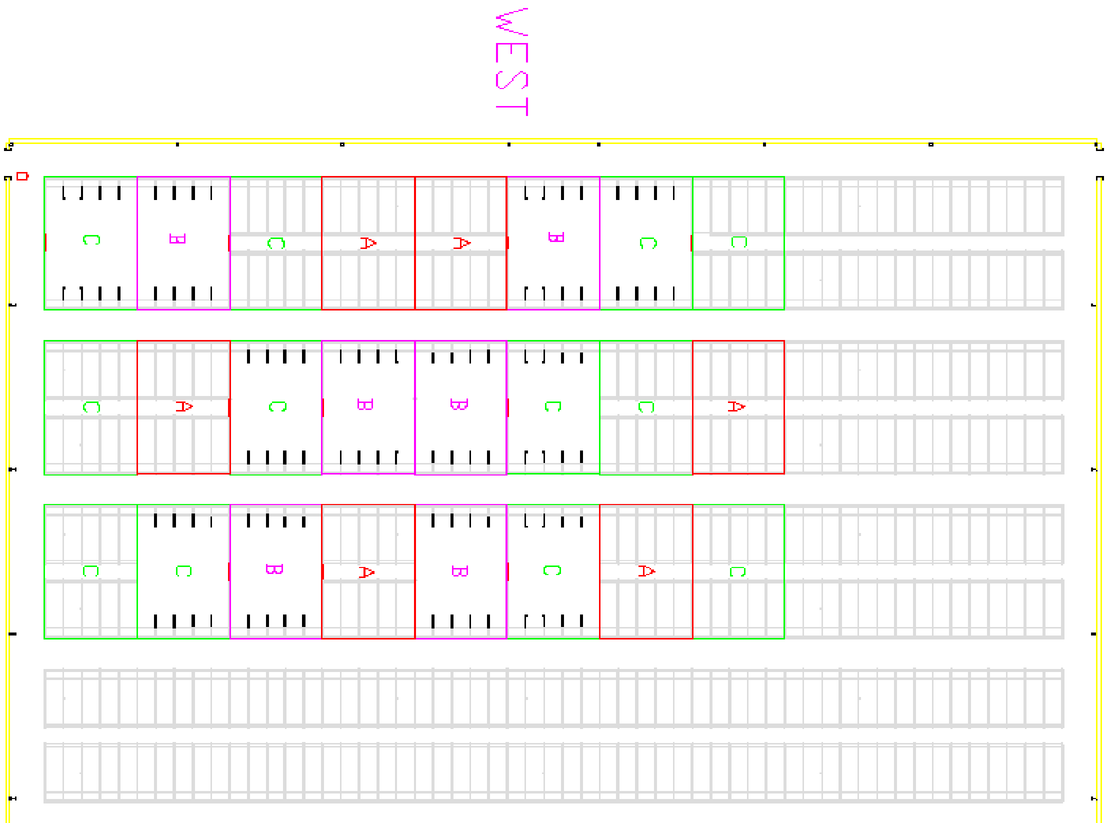

Figure 22: The experimental pen lay out within existing building of gestation stalls
Legend: Treatment A, GESTATION STALLS; Treatment B, GROUPS; Treatment C, GESTATION STALLS + GROUPS.

Measurements

Plasma Cortisol Concentrations

Eight sows from each 'group' in each time replicate (i.e. 6 'groups' or experimental units of each treatment (GESTATION STALL, GROUP and GESTATION STALL + GROUP) were chosen at random for sampling on days 2, 36 and 50 of treatment. Blood was collected by jugular venipuncture. If there were less than 8 sows in an experimental unit, then all the remaining sows were blood sampled. The blood samples were collected in the afternoon (approximately 1330 h) by trained personnel. Each sow was restrained with a rope (snout snare). Approximately 6 ml of blood was collected into heparinised tubes (BD Vacutainer® BD, Belliver Industrial estate, Plymouth, UK). A maximum of 2 minutes was allowed for obtaining the blood sample to avoid an acute stress response to handling confounding basal cortisol concentrations.

The individual samples were centrifuged at 7000 rpm and the plasma was poured off and stored frozen at -20°C until analysed. The samples were assayed for total cortisol at Monash University (Clayton, Vic). Samples from each pen were pooled using 200 μL aliquots from each individual sample. Plasma concentrations of total cortisol from the pooled samples were determined in duplicate 100-μL aliquots using an extracted radioimmunoassay according to the protocol developed by Bocking and Harding (1986) and validated for pig plasma using hydrocortisone H-4001 (Sigma Chemical Co., St Louis, MO) as standard.

Skin Injuries

All sows in each treatment were assessed and a modification of the assessment described by de Koning (1993) was used to describe skin lesions in both treatments. The assessment was simplified for the present experiment by reducing the number of areas in which the body of the sow was divided for injury data collection. Lesions were categorized into five categories: four of these categories were fresh lesions which included; (a) scratches; (b) abrasions; (c) cuts; and (d) abscesses, and the fifth category (e) included partially healed or old lesions. Each side of the sow's body was divided into 21 areas as shown in Figure 2 (Experiment 1) and described as follows: face (1), ear (2), neck (3), throat (4), processi scapulae (5), elbow (6), carpus (7), fetlock (8), coronary edge of the foreleg (9), hoof of the foreleg (10), sole of the foreleg (11), accessory digits of the foreleg (12), back and flank (13), tail and vulva (14), stifle (15), hock (16), coronary edge of the back leg (17), hoof of the back leg (18), sole of the back leg (19), accessory digits of the back leg (20) and udder (21). The number and the type of skin lesions were recorded on days 2, 36, and 50 of treatment from these data the number of both fresh (lesions categorized as (a) to (d)) and total injuries (fresh lesions (lesions categorized as (a) to (d)) and old lesions ((lesions categorized as (e)) were collated for each sows at each observation day.

Reproductive Performance

All of the sows farrowed in a common farrowing environment. The reproductive performance data collected included number of sows that returned to oestrus, pregnancy test negative and NIPs (not-in-pig sows, that is, sows confirmed pregnant but failed to farrow), which allowed farrowing rate to be calculated for each treatment. The litter size (total born, born alive, stillborn, mummified piglets) of each sow was also recorded.

Live Weight and Backfat

All sows were individually weighed and their backfat depth measured at the P2 site, using an ultrasound prior to entering their housing treatments and at day 98 of housing treatment (i.e. those sows that remained in treatment).

