Evaluation of the optimal space allowance for nursery pigs

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ABSTRACT

In comparison to grower/finisher pigs, relatively little is known about the effects of space allowance on nursery pigs. Because nursery pigs overlie, it has been hypothesized that the relative space allowance (*k* value) which is appropriate for finishing pigs may overestimate the requirements of nursery pigs. Therefore, the objective of this study was to determine the effects of space allowance on piglet behaviour, growth, and welfare. The study was completed in four blocks over four seasons using 1200 newly weaned pigs. Pigs were housed at six space allowances (*k* values: 0.0230, 0.0265, 0.0300, 0.0335, 0.0370 or 0.0390), in groups of 10 or 40 pigs/pen. All pigs were weighed weekly, and pen size was adjusted based on the predicted average body weight of pigs the following week. Overhead cameras were used to record group behaviour for eight hours on one day in weeks one, three and five. The percentage of animals standing, sitting, feeding, lying (sternal or fully recumbent) and overlying was recorded at 30 min intervals. The behaviour of four focal piglets per group (all female) was recorded continuously using the same footage as described for group observations. Videos were observed continuously for eight hours per day to measure feeding and drinking behaviour in focal pigs in weeks one, three and five. Salivary cortisol samples were collected from focal pigs in weeks one, three, five and six.

The results were analysed using Proc Mixed and Proc Glimmix procedures in SAS (9.4) with fixed effects of density, group size and week. Overall, growth (ADG) and G:F ratios were not affected by changes in space allowance. Although there tended to be an effect of space allowance on ADG in week five (P = 0.054), no clear relationship to changes in space allowance was observed. Pigs were observed sitting more (% frequency of observations) at lower space allowances (frequency of

observation (%) sitting: k = 0.0230: 43.54% vs. k = 0.0390: 31.18%. SEM = 4.05, P = 0.004). Fully recumbent lying is known to be a more restful posture and was higher at higher space allowances frequency of observation (%) fully recumbent: k = 0.0230: 49.13% vs k = 0.0390: 53.88%. SEM = 5.01, P = 0.049). As pigs aged the frequency of standing, sitting and feeding behaviours increased over time ($P < 0.05$). Pigs spent more time overlying in week one than in weeks three or five ($P < 0.001$). Space allowance had a significant effect on feeding behaviour time budgets, with pigs at lower space allowances eating more meals per day, but of shorter duration than those given higher space allowances (average bout duration: k = 0.0230: 76.8 s vs k = 0.0390: 99 s. SEM = 0.02, P = 0.003). Pigs at low space allowances also spent less time feeding compared to those at higher allowances (total feeding duration: k = 0.0230: 45.99 vs k = 0.0390: 50.83 min. SEM = 0.04, P = 0.038). The number of drinking bouts/day was highest at the lowest space allowance, while mean duration of drinking bouts was highest at the highest space allowance (drinking bouts per day: P = 0.037, average bout duration: P = 0.002). Group size had a significant effect on feeding bouts/day and drinking behaviour. Pigs in groups of 10 ate fewer meals but tended to have longer meals (Feeding bouts/day: P = 0.026; Average bout duration/min; P = 0.071) and pigs in groups of 40 spent more time drinking with longer bouts (P <0.01 for total drinking duration and drinking bouts/day). Salivary cortisol levels were also affected by space allowance, with pigs at higher space allowances having significantly higher cortisol levels (P = 0.025; SEM = 0.03), possibly because of higher activity levels.

In conclusion, although there was no effect of space allowance on production performance, reductions in space resulted in pigs changing resting (fully recumbent lying) and sitting postures which are related to space sharing and welfare. Moreover, lateral recumbency increased and overlying reduced over time, which suggests that effects of space restriction are greatest as pigs approach nursery. Therefore, on the basis of postural changes, the hypothesis that nursery pigs require less space than grower/finisher pigs due to overlying are not supported.

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LIST OF ABBREVIATIONS

ADFI	**Average daily feed intake**
ADG	**Average daily gain**
ANOVA	**Analysis of variance**
Avg	**Average**
BW	**Body weight (used for live weight)**
G:F	**Gain-to-feed ratio (feed efficiency ratio)**
ELISA	**Enzyme-linked immunosorbent assay**
k	**Space coefficient value used in space allocation equations**
kg	**kilogram**
SEM	**Standard error of mean**

1. LITERATURE REVIEW

1.1 Introduction

In swine production, the floor space allowance provided per pig impacts welfare and production economics. Offering more space can improve pig welfare, but decreases productivity per unit of floor space (Kornegay and Notter, 1984). In practical terms, the space provided to pigs must balance both economic and welfare considerations. A significant amount of research exists on the effect of space allowance in grow-finish pigs (see Edwards et al., 1988; McGlone and Newby, 1994; Ekkel et al., 2003; Pastorelli et al., 2006; Gonyou et al., 2006). In Canada, these studies have been used to produce guidelines for the minimum space allowance required for all growing pigs, from nursery to finishing stages (NFACC, 2014). However, at present, it is unclear whether nursery pigs have the same space requirements as grow-finish pigs, as comparatively little research has been done on the effects of space allowance on nursery pigs (6-25 kg) (EFSA, 2005; Gonyou et al., 2006).

Early studies on space allowance were mostly empirical, expressed by classifying pigs in a series of weight ranges and by describing space on a per animal basis (Bryant and Ewbank, 1974; Brumm and NCR-89 Committee on Management of Swine, 1996). Although these studies found that crowding reduced overall productivity, they could not identify a precise point at which growth depression occurred. More recently, an alternative approach, which expresses space allowance based on an allometric equation relating body weight to the floor area has been used. The equation is Area= $k \times BW^{0.667}$, where the area is floor space area in m^2, k is the floor space allowance coefficient, and BW is the pig body weight in kilograms, BW calculated to the power of 0.667 (Petherick and Baxter, 1981). This approach is more efficient as it allows for a more precise comparison of space allowances (Gonyou et al., 2006). Gonyou et al. (2006) performed a meta-analysis of space allowance using the allometric equation and determined a critical *k* value of 0.0335 for grow-finisher pigs, below which reductions in space allowance would negatively affect ADG. More recently, The Canadian Code of Practice for the Care and Handling of Pigs (NFACC, 2014) adopted this value as the minimum space allowance for grower-finisher and nursery pigs in Canada.

However, when evaluating optimal space allowance, parameters other than ADG should be considered. Minimum space allowance requirements should also be based on behavioural needs, rather than purely on growth performance as has been done in the past (Ekkel et al., 2003). Aside, from reducing growth, inadequate space allowance has been observed to adversely affect behaviour and welfare as evidenced by a higher risk of immune suppression and disease susceptibility and reduction in the ability of pigs to express normal behaviours (Turner et al., 2006).

It has been recommended that studies examining the space requirements of pigs should focus on changes in pig behaviour and understand the relevance of such changes to pig welfare (Ekkel et al., 2003). Petherick (1983) calculated the space needed for all animals to lie laterally. Since lateral lying requires more space than other postures, this space should also allow pigs greater freedom of movement. Averos et al. (2010) did a similar meta-analysis to Gonyou et al. (2006), to calculate how space allowance affected the percentage of time spent lying. It was found that lying time on slatted floors was reduced at *k* values below 0.039. The Canadian Code of Practice for the Care and Handling of Pigs (NFACC, 2014) has recommended this value as the 'ideal minimum space allowance' for pigs on fully or partially slatted floors because it promotes normal lying behaviour in pigs.

It is known that pigs smaller than 50 kg occupy up to 20% less area than larger pigs due to the tendency of smaller pigs to lie on top of each other (Boon, 1981). Therefore, the *k* value which is appropriate for finishing pigs may overestimate the requirements of nursery pigs.

Gonyou et al. (2006) pointed out that to accurately determine the critical point at which crowding occurs and the responses below that point, future work should measure growth rates at several stages, not just the final time point at nursery exit. Group size and seasonal differences also need to be evaluated in greater detail, as temperatures are known to impact lying patterns (Hyunh et al., 2005, Spoolder et al., 2012), but their long-term impacts are currently unknown. It has been advocated that due to the sharing of free space, pigs in larger groups may need less space (McGlone and Newby, 1994). However, the effects of group size on space allowance are inconsistent (Street and Gonyou, 2008). Young pigs often overlie each other, reducing the amount of space required per pen (Boon, 1981), but in warmer temperatures, overlying may be indicative of overcrowding (Gonyou et al., 2006). Hence, understanding the interaction between temperature and pig behaviour is essential. Physiological responses and the health status of pigs at the point at which crowding occurs are not often reported, making it hard to determine at what point crowding affects welfare.

The work presented in this thesis was done to evaluate the impact of space allowance on the growth, behaviour, and welfare of nursery pigs. The study considers six space allowances and two group sizes (10 and 40 pigs/pen) in nursery pigs to establish the critical cut-off point at which crowding occurs. The space allowances considered are both below and above the *k* value of 0.0335, required by Canadian Code of Practice for the Care and Handling of Pigs (NFACC, 2014). To address the areas where uncertainty remains, we examined measures related to production, behaviour, health, and welfare, while balancing for the effects of the season. The results will help to determine if the space requirements of nursery pigs differ from those of grower-finisher pigs.

1.2 Space allowance

Animals have three types of space requirements: static, dynamic and social (Pastorelli et al., 2006). Static space is the space that animals occupy at any one moment due to their physical size and shape. Thus dimensions of the animal are the primary determinants of static space requirements, represented by the size of the animal based on length, weight, and height (Ekkel et al., 2003). Petherick (1983) explains that just providing animals with their static spatial requirements is not adequate because additional space is required to perform normal functions such as feeding, drinking, elimination, and resting, which is categorised as the dynamic space requirement. Additional space is also needed for activities such as exploration, social interaction with other animals or removing themselves from visual contact with others; space needed for these activities is classified as social space (Baxter 1985; Ekkel et al., 2003; Whittaker et al., 2012). Therefore, if non-territorial species such as pigs do not have enough social space, then that will suppress or displace the activity leading to higher social aggression, with subordinate animals receiving more aggression (Petherick, 1983). With further reductions, pigs try to adapt behaviourally by changing dunging, lying and feeding patterns. However, if the stressor does not subside, the coping strategy redirects its biological resources, eventually affecting productivity (Moberg, 2000).

Establishing optimum space allowance is complex as space interacts with many aspects of the animal's environment, including the design of the pen, number of animals present; flooring (Phillips and Morris, 2000); build up of excreta (Randall, 1993); and the animal's ability to maintain thermoneutrality (Randall, 1993).

To carry out normal feeding behaviour; it is important for the pig to get to the feed trough and to remain there without feeling threatened (Baxter, 1985). Feeders and waterers should be constructed, located and maintained in such a way that they are available for all pigs in that area (NFACC, 2014). Previous studies by Walker (1991) and Nielsen et al. (1995) have shown that production can be maintained by feeding as many as 20 or 30 pigs from a single-space feeder. Gonyou and Lou (2000) stated that 12 pigs (26.8 kg, to 106 kg BW) could be fed from the same feeder without affecting productivity as compared to providing a second feeding space. The Canadian Code of Practice (NFACC, 2014) recommends the provision of sufficient feeder space to accommodate a maximum of 13 to 18 pigs/feeder space. Pigs are considered prandial drinkers and consume 75% of their daily water intake during or after a meal (Bigelow and Houpt, 1988). Position and flow rates on nipple waters recommendations depend on the age and size of the pigs in the pen. The Canadian Code of Practice (NFACC, 2014) recommends a daily intake of 1 to 2.5 L/day and flow rates of 0.5 to 1.0 litres/min for weanling pigs (BW 5-7 kg).

Pigs spend a lot of time lying; especially lateral lying which requires much space and therefore changes in lying behaviour can be used to identify stress or discomfort (Ewbank, 1982). Since pigs have a thin coat of hair, their choice of lying location is heavily influenced by the climatic environment around them (Baxter, 1985). There is evidence that when given appropriate space and thermal conditions, pigs will spend the majority of their time in a lateral lying position. If pigs are too warm, they will attempt to increase evaporative cooling and conductive heat loss by behavioural changes such as avoiding physical contact with other pigs and lying laterally (preferably on wet floors) (Huynh et al., 2004; Hillmann et al., 2004). If cold, pigs will huddle together and demonstrate ventral lying on dry/ bedded areas and higher mobility (Ducreau et al., 2002; Fraser, 1985; Hillmann et al., 2004). Spoolder et al. (2012), therefore concluded that space allowance requirements would vary according to the ambient temperatures.

Pigs are clean animals, and when given the opportunity will excrete in areas that are separate from their lying and feeding areas (Curtis, 1999). When space is restricted, the dunging patterns of pigs change, often with excretion happening in lying areas, which increases body soiling and the risk of disease (Baxter, 1985). Therefore, effective separation of lying and defecating areas suggests appropriate space allowance, meeting the dynamic space requirements of pigs (Temple et al., 2012).

Restriction of space takes away the animals' ability to choose how to utilise the space provided. If the spatial requirements of the pigs are not met, then normal activities are displaced into aberrant behaviours indicating reduced welfare (Ekkel et al., 2003). Therefore, when calculating space allowance, it is crucial that additional space requirements for dynamic and social behaviours be considered along with static space allowances.

1.2.1 Calculation of space allowance

Traditionally space allowances have been expressed as floor space area per pig (e.g. m^2/pig) (Harper and Kornegay, 1983; Brumm et al., 2001). These calculations overlook body area as an essential factor when calculating floor space requirements. Studies using such traditional measures of space allowance (Harper and Kornegay, 1983; Meunier-Salaun et al., 1987; Brumm et al., 2001) have found that reducing space allowance hampered the growth and productivity of animals, but were not able to precisely determine when crowding or growth reduction begins. To address these shortcomings, Petherick (1983) and Baxter (1984) used an allometric formula to calculate floor space requirements. Allometry denotes the relationships among physical measurements of an object and how these change as the size (volume) of that object changes (Gonyou et al., 2006). The formula converts body weight (BW) into a 2-dimensional concept (since floor surface area required per pig increases nonlinearly as they grow) yielding the equation $A = k * BW^{0.667}$ in which A is floor space allowance in m^2, BW is body weight in kg, and *k* is the space allowance coefficient. This approach allows us to better analyze the space requirements of a pig as the coefficient (*k*) is consistent over a range of body weights and can be used to compare studies with different endpoints (Gonyou et al., 2006).

The 'broken line method' (Robbins, 1986), assumes that as the space allowance increases, an increase in productivity occurs to a critical point, above which a plateau would occur (Gonyou et al., 2006). Broken line analysis can, therefore, be used to determine the *k* value at which growth performance would be negatively affected.

Gonyou et al. (2006) completed a meta-analysis on the effects of space allowance on ADG. The broken line analysis was performed on performance data from 21 studies of nursery and growing-finishing pigs at different space allowances (at least one value > 0.030 and one treatment < 0.034). The critical *k*-value below which ADG decreased was determined to be 0.0335 for both nursery (range 6 to 20 kg) and grow-finish pigs (85 to135 kg). The study found similar *k* values for nursery and grower-finisher pigs. However fewer data were available for nursery pigs.

Gonyou et al. (2006) concluded that most studies were ineffective at determining when space allowance becomes critical because the data were reported for the entire study, rather than at intervals that could be related with changing *k* values as the pigs grew.

1.2.2 Space allowance and welfare

1.2.2.1 Animal welfare

Broom (1986) defines welfare as ‘the state of an animal with regards to its ability to cope with its environment”. Three different but overlapping types of approaches to welfare have been articulated by social critics, ethicists, and others (Duncan and Fraser, 1997). The first approach is related to natural living, which emphasises the naturalness of the environment in which an animal is kept, and the ability of the animal to live according to its nature. The second is based on feelings and emphasises the affective experiences (feelings, emotions) of animals. The approaches related to natural living and affective states are emphasised by animal welfare scientists. The third is based on the biological functioning, which measures welfare regarding health and normal functioning of the animal’s biological systems. This measure is emphasized by farmers, veterinarians, and others with responsibility for animal care (Fraser et al., 1997). It is therefore recommended that animal welfare is assessed using a multifaceted approach including considerations for health and functioning, affective states, and natural living, but this is not always the case.

Some scientists have proposed conceptions of animal welfare that include one, two, or all three of the considerations mentioned above (Fraser et al., 1997). For example, the ‘five freedoms’ of the Farm Animal Welfare Council of the United Kingdom refer to affective experience (e.g., fear, hunger), biological functioning (e.g., injury, disease) and performance of natural behaviour (Ewbank, 1988). The concept of five freedoms arose from The Brambell Report of 1965 (Command Paper 2836, 1965). The report recommended that animals must have the freedom to stand up, lie down, turn around, groom themselves and stretch their limbs (Command Paper 2836, 1965). The Farm Animal Welfare Council (FAWC, 2010) developed these into the five freedoms which provide a framework for the evaluation of animal welfare.The freedoms define ideal states rather than standards for acceptable welfare (FAWC, 2010). The five freedoms are well known for farming, policymaking, and academic circles, as they have formed the basis for animal welfare legislation, codes of practice and farm animal welfare assessment and accreditation schemes.

Restricted space has the potential to impact all five freedoms. Freedoms two (i.e. freedom from discomfort) and four (i.e. freedom to express normal behaviour) seem to be most clearly affected. Pearce and Paterson (1993) observed that restricted space causes discomfort, forcing pigs to lie in their excreta, or closer to pen mates than they would otherwise choose. The opportunity to exercise, companionship and choice of microenvironment also decreases over the time as space allowance decreases as pigs grow. Thus crowding will inhibit the pig's freedom to express normal behaviour, consequently affecting welfare (Pastorelli et al., 2006). Other freedoms may be affected, depending on the degree of crowding and other factors.

1.2.2.2 Measuring animal welfare

Restricted space allowances can compromise pigs' health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living) (Pig Code of Practice Scientists' Committee, 2012).

Adequate space allowance will also result in a good performance (daily gain, feed intake, and growth to feed ratio) and health status of pigs. Therefore, performance measures such as daily gain, feed intake, growth to feed ratio, rates of mortality, injury or disease, or the incidence of aggression and stress responses can be evaluated (Pig Code of Practice Scientists' Committee, 2012). In addition to a healthy biological function, a sufficient space allowance should help to minimize suffering and allow pigs to experience positive emotional states (affective states). However, studying affective states in animals is difficult because of the subjective nature of such states. Behavioural, physiological and cognitive responses can be recorded and evaluated as indicators of emotion (Frazer, 2008).

Regarding natural living, floor space area available for pigs should accommodate the normal behaviour of pigs, space occupied by the body of a pig, the space required for feeding and dunging behaviours as well as the space needed for social behaviours (Pastorelli et al., 2006). Hence space requirements can be evaluated by determining time budgets and the floor surface area essential for the unrestricted performance of each behaviour (Pig Code of Practice Scientists' Committee, 2012).

Evaluating welfare by merely focusing on one single measure (behavioural/ physiological alteration) would be naïve, as stress, suffering or sickness cannot be identified by using a single indicator. Instead, welfare evaluations comparing different production and management conditions should consider multiple indicators of welfare, including measures related to behaviour, physiology, health, and production.

1.2.3 Effects of space allowance on welfare measures

1.2.3.1 Effects of space allowance on pig behaviour

Postures

Behaviour is often measured as an indicator of welfare (Salak-Johnson et al., 2012). In an attempt to become accustomed to and deal with environmental challenges or stressors, the most biologically economical mechanism available to an animal is its behaviour (Salak-Johnson et al., 2012). Nursery pigs on average spend between 40% and 60% of their time resting, and grow-finish pigs spend 80% of their time resting (Blackshaw, 1981; Ruckebusch, 1972). Therefore, having suitable lying space is essential for the welfare of pigs (Tuyttens, 2005). Additionally, understanding the daily lying patterns of pigs housed in unrestricted space allowances is helpful when evaluating suitable space requirements. Under thermoneutral conditions, Ekkel et al. (2003) found that pigs over 25 kg laid predominantly (>60% of pigs) in the fully recumbent position, and spent little time lying in contact with conspecifics.

Changes in lying posture have been shown to be a sensitive indicator of overcrowding. There is evidence to suggest that decreased space allowance compromises the ability for pigs to rest adequately (Averós et al., 2010). Averos et al. (2010) performed a meta-analysis to quantitatively assess the impact of space allowance, group size and floor characteristics on the lying behaviour of grow-finisher pigs (BW range: 19- 87 kg). There was also a significant interaction between the *k* value and floor type, which indicated that for growing-finishing pigs, the relationship between space allowance and lying, depended on the presence or absence of slats. In the case of slatted floors, the broken line regression analysis identified a threshold *k* value of 0.039, higher than the threshold of 0.035 by Gonyou et al. (2006) below which the performance of grow-finishers housed on wholly or partially slatted floors is negatively affected. It showed that the expression of lying behaviour might be altered before a reduction in performance becomes obvious. It was, suggested that to cope with a stressor, animals first make adjustments that are least demanding to their biological functioning. If however, the stressor does not subside, the coping strategy alters, and the pig redirects its biological resources, altering physiology and eventually affecting productivity (Moberg, 2000). Other postural behaviours such as standing are also affected by space allowance. The Amount of time spent standing increases with a decrease in space allowance (Bryant and Ewbank, 1974; Heitman et al., 1961). Additionally, the amount of time spent sleeping and resting decreases with a decrease in space allowance (Heitman et al., 1961) which may consequently increase the time spent standing.

Reductions in space allowance increase passive sitting behaviour. Dybkjaer (1992) observed that weaned piglets housed in barren pens with lower space (0.15 m^2/ pig – higher stress treatment) spent more time sitting passively than piglets housed in pens with straw bedding and greater space (0.30 m^2/pig – lower stress treatment). Because the treatments used by Dybkjaer (1992) were s designed to be higher stress/lower stress, it was concluded that this increase in sitting must be an indicator of stress. Pearce et al. (1989) had described this behaviour as passive sitting, defined as a strategy used by pigs to protect themselves from insufficiencies in their environment. However, in a study by Street and Gonyou (2008), there was no suggestion that higher stress levels due to crowding (measured from salivary cortisol concentrations) affected the behaviour of grower-finisher pigs (37-95 kg BW) housed at a restricted space allowance (0.52 m^2/pig versus 0.78m^2/pig) indicating no difference in sitting, and standing behaviours at both space allowances studied.

Maintenance behaviours (eating, drinking, defecating)

Feeding behaviour:

The feeding behaviour of pigs changes dramatically during the nursery period. The young pigs grow rapidly and need to adapt their feeding behaviour to various components of the nursery environment such as space allowance, group size, flooring conditions, and temperature (Averos et al., 2012).

In pig production, piglets do not eat much during the first few days after weaning (Bruininx et al., 2001, 2002). Moreover, weaning results in a sudden and complete transition from obtaining all or a majority of their nourishment from milk to having feed and liquid offered separately at two different locations. Piglets spend much time exploring their new environment and have difficulty adapting to the unfamiliar source of feed. This may help to explain the low duration of feeding observed on the first day after weaning (Bark et al., 1986). It can take up to 50 hours or more after weaning before all individuals have started eating (Bruininx et al., 2001).

As pigs grow, the overall time dedicated to eating decreases (Street and Gonyou, 2008), and older, bigger pigs consume feed more rapidly and spend less time eating (Gonyou and Lou, 2000). Street and Gonyou (2008) observed that space allowance did not affect average and total meal duration, or mean latency to the next meal in grow-finish pigs. However, during the final observation at 95 kg BW, the number of meals eaten and overall meal duration of crowded pigs was less than that of uncrowded pigs. These results suggest that even though the feeding patterns were not different during any particular observation period, the physical restriction enforced upon the pigs towards the trial end may have impacted feeding patterns, as access to feeders was hindered due to restricted mobility.

Drinking and dunging behaviour

There is little in the scientific literature regarding the effects of space allowance on the drinking or dunging behaviour of pigs. In general, pigs are prandial drinkers with 75% of their daily water intake occurs before, during or after a meal (Bigelow and Houpt, 1988). Mcleese et al. (1992) recorded higher water intake on the first day after weaning compared with the following days. High drinking activity may be due to the piglets trying to achieve a feeling of satiety by drinking water (Yang et al., 1981; Vargas Vargas et al., 1987), or due to the exploration of their new postweaning environment. In a detailed study of growing-finishing pigs (25 to100 kg BW) by Meunier-Salaun et al. (1987), space allowance treatments of 0.51, 1.01 and 1.52 m^2/pig showed no effect on drinking behaviour.

Pigs given adequate space will prefer to use dunging locations that are cooler, safer and secluded from lying areas (Baxter, 1986). Vermeer et al. (2014) observed that although grow-finish pigs (110 kg) under ‘comfort class’ conditions which offers each 110 kg grow-finish pigs housed at 2.4 m^2 with bedding displayed fixed dunging patterns, pigs in larger pens (58 vs 29 m^2; same number of pigs per pen) had cleaner lying areas as compared to pigs in smaller pens. Furthermore, pigs housed at higher space allowances (2.4m^2 vs 1.6 and 1.2 m^2) had cleaner solid floors compared to pigs in lower space allowances. These results suggest that pigs with more space make use of the opportunities for fixed dunging and lying patterns without being disturbed by pen mates.

Aggression

Aggression is a natural behaviour that contributes to the establishment of dominance relationships (Fu et al., 2016). Wild pigs cohabit in small, matriarchal, genetically related groups, and aggression is only observed during the mating season. However, in commercial pig farms sudden and repeated mixing of unrelated and unacquainted pigs may lead to alterations in behaviours leading to offensive and defensive attacks and submission (Turner et al., 2006; McGlone, 1986; Andersen et al., 2000; Camerlink et al., 2013).

The accretion of skin lesions coincides with involvement in aggressive behaviour. The location is essential for a correct interpretation. It determines whether the fight was a result of reciprocation or bullying (McGlone, 1985; Turner et al., 2006).

The number of skin lesions present is frequently measured via lesion scores (LS). Pigs in straw-bedded pens have lower lesion scores when provided with greater space allowances (32 kg/m² versus 50 kg/m²), (Turner et al. 2000). These results were similar to the findings of Vermeer et al. (2014) which suggested that low space allowance led to higher number of body lesions. Similarly, Fu et al. (2016) observed that the number of lesions in front and middle regions were highest in pigs (barrows with an initial body weight of 75 kg,) in the lowest space allowance (0.8 m²/pig- k=0.045 versus 1.6 m²/pig- k=0.090). These results suggest that time spent in reciprocal fighting is higher when space allowance is restricted. Stuckenborg et al. (2012) found a strong correlation between lesions scores on the front region (ears, face, and neck) and aggressive behaviours. It was thus suggested that lesion scores are an excellent tool to access aggression in pigs (Teixeira and Boyle, 2012), and that appropriate space allowance is a critical factor in preventing aggression in pigs (Fu et al., 2016).

Limiting aggression in intensively kept pigs is imperative to improve their welfare (Schaefer et al., 1990). Lesion score (LS) is an assessment tool which evaluates the outcomes of aggression. Hence, to successfully use LS as a measure of individual aggressiveness, the underlying behaviours and environmental conditions contributing towards the accumulation of these lesions should be well established (Turner et al., 2006).

1.2.3.2 Effects of space allowance on stress physiology

Moberg (1993) defined stress as a biological response to an incident that the individual perceives as a danger to its homeostasis. The stress response involves interactions between external events (stressors) and individual predispositions which give rise to measurable physiological changes (Ladewig et al., 1993). When the central nervous system perceives a potential threat to homeostasis (a stressor), it activates the hypothalamic-pituitary-adrenal axis (HPA) (Stewart et al., 2007; Chrourosus, 2009). Activation of the hypothalamic-pituitary-adrenal axis results in elevated corticotrophin-releasing hormone levels, stimulating the release of glucocorticoids such as cortisol from the adrenal cortex (Hicks et al., 1998). Although the stress response can be assessed by measuring components of the HPA-axis, the activity of the HPA axis is highly variable. Corticosteroid levels follow diurnal and seasonal patterns, which are further influenced by age, gender, and stressors (Gratacos-Cubarsi et al., 2006; Ruis et al., 1997) as well as by the nature, intensity, and duration of the stressful event (Einarson et al., 2008). Therefore, caution is advised when attempting to use physiological measures of stress to assess animal welfare.

Stressful events can be acute. Acute stress could be described as a brief initial elevation of glucocorticoid levels due to a sudden stressor such as heat/cold and shipping, which returns to normal baseline levels after a short time. Chronic stressors are longer-lasting and may be characterised by individual stressors (or a combination of stressors) such as high ambient temperature (Xin et al., 1992), social mixing (Bjork et al., 1988) and restricted space allowance (Kim et al., 2017). These conditions may have long-lasting effects (Wiepkema and Koolhaas, 1993) due to hypersecretion of the glucocorticoids which initiate potentially serious regulatory changes at different levels of the HPA axis (Jensen et al., 1966). Therefore, chronic elevations of physiological stress measures are indicative of general reduced welfare (Wiepkema and Koolhaas, 1993).

In pigs, cortisol is the main glucocorticoid released in response to stress (Bottoms et al., 2010). Measurement of circulating cortisol has become an important tool to measure stress responses (Bushong et al., 2000). Traditionally venipuncture has been used to collect blood for assessing plasma cortisol levels (Benson et al., 1986; Friend et al., 1988; Brown-Borg et al., 1993). Apart from the stress of handling and restraining animals for sample collection; venipuncture for collection of plasma is an additional stressor, prompting glucocorticoid release. Utilizing less invasive collection techniques such as saliva collection have been suggested to be a better alternative to plasma cortisol as a measure of stress, as it involves less handling and does not require venipuncture (Beerda et al., 1996; Lebelt et al., 1996). Salivary cortisol measures primarily free cortisol, rather than free and bound which is found in blood. Also, salivary cortisol increases within a very short time of plasma cortisol surge (Cook, 2012) which makes it a suitable measure of acute stress.

Stress due to crowding is typically chronic. Therefore assessing basal cortisol levels for establishing the degree of stress imposed by the pig's environment has limited usefulness (Rushen, 1991). When growing pigs are moved to a pen, crowding occurs gradually over time. However, Pearce and Paterson (1993) did not see any effects of continuous space restriction (k = 0.025 vs k = 0.048) on basal cortisol levels of growing pigs (25-100 kg) but reported depression in growth. These results show that because of the adaptation of the HPA axis over time, basal cortisol levels may not be the best pointer of chronic stress, and suggest that an exogenous adrenocorticotropic hormone (ACTH) challenge could be a more sensitive method for assessing the effects of environment stressors on adrenal activity. This test is grounded on the fact that exposure of an animal to chronic stress changes the responses of the adrenal gland to successive acute stressors (Sakellaris and Vernikos-Danellis, 1975).

When Pearce and Paterson (1993) exposed pigs to an adrenocorticotropic hormone challenge, crowded pigs (k = 0.025) responded with significantly higher concentrations of cortisol in response to ACTH challenge than uncrowded pigs (k = 0.048), indicating that crowded pigs were chronically stressed. Anil et al. (2007) studied the effects of allometric space allowance on grower-finisher pigs (30.56 to; 116 kg BW) at four space allowances-(k- 0.034, 0.031, 0.027 and 0.037) found that basal cortisol concentrations were not elevated by space restriction, which agrees with the previous studies of Pearce and Paterson (1993) and Meunier-Salaun et al. (1987). Anil et al. (2007) therefore, suggested that measurement of the HPA axis activity must be considered on the possibility that chronic stress results in hyperactivity of the adrenal cortex. Although more costly and difficult to do, an exogenous ACTH challenge would be a more sensitive and reliable method for assessing environmental effects on adrenal activity.

1.2.3.3 Effects of space allowance on pig's immune response

The interaction between animals and their environment is complex, and all living organisms have developed mechanisms to cope with environmental stimuli related to their environment (Salak-Johnson and McGlone, 2007). The immune response is one such mechanism. There are two main types of immune response, innate and adaptive. Innate immunity refers to the nonspecific defense mechanism acting as the first line of defense, and adaptive immunity relates to the antigen-specific response which develops over time and is more complex (Salak-Johnson and McGlone, 2007). Macrophages and dendritic cells initiate adaptive immune responses by presenting antigens to naïve lymphocytes to initiate a cell-mediated or humoral response (Salak-Johnson and McGlone, 2007). For ideal growth and performance of pigs, proper development of humoral and cellular functions of the immune system is crucial (Sinkora et al., 2002). The process of antibody production by B cells which leads to the destruction of extracellular microorganisms and prevents the spread of intracellular infections is called humoral immunity. In contrast, cellular immunity involves the activity of T-lymphocytes derived from the thymus gland. T-lymphocytes directly destroy the virally infected cells. The activation of immune response promotes secretion of multiple pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α (Colditz, 2002; Pie et al., 2004; Sinkora et al., 2002).

Acute and chronic stressors affect the immune response in different ways. Acute stressors such as heat or transportation often have limited suppressive effects on immune response, whereas chronic stressors such as heat and social stress most often lead to immune suppression, (McGlone et al., 1993; Morrow-Tesch et al., 1994; Hicks et al., 1998; Salak-Johnson and McGlone, 2007).

Restricted space could be considered a chronic stressor (Meunier-Salaun et al., 1987; Pearce and Paterson, 1993), so could be expected to cause immunosuppression. However, the relationship between space allowance and the immune response is complicated and not well studied. Multiple methods have been used with variable results. Some studies, but not all, have demonstrated effects of crowding on the immune response. Kornegay et al. (1993) observed no difference in the humoral immune response measured by the level of antibodies produced after primary and secondary injection of ovalbumin in inadequate and restricted floor space allowances (0.14 versus 0.28 m^2/pig). These results suggested that the lack of an effect could be because the restriction of space was not overly stressful. Turner et al. (2000) investigated the effect of space allowance (50 kg/m^2 vs 32 kg/m^2) on performance, aggression and immune competence of growing pigs (initial BW 29.7±0.16 kg) housed on deep-litter straw at two group sizes (20 vs 80). It was observed that following the first intra-muscular injection of inactivated Newcastle disease virus, the humoral immune response was significantly weaker in pens with restricted space allowance, suggesting the greater extent of stress experienced when space allowance is low. Turner et al. (2000) suggest that although higher space allowances did not result in any improvement in growth performance, the higher prevalence of aggression and depressed immune response in pigs housed at lower space allowances advocates the use of higher space allowances.

Overproduction of cytokines such as IL-1β disturbs immune function in pigs (Colditz, 2002). Oh et al. (2010) measured the concentration of cytokines IL-1β, and TNF-α to ascertain the influence of crowding stress on the cellular immunity of weaned pigs. Reducing the space allowance from 0.43 to 0.21 m^2/pig in weaned pigs (6 to 15 kg BW) led to a linear increase in the cytokine IL-1β and cortisol concentrations over time, disrupting the cellular immune response in piglets (Oh et al., 2010). These results suggest that the space allocation for maximum growth performance and immune responses of nursery pigs (until 15 kg BW) is between 0.30 m^2/pig and 0.43 m^2/pig.