Statistics

Univariate General Linear Model (SPSS 18.0, SPSS Inc., Chicago, Illinois, USA) was used to examine the effects of housing treatment post-mating. The group (i.e. pen or group of 10 gestation stalls) was the experimental unit for comparisons between treatments and replicate was used as a blocking factor. Treatment was tested using replicate x treatment as the error. The data for total and fresh injuries were transformed prior to the analysis to avoid the residual variation increasing as the mean increased. *Post hoc* tests were conducted to identify differences between individual viewing treatments and period using Least Significant Difference tests. Chi-squared analysis was conducted on farrowing rate.

Results

There were 20 sows removed from the experiment in the third replicate (5 sows from GESTATION STALL, 5 sows from GROUP and 10 sows from GESTATION STALL + GROUP on day 60 of treatment for production reasons). These sows were included in the day 2, 36 and 50 measurements on cortisol concentrations and injury as they were still in treatment, however they were not included in the farrowing rate analysis, as their housing accommodation was changed in late gestation.

Plasma Cortisol Concentrations

As shown in Table 3, there were significant treatment effects on plasma cortisol concentrations at days 2 (P=0.003)) and 50 (P=0.002). Furthermore there was a tendency (P=0.057) for treatment effects on day 36. Cortisol concentrations were higher (P=0.003) in the GROUP treatment than the GESTATION STALL and GESTATION STALL + GROUP treatment at day 2. At day 50, sows in the GROUP treatment had higher cortisol concentrations than those in the GESTATION STALL treatment (P=0.032) and the GESTATION STALL + GROUP treatment (P=0.001) but there was no difference between sows in the GESTATION STALL and the GESTATION STALL + GROUP treatments (P=0.140).

Table 3: Effect of housing treatments on plasma cortisol concentrations (ng/ml) and injuries (means ± SED presented)

	GESTATION STALL	GROUP	GESTATION STALL + GROUP	P value	SED
Cortisol					
Day 2	12.79[a]	19.83[b]	12.79[a]	0.003	1.567
Day 36	22.61	29.03	23.52	0.057	1.998
Day 50	21.07[a]	26.63[b]	17.28[a]	0.002	1.784
Total Injuries*					
Day 2	3.47[a](11.67)	6.35[b](41.39)	3.54[a]11.92)	0.000	0.195
Day 36	3.68[a](14.09)	5.45[b](30.33)	6.81[c](48.95)	0.000	0.353
Day 50	3.45[a](12.19)	5.12[b](26.56)	5.86[b](34.39)	0.000	0.265
Fresh Injuries*					
Day 2	2.34[a](5.15)	5.57[b](31.84)	2.22[a(]4.48)	0.000	0.198
Day 36	2.41[a(]6.75)	3.75[b](14.58)	6.15[c](41.17)	0.000	0.371
Day 50	3.45[a](3.16)	5.12[b](8.24)	5.86[b](9.85)	0.000	0.265

Within rows, significant differences are indicated by different superscripts; [a,b,c] $P<0.05$

*: Data square root transformed prior to statistical analysis. Transformed means are presented and back transformed means (injuries/sow) presented in parentheses.

Skin Injuries

There were significant (P=0.000) treatment effects on both total and fresh injuries at days 2, 36 and 50 and the patterns of treatment effects were similar for both total and fresh injuries (Table 3). Incidence of total injuries was higher (P=0.000) in the GROUP treatment than the GESTATION STALL and GESTATION STALL + GROUP treatment at day 2. At day 36, the incidence of total injuries in the GESTATION STALL + GROUP treatment was higher (P=0.009) than in the GROUP treatment, which in turn were higher (P=0.001) than those in the GESTATION STALL treatment. At day 50, the incidence of total injuries in the GESTATION STALL + GROUP treatment tended to be higher (P=0.054) than in the GROUP treatment, which in turn were higher (P=0.000) than those in the GESTATION STALL treatment. A similar pattern existed for treatment effects on fresh injuries at days 2 to 50.

Reproductive Performance

As shown in Table 4, there were no effects (P>0.05) of treatment on farrowing rate, number of piglets born alive, number of stillborn piglets and number of mummified piglets. Replicates effects on farrowing rate were apparent with mean farrowing rates of 91.7% (inseminated in September 2009), 83.9% (January 2010) and 77.4% (March 2010). Furthermore, there were no effects (P>0.05) of treatment on number of sows removed for non-reproductive reasons (i.e. removed because of injury or death).

Table 4: Effect of housing treatments on reproductive performance and change in live weight and backfat of the sow (means ± SED presented)

	GESTATION STALL	GROUP	GESTATION STALL + GROUP	P value	SED
Sows mated (number)	175	175	170	-	-
Sows removed for non-reproductive reasons (number)	6	10	7	0.566	-
Farrowing rate%*	78.1	82.1	80.0	0.639	-
Piglets born alive	10.34	10.40	10.92	0.431	0.341
Stillborn piglets	0.90	0.94	0.80	0.628	0.101
Mummified piglets	1.05	1.04	1.05	0.740	0.014
Weight gain (kg)	57.18	59.87	56.74	0.543	2.159
P2 backfat gain (mm)	2.13	3.69	2.71	0.292	0.700
Coefficient of variation in live weight day 98	9.1	8.0	7.8	0.285	0.559

* % FR farrowing rate is calculated as number of failed pregnancies/sows mated. Chi squared analysis, Farrowing rate: P>0.05; X^2=0.639; Sow removals for non-reproductive reasons: P>0.05; X^2=0.1.14.

Live Weight and Backfat

As shown in Table 4, there were no effects (P>0.05) of treatment on change in live weight and backfat of sows.

Discussion

The hypothesis of this experiment was that sows housed in group housing with shoulder feeding stalls and 1.5m^2 per sow pen space from either 1 or 35 days post insemination will have similar welfare and reproductive performance to those housed in stalls for their entire gestation. The hypothesis was accepted.

A broad examination of the physiological, health and fitness responses of sows was used in this experiment to examine sow welfare (Barnett and Hemsworth, 2009). There were significant effects of treatment on plasma total cortisol concentrations at days 2 and 50 of treatment. Sows housed in groups had higher cortisol concentrations at days 2 and 50 of treatment than those in gestation stalls or those initially in gestation stalls and then in groups from 36-38 days of post-insemination. In contrast, there were no effects of treatment on cortisol concentrations at day 36 of treatment, however there was a strong trend (P=0.057) for the sows housed in groups to have higher cortisol at this time. These effects of treatment on stress will be considered later.

Although there were treatment effects on cortisol concentrations at day 2 of treatment, there were no treatment effects on farrowing rate. While it is generally agreed that stress can impair reproduction, Turner et al. (2005) in a review of the literature concluded that reproduction in female pigs is resistant to the effects of acute or repeated acute stress or acute or repeated acute elevation of cortisol, even if these occur during the series of endocrine events that induce oestrus and ovulation. In contrast, the authors concluded that prolonged stress and sustained elevation of cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appear to be resistant to the effects of prolonged stress or sustained elevation of cortisol. In Experiment 1 of this project, high cortisol concentrations were implicated in the effects of space on farrowing rate. Thus in the present experiment, the magnitude of the cortisol response to group housing with stalls may not have been sufficient to impair reproductive performance (i.e. farrowing rate). Furthermore there were also no treatment effects on litter size (born alive, stillborn or mummified piglets) in the present experiment.

The time of mixing the two group treatments in the present experiment (i.e. within 1-3 days or 36-38 days post-insemination) was also conducive to high reproductive performance. Kirkwood and Zanella (2005) found that sows grouped at day 2 post-insemination in pens with floor feeding had a higher farrowing rate than those grouped at about day 14 post-insemination. However, litter size was not affected by time of grouping in the experiment of Kirkwood and Zanella (2005). Spoolder et al. (2009) using data extended from Geudeke (2008) found that farms in which sows were grouped 1-2 weeks after insemination had a higher percentage of rebreeding than farms in which sows were grouped later. The general consensus in the scientific literature is that most embryonic death occurs within the first 30 days of gestation, as the first 30 days of gestation is a sensitive time when a range of environmental, social, genetic, nutritional, hormonal and biochemical factors are interacting with each other, all having significant influences on conception rate and ultimate litter size (Ashworth and Pickard, 1998). After the fertilised ovum undergoes cell differentiation and replication, the blastocyst becomes attached to uterine wall. This process of embryo implantation begins 12 to 13 days post-conception and is usually complete by day 16 (Dantzer and Winther, 2001). Therefore, it is generally accepted that the most suitable time to group sows is prior to embryo implantation at 12 days or wait until after 30 days of gestation. Little is known of the effects of the timing of mixing in the immediate period after insemination and thus further research is required to examine the most appropriate time to mix sows into groups within the first week after their second insemination, especially as the Australian pork industry moves towards elimination of gestation stalls entirely Furthermore, the investigation of strategies to mix sows into groups or familiarize them prior to insemination, thus perhaps reducing aggression post-insemination, requires investigation.

Although there were treatment effects on cortisol concentrations at days 2 and 50 of treatment, there were also no treatment effects on live weight gain and P2 backfat gain. As with farrowing rate, the treatment effects on stress may not have been sufficient to affect live weight and backfat. These data indicate that the shoulder stall feeding system in the group pens were successful in allowing each sow to receive adequate food to ensure her dietary requirements for maintenance and pregnancy were met. The individual shoulder stalls may have protected the sow during feeding and the automatic feed delivery system (which was the same across housing treatments) allowed feed to be delivered across pens simultaneously. Furthermore there were no significant differences in the number of sows removed from the treatments due to injury or death.

There were treatment effects on total and fresh injuries at days 2, 36 and 50 of treatment. At day 2, injuries were higher in those sows housed in groups at the time than those housed in stalls (i.e. housed individually in gestation stalls or housed individually in gestation stalls and subsequently at 36-38 days of post-insemination in groups). Similarly, at both 36 and 50 days of treatment, injuries were higher in those sows housed in groups at the time (i.e. groups with feeding stalls or previously housed individually in gestation stalls until 36 days when they were housed in groups) than those housed in stalls (i.e. housed individually in gestation stalls). While aggression is likely to lead to skin lesions (Turner et al., 2006), contact with pen fixtures arising from movement in the pen and avoidance of other sows and slippery floors may also affect the incidence of injuries. These results suggest that the design of the shoulder feeding stalls in the group pens and/or the space available in these group pens in the present experiment may not have been sufficient to reduce skin lesions to levels seen in gestation stalls. While care is required in comparing results between experiments, the mean total injuries were 29 injuries/sow in Experiment 1 vs. 27 and 35 in the two group treatments in Experiment 2.

The finding that cortisol concentrations at days 2 and 50 were higher in sows housed in groups throughout gestation than sows housed in gestation stalls and those initially in gestation stalls and then housed in groups from 36-38 days of post-insemination, requires consideration. While treatment effects on cortisol may not have been sufficient to affect farrowing rate, these treatment effects on cortisol suggest that high levels of aggression may persist in the groups mixed shortly after insemination. Hemsworth et al. (2006) found that mixing in large groups on deep litter at 35 days after mating rather immediately after mating reduced both aggression and plasma cortisol concentrations at the time of mixing. If this is a real effect on cortisol in the present experiment, design aspects of these group pens to reduce aggression, such as space and the length of the feeding stalls in these pens, require investigation. Based on the results of Experiment 1 in this project, the floor space of 1.5 m^2 in the present experiment may not have been sufficient to reduce aggression and cortisol concentrations early post-mixing even with the provision of shoulder feeding stalls.

Another objective of this experiment was to assess the concept of converting existing gestation stalls into group pens (housing 10 sows with 1.5m^2 pen space allowance per sow). This modification was achieved by using part of the existing gestation stall as a shoulder feeding stall, and also back aisle space as pen space (see photographs 1 to 3). This concept enabled an existing gestation shed of gestation stalls to be converted to group housing without reducing the number of sows that were housed in the shed (i.e. 100% of sows previously housed in stalls converted to 100% of sows housed in groups). The farrowing rate was not reduced when sows were housed in the modified pens. The shoulder feeding stalls allowed the intended daily feed requirements to be delivered to individual sow, as indicated by live weight variation.