The reduction in cell-mediated response observed in some of the studies discussed above indicates that crowding stress due to space restriction is a chronic stressor. Crowding stress due to restricted space allowances during nursery period has detrimental effects on cellular immune response and growth rate of weaning pigs (Oh et al., 2010). This is because proinflammatory cytokines cause a shift in nutrient partitioning away from the skeletal muscle accretion, towards the metabolic responses necessary to support the immune system (Klasing and Johnstone, 1991). Furthermore, inflammatory cytokines also stimulate the secretion of stress hormones such as cortisol, consequently decreasing the secretion of growth hormone (GH) (Fan et al., 1994). Therefore, it is crucial to utilise this information to optimise pig production systems, as inadequate space allowances not only disrupt immune functions but also adversely affected production performance

1.2.4 Temperature and space allowance

Pigs are homeothermic animals with a body temperature of 39ºC (Baxter, 1984) and protecting pigs from temperature fluctuations is critical. When the environmental temperature around the pig is lower than the pig's body temperature pigs will lose heat via convection with ambient air and via conduction to the floor, walls and other pigs. Pigs must, therefore, be housed at thermo-neutral temperatures that will assist them to reach and maintain normal body temperatures. Thermo-neutral zones are usually characterized as the temperature within which an animal's total heat production is approximately constant for given energy intake (CIGR 1984).

The animal's ability to dissipate heat in hot and humid environments and to conserve body heat in cold conditions is affected not only by the thermal environment of the pig but also by interactions with space allowance (Petherick and Phillips, 2009). The interaction between the thermal environment and space allowance is essential as the pigs' activity is decreased in hot and humid conditions and increased to generate metabolic heat in cold conditions (Hicks et al., 1998; Randall, 1993). Pigs rely on a variety of behavioural adjustments for thermoregulation. To achieve thermoregulation, pigs in warmer ambient temperatures (>20 to 24ºC depending on the weight) would attempt to increase their respiratory rate and evaporative heat loss through behavioural changes such as wallowing. Pigs in this situation avoid physical contact with other pigs, reduce general activity and rest lying laterally (Bracke, 2011; Huynh et al., 2004; Hillmann et al., 2004), hence requiring more space. On the other hand, pigs in cooler environments decrease their heat loss by lying in sternal recumbency (reducing floor contact) (Baxter, 1986; Ekkel et al., 2003). To reduce heat loss and conserve body heat, pigs tend to huddle together and change lying postures from lateral to sternal below the thermo-neutral zone (Geers et al., 1987; Young et al., 1989; Harmon et al., 1997; Hayne et al., 2000). Pigs in cooler environments are more active (more time standing and sitting behaviours as compared to lying) with higher feed consumption and maintenance energy requirements (Petherick, 1983; Hicks et al., 1998). Therefore, in relation to space requirements, pigs at higher ambient temperatures will require more space to accommodate postural behaviours than in cooler conditions. If however, the pigs are still too warm, reductions in feed intake and consequently weight gains are observed (Hyun et al., 2005).

When pigs are housed in thermo-neutral conditions, there is no apparent requirement for pigs to change their postures (Ekkel et al., 2003). However, thermo-neutral temperatures vary with age. Nursery piglets are more vulnerable to chilling than older animals. Thus, in commercial practice, it is recommended that ambient temperatures be warmer when pigs are first weaned (35ºC (Range- 33-37); 4-5 days post weaning). Temperatures are gradually adjusted down (27 ºC (Range- 24-30); 5-20 kg in weaned pens) (NFACC, 2014).

1.2.5 Effects of space allowance on pig production

1.2.5.1 Daily gain and feed intake

Reducing space allowances reduces performance in all classes of growing pigs (in weanlings- Hugh and Reimer, 1967; growers- Jensen et al., 1973; and grow-finish pigs-Pearce and Paterson, 1993; Brumm and Miller, 1996; NCR-89 Committee on Swine Management, 1996). However, it has been calculated that production is more profitable when the number of pigs per unit of building space is maximised, despite some reduction in individual pig performance (Kornegay et al., 1993). Thus, the optimal space allowance involves a balance between animal welfare and the economics of pork production.

Restricted space allowance limits the free movement of pigs in the pen and can limit access to the feeding area. As discussed in section (1.2.3.1), when space is limited, pigs will first alter their feeding behaviour to accommodate for reduced access to the feeder. If crowding is extreme, the resulting stress from this could lead to decreased feed intake among space restricted pigs (Gonyou et al., 1999). Since reduced space allowances causing a reduction in feed intake often result in a reduction in ADG, feed intake is valuable as a performance measure (Whittemore, 1986; Brumm et al., 2001). Using a meta-analysis of 21 studies which measured the performance of nursery and grower-finisher pigs, Gonyou et al., (2006) estimated a critical k value of 0.0335 for grower-finisher pigs. The ADG for grow-finish pigs were significantly reduced when space allowances were provided below these values. Other researchers such as Meunier-Salaun et al. (1987) and Street and Gonyou, (2008) also reported lower average daily gains and less frequent eating in grow-finish pigs when space allowances of $k < 0.034$ were compared with higher space allowances.

Similar to grower-finisher pigs, the literature on nursery pigs shows that reducing floor space allowances during the nursery period negatively affects growth. In a review of the literature, Kornegay and Notter (1984) reported that increasing space allowance increased ADG and ADFI in weaning (average final weight of 21.1 ± 0.6 kg; *k*=0.024), but the effect on feed efficiency was much smaller indicating that increased ADG was primarily due to the increased ADFI.

In a more recent study, Oh et al. (2010) investigated the effects of space allocation coefficient, *k*, 0.073, 0.052, 0.047 and 0.038 during the nursery period on growth, stress and immunity in pigs. A linear decrease in ADG with decreasing space allocation was seen within 28 days of the experiment. It was suggested that a space allowance between 0.0.052 and 0.073 m^2/pig maximises growth and immune response of weaning pigs up to 15 kg BW. Logically, a decrease in feed intake results in a reduced intake of nutrients, thus reducing gains. However, research shows that concentrating nutrients by addition of fat, lysine, or soybean meal did not alleviate the depression in performance associated with space allowance restrictions (Kornegay et al., 1993; Brumm and Miller, 1996; Edmonds et al., 1998). Lack of response to dietary modifications when pigs are crowded, is because the potential for lean growth in pigs is decreased, resulting in reduced feed intake (Chapple, 1993). Therefore the modification of the nutrient composition of diets is not recommended when space allocation is restricted.

In conclusion, results from numerous studies indicate that performance is negatively affected when space is restricted. While it is plausible that decreased ADG due to decreased space allowance could be due to a decrease in ADFI. However, increasing the energy content of the ration cannot alleviate impact of restricted space

1.2.5.2 Gain to feed

Feed is the most costly input in pig production, accounting for over 60% of production costs (Patience et al., 2015), so to be profitable it is essential to have efficient feed conversion. Feed efficiency (G:F) is on the ratio of growth achieved to feed consumed (Patience et al., 2015). Changes in feed efficiency are observed when either daily gain or daily feed intake changes. It also changes if both variables change but in opposing directions. Therefore, to have a better understanding of the pig's performance, it is imperative to consider feed intake and weight gains together in the calculation of feed efficiency (Smarakone and Gonyou, 2006).

There is much information on the effect of space allowance on G:F in grow-finishers, however, the results are inconsistent. For example, some studies have found an improvement in feed efficiency with an increase in space allowance (Street and Gonyou, 2008; Zhang et al., 2013). In a grower-finisher study (95 kg of BW; *k* = 0.025) by Street and Gonyou (2008), it was observed that crowding reduced overall productivity, with the most significant effect late in the study when pigs were most crowded. Uncrowded pigs (0.78m^{2}per pig had higher G: F (0.40 vs. 0.37) than crowded pigs (0.52 m^2). Street and Gonyou (2008) showed that feed intake did not decrease if the number of pigs per feeder space remained the same, even with decreased space allowance. However, the degree of physical restriction (hindering feeder access) imposed near the end of the study when the pigs were most crowded decreased G:F (decreased gain). In contrast, others researchers such as Meunier-Salaun et al. (1987) and Turner et al. (2000) found an improvement in feed efficiency with a decrease in space allowance. Meunier-Salaun et al. (1987) observed an increase in feed efficiency of 7% and 14% in grower pigs and finisher pigs respectively at a space allowance of *k*=0.024 as compared to space allowances- *k*=0.032 and 0.047. Turner et al. (2000) investigated the effect of space allowance on performance, aggression and immune competence in growing pigs (start weight 29.7± 0.16 kg), housed at two space allowances (50 kg/m² versus 32 kg/m²) in solid bedded systems and two group sizes (20 or 80) in a six-week trial period. It was observed that lower space allowances, irrespective of group size, did not affect ADG, but that pigs in the lower space allowance tended to consume less feed, resulting in improved feed efficiency.

When Brumm et al. (2001) investigated interactions of swine nursery and grow-finish space allocations on performance in a two-part wean to finish the study, it was observed that there was no significant effect of decreasing space allocation from 0.43 to 0.21m^2 on feed efficiency. These findings are in agreement with the study of Turner et al. (2003), which reported no effect of crowding on feed conversion ratio during the nursery period. Similarly, when Oh et al. (2010) investigated the effect of space allowance on growth performance and immune system in weaning pigs (initial BW- 6.02 kg) it was found that a reduction in space allowance (0.43 m^2/pig-10 pigs/pen to 0.21m^2/pig- 20 pigs/pen) had no significant effect on Gain: Feed (G: F) from weaning to 28 days post-weaning.

The literature on nursery pigs shows that reducing floor space allowances has variable effects on feed efficiency. In a review of the literature, Kornegay and Notter (1984) reported that every 0.1 m² increase in space allowance per pig decreased feed efficiency in nursery pigs (final body weight 21.1 ±0.6 kg) by 1.2%. Whereas others such as Kornegay et al. (1993), Brumm et al. (2001) and Oh et al. (2010) found no effect of space allowance on feed efficiency in crowded weaner pigs. Reductions in space allowance resulting in reduced ADG and ADFI with no effects on feed efficiency indicate that decrease in ADG was primarily caused by a reduction in feed intake. Kornegay et al. (1993) looked at the effect of dietary lysine on performance and immune response of weanling pigs (Initial weight 7.1 kg; age 28 days) at two space allowances (0.28 and 0.14 m²/pig). Floor space allowance and lysine by floor space allowance interaction did not have a significant effect on G: F ratio in these pigs. It was suggested that addition of more lysine might not be useful to overcome the reduction in performance due to constrained floor space allowances (Kornegay et al., 1993).

When reduced space allowance results in an equal reduction in ADG and ADFI but no effect on Gain-Feed; it indicates that decrease in gain was primarily caused by a reduction in feed intake. However, lower space allowances do not affect ADG, but pigs tend to have a higher Gain-Feed. This suggests that pigs perform more locomotory behaviours at higher space allowances which lead to higher energy expenditure, thus limiting slightly the performance benefits of providing a higher space allowance (Turner et al. 2000).

1.3 Group size

1.3.1 Effects of group size on pig production

When studying space allowance in intensive swine production systems, crowding can be imposed by changing the pen size to reduce the space allowance per pig, or by increasing the number of pigs/pen within a static pen (Randolph et al., 1981). In the first option, pen size varies and so has a potentially confounding effect, and in the second, space allowance is confounded by group size. Some studies have varied group size to change the space allowance per pig. Both of these approaches have been successful in demonstrating the effects of crowding (Whittaker, 2012). To run a successful hog operation, efficient utilization of space without detrimental effects on the well-being of pigs is crucial. Lately, housing pigs in large pens have become an increasingly common feature in production systems. Ease of management and better use of resources and economic benefits has led to larger group sizes of pigs in commercial establishments (Wolter and Ellis, 2002).

Studies on group size have generated different outcomes. Research examining wean-to-finish systems reported that housing newly weaned pigs (17 days of age; initial BW 5.9± 0.9 kg) in large groups (100 pigs/pen vs 25 or 50 pigs/pen) caused a reduction in daily feed intake and gains for the first 6 to 8 weeks post-weaning (Wolter et al., 2000; Wolter et al., 2001). However, as the animals continued to grow, differences in performance due to group size (20 vs 100 animals) diminished (Wolter and Ellis, 2002). Similarly, a study comparing groups of 10 and 90 pigs in the nursery and grower-finisher stages found that reductions in ADG and ADFI due to group size were greater in large groups of nursery pigs as compared to grow-finish pigs (Verdoes et al., 1998). Two similar studies had also shown that when housing growing-finishing pigs in large groups, there was no indication of undesirable, long-term effects on their performance (Wolter et al., 2001; Turner et al., 2003).

Research has shown that increasing group size compromises the performance of weaned pigs. Increasing group size from 25 to 50 pigs/pen in weaned pigs (age-17 days; initial BW 5.9± 0.9 kg) with constant feeder space (4.3 cm/pig) and space allowance (0.68m²/pig) led to a decrease in the growth rate of pigs at the end of 8 weeks (Wolter et al., 2001). However, a study on similarly aged pigs by O'Connell et al. (2004) with a space allowance of 0.38 m²/pig did not find any effect of increased group size (range 10 to 60 pigs/pen) on production parameters up to 10 weeks of age post-weaning. Edwards and Turner (2000) suggested that the reason for the difference in the two studies might be because the space allowance used in the Wolter et al. (2001) study was higher than in the O'Connell et al. (2004) study, and this may have resulted in reduced performance in the large group pen. This explanation agrees with

Turner et al. (2000), who suggested that the increased energy expenditure required for locomotion to access feeding and drinking points when pigs are housed in larger groups may contribute to reduced performance.

The efficiency of tissue deposition is often measured by feed use to weight gain ratio (FCR). In an 8-week wean to finish study, Wolter et al. (2001) reported that feed efficiencies were poorer in large groups of pigs (groups of 50 and 100) as compared to groups of 25. Turner et al. (2003) reviewed the implications of group size on performance using a meta-analysis of data from 20 different studies. It was reported that reduction in feed intake in the weaner stage (from weaning to 39 kg) was not present in the grow-finish (31to 68 kg) stage. Reduced ADG of weaner pigs was almost fully explained by a reduction in ADFI, with a consequent negligible effect on FCR. In the grower-finisher, however, reductions in ADG were not accompanied by a significant decrease in ADFI and thereby resulted in a reduction in growth efficiency.

In summary, the effects of group size on daily gains are not as great in grower-finisher pigs as in younger pigs. In younger pigs, large groups can result in decreased feed consumption, so it is important to monitor behaviour, feed consumption and growth during the initial stages when pigs are assigned to nurseries (Spoodler et al., 1999; Schmolke and Gonyou, 2000; Turner et al., 2002). Depressions in growth observed during these weeks may cause more significant effects on growth performance at later stages and consequently reduces profitability due to delayed marketing.

1.3.2 Effects of group size on pig behaviour

Pigs adopt different approaches to active or resting behaviours depending upon the size of their pen group (Estevez et al., 2007). Assuming that pigs are given adequate space, food, and water, there is little evidence that large group sizes result in decreased welfare, given that pigs can adapt to different group sizes by altering their social behaviours (Estevez et al., 2007; Turner et al., 2001). For example, grower-finisher pigs housed in larger groups (18 pigs at 0.52 m^2/pig versus 108 pigs at 0.78m^2/pig; average weight 55 kg) were shown to eat fewer meals and had a greater latency to the next meal, but took longer to eat each meal when compared to pigs housed in small groups (Street and Gonyou, 2008). A reduction in feeding due to crowding was only observed in small groups. Crowded pigs (0.52 m^2/pig) in this study ate fewer meals and spent less time eating overall, but feed intake did not differ from uncrowded pigs, suggesting that the crowded pigs consumed feed more rapidly than uncrowded pigs (Street and Gonyou, 2008).

Feeder placement and feeder space allowance also play a vital role in the feeding behaviour of pigs. Regardless of group size, pigs are social feeders and prefer to eat at the same time (Spoodler et al., 1999; Wolter et al., 2000) resulting in increased competition for feeder space. A study looking at the feeding behaviour of pigs at different group sizes found that pigs in groups of 20 ate more rapidly than those in groups of 5, 10 or 15, and had shorter feeding times (Nielson et al., 1995). However, in this study, group size was confounded by feeder space allowance. In a similar study where feeder space allowance was controlled, Turner et al. (2002) did not see any effects of group size (20 pigs/pen vs. 80 pigs/pen) on feeding bout duration or the number of feeding bouts, even though the pigs in groups of 20 occupied the feeder for more time per day (24 hrs). Thus, when feeder space is controlled, group size appears to have a little overall impact on feeding behaviour.

Some other behaviours have been studied to determine if they are affected by group size. This research has shown that most behaviours have no relationship with group size. However, Street and Gonyou (2008) observed that the proportion of time grower-finisher pigs (38-95 kg) spent sitting was higher in smaller groups (18/pen) at all observed times (0700 to 1800) as compared to pigs housed in larger groups (108/pen). Conversely, no effects of group size (10, 20, 40 or 80 pigs/pen) were reported for manipulative, standing and lying behaviours (Spoodler et al., 1999). Averos et al. (2010) in a meta-analysis of 22 studies looking at the impact of space allowance and group size on lying behaviour, noted that group sizes had no impact on total lying behaviours of the grower-finisher pigs. Schmolke et al. (2004) concluded that, regarding behavioural time budgets, pigs housed in larger groups were no different from pigs housed in the smaller group sizes.