In summary, cortisol concentrations at days 2 and 50 were higher in sows housed in groups with shoulder feeding stalls throughout gestation than sows housed in gestation stalls and those initially housed in gestation stalls and then housed in groups with shoulder feeding stalls from 36-38 days of post-insemination. Furthermore, sows housed in group pens with shoulder feeding stalls at the time of injury assessment had a higher incidence of injuries. There were no effects of treatment on reproduction or live weight and backfat change. From a welfare perspective, attention should be given to the design aspects of these group pens, such as the design of the stalls in the group pens and the pen space available in these group pens, in order to reduce the cortisol concentrations and injuries found in sows mixed in groups shortly after insemination. As seen in Experiment 1 of this project, aggression and stress associated with mixing early post-insemination are important concerns in group-housed sows.

General Discussion and Conclusions

One of the most consistent effects found in Experiment 1 were those of floor space allowance on several parameters early in the treatment period. A key finding was the effects of space on aggression at feeding at day 2 of treatment, both total and free cortisol concentrations at day 2 of treatment and farrowing rate. For all four variables, there was a linear relationship with space: there was a general decline in aggression and both total and free cortisol concentrations with increasing space, while there was general increase in farrowing rate with increasing space. Aggression was not measured later in the treatment period, but there was no evidence that space affected total or free cortisol concentrations at days 9 and 51 of treatment. Surprisingly, there was no evidence that space affected fresh or total injuries at day 2 of treatment or subsequently at days 9, 23 and 51 of treatment.

These results on the effects of space on aggression and stress in grouped sows are generally supported by a number of previous experiments on gilts (Hemsworth et al., 1986; Barnett et al., 1992; Barnett, 1997). In addition to the evidence that cortisol concentrations are elevated at 9-11 days of treatment at 1.0 m^2 than 2.0 or 3.0 m^2/gilt (Hemsworth et al., 1986), these previous experiments show that cortisol concentrations are elevated at (1) 12 weeks of treatment at a space allowance of 1.0 m^2 than 3.0 m^2 per gilt (Hemsworth et al., 1986); (2) at 28-29 and 49-51 days of treatment at a space allowance of 1.0 m^2 than 2.0 m^2 per gilt (Barnett et al., 1992); and (3) at 36 and 53 days of treatment at a space allowance of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt (Barnett, 1997). In contrast, the present experiment indicates a relationship between space and cortisol concentrations at day 2 of treatment but not days 9 and 51 of treatment. It is not clear why there were no long terms effects of space on stress in the present study. One explanation is that sows may adapt to low space allowances. There is evidence, particularly in rodents, that as gestation proceeds and during lactation there is a dampening of the HPA axis' response to stressors (Lightman et al., 2001). Nevertheless, these results highlight the importance of sufficient space in order 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.

There were no effects of space on fresh or total injuries at days 2, 9, 23 and 51 of treatment in the present experiment. While Barnett et al. (1992) found increases in both aggression and cortisol concentrations at a floor space of 0.98 m^2, there was no effect of space on skin lesions at day 10 of treatment. However there is evidence that space can affect injuries in sows. Weng et al. (1998) found that aggression in sows in groups of 6 on days 6 and 7 of treatment was higher at a space allowance of 2.0 m^2/sow than at 2.4 and 3.6 m^2/sow, which in turn was higher than at 4.8 m^2/sow. The total number of skin lesions measured on day 7 of treatment generally reflected the level of aggression: number of lesions was higher at 2.0 m^2/sow than 2.4 m^2/sow, which in turn was higher than in 3.6 and 4.8 m^2/sow. Salak-Johnson et al. (2007) found that sows in groups of 5 at a space allowance of 1.4 m^2/sow had consistently higher lesion scores than those at 2.3 or 3.3.

m^2/sow. In the studies by Weng et al. (1998) and Salak-Johnson et al. (2007), sows were introduced to their treatments at 25 days post-insemination and 7-10 weeks post-insemination.

There are several explanations for the conflicting results on the effects of injuries. Weng et al. (1998) found short term effects of space on skin lesions. While established groups of sows were studied from mid to late gestation, the incidence of injuries generally appeared lower than in the present experiment. Furthermore, differences between studies in design features of the pen such as flooring and shape may also affect injuries (Karlen et al., 2007). In contrast to these results, Salak-Johnson et al. (2007) found that skin lesions in sows were higher in the short and long term at 1.4 m^2/sow than at 2.3 or 3.3. m^2/sow.

With the effects of space on aggression and cortisol at day 2 of treatment found in the present experiment, the effects of space on farrowing are not unexpected since there is evidence that stress post-insemination can adversely affect reproductive performance of sows. It is generally agreed that stress can impair reproduction and Turner et al. (2005) in a review of the literature concluded that prolonged stress and sustained elevation of cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appears to be resistant to the effects of prolonged stress or sustained elevation of cortisol. In contrast to the present study, Salak-Johnson et al. (2007) found no effects of floor space allowance (1.4, 2.3 or 3.3. m^2/sow) on the reproductive performance of the sows. However, sows were introduced to their treatments at 25 days post-insemination, a period in which complete reproductive failure is less likely (Ashworth and Prickard, 1998).

The other consistent effect found in the present experiment was that of group size on injuries. While aggression at day 2 of treatment was not affected by group size, the incidence of total skin lesions was affected by group size. Groups of 10 had consistently low injuries from days 9 to 51, with the highest incidence of total injuries at days 9 and 23 in groups of 30 and at day 51 in groups of 80. In relation to fresh injuries, a low incidence of fresh injuries at day 9 was associated with a group size of 10. It should be recognized that fresh injuries provide information on injuries over a smaller timeframe than total injuries which include both fresh and old injuries.

There is little information in the literature on the effects of group size on injuries in sows. Edwards et al. (1993) reported that commercial experience has suggested that aggression is reduced when sows are mixed into larger groups. Most of the limited number of studies on the effects of group size are confounded by space allowance or feeding system. Research by Taylor et al. (1997) has shown that varying group sizes, of 5, 10 20 and 40 sows with a space allowance of 2.0 m^2/sow, while aggression, which was measured on days 1 and 2 of treatment, increased as group size increased, the number of lesions, measured on days 5 and 53 of treatment, were similar across treatments. Taylor et al. (1997) found no treatment effects on reproductive performance. While aggression is likely to lead to skin lesions (Turner et al., 2006), as suggested earlier other factors such pen design and flooring may affect the incidence of injuries.