Overall, it appears that pigs adjust their feeding behaviour in larger groups, likely due to increased difficulty in accessing the feeder. However, very few differences have been found in other behaviours or postural changes. Moreover, the results must be interpreted with care due to confounding factors such pen size, layout and feeder space allowance.

1.3.3 Interaction of space allowance and group size

Adjusting space allowance by changing the number of pigs per pen is a common method for studying the effects of space allowance under commercial conditions. Standard pen size is used, and space allowance is reduced by adding more animals per pen. However, with this method, space per pig and group size are confounded. When studying the effects of space allowance and group size, some researchers have found interaction effects between space allowance and group size, while others have found no effect.

Wolter et al. (2000) reported an interaction of group size and floor-space allowance for G:F in the nursery post-weaning. The floor-space was constant (k =

0.030) for the first four weeks after weaning. It was observed that the first week, crowded pigs (*k* = 0.030) in groups of 100 per pen had lower G/F as compared to uncrowded pigs, but the opposite was observed for pigs in groups of 20 per pen. This was the only significant interaction of group size and space allowance and was only seen during weaner period. There were no effects of the reduced space allowances for groups of 20 and 100 pigs per pen on ADG or feed intake, even though the actual floor space was 13% lower. Therefore this study supports the hypothesis of McGlone and Newby (1994) which states that it is possible to decrease the effective space provided without causing any alterations in performance. However, Wolter et al. (2000) did not test the relationship between space allowance and group size directly, and therefore this warrants further research. Some other studies conducted during this period have sometimes confounded group size with space allowance (Wolter et al., 2002), or with feeder space per pig (Wolter et al., 2003).

There are other studies which did not find any space allowance by group size interactions. Turner et al. (2000) did not find any interactions between group size and space allowance in growing pigs (initial weight: 29 kg; six-week study). They did, however, observe that reductions in space allowance or increases in group size were each capable of depressing performance independently. Thus, pigs in groups of 80 (irrespective of space allowance) displayed on average 6.6% lower ADG than those in groups of 20. This effect was not apparent in first two weeks of the experiment, and the authors suggest that reduction in ADG could have been either a chronic response to greater locomotor activity from moving between different pen areas, thus increasing the use of energy or social stress caused by the continued presence of many other animals.

Street and Gonyou (2008) also did not find any interaction between space allowance and group size. They observed an overall increase of 3.5% in weight gains when grower pigs were reared in small groups (18 pigs at 0.78 m²/pig) compared to large groups (108 pigs at 0.78 m²/pig). In this study, ADG was most affected in first two weeks of the study. However, by the end of the trial (8^{th} week), ADG's in large and small groups were identical. Effects on productivity in this study were limited to an initial period of adaptation, whereas the effects of crowding were evident at the end of the production period. The authors suggested that a higher degree of physical restriction (decreasing mobility) imposed on pigs at the end of the trial may have hindered feeder access leading to lower feed conversions. In this study both crowding and large group housing negatively affected pig performance. Pigs in large groups were negatively affected by space restriction sooner than pigs in small groups. It was concluded that effects from these two management factors work independently. Effects on productivity were limited to the initial period of adaptation to the large group system, and effects of crowding were only evident at the end of the production period when crowding is greatest. The authors conclude that pigs in large groups and small groups adapted to space restriction similarly. Therefore, housing pigs in large groups may not be as detrimental to grower-finisher pigs as was presumed (Edwards et al., 1988).

1.4 Conclusions

The swine industry is changing; there is increasing pressure on producers to be economically efficient while improving pig welfare and reducing environmental impact. Floor space allowance is important for both economic and welfare reasons. In grow-finisher pigs, using an allometric approach and broken line analysis to express space allowance has been a useful tool to determine the *k* values, at which crowding becomes detrimental. In contrast, relatively little is known about the effects of space allowance in nursery pigs. The *k* value which is applicable for finishing pigs may overestimate the requirements for nursery pigs, largely due to their propensity to overlie. Numerous results from various researchers show that restricted space allowances reduce the welfare of the pigs as the ability to perform some behaviours is restricted by a reduction in space allowance. However, the literature on housing pigs in large groups is inconsistent. While some researchers believe that pigs in larger groups may be able to use space more efficiently, others are sceptical. Even though an attempt to define measures of stress is difficult, physiological measures such as cortisol and immune response assessment seem to be useful. The following study was designed to address the question of how much space allowance is necessary for nursery pigs housed in two group sizes and to determine how pigs respond to variation in space allowance and group size regarding behaviour, growth and welfare.

2. THE EFFECTS OF SPACE ALLOWANCE ON NURSERY PIG GROWTH, BEHAVIOUR AND STRESS PHYSIOLOGY

2.1 Introduction

Floor space allowance impacts welfare and production economics. In practical terms, the space provided to pigs must balance both economic and welfare consideration. Significant research on the effect of space allowance has been carried out in grow-finish pigs (see Edwards et al., 1988; McGlone and Newby, 1994; Ekkel et al., 2003; Pastorelli et al., 2006) and these results are currently being used as guidelines for minimum space allowance required for nursery pigs (NFACC, 2014). However, it is unclear whether nursery pigs have the same space requirements as grower-finisher pigs, as not much is known about the effects of space allowance on nursery pigs (EFSA, 2005, Gonyou et al., 2006).

There is some concern that the *k* value which is appropriate for finishing pigs may overestimate the requirements of nursery pigs. Even though the growth rate is limited at higher densities overall farm productivity increases with higher numbers of pigs per unit of the building, (Kornegay and Knotter, 1984). Turner et al. (2000) determined that the welfare of the pig could be adversely affected by higher stocking densities leading to higher risk of immune suppression and increase in disease susceptibility as well as impeding the ability of pigs to fully express normal behaviour.

It is important that the space allowances be calculated based on what space an animal needs, rather than purely by production performance (Ekkel et al., 2003). The studies associated with space requirements should focus on changes in the behaviour of pigs and establish the welfare relevance of such changes (Ekkel et al., 2003). Some effects of temperature on lying pattern have been postulated by Hyunh et al. (2005) and Spoolder et al. (2012). Therefore it is imperative that group size and seasonal effects should be determined more precisely. McGlone and Newby (1994) proposed that larger groups of pigs require less space due to space sharing. However, Street and Gonyou (2008) challenged the above findings and suggested that at higher space allowances a decrease in ADG was higher than in small groups.

The hypotheses of the study are that:

- Nursery pigs require less space to achieve maximum ADG than grow-finish pigs.
    - This is because the *k* values appropriate for grow-finish pigs overestimate the space requirements of nursery pigs due to their propensity to overlie.
- To cope with a stressor, animals first make adjustments which are least demanding in terms of their biological functioning.
    - Space allowance will, therefore, affect the behaviour of nursery pigs before effects on production are apparent.
- Housing pigs in larger groups will not influence piglet growth and welfare when adequate resources (feed, water) are provided.

The two main objectives of the study are:

- To determine the effect of space allowance, group size and their interactions on nursery pig growth and feed efficiency.
- To determine the effect of space allowance on behaviour, in particular, the amount of space required to accommodate normal resting postures.

2.2 Materials and Methods

2.2.1 Animal Housing

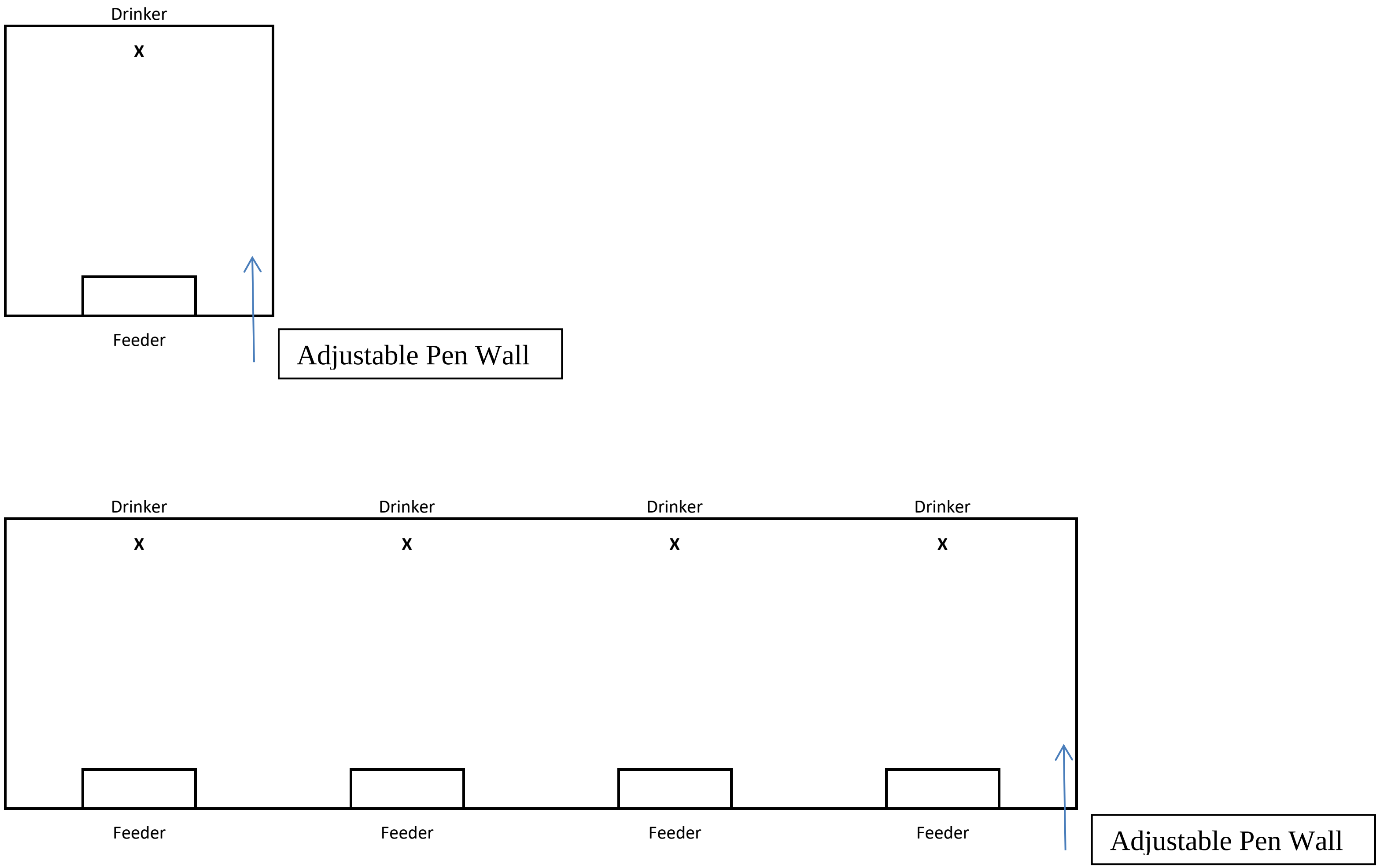
All experimental procedures performed in this study were approved by University of Saskatchewan's Animal research and ethics board and adhered to the Canadian Council on Animal Care guidelines for humane animal use (Canadian Council on Animal Care, 2009).

The study was conducted at the Prairie Swine Centre's nursery barn in Saskatoon, Saskatchewan. A total of 1,200 newly-weaned pigs (PIC genetics, Camborough cross: Yorkshire*Landrace) were housed in fully slatted pens and fed ad-libitum (feed composition for experimental diets in Appendix: Table A.7). As a standard barn practice, artificial lighting was provided from 07:30 to 16:00. Despite changing space allowance treatments, the availability of feeder space and nipple drinkers (on a per pig basis) were kept constant between treatments.

Piglets were weaned at 28 ±2 days of age and were placed in the nursery at one of six different space allowances (k = 0.023, 0.0265, 0.0300, 0.0335, 0.0370, or 0.0390) and one of two group sizes (10 or 40 pigs/group). The space allowances span a range of values used in commercial practice and the suggested optimum (0.0335) as determined by Gonyou et al. (2006), and two values above the optimum up to the value recommended by Averos et al. (2010). Studying the space requirements at two group sizes would help to determine whether the space requirements per pig differ between large and small groups. Pens were square for groups of 10 and rectangular for groups of 40. Four replicates were completed (one each in winter, spring, summer, and fall), with one pen of each density and group size per replicate. The pigs remained in nursery pens for five weeks and were weighed weekly on a pre-determined day.

The pen space allowance treatments were adjusted weekly to maintain k values throughout each trial, to identify the critical stages within nursery period that may adversely affect performance and welfare. Following the weekly pig weighing, pen dimensions were adjusted based on the predicted average body weight of pigs at the end of the following week and the pen treatment *k* value using movable partitions. Space allowance was determined using the allometric equation: area = k*$BW^{0.667}$, where the area is floor space area in m^2, *k* is the floor space allowance coefficient, and BW is the pig body weight in kilograms, BW calculated to the power of 0.667 is the allometric body size (Petherick and Baxter, 1981).

Figure 2.1. Pen layout for pigs in groups of 10 and 40. Feeder dimensions were 4.6 cm/pig, x denotes placement of nipple drinkers.



2.2.2 Data Collection and Records

On the day before weaning, five to 10 litters were weighed, assigned to treatment and ear tagged. Pigs were enlisted in the trial only if they fell within 5.5 to 11.0 kg BW. One room was filled per week with one space allowance treatment, in pens of 10 and 40 pigs per room. Litters were mixed and were randomly distributed among treatment pens based on pen requirements of one large male and female, one medium male and female, one small male and female pig for immunological testing and four females for behavioural and cortisol testing. This made up the entire pen of 10 pigs for the small pen groups. The remaining 30 pigs in pens of 40 pigs were randomly selected and were balanced for gender (15 male and 15 female).

2.2.2.1 Production data

No creep feed was provided in farrowing. Pelleted feed was used in the nursery rooms. The feed was weighed into feeders (2 to 3 times per week to ensure ad libitum feed), and weigh backs were done to record feed consumption. Animals were weighed weekly, and pen size was adjusted based on the projected weight of the pen group the following week (Table 2.3). The nursery feeders were 46 cm wide (internal width), with three sections (head holes). Therefore, one feeder with ten piglets provided 4.6 cm/pig of feeder space. Feed remaining in the feeder and pig weights were recorded on the day of mixing, and subsequently once per week, on a set day each week for the remainder of the trial (Table 2.3). The feed consumption and pig weights were used to calculate ADG, average daily feed intake and Gain:Feed.

2.2.2.2 Behavioural data

On one day per week, group and focal pig behaviour were recorded in weeks one, three and five during 8 hrs of daylight (08:00-16:00) using video cameras mounted directly above each pen. For focal pig behaviour, to evaluate the potential effects of density on feeding and drinking behaviour, four focal pigs, all female and near the median weight (average initial BW range 7 to 8 kg/pig), were selected per pen group and marked for closer observation of behavioural time budgets. For replicate one and part of replicate two, Sony Handycam DCR-SR68 video cameras (Sony Corp, New York) were used. For the remainder of the trial (remainder of replicate two, and replicates three and four) CCTV cameras (RS-900 Digital video cameras, Rostech, St-Laurent, Quebec) connected to a video recorder (Galaxy H.264 Digital Video Recorder, Galaxy Canada, Markham, ON) were used to record pigs' behaviour.

Group behaviour of all pigs was transcribed via scan sampling at intervals of 30 minutes (See ethogram, Table 2.1). Frequency and duration of all feeding and drinking events in focal pigs were continuously observed using BORIS (Behavioural Observation Research Interactive Software, University of Torino) during an 8-hr period (08:00 - 16:00) in nursery weeks one, three and five (See ethogram, Table 2.2).

Table 2.1 Ethogram of postures for group behaviour. Adapted from Ekkel et al. 2003.

Posture	Definition
Standing	Standing, walking or running, body supported by three or more legs, position change possible
Sitting	Body supported by one or two front legs
Lying	Lying on side or belly, body not supported by any of the legs, position not changed
Lying Behaviour	
Sternal	The animal is lying on the belly with at least two legs folded under the body
Fully recumbent	The animal is lying on the side with all four legs stretched out

Table 2.2 Ethogram of feeding and drinking behaviour in focal pigs adapted from Vermeer et al., 2014.

Behaviour	Definition
Feeding	Head in the feeder. The pig can move out for up to 10 seconds within a single bout.
Drinking	Snout in contact with the drinker. The pig can move away for up to 10 seconds within a single bout.

2.2.3 Aggression, stress physiology and immune response

2.2.3.1 Skin lesion scoring

As an indicator of aggressive behaviour, all pigs were scored periodically for skin lesions. Scoring was performed on days zero following nursery placement and then weekly until the end of the trial. For lesion scoring, pigs' bodies were divided into three sections: front (from snout to front of shoulder), middle (shoulder to the front of the hip) and rear (from hip to tail). Each section was given a score of 0 to 4 (See Table 2.3). The skin lesion score adapted from Hodgkiss et al. (1998) was used to estimate aggressive interactions. Only injuries that appeared red and had not started to heal (by forming a scab) were recorded during each observation. To maintain consistency, the lesion scores were assessed by two trained observers throughout the trial.

Table 2.3 Description of categorical scoring for skin lesions (Hodgkiss et al., 1998).