There were also relationships between the treatments and live weight and backfat gain. Live weight gain was highest in groups of 10 and backfat gain was highest in a floor space of 1.4 m^2. Explanations for these relationships are not obvious. Sows in groups of 10 had consistently low injuries throughout the study and thus it is possible that these sows may have been more settled around feeding, allowing for less feed wastage and increased feed intake. The higher backfat gain in the groups with 1.4 m^2 is surprisingly particularly since sows in these groups had higher cortisol concentrations early in the study. However, Sargent (2001) found that ACTH treated pigs had a higher feed intake, were fatter at the carcass P2 back fat and leg fat sites and had more visceral fat. Sows with reduced space in the present study had elevated cortisol concentrations early in the study and perhaps stress at this stage of reproduction may have affected fat deposition during gestation. In contrast to these results, Salak-Johnson et al. (2007) found that sows grouped 25 days post-insemination in pens at 1.4 m^2/sow generally had lower condition score, body weight and backfat throughout gestation than those in pens at 2.3 or 3.3 m^2/sow.

In conclusion, the present results indicate that space affects aggression, stress physiology and reproduction in sows. While the effects of space on stress physiology were found early in treatment, the effects of space on farrowing rate highlight that stress might be biologically important in the period shortly after in the formation of a static group of sows that have been recently inseminated. Furthermore, the results indicate that the effects of space are most pronounced early after grouping. Indeed, it appears that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the importance of sufficient space in order 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.

While these effects of space early after grouping have sow productivity implications, interpreting the welfare implications is problematic. When relying on behavioural, physiological and fitness measures to determine welfare risks, a judgement is made about what degree of change in these indicators is likely to indicate that a sow's welfare is compromised. Furthermore, the management of animals by humans in our society is basically governed by two important principles and applies to a range of animal uses from individual pets to livestock production. These principles are on the one hand, management to comply with the objectives of human profit, benefits or pleasure, and, on the other hand, management responsibilities under a duty of humane care of animals. Thus it is implicit that animal use in our society involves a level of compromise to the animal. While decisions on animal use are often highly controversial, Governments and others often set farm animal welfare recommendations and standards based, to varying degrees, on considerations such as the harms and benefits to the animal caused by the animal use as well as broader harms and benefits to the animal owner, the environment and the economy. Based on the effects of space on aggressive behaviour, cortisol concentrations and farrowing rate, it is credible to judge that, within the range of sow densities in this study, sow welfare improves as floor space allowance increases. This judgement is supported by the results of Hemsworth et al. (1986), Barnett (1997), Weng et al. (1998) and Salak-Johnson et al. (2007).

The space allowance at which sow welfare is acceptable is difficult to determine from the present results. Farrowing rate appears to be linearly related to space up to 3.0 m^2/sow. Furthermore, the response of farrowing rate to space differs with replicate. By far the largest response, with farrowing rate increasing from 1.4 m^2/sow to 3 m^2 /sow occurred in one replicate studied in summer. A weaker, but still positive, response occurred in another replicate studied in spring. On the other hand, there was no farrowing rate response to space allowance in two other replicates studied in autumn and spring. Sows studied in summer may have experienced what might be considered as 'seasonal infertility'.

While there were replicate effects on the farrowing rate response of sows to space, there were no replicate effects on the results for total and free cortisol at day 2. Although the results are in accord with a linear decline in day 2 cortisol from 1.4 $m^2_{/}$/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

Therefore these results indicate that in summer anything less than 3 m^2/sow may compromise reproductive productivity. In conditions in which the other replicates were studied, farrowing rate might not be compromised even at a space allowance of 1.4 m^2/sow. Furthermore, these results suggests that the effects of seasonal infertility may be alleviated in groups of sows by ensuring floor space allowances somewhere greater than 3 m^2/sow.

In relation to seasonal infertility, the results also indicate that although there was no replicate effect on aggression and stress, the fertility of sows in summer was more susceptible to stress than in other replicates. This raises the question of whether an important feature of seasonal infertility in sows is an increased susceptibility to stress at this time of the year: while the cortisol response to space was not affected by replicate, the farrowing rate response to space was affected by replicate. This clearly requires further investigation because of the general practical implications of seasonal infertility. Furthermore in relation to the present topic, further research is clearly required because sows may require more space in summer to maintain their fertility.

While there were no effects of group size on aggression, cortisol concentration or reproduction, sows in groups of 10 generally had less injuries throughout the study and, although difficult to explain, is an outcome that is desirable from a welfare perspective.

In Experiment 2 it was found that sows housed in group housing with shoulder feeding stalls and 1.5m^2 per sow pen space from either 1-3 days or 36-38 days post insemination had similar reproductive performance to those housed in stalls for their entire gestation. It was also found that sows housed in groups with feeding stalls had higher cortisol concentrations at days 2 and 50 of treatment than those in gestation stalls or those initially in gestation stalls and then in groups from 36-38 days of post-insemination. In contrast, there were no effects of treatment on cortisol concentrations at day 36 of treatment, however there was a strong trend for the sows housed in groups from mating to have higher cortisol at this time. While it is generally agreed that stress can impair reproduction, the literature indicates that prolonged stress and sustained elevation of cortisol are required to disrupt reproductive processes in female pigs (Turner et al., 2005). Thus it appears that in Experiment 2 the magnitude of the cortisol response to group housing with stalls may not have been sufficient to impair reproductive performance.

Although there were treatment effects on cortisol concentrations at days 2 and 50 of treatment, there were also no treatment effects on live weight gain and P2 backfat gain. As with reproductive performance, the treatment effects on stress may not have been sufficient to affect live weight and backfat. These data indicate that the shoulder stall feeding system in the group pens were successful in allowing each sow to receive adequate food to ensure her dietary requirements for maintenance and pregnancy were met. The individual shoulder stalls may have protected the sow during feeding and the automatic feed delivery system (which was the same across housing treatments) allowed feed to be delivered across pens simultaneously. Furthermore there were no significant differences in the number of sows removed from the treatments due to injury or death.

There were treatment effects on total and fresh injuries at days 2, 36 and 50 of treatment. At day 2, injuries were higher in those sows housed in groups at the time (i.e. housed in groups with shoulder feeding stalls) than those housed in stalls (i.e. housed individually in gestation stalls or housed individually in gestation stalls and subsequently at 36-38 days of post-insemination in groups). Similarly, at both 36 and 50 days of treatment, injuries were higher in those sows housed in groups at the time (i.e. groups with feeding stalls or previously housed individually in gestation stalls until 36 days when they were housed in groups) than those housed in stalls (i.e. housed individually in gestation stalls). While aggression is likely to lead to skin lesions (Turner et al., 2006), contact with pen fixtures arising from movement in the pen and avoidance of other sows and slippery floors may also affect the incidence of injuries. These results suggest that the design of the shoulder feeding stalls in the group pens and/or the space available in these group pens may not have been sufficient to reduce skin lesions to levels seen in gestation stalls.