Score	Description of category
0	Absent of all skin injuries
1	Mild superficial wounds
2	Moderate superficial wounds and/or <2 deep wound
3	Severe superficial wounds and/or 2-5 deep wounds
4	Very severe superficial wounds and/or >5 deep wounds

2.2.3.2 Salivary cortisol

Saliva samples were analysed for salivary cortisol as a measure of stress physiology. The saliva samples were collected on days zero, 14, 28, and 35 from the same focal pigs that were evaluated for behaviour (Table 2.4). Sample collection was done using a 12 to 24-inch length of 100% cotton rope, approximately 5mm in diameter. The mid-point of the rope was placed in the piglet's mouth, and the ends were tied together at the back of the head, behind the ears. The piglet was then placed back in pen and left for a minimum of 5 min, or longer if required until part of the rope was saturated with saliva. The rope was removed, and the section with saliva was cut out and placed in a 12 ml centrifuge tube. The samples were then centrifuged at 1800 x g for five min (Beckman TJ-6 Centrifuge, Beckman Coulter, Mississauga, Ontario, Canada). If the rope slipped, the rope was secured at the top of the tube, and the centrifugation process was repeated until a minimum of 0.5 ml of sample was collected. Saliva samples were then transferred to 2 ml labelled storage tubes and stored at -20° C until analysis. The Immulite/ Immulite 1000 cortisol assay (Simens Healthcare Diagnostics Inc., UK) used for the quantitative measurement of salivary cortisol in a commercial laboratory (Prairie Diagnostic Services, Saskatoon, SK). The

Immulite cortisol assay is a solid-phase, competitive chemiluminescent enzyme immunoassay, with an analytical sensitivity of 0.2 µg/dL (5.5 nmol/L).

2.2.3.3 Immune response

Six pigs per pen group were selected for an immune response challenge (the four focal behaviour pigs were excluded). Blood samples were collected via jugular venipuncture in the second, fourth and fifth week of study. Immediately following blood sampling in weeks two and four, the pigs received injections of Porcillus M.hyo (Respisure-ONE, Pfizer, Location), an inactivated vaccine for *Mycoplasma hyopneumoniae.* Only two injections were given (Table 2.4). Blood samples were collected in 10 ml vacuum tubes (Vacutainer; BD vacutainer, Canada). Once collected, blood samples were allowed to clot at room temperature for 10 min before they were centrifuged at 830 × g for 10 min (Beckman TJ-6 Centrifuge, Beckman Coulter, Mississauga, Ontario, Canada). Serum was transferred to storage vials and stored in a -20 °C freezer until analysis. Serum samples were analyzed for *Mycoplasma hyopneumoniae* specific IgG in a commercial laboratory (Biovet Inc., St-Hyacinthe, QC) using a specific immunoperoxidase assay for pig IgG as a measure of immune competence.

Table 2.4 Timeline for data collection.

Pigs enter					**Nursery exit**
Day 0	**Day 7**	**Day 14**	**Day 21**	**Day 28**	**Day 35**
Saliva sample focal pigs		Saliva sample focal pigs		Saliva sample focal pigs	Saliva sample focal pigs
Entry weight	d7 weight	d14 weight	d21 weight	d28 weight	d35 weight
Adjust pens	d7 pen adjust	d14 pen adjust	d21 pen adjust	d28 pen adjust	d35 pen adjust
Weigh in feed	d7 feed	d14 feed	d21 feed	d28 feed	d35 feed
Select and mark focal pigs	Remark focal pigs	Remark focal pigs	Remark focal pigs	Remark focal pigs	Remark focal pigs
		Select &mark immune focal pigs Blood sample #1	Remark immune focal pigs	Remark immune focal pigs Blood sample #2	Remark immune focal pigs
		First M Hyo injection		Sec M Hyo injection	

2.2.5 Statistical analysis

Data were analyzed using the Proc Mixed and Proc Glimmix procedures of SAS 9.4 (SAS Inst Inc., Cary, NC). Residuals were checked for normality using the Shapiro-Wilk test and data were transformed when necessary. The pen was used as the experimental unit for all the parameters observed. Initial models were tried with interactions when the interactions were not significant; they were removed.

Initially, a repeated measures model was tried for all production measures. Finally, production data were analyzed separately using Proc Mixed for weeks one, three and five. The model included main effects of space allowance and group size and their interaction. When the interaction was clearly not significant ($P > 0.25$), it was removed from the model. The pen was the experimental unit and replicate used as the random effect.

Focal behaviour analysis for feeding and drinking pattern time budgets was done using Proc Mixed and Proc Glimmix. The pig was considered a random effect. The data were not normally distributed, so were transformed using square root for feeding and drinking bouts/day. A log transformation was used for analysis of average feeding bout duration (min) and total drinking duration (min). The data for the total duration of feeding (min) and average drinking bout duration (min) could not be transformed using log and square root transformations and were therefore analyzed using proc Glimmix with Poisson distribution.

To analyse group behaviour, percent frequency of observations were calculated as the number of observations of behaviour per total number of observations. The number of animals (%) was calculated as an average number of animals performing a behaviour when observed. Percent frequency standing, sitting, feeding and full recumbency was analysed using Proc mixed. Proc Glimmix with

Poisson distribution was used for percent frequency sternal and overlying behaviour. Average percent standing, sternal, recumbent and overlying behaviours were analysed using Proc mixed. Average percent sitting and feeding was analysed using Proc Glimmix with Poisson distribution. The week was considered the random effect.

Skin lesion scores were analysed using Proc Glimmix with Poisson distribution (repeated measures). The pig was considered the random effect. Proc Glimmix with Poisson distribution was used to analyse salivary cortisol concentrations. The pig was considered the random effect. The immune response in week five was analysed using Proc mixed. Room was considered random effect. Temperature and humidity data were analysed using Proc Mixed. Room was considered as a random effect.

The level of significance was set at $P \leq 0.05$; values between 0.05 and 0.10 were considered a trend, and those > 0.10 were non-significant.

A break-point analysis was conducted with the goal of identifying the minimum space allowance giving maximum ADG for nursery pigs. However, because there was no linear relationship between space allowance and ADG the broken line analysis did not indicate a cut-off in response to the space allowance treatments.

2.3 Results

2.3.1 Production

Space allowance: There was a treatment effect of space allowance on average BW (average BW are included in the appendix: Table. A.1); however no clear response could be discerned ($P < 0.05$, Table 2.5). There was no association of space allowance and ADG (ADG are included in the appendix: Table. A.2) in weeks one and three. However, there tended to be an effect of space allowance on ADG in week five ($P = 0.054$), with the highest ADG, observed at a k value of 0.023 and lowest

ADG at a *k* value of 0.037. A treatment effect on G:F ratio (average G:F are included in the appendix: Table. A.3) was observed ($P < 0.05$, Table 2.5) but again, no clear relationship to changes in space allowance was observed.

Group size: There was no effect of group size on average BW, ADG or feed efficiency (G: F) ($P > 0.05$, Table 2.5).

Break point analysis: A break-point analysis was conducted with the goal of identifying the minimum space allowance giving maximum ADG for nursery pigs. Because there was no linear relationship between space allowance and ADG, the broken line analysis did not indicate a cut-off in response to the space allowance treatments.

Table 2.5 Effects of space allowance (density) and group size on body weight, average daily gain (ADG) and feed efficiency (G: F) of nursery pigs in weeks one, three and five (LS Means, n=8 per treatment for density; n=24 per treatment for group size).*

Item	Density (*k* value)						SEM	Group size (pigs/pen)		SEM	P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390		10	40		Density	Group size
Week 1												
BW (kg)	8.45^{bc}	8.17^{c}	8.50^{bc}	8.74^{bc}	8.48^{bc}	8.85^{a}	0.15	8.58	8.49	0.10	0.014	0.395
ADG (kg/d)	0.089	0.099	0.100	0.070	0.086	0.096	0.01	0.095	0.085	0.01	0.138	0.151
G: F	0.903^{a}	0.850^{c}	0.815^{c}	0.602^{b}	0.836^{c}	1.007^{a}	0.07	0.850	0.821	0.04	0.003	0.576
Week 3												
BW (kg)	13.06^{a}	12.55^{b}	12.99^{b}	13.44^{a}	12.35^{c}	13.30^{a}	0.36	13.056	12.844	0.31	0.013	0.268
ADG (kg/d)	0.420	0.398	0.405	0.393	0.379	0.418	0.02	0.414	0.390	0.02	0.419	0.068
G: F	0.759	0.755	0.765	0.751	0.781	0.791	0.04	0.791	0.743	0.03	0.954	0.097
Week 5												
BW (kg)	21.72^{b}	21.21^{b}	21.75^{b}	22.15^{a}	20.70^{c}	22.19^{a}	0.68	21.75	21.48	0.62	0.034	0.352
ADG (kg/d)	0.739^{a}	0.698^{b}	0.695^{b}	0.724^{b}	0.643^{c}	0.670^{b}	0.03	0.706	0.693	0.03	0.054	0.435
G: F	0.718^{b}	0.650^{b}	0.643^{b}	0.781^{a}	0.653^{b}	0.660^{b}	0.04	0.691	0.677	0.03	0.026	0.580

* No interactions between space allowance and group size were observed.
^{a,b,c} Means within a row with different superscripts differ significantly ($P \leq 0.05$).

2.3.2 Behavioural time budgets

Data discussed below were collected from focal pigs using continuous observations. Means and standard deviations for time budgets are included in the Appendix (Table A.4).

Interactions: A significant density by week interaction was seen for total feeding duration (*P* = 0.010; Figure 2.2). Overall, total feeding durations were lowest in week one across the six space allowances studied. In most space allowances a consistent pattern was found, with feeding durations increasing in week three, and dropping off again in week five. The only exception was observed at the highest space allowance of 0.0390 where there were no significant differences across weeks one, three and five.

Space allowance: Space allowance had a significant effect on feeding and drinking behaviours. Pigs at lower space allowances tended to have more meals per day (*P* = 0.053), but of shorter bout duration (*P* = 0.003), and spent less time feeding overall (*P* = 0.038) when compared to pigs at higher space allowances (Table 2.6). However, a consistent pattern among the six space allowances was not observed. The relationship between space and drinking is not as clear. Drinking bouts were highest at a space allowance of *k*=0.0230 and lowest at a space allowance of *k* = 0.0335 (*P* < 0.05). However average bout duration and total duration for drinking were highest for space allowance *k* = 0.0390 and lowest for *k* = 0.0265 (*P* < 0.05; Table 2.6).

Group size: Pigs in groups of 10 ate fewer meals (*P* = 0.026). Meal duration tended to be longer in groups of 10 compared to groups of 40 (Table 2.6). Significant effects of group size were also found for drinking behaviour. Pigs in groups of 10 spent less time drinking each day (*P* < 0.001) with fewer (*P* < 0.01) and shorter drinking (*P* < 0.01) bouts per day compared to groups of 40 pigs (Table 2.6).

Age: Nursery week had a significant effect on feeding and drinking behaviours. Pigs in week three were observed to have more feeding bouts per day (P = 0.001) compared to weeks one and five. Total duration spent feeding was highest in week three and lowest in week one (P < 0.001). Pigs in week one had shorter average bout durations for feeding as compared to weeks three and five (P < 0.001; Table 2.7). In contrast, the number of drinking bouts per day was higher in week five than in weeks one or three (P < 0.001; Table 2.7). Total duration spent drinking increased over time from week one to week five (P < 0.001). Average bout durations for drinking also increased from week one to week five in a consistent fashion (P < 0.001; Table 2.7).

Table 2.6 Effects of space allowance (density) and group size on the feeding and drinking behaviour of nursery pigs (LS Means; n=6 per treatment for density; n=18 per treatment for group size).[1]

Item*	Density (*k* value)						SEM	Group size (pigs/pen)		SEM	P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390		10	40		Density	Group
Feeding behaviour:												
Feeding bouts/day	37.15[a]	32.95[ab]	29.21[b]	27.37[b]	33.45[ab]	30.31[b]	0.21	29.54	33.85	0.12	0.053	0.026
Total duration (min)**	45.989[ab]	46.247[ba]	40.109[b]	40.784[b]	50.892[a]	50.826[a]	0.06	44.443	46.801	0.04	0.038	0.319
Avg bout duration (min)	1.275[bc]	1.393[bc]	1.219[c]	1.326[bc]	1.451[ab]	1.654[a]	0.03	1.440[a]	1.326[b]	0.02	0.003	0.071
Drinking behaviour:												
Drinking bouts/day	25.093[a]	19.730[bc]	20.260[bc]	18.831[c]	23.205[ab]	23.198[abc]	0.17	19.941	23.455	0.10	0.037	0.007
Total duration (min)	5.371[ab]	4.097[c]	4.467[bc]	4.331[bc]	4.964[abc]	6.000[a]	0.08	4.197	5.554	0.04	0.045	<0.001
Avg bout duration (min)**	0.239[bc]	0.221[c]	0.241[bc]	0.265[ba]	0.231[bc]	0.308[a]	0.06	0.232	0.268	0.04	0.002	0.006

[1] No interactions between space allowance and group size were observed.
*Continuous observation using video cameras from 08:00- 16:00.
**LS Means were back-converted using antilog.
[a,b,c] Means within a row with different superscripts differ significantly ($P \leq 0.05$).

Table 2.7 Effects of age (nursery week) on feeding and drinking behaviour of nursery pigs (LS Means; n= 12 per week).

Item*	Nursery week			SEM	P value	
	1	3	5		Week	Density*Week
Feeding behaviour:						
Feeding bouts/day	27.33[b]	35.91[a]	32.03[b]	0.15	0.001	0.176
Total duration (min)**	36.144[c]	54.686[a]	48.995[b]	0.04	<0.001	0.010
Avg bout duration (min)	1.174[b]	1.440[a]	1.549[a]	0.02	<0.001	0.524
Drinking behaviour:						
Drinking bouts/day	17.321[b]	20.139[b]	28.231[a]	0.12	<0.001	0.258
Total duration (min)	3.368[c]	4.384[b]	7.452[a]	0.06	<0.001	0.157
Average bout duration (min)**	0.212[c]	0.248[b]	0.297[a]	0.04	<0.001	0.306

*Continuous observation using video cameras from 08:00-16:00.
**LS Means were back-converted using antilog.
[a,b,c] Means within a row with different superscripts differ significantly ($P \leq 0.05$).

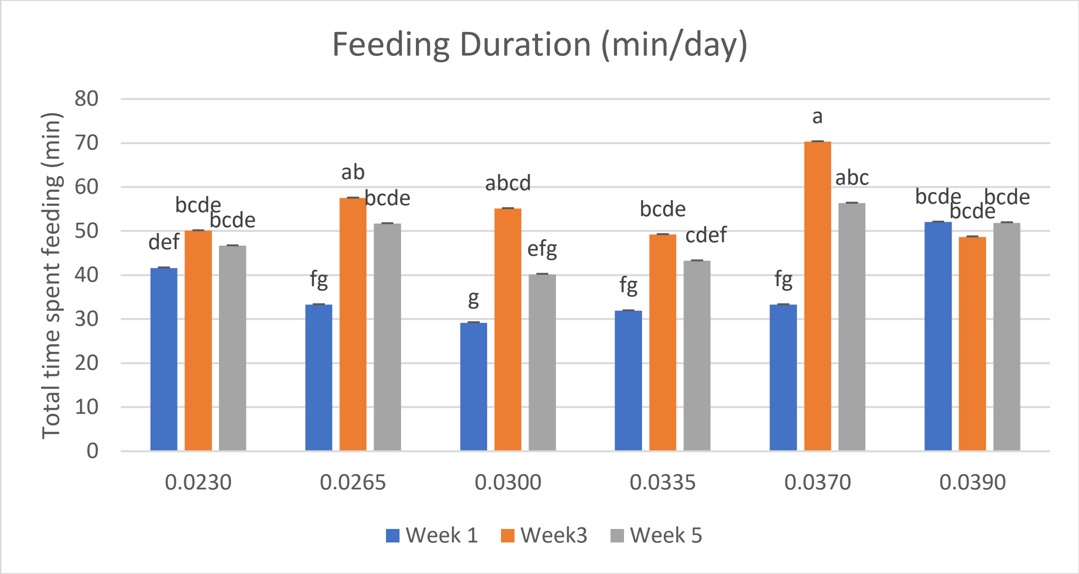


Figure 2.2. Density by week interactions for total feeding duration per day* in minutes. Feeding behaviour was recorded using continuous observations from 08:00-16:00. Space allowance treatments: k = 0.0230, 0.0265, 0.0300, 0.0335, 0.0370 and 0.0390. *Day indicates an 8 hour period.

2.3.3 Feeding behaviour and postural adjustments

Data described below is the group behaviour of all pigs based on time-lapse observations.

Space allowance: No effect of space allowance was observed on the frequency % or average % of animals standing (*P* > 0.05; Table 2.8). The % frequency of sitting observations was reduced as space allowance increased (*P* = 0.004; Table 2.8), and the percentage of pigs sitting tended to be lower at higher space allowances (*P* = 0.069; Table 2.8). No significant effect of space allowance was seen on the % frequency or average % of animals feeding. Pigs were feeding in approximately 53% of observations, with an average of 14% of animals feeding (*P* > 0.05; Table 2.8).

The % frequency of pigs lying fully recumbent was higher at *k* values of 0.0265 and 0.039 (*P* = 0.049), and the average % of animals lying fully recumbent tended to be higher in these treatments (*P* = 0.089). Sternal and overlying behaviours were not affected by changes in space allowance (*P* > 0.05; Table 2.9).