The finding that cortisol concentrations at days 2 and 50 were higher in sows housed in groups throughout gestation than sows housed in gestation stalls and those initially in gestation stalls and then housed in groups from 36-38 days of post-insemination, requires consideration. While treatment effects on cortisol may not have been sufficient to affect farrowing rate, these treatment effects on cortisol suggest that high levels of aggression may persist in the groups mixed shortly after insemination. Hemsworth et al. (2006) found that mixing in large groups on deep litter at 35 days after mating rather immediately after mating reduced both aggression and plasma cortisol concentrations at the time of mixing. If this is a real effect on cortisol in the present experiment, design aspects of these group pens, such as space and the length of the feeding stalls in these pens, require investigation. Based on the results of Experiment 1 in this project, the floor space of 1.5 m^2 in the present experiment may not have been sufficient to reduce aggression and cortisol concentrations early post-mixing even with the provision of feeding stalls.

Another objective of this experiment was to assess the concept of converting existing gestation stalls into group pens (housing 10 sows with 1.5m^2 pen space allowance per sow). This modification was achieved by using part of the existing gestation stall as a shoulder feeding stall, and also back aisle space as pen space (see photographs 1 to 3). This concept enabled an existing gestation shed of gestation stalls to be converted to group housing without reducing the number of sows that were housed in the shed (i.e. 100% of sows previously housed in stalls converted to 100% of sows housed in groups). The farrowing rate was not reduced when sows were housed in the modified pens. The shoulder feeding stalls delivered the intended daily feed requirements to individual sow, as indicated by live weight variation.

In summary, cortisol concentrations at days 2 and 50 were higher in sows housed in groups with shoulder feeding stalls throughout gestation than sows housed in gestation stalls and those initially housed in gestation stalls and then housed in groups with shoulder feeding stalls from 36-38 days of post-insemination. Furthermore, sows at the time of injury assessments that were housed in group pens with shoulder feeding stalls and with a floor space allowance of 1.5 m^2/sow had a higher incidence of injuries. There were no effects of treatment on reproduction or live weight and backfat change, presumably because the stress effects were not sufficient to affect biological functioning.

Implications and Recommendations

In conclusion, the results of Experiment 1 indicate that space affects aggression, stress physiology and reproduction in sows. While the effects of space on stress physiology were found early in treatment, the effects of space on farrowing rate highlight that stress might be biologically important in the period shortly after in the formation of a static group of sows that have been recently inseminated. Furthermore, the results indicate that the effects of space are most pronounced early after grouping. Indeed, it appears that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the importance of sufficient space in order 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.

While these effects of space early after grouping have sow productivity implications, interpreting the welfare implications is problematic. Based on the effects of space on aggressive behaviour, cortisol concentrations and farrowing rate, it is credible to judge that, within the range of sow densities in this study, sow welfare improves as floor space allowance increases. This judgement is generally supported by the previous results.

It is difficult to determine what is an adequate space allowance for grouped sows from the results of the present experiment. Although the results are in accord with a linear decline in day 2 cortisol from 1.4 m^2/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

Therefore, further research is required to examine the effects of space allowance in the range of 1.8 to 2.4m^2/sow in more detail. Particular attention should be given to the effects of space and time of mixing relative to insemination (days 1 to 4 post-mixing), since this is the period when aggression and stress are likely to be most pronounced and their effects on reproductive performance are highly likely. There is a clear need to examine the effects of varying space during gestation ('staged-gestation penning' in order to provide increased space immediately after insemination) as well as the use of and design features of a dedicated mixing pen. The research on pen design should also include an examination of the effects of pen features such as feeding stalls and feeding systems, since these are likely to affect aggression and stress.

The results of Experiment 2 indicate that housing sows in groups with shoulder feeding stalls, either throughout gestation or from 36-38 days of post-insemination, results in similar reproductive performance and growth characteristics as sows housed in gestation stalls.

Furthermore, this experiment demonstrated the feasibility of converting existing gestation stalls into group pens by using part of the existing gestation stalls as shoulder feeding stalls and the back aisle space as pen space.

However, from a welfare perspective, it is recommended that further research is conducted on the design aspects of these group pens, such as the design of the feeding stalls and the pen space available in these pens, in order to reduce stress and injuries in sows mixed in groups shortly after insemination. Furthermore, since little is known of the effects of the timing of mixing in the immediate period after insemination and further research is required to examine the most appropriate time to mix sows into groups within the first week after their second insemination. There may also be opportunities to mix sows into groups or familiarize them prior to insemination to reduce aggression post-insemination and this aspect also requires investigation.

While further research is clearly required, it is necessary to consider the implications of these results for other group housing systems. There are many variations in the design of group housing systems, however the present results on the effects of space and group size have implications for group housing in general. It is known that design features such as feeding system can impact on aggression and stress, but nevertheless where there is competition for resources, whether it be feed, lying space, etc., the principles of effects of floor space and group size found here are likely to have implications for the following reasons.

When deciding on the adequacy of space for group-housed sows, a number of factors can be considered. The most important criteria must be that there is adequate space to avoid physical injury at feeding and accessing other resources as well as when moving around the pen. Design features that affect these behaviours, such as feeding stalls and lying stalls, may have to varying degrees implication on the space required to minimize aggression and physiological stress. Nevertheless, the minimum space under conventional floor feeding system may be similar to that required with group housing with EFS and perhaps even feeding stalls. Indeed, more total space may be required with feeding stalls to ensure freedom of movement outside the stall.

Detailed Description of Intellectual Property

Information generated at this stage of the RD&E process, while creating intellectual property value, does not lead to patentable outcomes.

Technical Summary

Two experiments were conducted in this project to examine the effects of floor space allowance, group size, feeding stalls in groups and time of mixing on the welfare of sows grouped after insemination were examined. Implicit in this research is the objective of providing scientific data to inform an animal welfare standard for sows mixed in groups post-insemination.