Group size: The % frequency of standing, sitting and feeding was higher in pigs in groups of 40 compared to groups of 10 (*P* < 0.001; Table 2.8). However, the average % of animals standing, sitting and feeding was higher in pigs housed in groups of 10 compared to 40 (P ≤ 0.001). Similarly, the % frequency of sternal and overlying behaviours was significantly higher in groups of 40 versus groups of 10 (*P* < 0.001; Table 2.9), while the average % of animals in sternal and overlying behaviours was higher in groups of 10 compared to groups of 40 (*P* < 0.001; Table 2.9). Group size did not affect % frequency of observations with pigs in fully recumbent posture (*P* = 0.189; Table 2.9). However, the average percentage of pigs lying in a fully recumbent posture was higher in groups of 10 compared to groups of 40 (*P* < 0.001; Table 2.9).

Age: Time spent standing (% frequency) was the higher in weeks three and five compared to week one (*P* < 0.001). The % of animals standing was highest in week three and lowest in week five (*P* < 0.0001; Table 2.10). The % frequency of sitting increased as pigs grew, and was observed to be highest in week 5 (*P* < 0.001; Table 2.10). However, the percentage of pigs sitting was observed to be higher in week one compared to week three, with week five being intermediate (*P* = 0.0015; Table 2.10). The % frequency of feeding was significantly higher in weeks three and five as compared to week one (*P* < 0.001; Table 2.10). In contrast, the average % of pigs feeding was not significant; there was a tendency for fewer pigs to be feeding in week five compared to weeks one and three *(P* = 0.056; Table 2.10).

The % frequency of pigs lying sternally was not significantly different in the five weeks studied (*P* = 0.545; Table 2.11). However, the percentage of pigs showing sternal lying at a given time was higher in week one compared to weeks three and five (*P* < 0.001; Table 2.11). Both the % frequency and average % of pigs lying fully recumbent were significantly higher in week five in comparison to weeks one and three (P < 0.001; Table 2.11). Nursery week did not affect the % frequency of pigs showing overlying behaviours (P = 0.587; Table 2.11). However, the average percentage of pigs overlying was significantly greater in week one in comparison to weeks three and five (P < 0.001; Table 2.11).

Table 2.8 Effect of space allowance (density) and group size on postural and feeding behaviours of nursery pigs (LS Means; n=6 per treatment for density; n=18 per treatment for group size).[1]

Item	Density (*k* value)						SEM	Group size (pigs/pen)		SEM	P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390		10	40		Density	Group
Frequency of observations (%)*:												
Standing	70.00	64.58	68.47	70.43	67.83	65.97	3.64	55.48	80.29	3.01	0.536	<0.001
Sitting	43.543[a]	38.411[bc]	36.943[bc]	40.714[bc]	30.154[c]	31.183[c]	4.05	28.48	45.17	3.37	0.004	<0.001
Feeding	59.11	49.2	55.86	54.19	52.96	51.61	3.29	41.68	65.96	2.44	0.149	<0.001
Number of animals (%)**:												
Standing	36.04	32.48	35.63	37.19	36.26	34.57	1.60	40.89	29.82	0.92	0.374	<0.001
Sitting***	10.480	10.105	9.232	9.427	7.544	8.701	0.08	14.488	5.837	0.05	0.069	<0.001
Feeding***	13.538	13.670	13.461	13.114	17.041	14.105	0.12	16.819	11.818	0.07	0.606	0.001

[1] No interactions between space allowance and group size were observed.
[a,b,c] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
*Frequency of observations calculated as: (number of observations of behaviour/total observations) x 100.
**Number of animals calculated as: (average number of animals performing a behaviour when observed/total number of animals when observed) x 100.
***LS Means were back-converted using antilog.

Table 2.9 Effect of space allowance (density) and group size on the lying behaviour of nursery pigs (LS Means; n=6 per treatment for density; n=18 per treatment for group size).[1]

Item	Density (*k* value)						SEM	Group (pigs/pen)		SEM	P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390		10	40		Density	Group
Frequency of observations (%)*:												
Sternal**	95.986	98.190	98.003	97.622	96.670	97.710	0.01	95.976	98.761	0.01	0.298	<0.001
Recumbent.	49.13[b]	55.74[a]	45.56[b]	41.36[b]	43.74[b]	53.88[a]	5.01	46.22	50.25	3.97	0.049	0.189
Overlying**	90.577	93.738	92.158	92.075	89.300	93.251	0.02	87.549	96.342	0.01	0.299	<0.001
Number of animals (%)***:												
Sternal	55.10	55.17	58.28	56.61	60.77	54.01	2.59	61.19	52.11	1.89	0.245	<0.001
Recumbent.	19.34	21.27	17.00	16.46	18.07	23.63	2.06	26.74	11.85	1.32	0.089	<0.001
Overlying	65.86	68.02	67.02	64.17	68.97	63.47	2.62	75.86	56.65	1.93	0.423	<0.001

[1] No interactions between space allowance and group size were observed.
[a,b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
*Frequency of observations calculated as: (number of observations of behaviour/total observations) x 100.
** LS Means were back converted using antilog.
***Number of animals calculated as (average number of animals performing behaviour when observed/total number of animals when observed) x 100.

Table 2.10 Effects of age (nursery week) on the standing, sitting and feeding behaviour of nursery pigs (LS Means; n= 12 per week).[1]

Item	Nursery week			SEM	P value
	1	3	5		Week
Frequency of observations (%)*:					
Standing	57.24^{b}	73.17^{a}	73.24^{a}	3.18	<0.001
Sitting	30.74^{b}	35.62^{b}	44.11^{a}	3.55	<0.001
Feeding	40.94^{b}	62.47^{a}	58.04^{a}	2.68	<0.001
Number of animals (%)**:					
Standing	36.56^{b}	42.31^{a}	27.21^{c}	1.13	<0.001
Sitting***	10.154^{a}	8.002^{b}	9.573^{ab}	0.06	0.015
Feeding***	15.103^{a}	15.685^{a}	11.830^{b}	0.09	0.057

[1] No interactions between space allowance and nursery week were observed.
[a,b,c] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
*Frequency of observations calculated as: (number of observations of behaviour/total observations) x 100.
**Number of animals calculated as (average number of animals performing behaviour when observed/total number of animals when observed) x 100.
***LS Means were back-converted using antilog.

Table 2.11 Effects of age (nursery week) on the lying behaviour of nursery pigs (LS Means; n= 12 per week).[1]

Item	Nursery week			SEM	P value
	1	3	5		Week
Frequency of observations (%)*:					
Sternal**	96.921	97.388	97.768	0.01	0.545
Recumbent	35.37[b]	38.63[b]	70.69[a]	4.26	<0.001
Overlying**	91.442	91.341	92.740	0.01	0.587
Number of animals (%)***:					
Sternal	63.58[a]	55.01[b]	51.36[b]	2.09	<0.001
Recumbent	13.63[b]	15.33[b]	29.51[a]	1.54	<0.001
Overlying	72.75[a]	63.85[b]	62.16[b]	2.13	<0.001

[1] No interactions between space allowance and nursery week were observed.
[a,b] Means within a row with different superscripts differ ($P \leq 0.05$).
*Frequency of observations calculated as: (number of observations of behaviour/total observations) x 100.
**LS Means were back-converted using antilog.
***Number of animals calculated as (average number of animals performing behaviour/total number of animals when observed) x 100.

2.3.4 Aggression, stress physiology and immune response

2.3.4.1 Skin Lesions

Interactions: There were significant interactions between space allowance and week for overall lesion and front lesions scores. Overall lesion scores were lower in week one and increased over time. The lesion scores in higher space allowances (0.0335, 0.037 and 0.039) were significantly lower than lower space allowances (0.023, 0.0265 and 0.030) in week five (Figure 2.3).

Front lesion scores increased over time, but in week five, the three lowest space allowances (*k*= 0.0230, 0.0265, 0.0300) had more injuries than three highest (*k*= 0.0350, 0.0370, 0.0390; $P < 0.05$; Figure 2.4).

Space allowance: Overall injury scores were low (Mean ±SD: 0.67 ±0.41 Mean ±SD on a scale of 0-4). However, a trend was observed ($P = 0.093$; Table 2.12), with pigs in the lowest space allowance ($k = 0.023$) demonstrating the highest lesion scores, followed by those in the highest space allowance ($k = 0.0390$). Space allowance also did not significantly affect lesion scores in the front, middle or rear portion of the pigs (Table 2.12).

Group size: Pigs in groups of 40 had a higher average incidence of lesions than those in groups of 10 ($P = 0.007$). Front, middle and rear lesion scores were also recorded to be higher in groups of 40 compared to groups of 10 ($P < 0.05$; Table 2.12).

Age: Lesion scores increased over time. Effect of week and location on average lesion scores is included in the Appendix (Table A.5). Pigs in week five had higher lesion scores as compared to week three, and week three values were higher than week one (P < 0.001; Table 2.13). Similar results were seen when lesion scores were analysed separately by location (front, middle, and rear. $P < 0.001$; Table 2.13).

Table 2.12 Effects of space allowances (density) and group sizes on overall injury scores of nursery pigs (n=8 per treatment for density; n=24 per treatment for group size).[1]

Item*	Density (*k* value)							Group (pigs/pen)			P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390	SEM	10	40	SEM	Density	Group
Injury scores	0.619	0.484	0.554	0.489	0.532	0.591	0.04	0.500	0.589	0.03	0.093	0.007
By Location												
Front	0.927	0.774	0.865	0.844	0.766	0.894	0.04	0.796	0.892	0.02	0.111	0.023
Middle	0.521	0.379	0.463	0.445	0.459	0.493	0.07	0.415	0.505	0.04	0.223	0.013
Rear	0.333	0.242	0.237	0.314	0.328	0.330	0.10	0.264	0.327	0.05	0.288	0.020

[1] No interactions between space allowance and group size were observed.
*LS Means were back-converted using antilog.
Injury scores were measured on a scale of 0 to 4, where 0 was absence of injuries, and 4 was very severe superficial wounds.

Table 2.13 Effects of age (nursery week) on overall injury scores of nursery pigs based on the week (n=16 per week).

Item*	Nursery week			SEM	P value	
	1	3	5		Week	Density*Week
Injury scores	0.271[c]	0.532[b]	1.105[a]	0.03	<.0001	0.001
By Location						
Front	0.598[c]	0.800[b]	1.252[a]	0.03	<.0001	0.002
Middle	0.184[c]	0.465[b]	1.119[a]	0.04	<.0001	0.010
Rear	0.078[c]	0.334[b]	0.977[a]	0.06	<.0001	0.013

[a,b,c] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
*LS Means were back-converted using antilog.
Injury scores were measured on a scale of 0 to 4, where 0 was absence of injuries, and 4 was very severe superficial wounds.

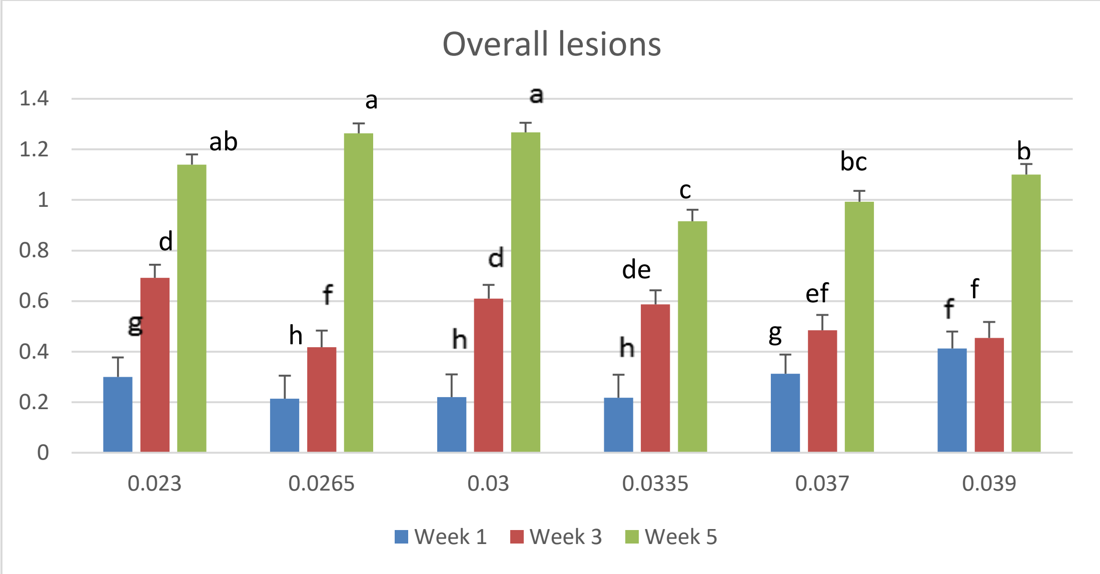


Figure 2.3 Density by week interaction for overall lesion score. Score range- 0-4. Score 0- absent of all skin injuries; Score 1-Mild superficial wounds; Score 2- Moderate superficial wounds and <2 deep wounds; Score 3- Severe superficial wounds and/or 2-5 deep wound; Score 4- very severe superficial wounds and/or >5 deep wounds. Space allowance treatments: *k* = 0.0230, 0.0265, 0.0300, 0.0335, 0.0370 and 0.0390.

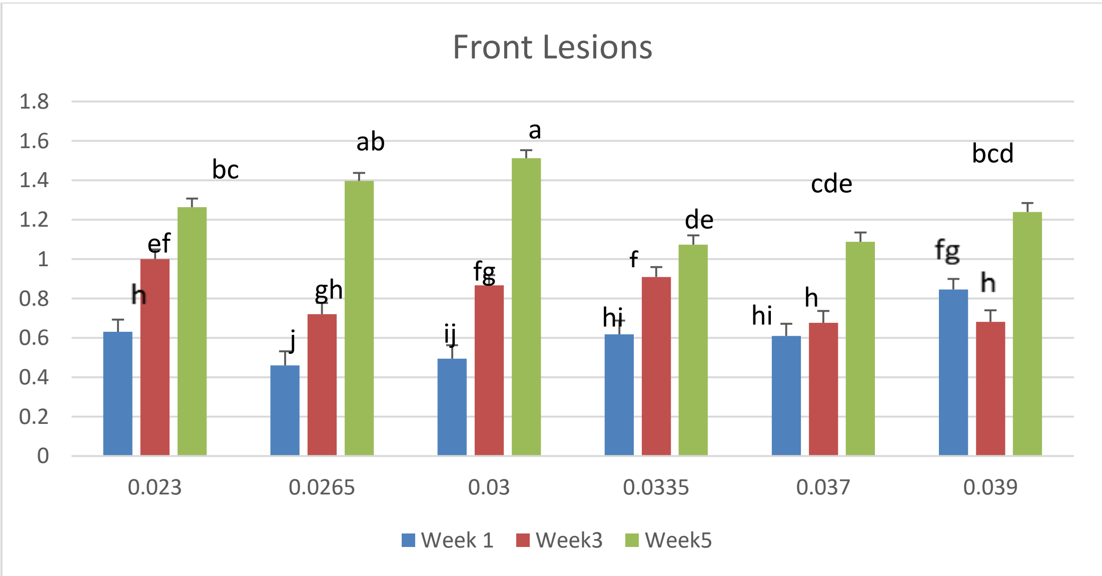


Figure 2.4 Density by week interactions for front lesion score. Score range- 0-4. Score 0- absent of all skin injuries; Score 1-Mild superficial wounds; Score 2- Moderate superficial wounds and/or <2 deep wounds; Score 3- Severe superficial wounds and/or 2-5 deep wound; Score 4- very severe superficial wounds and/or >5 deep wounds. Space allowance treatments: *k* = 0.0230, 0.0265, 0.0300, 0.0335, 0.0370 and 0.039.

2.3.4.2 Salivary cortisol

Average cortisol concentrations were observed to be highest during week one (Mean 20.7; Range 5.5- 73.1 ng/ml) and then decreased over time, with the lowest values recorded in week six (Mean-7.73; Range 5.5- 22.4 ng/ml; Table 2.14).

Interactions: Density-by-week interactions were observed. Salivary cortisol concentrations were significantly higher in week one versus weeks three, five and six. The salivary cortisol response to space allowance varied across the different weeks (density by week interaction, $P < 0.05$) but no consistent pattern was observed (Figure 2.5).

Space allowance: Pigs provided with higher space allowances (k =0.037 and k =0.039) were having higher cortisol levels ($P = 0.025$; Table 2.15).

Group: Cortisol values were not affected by group size (10 versus 40 pigs. $P > 0.05$; Table 2.15).

Age: Pigs in weeks five and six had lower cortisol levels compared to weeks one and three ($P < 0.001$; Table 2.16).

Table 2.14 Means and SD of salivary cortisol concentrations in pigs in nursery weeks 1-6 (ng/ml).

Variable	N	Mean	Range	Std Dev
*Week 1	187	20.70	5.50 - 73.10	13.09
Week 2	187	9.59	5.50 - 40.60	5.06
Week 4	192	8.38	5.50 – 29.00	4.36
Week 5	168	7.73	5.50 - 22.40	3.29

*Week 1- Day 0; Week 2- Day 14; Week 4- Day 28; Week 5- Day 35.