Experiment 1

The objectives of Experiment 1 were to determine the effects of floor space allowance and group size on the welfare of sows grouped after insemination.

In this experiment, a total of 3,120 mated sows, in four time replicates (780 sows per replicate) over 13 months were studied. The sows were crossbred (Landrace x Large White) of mixed parity and of good health at the beginning of the study. Sows were inseminated twice and were introduced to the post-mating housing treatments within 1-7 days of mating. A 3x6 factorial design was used to examine two main effects imposed post-mating: 1) Group size at 3 levels, 10, 30, 80 sows per pen; and 2) Floor space at 6 levels, $1.4m^2$, $1.8m^2$, $2.0m^2$, $2.2m^2$, $2.4m^2$, $3.0m^2$ per sow.

A common approach used by scientists to judge animal welfare has been on the basis that difficult or inadequate adaptation will generate welfare problems for animals and thus a broad examination of the behavioural, physiological, health and fitness responses of sows was undertaken in this project to assess biological functioning of the animals. Basically this involved assessing the risks to the welfare of an animal at two levels (1) the magnitude of the behavioural and physiological responses to the stressor and (2) the biological cost of these responses. These behavioural and physiological responses include abnormal behaviours, such as stereotypies and redirected behaviours, and the stress response, respectively, while the biological cost includes adverse effects on the animal's ability to grow, reproduce and remain healthy and injury-free. In this experiment, the following measurements were taken to assess the effects of space and group size on sow welfare: cortisol concentrations, a redistribution of white blood cells, specifically the neutrophil to lymphocyte ratio, aggression, skin injuries and reproductive performance.

Each measurement was analysed using a series of restricted maximum likelihood (REML) mixed model analyses that, as well as treatment effect combinations being examined, a priori included a fixed effect for replicate and random effects for row within replicate, sub-replicate within replicate and the interaction between row and sub-replicate within replicate. In all REML analyses, the experimental unit was all sows being measured in a pen within a replicate.

One of the most consistent effects found in the present experiment was the effects of space on aggression at feeding at day 2 of treatment, both total and free cortisol concentrations at day 2 of treatment and farrowing rate. For all four variables, there was a linear relationship with space: there was a general decline in aggression and both total and free cortisol concentrations with increasing space, while there was general increase in farrowing rate with increasing space. Surprisingly, there was no evidence that space affected fresh or total injuries at day 2 of treatment or subsequently at days 9, 23 and 51 of treatment.

These results on the effects of space on aggression, stress and reproduction in grouped sows are generally supported by a number of previous experiments on gilts. While previous research on gilts has shown that cortisol concentrations are elevated in both the short and long term at a space allowance of 1.0 m^2 than 1.4 or 2.0 m^2 per gilt, the present experiment indicates a significant relationship between space (in the range of floor space allowances from 1.4 to 3.0 m^2) and cortisol concentrations at day 2 of treatment but not days 9 and 51 of treatment. There are several explanations for these conflicting results on the effects of space in the long term. It is possible that in the present experiment sows may have adapted to low space allowances. There is evidence in other species that as gestation proceeds, particularly in late gestation, and during lactation there is a dampening of the hypothalamic-pituitary-adrenal (HPA) axis' response to stressors. While sows were removed from treatment in the present experiment if they suffered reproductive failure or injury or escaped from their pens and thus sufficient space may have been provided to reduce stress in pens with allocated low space allowances, only a small percentage of sows were removed from the study shortly after the commencement of treatment (e.g. only 0.95% of sows were removed prior to day 9 of treatment).

With the effects of space on aggression and cortisol at day 2 of treatment found in the present study, the effects of space on farrowing rate are not unexpected since there is evidence that stress post-insemination can adversely affect reproductive performance of sows. Prolonged stress and sustained elevation of cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appears to be resistant to the effects of prolonged stress or sustained elevation of cortisol.

While there were no detectable replicate effects for most of the variables studied, examination of the results for farrowing rate and, in particular, how the response differs with replicate, indicates that the response of farrowing rate to space differs with replicate. One replicate, which appeared to experience 'seasonal infertility', showed the largest response, with farrowing rate increasing markedly from 1.4 m^2/sow to 3 m^2/sow. A weaker, but still positive, response occurred in another replicate studied in spring. On the other hand, there was no farrowing rate response to space allowance in the other two replicates studied in autumn and spring.

Surprisingly, while the present experiment and other experiments on gilts and sows have shown that reduced space increases aggression, there were no effects of space found on incidence of skin lesions in the present experiment. There is evidence that space does not affect skin lesions in gilts but contrary evidence in two previous experiments that space does affect skin lesions in sows. However in these experiments, sows were studied in established groups and in one of these experiments, the incidence of skin lesions were low relative to the present experiment.

The other consistent effect found in the present experiment was that of group size on injuries. While aggression at day 2 of treatment was not affected by group size, the incidence of total skin lesions was affected by group size. Groups of 10 had consistently low injuries from days 9 to 51, with the highest incidence of total injuries at days 9 and 23 in groups of 30 and at day 51 in groups of 80. In relation to fresh injuries, a low incidence of fresh injuries at day 9 was associated with a group size of 10. There is little information in the literature on the effects of group size on injuries in sows. There is anecdotal evidence that aggression is reduced when commercial sows are mixed into larger groups but a previous experiment has shown that in varying group sizes, of 5, 10 20 and 40 sows with a space allowance of 2.0 m^2/sow, while aggression increased as group size increased, the number of lesions was similar across treatments.

There were also relationships between the treatments and live weight and backfat gain. Live weight gain was highest in groups of 10 and backfat gain was highest in a floor space of 1.4 m^2. Explanations for these relationships are not obvious. Sows in groups of 10 had consistently low injuries throughout the study and thus it is possible that these sows may have been more settled around feeding, allowing for less feed wastage and increased feed intake. The higher backfat gain in the groups with 1.4 m^2 is surprisingly particularly since sows in these groups had higher cortisol concentrations early in the study, but there is some evidence in the literature that stress may lead to increased fat deposition.

Thus these results indicate that space affects aggression, stress physiology and reproduction in group-housed sows. However, the effects of space are most pronounced early after grouping, which suggests that sows may adapt later in gestation to reduced space, although this obviously requires rigorous investigation.