Table 2.15 Effect of space allowance (density) and group size on salivary cortisol levels (ng/ml) in nursery pigs. (n=8 per treatment for density; n=24 per treatment for group size).[1]

Item	Density (*k* value)						SEM	Group (pigs/pen)		SEM	P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390		10	40		Density	Group
Cortisol*	9.994[b]	9.775[b]	10.105[b]	10.162[b]	11.873[a]	11.843[a]	0.06	10.913	10.277	0.03	0.025	0.151

[1] No interactions between space allowance and group size were observed.
[a,b] Means within a row with different superscripts differ by P≤ 0.05.
*LS Means were back-converted using antilog.

Table 2.16 Effect of age (nursery week) on salivary cortisol levels (ng/ml) in nursery pigs (n=16 per week).

Item	Nursery week				SEM	P value	
	1	3	5	6		Week	Density*Week
Cortisol*	20.273[a]	9.553[b]	8.242[c]	7.879[c]	0.04	<0.0001	0.002

[a,b,c] Means within a row with different superscripts differ by P≤ 0.05.
*LS Means were back-converted using antilog.

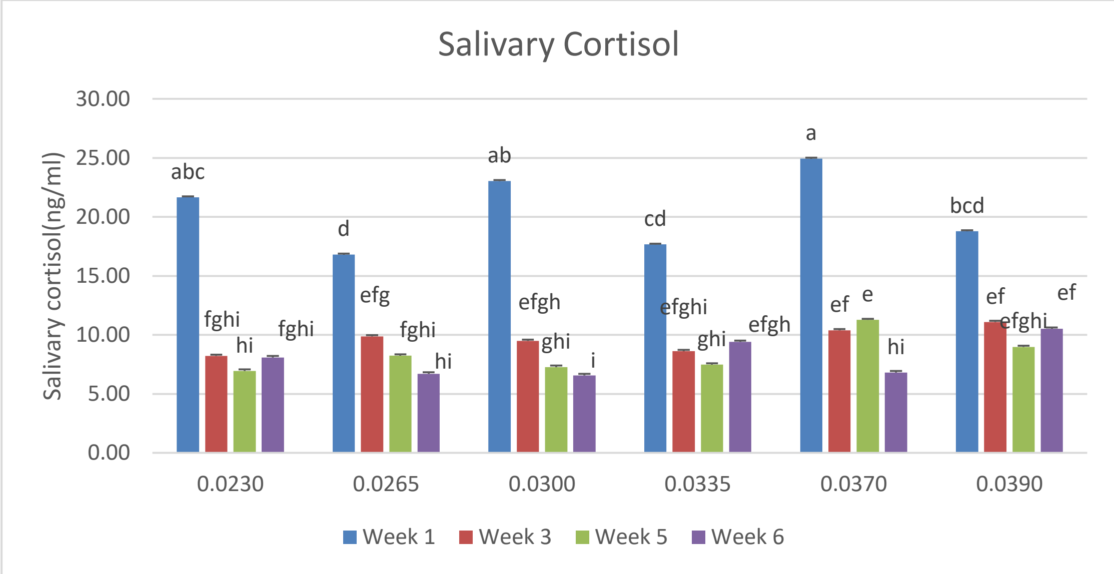


Figure 2.5. Density by week interactions for salivary cortisol concentrations. Space allowance treatments: *k* = 0.0230, 0.0265, 0.0300, 0.0335, 0.0370 and 0.0390.

2.3.4.3 Immune response

Blood samples were tested using an enzyme-linked immunosorbent assay (ELISA) for the presence or absence of *Mycoplasma hyopneumoniae* antibodies using the sample to the positive ratio (S/P). S/P ratio values of < 0.3 were considered negative, the ratio of 0.3-0.4 considered a suspect and ratio > = 0.4 were considered positive. Means and standard deviation for S/P ratios are included in Appendix (Table A.6).

Space allowance. Space allowance affected S/P ratio (the sample to positive ratio) for *Mycoplasma hyopneumoniae* (P = 0.018; Table 2.17). Pigs given a space allowance of k = 0.037 had the lowest ratios compared to other space allowances. However, *M. hyopneumoniae (M. Hyo.)* ratios did not show a consistent response across the space allowance treatments (Table 2.17).

Group size. S/P ratios were not affected by group size (10 versus 40 pigs. P > 0.05; Table 2.17).

Table 2.17 Effect of space allowance (density) in week five on Sample-to-positive ratio (S/P ratios) of antibodies to Mycoplasma hyopneumoniae (n=8 per treatment for density; n=24 per group size treatment per week).[1]

	Density (*k* value)							Group (pigs/pen)			P value	
	0.0230	0.0265	0.0300	0.0335	0.0370	0.0390	SEM	10	40	SEM	Density	Group
S/P ratio	0.733[b]	0.732[b]	0.773[b]	0.815[a]	0.588[c]	0.699[b]	0.04	0.745	0.702	0.025	0.018	0.199

[1] No interactions between space allowance and group size were observed.
[a,b,c] Means with different superscripts differ by P< 0.05.

2.3.5 Temperature and Humidity

Average relative humidity readings taken inside the room were highest in replicate one (summer; range- 53.38-76.8) and lowest in replicate two (fall; range- 31.71--59.88; Table 2.18). Average temperatures were highest in replicate one (summer; range- 20.85-26.97) and lowest in replicate three (winter; range- 19.26-27.59; Table 2.20).

Space allowance: Humidity and temperature values were similar across all space allowance treatments ($P > 0.05$; Table 2.18).

Age: The humidity levels did not differ from week one to week five However, humidity levels tended to increase over time (relative humidity 56%). The average temperature decreased from 26.6°C in week one to 21.5°C in week five of the experiment, following the barn nursery room protocols (Table 2.19).

Table 2.18 Effect of space allowance on temperature and humidity levels in nursery rooms (LS Means; n=8 per treatment for density).

Item	Density (*k* value)						SEM	P values
	0.0230	0.0265	0.0300	0.0335	0.037	0.0390		Density
Average relative humidity (%)	53.34	50.63	51.42	55.93	50.99	54.28	3.44	0.860
Average temperature(°C)	23.95	22.72	23.93	23.73	23.59	24.23	0.49	0.302

Table 2.19 Effects of the age (nursery week) on humidity and temperature levels in nursery rooms (LS Means; n=16 per week).

Item	Nursery week			SEM	P-values
	1	3	5		Week
Average relative humidity (%)	48.54	53.41	56.35	2.44	0.088
Average temperature (°C)	26.55^{a}	22.97^{b}	21.54^{c}	0.38	<.0001

^{a,b,c} Means within a row with different superscripts differ by P≤ 0.05.

Table 2.20 Variation in average temperature and humidity values across seasons (Replicates 1-4*).

Variable	N	Mean	Range	Std Dev
Average relative humidity (RH %)				
Rep 1	14	67.52	53.38-76.8	6.28
Rep 2	18	46.06	31.71--59.88	7.31
Rep 3	17	52.16	39.58-62.27	6.72
Rep 4	15	49.53	35.77-64.94	7.71
Average temperature (°C)				
Rep 1	14	23.92	20.85-26.97	1.87
Rep2	18	23.8	20.01-27.34	2.64
Rep 3	17	23.44	19.26-27.59	2.55
Rep4	17	23.53	19.24-26.81	2.51

*Rep 1- Summer 2014; Rep 2- Fall 2014; Rep 3- Winter 2014; Rep 4- Spring 2015.

3. DISCUSSION

3.1 Space allowance

The present study addressed the topic of space allowance in nursery pigs. An allometric approach was used with multiple space allowances with an intention to identify a break point at which crowding occurs. Two group sizes were studied to determine if group size would affect the optimal space allowance and if there was an interaction between space allowance and group size. To maintain space allowances as pigs grew, pen size was adjusted weekly.

3.1.1 Production

Earlier studies have shown that reduced space allowances led to reduced ADG (Wolter et al., 2000; Brumm et al., 2001; Gonyou et al., 2006). The space allowances provided ranged above and below the Canadian Code of Practice (NFACC, 2014) recommended value of $k = 0.0335$, and was found that ADG was similar across all six space allowances provided, except for week five where ADG was highest at the lowest space allowance and with no consistent relationship among other treatments. In contrast, Oh et al. (2010) found that decreasing space allowances (ranging from k = 0.073 to 0.038) resulted in a linear decrease in ADG in weaning pigs up to 15 kg BW. Space allowance treatments affected feed efficiency only during weeks one and five in the present study. In contrast, Brumm et al. (2001) showed that during a 35-day nursery period, the space allowance of $k = 0.0216$ vs $k = 0.0337$ did not influence feed efficiency. One reason why crowding did not significantly affect ADG and G: F in our research could be because the research herd studied has a high health status, moderate group size and low-stress environment, which buffered the potential impact of space allowance on piglet growth.

3.1.2 Feeding and drinking behaviours

We hypothesized that low space allowances would result in reduced feeding time, as it would be harder for the pigs to reach the feeder. In this study, space allowance did have a significant effect on behavioural time budgets for feeding behaviour, Focal pigs at lower space allowances (k = 0.0230) ate more meals per day, but of shorter duration, and spent less time feeding overall compared to pigs at higher allowances (k = 0.039). Street and Gonyou (2008) similarly reported that the average number of meals eaten by pigs in crowded groups was lower than that observed in uncrowded groups. Their results also showed that crowded pigs had shorter meal duration and ate meals at less frequency (Street and Gonyou, 2008). Thus, it is possible that pigs at low space allowance may have compensated by eating more quickly.

Restricted access to feeders and drinkers has been reported to reduce production performances in pigs (Turner et al., 2000). However, access to feeders was not an issue in our experiment as in this study feeder space per animal was constant in all six space allowances provided. Thus, although crowding may have occurred piglets were still able to access feed and water.

The effect of space allowance on drinking behaviour was significant for drinking bouts/day, total duration and the mean duration of drinking bouts. However, the relationship of drinking behaviour to space allowance was not consistent. Our results are in contrast to the findings of Meunier-Salaun et al. (1987) where drinking activity was not affected by the area restriction (0.34, 0.68 or 1.01 m^2 lying area per pig; BW-25-100 kg).

3.1.3 Postural behaviours

To cope with a stressor, animals first make adjustments that are the least demanding on their biological functioning (Averos et al., 2010). If however, the stressor does not subside, the coping strategy redirects its biological resources, eventually affecting productivity (Moberg, 2000). Growing pigs spend a significant portion of their day (40 to 60%) lying and sleeping, both of which are comfort behaviours (Blackshaw, 1981). The ability to lie comfortably is therefore considered important for pig welfare (Tuyttens, 2005). Insufficient space allowance can compromise pigs' ability to perform this activity (Averos et al., 2010). The frequency of behavioural observations from our experiments showed that pigs lie down for many hours of the day, with pigs lying in sternal, fully recumbent and overlying postures in >97%, >50% and >90% of the observations respectively. Ekkel et al. (2003) reported that nursery pigs, predominantly prefer to lie in fully recumbent postures when provided a reasonable amount of space. We observed that fully recumbent lying behaviour was observed more frequently at a *k* value of 0.0265 and 0.039, and the percentage of pigs lying in fully recumbent postures was also higher at the *k* value of 0.0265 and 0.0390. This confirms that if given an opportunity, pigs would use the extra space. However, the reason for increased incidence of this behaviour at a *k* value of 0.0265 is unclear.

In this study, sternal postures were not affected by the change in space allowance. When space is restricted, pigs will shift from fully recumbent lying to sternal lysing which is less space demanding. Street and Gonyou (2008) had hypothesized that finishing pigs shift their lying postures from fully recumbent to less space-demanding sternal lying under crowded conditions. However, no difference was observed among the space allowance treatments in our study. This lack of difference in lying behaviour between treatments suggests that pigs perceived these settings as similar. In contrast, Anil et al. (2007) observed that lack of sufficient space (< 0.0335) reduced the tendency of grow-finisher pigs to lie laterally, consequently increasing sternal lying.

It has been suggested that nursery pigs have lower static space requirements, because of their willingness to overlie their pen mates (Boon, 1981; Gonyou et al., 2006). However, in warmer temperatures, pigs prefer to lie separately, and in this situation, overlying may indicate overcrowding (Gonyou et al., 2006). Hence, the interaction between temperature and pig behaviour is important when interpreting postural changes. In the context of the present study, the suggestion that overlying indicates overcrowding does not hold true as overlying behaviours was similar among the six space allowances studied. Our results show that at nursery entry pigs preferred to lie on top of each other regardless of the space provided. Moreover, temperatures and humidity levels were consistent across the six space allowance treatments, so environmental conditions did not affect our results. Consequently, there was no need for the pigs to adjust their postures because of the environment. Overlying behaviours did, however, reduce over time, either due to increasing size of the pigs or due to the lower ambient temperatures in weeks three and five or both, although no interactions with space allowance were observed.

Previous studies had found that pigs spent more time standing when space allowances were decreased (Bryant and Ewbank, 1974; Heitman et al., 1961). On the contrary, in the current study, there was no effect of space allowance on the frequency or proportion of animals standing.

Actual floor space used by pigs in sitting posture is less than the floor space required for other postures such as standing or lying and thus can be interpreted as a response to crowding. We noted that the pigs were sitting more frequently at lower space allowances and although the proportion of the time pig's displayed sitting was not significantly greater, a trend was observed with more pigs sitting at lower space allowances. Motionless standing or sitting has also been suggested to be inactive 'cut off' strategy adopted by pigs in response to the stress of restricted space allowance (Pearce and Peterson, 1993). Pearce and Paterson, (1993) observed more motionless sitting or standing in crowded pigs (k = 0.025) than their uncrowded peers (k = 0.048). Thus, changes in sitting behaviour can be used as an early indicator of stress in nursery pigs.

3.1.4 Lesion scores

Inadequacies in the environment such as limited space can lead to a greater incidence of aggression and increase in the frequency of lesions in pigs (de Koning, 1984). In the present study, lesion scores were not affected by variation in space allowance. However, we did observe a tendency for overall lesion scores, with pigs in the lowest space allowance (k =0.023) demonstrating the highest lesion scores. Anil et al. (2007) found similar results in grower-finishers, where they observed that the incidence of bites was increased at lower space allowances. Anil et al. (2007) concluded the decrease in resting space and competition to gain access to the feeder at reduced spaces might lead to higher aggression and injuries. Also, increased social tension at lower spaces makes it difficult for the pig to escape from the aggressor due to the proximity of other pen mates leading to elevated lesion scores (Baxter, 1985).

3.1.5 Salivary cortisol

In the present study, we observed that the salivary cortisol levels consistently increased with an increase in space allowance. Increased activity levels have been associated with an increase in corticosteroid concentrations (Wong and Harber, 2006). It is likely that pigs in the present study at higher space allowance had a more significant area to manoeuvre and were more active which resulted in higher salivary cortisol levels. In this study, salivary cortisol was assessed, which reflects free (unbound) cortisol. This is the most important portion so is a better measure than total blood cortisol. However, the inclusion of adrenal morphology or other adrenal function tests may have helped us to interpret our data better; however, assessing all these variables was beyond the scope of this experiment**.**

3.1.6 Immune response

We used two injections of inactivated vaccine for *M. Hyo* as a measure of immune competence. The S/P ratios of *M. Hyo* antibodies showed a significant increase following the second injection. In the present experiment, space allowance had a significant effect on the S/P ratios (sample-to-positive ratio) during week five. However, a clear response could not be discerned. Pigs at an intermediate space allowance of k =0.037 had the lowest S/P ratios in comparison to other space allowances suggesting poorer immune function. Pigs at this space allowance also had the lowest ADG at a k value of 0.037 in week five. There could be a room effect, as pigs in one space allowance treatment (both 10 and 40 pigs) were held in one room, although the room changed in each block. This suggests that pigs housed at k =0.037 might have faced some additional challenges which led to a reduction in titers as well as reduced ADG's. Overall our immune response trial was not efficacious. We used the Respisure® vaccine in our trial, and this vaccine apparently does not produce high antibody titers, even after two doses, particularly if maternal antibodies are present at moderate to high levels. Furthermore, S/P ratio is intended as a diagnostic response to differentiate positive from negative specimens. It is not a reliable quantitative assessment and only gives a rough indication of the specimen's antibody titer. For an accurate quantitative assessment, a titration with a dilution sequence would have been a better alternative. In retrospect, an alternative measure of immune competence such as the heterophil/lymphocyte ratio would have been a better choice (Leek et al., 2004).

3.2 Group size

In addition to space allowance, another important factor affecting social interaction among pigs is the group size. It has been suggested that larger groups require less space, due to sharing of free space (McGlone and Newby, 1994). Nevertheless, this has also been disputed (Street and Gonyou, 2008). In the current study, pigs were housed in groups of 10 and 40 to study interactions between group size and space allowance.

3.2.1 Production

We did not find any interaction between space allowance and group size for growth, feed intake or feed efficiency. Moreover, group size (10 vs 40 pigs/pen) did not affect average body weight, ADG or G: F of nursery pigs. Previous studies comparing effects of group sizes on performance have been inconclusive (Edwards and Turner, 2000). McGlone and Newby (1994) suggested that space requirements for finishing pigs in large groups may be less than in small groups (or individual pigs) due to sharing of a more substantial total floor area. While some studies support these findings, others found no difference in performance based on group size. For example, Wolter et al. (2000) indicated that pigs could be successfully reared in wean-finish facilities from weaning to market weight (i.e., 6-116 Kg) in groups of 25-

100 pigs without any changes in performance. In contrast, Street and Gonyou (2008) and Turner et al. (2000) found that housing grower pigs in larger groups (108 vs 18 and 80 vs 20 respectively) negatively affected performance irrespective of the space allowance. However, In nursery pigs, O'Connel et al. (2004) did not find any differences in pigs' performance when housed in groups of 10, 20, 30, 40 or 60 at a floor space corresponding to k =0.038. Increased energy expenditures required for locomotion for accessing feed and water when pigs are housed in larger groups may contribute to reduced performance. Large groups in our study had 40 pigs which are a small group size relative to that used in commercial facilities. Our results suggest that housing pigs in larger groups are not a problem when adequate resources (feed, water) are provided. Since management tends to be easier with larger groups, many commercial farms have been trending towards larger groups (Cho and Kim, 2011).