While there were replicate effects on the farrowing rate response of sows to space, there were no replicate effects on the results for total and free cortisol at day 2. Although the results are in accord with a linear decline in day 2 cortisol from 1.4 m^2/sow to 3 m^2/sow, the results are also in accord with a decline in cortisol from 1.4 m^2/sow to 1.8 m^2/sow and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to be able to determine which of these scenarios is more biologically correct. Thus in terms of animal welfare at mixing, it is impossible to give guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely to be too small.

While there were no effects of group size on aggression, cortisol concentration or reproduction, sows in groups of 10 generally had less injuries throughout the study and, although difficult to explain, is an outcome that is also desirable from a welfare perspective.

Experiment 2

The objectives of Experiment 2 were to determine the effects of feeding stalls in groups and time of mixing on the welfare of sows grouped after insemination. This experiment also examined the feasibility of modifying existing gestation stalls to group pens with shoulder feeding stalls. The feasibility was assessed in terms of the practicality of the group housing system as well as the stress, injuries and reproductive success of the sows in the group housing system relative to those in gestation stalls.

A total of 540 mated sows, in three time replicates (180 sows per replicate) over 12 months, were studied. The sows were Large White x Landrace of mixed parity and good health at the beginning of the experiment. The sows were artificially inseminated in individual mating stalls and, after their second insemination, were randomly allocated to housing treatment.

The following three housing treatments were studied:

1. GESTATION STALL: Sows were housed in individual gestation stalls for their entire gestation. The stalls were 0.6 m wide x 2.1 m in length including the feed trough.
2. GROUP: Sows were housed in groups of 10 from day 1 of treatment. The pens were 4.9m long x 3m wide providing 1.5m^2 of floor space per sow. The pens contained 10 shoulder feeding stalls that were 0.8m long x 0.6m wide.
3. GESTATION STALL + GROUP: Sows were housed in individual gestation stalls from day 1 to day 35 and then mixed in groups of 10 in pens with 10 shoulder feeding stalls until the remainder of gestation. The gestation stalls and the group pens with shoulder feeding stalls were identical to those used in the first two treatments. At day 35, 'non-experimental' sows that were of the same stage of pregnancy and had been housed in gestation stalls were used to replace sows allocated to the treatment that were not pregnant in order to ensure group sizes of 10 at mixing. These non-experimental sows were not included in the data analysis.

It was found that sow cortisol concentrations at days 2 and 50 were higher in sows housed in groups with shoulder feeding stalls throughout gestation than sows housed in gestation stalls and those initially housed in gestation stalls and then housed in groups with shoulder feeding stalls from 36-38 days of post-insemination. Furthermore, sows housed in group pens with shoulder feeding stalls at the time of injury assessment had a higher incidence of injuries. There were no effects of treatment on reproduction or live weight and backfat change.

Thus it appears that the effects of group housing system on stress were not sufficient to affect the biological fitness of the sow in terms of live weight and back fat change during gestation, farrowing rate, litter size and number of still born piglets.

From a welfare perspective, it is clear that attention should be given to the design aspects of these group pens, such as the design of the feeding stalls in the group pens and the pen space available in these group pens, in order to reduce the cortisol concentrations and injuries in sows mixed in groups shortly after insemination. As seen in Experiment 1 of this project, aggression and stress associated with mixing early post-insemination are important concerns in group-housed sows.

The second objective of this experiment was to assess the concept of converting existing gestation stalls into group pens (housing 10 sows with 1.5m^2 pen space allowance per sow). This modification was achieved by using part of the existing gestation stall as a shoulder feeding stall, and also back aisle space as pen space. This concept enabled an existing gestation shed of gestation stalls to be converted to group housing without reducing the number of sows that were housed in the shed (i.e. 100% of sows previously housed in stalls converted to 100% of sows housed in groups). Housing sows in this group housing system allowed sows to achieve similar reproductive performance and growth characteristics of sows housed in gestation stalls.

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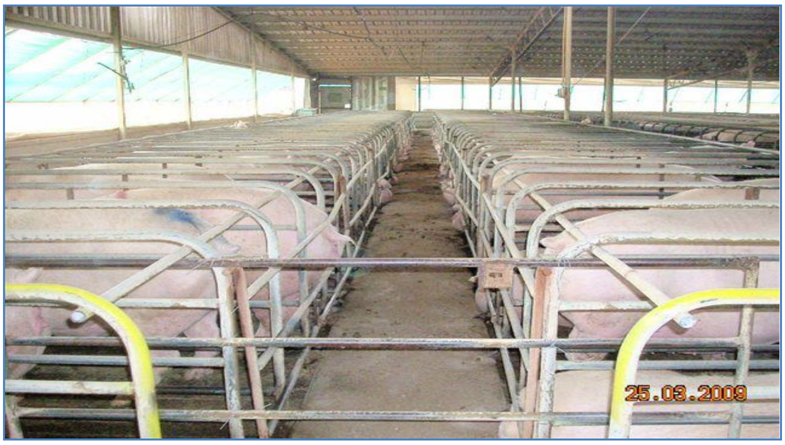
Photographs



Photograph 1: Sow gestation stalls

Photographs 2 and 3: Group pens- Sows stalls that have been converted to group pens with shoulder feeding stalls by utilising existing back alley space and existing feeding trough at the front of the gestation stall. Sows were housed in groups of 10 with 1.5m^2 of pen space per sow

Appendix 1 - Comparison of Aggression at Feeding on the First to Third Days Following Mixing

The aggressive behaviour at feeding of 120 of the study sows in groups of 10 with a floor space of $1.8m^2$/sow was used to examine the relationships between aggressive behaviour of at feeding of individual sows over the first three days following mixing (days 1-3). As shown in Table 1.1, the aggressive behaviour of individual sows on any of the first three days post-mixing is highly correlated (P=0.000) with each of the other days. Thus measurement of aggressive behaviour on any of these three days provides a good estimate of aggression over the first three days post-mixing.

Table 1.1: Spearman rank order correlations between aggressive behaviour at feeding of individual sows over the first three days following mixing

	Aggressive behaviour at feeding		
	1st day post-mixing	**2nd day post-mixing**	**3rd day post-mixing**
Aggressive behaviour at feeding			
1st day post-mixing	1.00	0.542 (0.000)	0.695 (0.000)
2nd day post-mixing	-	1.00	0.685 (0.000)
3rd day post-mixing	-	-	1.00

Probability values presented in parentheses.