3.2.2 Feeding and drinking behaviours

In the current study, group size affected feeding behaviour time budgets, with focal pigs in smaller groups eating fewer, but longer meals compared to the focal pigs in larger groups. In contrast, Nielsen et al. (1995) reported that grower pigs in larger groups of 20 modify their behaviour in response to competition and social environment. Pigs made fewer but longer visits to the feeder due to the decreased accessibility of food resulting in more and faster eating than in smaller groups (5, 10 and 15). However, in the Nielsen et al. (1995) study, group size was confounded by feeder space allowance, suggesting that the results could be due to reduced feeder space and not group size. Feeding behaviours were also recorded via time-lapse video recordings of all pigs in the experiment. We observed that the frequency of pigs' feeding was higher in large groups, but when feeding, a higher proportion of pigs were displaying this behaviour in small groups. Higher frequency of behaviours in larger groups can be explained simply by the fact that more pigs were present. Hence behaviour was more likely to occur, and a higher proportion of feeding behaviour in small groups indicates a greater synchrony of behaviours.

Group size also affected time budgets for drinking behaviour. Drinking bouts per day, total duration and average bout duration for drinking were higher in larger group sizes. These results agree with the findings of Turner et al. (1999) where water usage per pig was higher in groups of 60 compared to 20. Two possible explanations are that pigs in larger groups may play more with the waterers, or that they are more active and therefore drinking more.

3.2.3 Postural behaviours

In general, we observed that pigs demonstrated postural behaviours such as lying, sitting and standing more frequently in large groups (% of observations), although when observed, more pigs were participating in these activities in small groups. Lying is important, and pigs in our study spent the majority of their time lying. Higher frequency of behaviours indicated in larger groups can be explained by the fact that more pigs were present, so the behaviour was more likely to occur. It is possible that the McGlone and Newby (1994) theory that pigs in large groups require less space was true in the present context. In the larger group size of 40, there was extra space due to space sharing, so the pigs did not feel as restricted even under the same space allowance and therefore spent less time sitting and standing, and more time in exhibiting comfort behaviours such as lying. A higher proportion of animals displaying these behaviours in small groups are a possible indication of greater synchrony of behaviours in small groups. In contrast, others such as Turner et al. (2003), Schmolke et al. (2004) and Street and Gonyou (2008) failed to see a clear effect of group size on lying behaviour.

3.2.4 Injury scores

Overall, group size had a significant effect on lesion scores. Pigs in larger groups of 40 had a greater overall incidence of lesions than in the smaller groups of 10. Higher incidence of lesions was found on the front than other regions, likely due to fighting. Numerous studies have evaluated the effect of group sizes on lesion scores. Grower-finisher pigs housed in large groups (80) had higher lesion scores than those in groups of 20 or 40 (Spoodler et al., 1999). Similarly, Street and Gonyou (2008) observed that pigs in groups of 108 had a higher incidence of skin abrasions and lameness scores than pigs in groups of 18. Street and Gonyou (2008) explained this result by observing that pigs in large groups spent more time lying fully recumbent which led to frequent posture changes resulting in higher skin abrasions. Similarly, in the current study, pigs in larger groups exhibited higher frequency of fully recumbent lying behaviours which could have led to higher lesion scores. Anderson et al. (2004) observed that in newly weaned pigs, the number of fights decreased with an increase in group size, but the fights lasted longer in larger groups (24 pigs) compared to groups of 12. They concluded that pigs alter their behaviour according to how the competitive situation changes with group size. Therefore, it is possible that pigs in larger groups in the current study were involved in fights for longer periods of time, leading to higher lesion scores. If we had recorded aggressive behaviours in addition to lesion scores, it would have helped in interpreting the effects of space and group size on aggression.

3.3 Effects of Age

During the nursery phase pigs soon adapt to weaning and grow very rapidly.

All measures in this study including growth, behaviour and physiology changed significantly over time.

3.3.1 Feeding and drinking behaviours

In general, with increasing age, there is a decrease in the number of feeding bouts per day, an increase in daily feed intake and an increase in the rate of eating during meals, leading to larger feeding bouts and longer interbout intervals (Bigelow and Houpt, 1987). As pigs aged, we observed an increase in the total duration of time spent feeding in focal pigs between weeks one and three, followed by a decrease in week five. Feeding bouts /day were also observed to be higher in week three than in week one and five. However, average bout duration for feeding increased consistently as the pigs grew, which was expected. Similarly, when the frequency of feeding observations and proportion of pigs feeding was recorded (using time-lapse videos); we observed pigs feeding more frequently in week three compared to week one, but the behaviour dropped off again in week 5. These findings indicate that after an initial adjustment in week one the pigs reach a peak in time spent feeding by week three. Our results agree with those of Hyun (1997) who found that as pigs grow, the proportion of time spent eating decreases.

The age of pigs also had a significant effect on the drinking behaviour time budgets recorded in focal pigs. The number of drinking bouts/day, average bout duration and total duration of drinking in our study were significantly higher in week five than in weeks one or three. Meiszberg et al. (2009) observed that amount of water consumed increased as nursery pigs grew (comparison of days 0 and 14 after weaning). Thus, we conclude that drinking requirements increase as pigs get older and that pigs show a steady increase in time spent drinking.

3.3.2 Postural behaviours

In this study, the frequency of observations and proportion of pigs demonstrating fully recumbent postures were higher in week five relative to week one or three. Pigs change their preferred lying behaviour from sternal to fully recumbent as they grow (Ekkel et al., 2003). Street and Gonyou (2008) observed that percent time lying sternally in finishing pigs, decreased from 24.5 % to 20% over time. In our trial, the frequency of observations of sternal lying was not different from weeks one to five studied, but the proportion of pigs lying sternally at a given time was higher in week one compared to weeks three and five. These results are in agreement with studies by Street and Gonyou (2008) and Ekkel et al. (2003) which found that pigs prefer to lie in fully recumbent postures as they grow. We hypothesized that overlying would decrease with age. Our results show that pigs showed reduced willingness to overlie over time. There could be two possible reasons; one is that overlying among heavy pigs simply wasn't comfortable. Also, temperatures in the nursery are programmed to reduce over time, to facilitate easy transition of nursery pigs from the farrowing room. Overlying behaviours are expected to be higher at lower temperatures and fully recumbent behaviours to be lower at lower temperatures. However, lower temperatures are not explaining the overlying and fully recumbent behaviours in the present study. So the argument that nursery pigs need less space due to their propensity to overlie does not hold true as the nursery pigs are not overlying at nursery exit as much as they are overlying at nursery entry, so this behaviour should not be used to justify reduction space allowances.

Standing was observed more frequently in weeks three and five than in week one. When pigs were observed standing, a lower proportion of animals were observed standing in week five than in earlier weeks. These results suggest that since pigs prefer to devote more time lying as they grow (Ekkel et al., 2003), they spend less time displaying other behaviours.

Pigs were observed sitting more frequently as they grew. The proportion of pigs sitting was highest in week one as compared to weeks three and five. In standard housing systems, increased sitting behaviour with age can be due to an increase in body mass which decreases the total space availability, limiting the pig's ability to get involved in other activities (Anil et al., 2007). However, in our study, as we adjusted space weekly throughout the experiment, so crowding was relatively constant throughout the nursery period. Our findings suggest that pigs sat more in week one because they were adjusting to the novel environment of the nursery.

3.3.3 Lesion scores

Interestingly, lesion scores consistently increased from weeks one to five in this study, with the most lesions observed when pigs were older and larger. Previous researchers had noted that when unfamiliar pigs were brought together, intense fighting occurs and a hierarchy order is established within 24 hours (Turner et al., 2017). Several factors such as age, breed, space allowance, can affect aggression during this period (Samarakone and Gonyou, 2008). In our study, pigs had been mixed the day before when the lesion scores for week one were taken. The lesion scores were low at this time but were higher as the pigs grew (week 5). Pigs were less willing to share space at this time, as confirmed by reduced overlying behaviour, and preferred lying in lateral recumbency, which requires more space. Another possible reason could be that reduced space may increase completion for resting space which may also increase aggression thereby increasing injuries (Anil et al., 2007).

Results showed that pigs are less tolerant of space sharing as they approach nursery exit. This means that they are more sensitive to the effects of crowding as they grow. Baxter (1985) suggested that pigs in stable groups show aggression due to feeding competition because of limited resources (e,g, feeder space). Even though the number of feeders may remain the same and feed is provided ad libitum, the higher injury scores in the late grower-finisher period may be associated with the increasing size of pigs causing greater competition to gain access to the feeder, resulting in aggression (Anil et al., 2007). In our study there was always one feeder/10 pigs thus space available at the feeder decreased over time, possibly leading to more aggressive encounters and increased lesion scores.

3.3.4 Salivary cortisol

In young pigs, circadian cortisol rhythms and other circadian rhythms may be weak or absent (Ingram et al., 1985; Evans et al., 1988) however a circadian rhythm of salivary cortisol was demonstrated in 8-week old piglets (Ekkel et al., 1996). Later, gradual development of a distinct circadian rhythm of total cortisol plasma was observed as the pigs grew, reaching an adult profile near puberty (Evans et al., 1988). Ruis et al. (1997) that adult circadian rhythm profiles of salivary cortisol are reached at about 20 weeks of age.

We observed that cortisol levels in nursery pigs reduced over time, between the ages of five and nine weeks. These results agree with the observations of Anil et al. (2007) in grower-finisher pigs where it was found that cortisol levels decreased with age. Anil et al. (2007) suggested that smaller pigs had more space available during the early stages of their trial leading to higher activity and higher cortisol levels.

4. CONCLUSIONS

Due to the propensity of young piglets to overlie, it was hypothesised that the space requirements of nursery pigs would be lower than those for grower-finisher pigs. However, in this study increasing or decreasing the space allowance above or below the Canadian Code of Practice (NFACC, 2014) requirement of k=0.0335 for grower-finisher and nursery pigs resulted in significant effects on comfort behaviours. Pigs at lower space allowances had more feeding and drinking bouts, but of shorter duration. Lateral lying is known to be a more restful posture and was observed more frequently at higher space allowances, while pigs at lower space allowances were observed to be sitting more. The actual floor space used by pigs in sitting postures is less than the floor space required for other postures such as standing and lying, so this behaviour is interpreted as a response to crowding and has previously been associated with poor welfare. Pigs spent more time overlying in week one than in weeks three or five. On the basis of postural changes we reject the hypothesis that nursery pigs require less space due to overlying. In contrast, measures of production (ADG and G:F) were not affected by space allowance, so the production results neither confirmed nor refuted the hypothesis.

It was also hypothesised that housing pigs in larger groups would not influence piglet growth and welfare when adequate resources (feed, water) were provided. Productivity was similar in large (40 pigs) and small (10 pigs) group sizes, but piglets' behaviour patterns changed with group size. The frequency of feeding and drinking events was higher in larger groups. Moreover, pigs in small groups had more synchronous behaviour. In small groups, pigs lay, sat and stood for less time, but a higher proportion of the group did the behaviour at once. No interactions between group size and space allowance were found. Because group size did not affect ADG or behavioural differences related to welfare, these results support the hypothesis that group size does not affect growth and welfare.

In conclusion, although there was no effect of space allowance on production performance, reductions in space resulted in pigs changing resting (fully recumbent lying) and sitting postures which are related to space sharing and welfare. Moreover, lateral recumbency increased and overlying reduced over time, which suggests that effects of space restriction are greatest as pigs approach nursery exit. Therefore, on the basis of postural changes, the hypothesis that nursery pigs require less space than grower/finisher pigs due to overlying are not supported.

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6. APPENDIX

Table A.1 Average body weights (mean and SD) in nursery pigs by space allowance treatment, group size and nursery week.

Average Weight (kg)					
Item	K value	**N**	**Mean**	**Range**	**Std Dev**
Density (*k* value)	0.023	24	14.41	8.14-23.56	5.65
	0.0265	24	13.98	7.75-24.28	5.66
	0.03	24	14.42	7.83-23.82	5.7
	0.0335	24	14.77	8.21-24.4	5.75
	0.037	24	13.84	7.95-22.58	5.32
	0.039	24	14.78	8.49-24.2	5.72
Group	10	72	14.46	7.75-24.4	5.62
	40	72	14.27	7.8-24.2	5.52
Week	1	48	8.53	7.75-9.53	0.43
	3	48	12.59	11.01-15.09	0.88
	5	48	21.62	17.89-24.4	1.48

Table A.2 Average daily gains (mean and SD) in nursery pigs by space allowance treatment, group size and nursery week.

ADG (kg/day)					
Item	K value	**N**	**Mean**	**Range**	**Std Dev**
Density (*k* value)	0.023	24	0.42	0.08-0.78	0.27
	0.0265	24	0.39	0.02-0.84	0.26
	0.03	24	0.4	0.07-0.78	0.25
	0.0335	24	0.38	0.03-0.82	0.27
	0.037	24	0.37	0.05-0.77	0.24
	0.039	24	0.4	0.03-0.77	0.26
Group	10	72	0.4	0.02-0.82	0.26
	40	72	0.39	0.03-0.84	0.25
Week	1	48	0.09	0.02-0.14	0.03
	3	48	0.4	0.28-0.51	0.05
	5	48	0.69	0.39-0.84	0.01

Table A.3 Average values (mean and SD) for Gain: Feed (G:F) in nursery pigs by space allowance treatment, group size and nursery week.

G:F					
Item		**N**	**Mean**	**Range**	**Std Dev**
Density (*k* value)	0.023	22	0.8	0.67-1.01	0.09
	0.0265	22	0.85	0.3-1.73	0.32
	0.03	22	0.74	0.51-1.11	0.13
	0.0335	24	0.73	0.39-1.34	0.21
	0.037	24	0.84	0.55-1.93	0.34
	0.039	24	0.79	0.26-1.15	0.21
Group	10	70	0.8	0.26-1.73	0.24
	40	70	0.78	0.39-1.93	0.23
Week	1	48	0.88	0.26-1.93	0.3
	3	48	0.81	0.48-1.73	0.21
	5	44	0.68	0.4-1.03	0.11

Table A.4. Average values (mean and SD) for feeding and drinking behaviour time budgets in focal pigs.

Means of Time budgets				
Item	**N**	**Mean**	**Range**	**Std Dev**
Feeding bouts/day*	407	34.89	1-112	20.51
Total duration (min)	407	47.01	0.07-142.75	25.26
Avg bout duration (min)	407	1.48	0.07-7.49	0.73
Drinking bouts/day	405	23.65	1.00-81.00	14.26
Total duration (min)	405	6.44	0.18-55.42	6.45
Avg bout duration (min)	405	0.25	0.09-1.15	0.01

*Continuous observation using video cameras from 8am-4pm.

Table A.5. Average values (mean and SD) for body lesion scores by nursery week and body location.

	N	Mean	Range	Std Dev
Average lesions by week				
Week 1	1198	0.29	0-2	0.36
Week 2	1198	0.57	0-2.67	0.48
Week 3	1198	1.17	0-3	0.6
Average lesions by position				
Front	1198	0.91	0-2.67	0.42
Middle	1198	0.63	0-2	0.41
Back	1198	0.5	0-10	0.47

Table A.6. Average values (mean and SD) for Mycoplasma hyopneumoniae sample to positive (S/P) ratios.

Variable	**N**	**Mean**	**Range**	**Std Dev**
Sample1	285	0	0-0.07	0.01
Sample2	283	0.04	0-1.34	0.16
Sample3	277	0.63	0-1.9	0.33

Table A.7. Composition of experimental diets.

Item	Phase*	
Ingredient, Kg	Starter	Pre-grower
Ground Wheat	347.01	468.02
Soybean Meal 46.0% CP	230.00	124.66
Corn DDGS	100.00	150.00
Whey Permeate	100.00	-
Oat Groats 12.0% CP	70.00	-
Peas Ground	50.00	200.00
Pork White Grease	39.41	20.30
IPC 700 Fishmeal	26.66	-
Limestone (Coarse Calcium)	12.50	15.90
L-Lysine HCl 99.0%	5.37	5.40
Mono-cal 21% P	4.83	5.54
Zinc Oxide 72%	4.00	-
Salt Bulk	3.33	4.54
GFC Starter micro 2.0 NSP	2.00	2.00
DL-Methionine 99.0%	1.87	1.30
L-Threonine 98.5%	1.53	1.53
Choline Chloride 60%	0.80	-
Copper Sulfate 25%	0.40	0.40
L-Tryptophan 98.0%	0.30	0.41
Total	1000.00	1000.00

*Phase: Starter: Net energy 2.45 MCal/kg, was fed from BW Range- 8 to 10 Kg (week 1); Pre-grower: Net energy 2.40 MCal/kg, was fed from BW Range- 10 to 30 Kg (weeks 2-5).