RESEARCHREPORT

ANIMAL WELFARE

Title: Effect of stocking density on the welfare and performance of grow-finish pigs **- NPB #04-093**

Investigator - John Deen

Institution: University of Minnesota

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Abstract

Welfare and performance of grow-finisher pigs were evaluated in groups of 19 barrows, in 2 levels of group weight composition, uniform (pigs of body weight above 25 and below 75 percentiles) or varying body weights (pigs of body weight below 25 and above 75 percentiles) and at 4 levels of floor space allowances calculated allometrically for a final slaughter weight of 116 kg by using 'k' values of 0.027, 0.031, 0.034, and 0.037. The four space allowances were 0.64 m^2/pig (SA0.64), 0.74m^2/pig (SA0.74), 0.81m^2/pig (SA0.81), and 0.88 m^2/pig (SA0.88). The trial was conducted in Eastern Minnesota on a commercial farm with fully slatted floor following a 4 x 2 factorial design across 32 pens. Behavior data using video camera and time-lapse VCR, total injury scores (TIS) and saliva samples were collected from 5 randomly identified focal pigs from each pen. Behavior observation, injury scoring and saliva collection were started when pigs reached body weight of 75 kg in any one of the pens. Saliva collection and injury scoring were conducted at weekly intervals and behavior observation at two week intervals. Video tapes were analyzed for agonistic and non-agonistic social interactions and postural behaviors, using the software "Observer". Saliva samples were analyzed for cortisol concentration using radioimmunoassay. Pigs were individually weighed at the start and again at bi-weekly intervals up to 6 weeks and weekly thereafter up to 14th week of the trial. Actual 'k' value for each pen, average daily gain (kg/day - ADG) and pen efficiency were determined. Incidence of diseases and mortality observed during the study period were recorded. The data were analyzed using descriptive statistics, repeated measures of ANOVA, one way ANOVA and multivariate linear regression.

The pigs in SA0.64 had lower (P<0.05) ADG than those in SA0.88 and SA0.81 whereas pigs in SA0.64 and SA0.74 did not differ (P>0.05) in ADG. Pigs in SA0.88 reached a k of 0.037 at 13-14 weeks after the start of the trial, at an ADG of 1.08. Pigs in SA0.64, SA0.74 and SA0.81 reached the same k at 7-8, 10, and 12 weeks respectively after the start of the trial, with corresponding ADGs of 0.83, 1.0 and 0.94. ADG had a positive association (P<0.05) with body weight and a negative association with calculated k $\leq$0.030. Weight categories did not differ (P>0.05) in final body weight at 14th week. Pigs in SA0.64 had higher (P<0.05) overall pen efficiency (1.344 Kg daily gain/ m^2 space) than those in SA0.74, SA0.81 and SA0.88 (1.224, 1.131 and 1.063 Kg daily gain/ m^2 space respectively). Pen efficiencies were not different (P>0.05) among the space allowance treatments during the final three weeks.

Pigs in SA0.64 had higher (P<0.05) TIS than those in SA0.88 and SA0.81. Total injury scores were different (P<0.05) across different time points. Cortisol concentrations (ng/ml) did not differ (P>0.05) with space allowance treatments. Salivary cortisol concentration was higher (P<0.05) at initial stages of grow-finish period. Average number of aggressive interactions were higher (P<0.05) in SA0.64 compared to that in SA0.88 and SA0.81.

Pigs in SA0.64 spent a lower (P<0.05) proportion of time lying in preferred areas (body supported on side walls of the pen rather than at the central area or near the feeder) than pigs in SA0.88 and SA0.81. Pigs in the varying weight group spent higher proportion of time lying in preferred area (P<0.05) than pigs in the uniform weight group. Pigs spent less (P<0.05) proportion of time in preferred lying area at later stages of grow-finish period. The proportions of time spent on lateral recumbency and on lying in isolation were less (P<0.05 for both) at later stages of grow-finish period. Pigs in SA0.74 and SA0.64 spent lower proportion of time (P<0.05) lying isolated than pigs in SA0.81. Proportion of time spent lying (irrespective of location and posture) was less (P<0.05) and that on sitting, standing and exploratory behavior were higher (P<0.05 for all) in the final stages of grow-finish period. Uniform weight group showed more (P<0.05) exploratory behavior than varying weight group. Mortality rate observed was 3.45 %.

The results indicated welfare benefits in terms of postural behavior, lower injury scores and aggression in higher space allowance treatments. The performance and welfare of pigs in 0.81m^2/pig and 0.88m^2/pig were comparable at market weight of 116kg. Allotting grow-finishers according to uniformity or variation in body weight may not provide any differential benefit in ADG or overall welfare. Although, a beneficial effect was observed in terms of ADG, injury scores, aggression and lying behavior by increasing space allowance, an increase in space allowance from 0.64 to 0.74m^2/pig did not result in significant benefit. Similarly reducing space allowance from 0.81 to 0.74 m^2/pig also did not cause further disadvantages in terms of ADG, lying behavior, injuries and aggression. It may be concluded that in fully slatted floor, space allotted considering the final market weight of barrows, corresponding to ‘k’ values of 0.037 and 0.034 appear to be acceptable when compared to a ‘k’ value of 0.27 in production and welfare terms. A ‘k’ value of 0.031 was intermediate to higher (0.037 and 0.34) and lower (0.027) ‘k’ values.

Introduction

The welfare of grow-finish pigs is often assessed in terms of performance variables such as average daily gain (ADG), average daily feed intake or feed to gain ratio; indicators related to behavior, injuries and physiology are less commonly measured. Although poor welfare may be reflected in production performance, it alone cannot quantify welfare and it is important to consider as many variables as possible to get an accurate assessment of the pig’s well-being given its multi-dimensional nature. As in any other farm animal species, most of the concerns of well-being in grow-finishers are associated with the housing system. One of the important parameters of housing is stocking density. Even when there is no adverse effect on performance, a higher stocking density may have negative effect on well-being in terms of behavior, physiology and health. Efficient utilization of pen space is important for pork production. Increasing stocking density may improve pen space utilization and profitability, however, the floor area needs to be allotted in such a way that there is a balance between animal well-being and financially efficient pen space utilization (Gonyou and Stricklin, 1998).

Most of the previous studies for evaluating floor space allowance have been based on production performance of pigs (Brumm and Committee on management of swine1996; Edwards *et al*., 1988; NCR-89 Committee on confinement management of swine, 1993). However, the animal and its physical dimensions are the primary determinants of spatial definition (Ekkel *et al*., 2003; Hurnik and Lewis, 1991; Petherick and Baxter 1981). The space requirement of a pig in a group includes static space determined by its body dimensions and space needed to perform normal functions such as feeding, drinking, elimination, resting and interacting with other pigs and stockpersons. Lack of space may lead to suppression or displacement of one or more activities causing aberrant behavior and physiological changes leading to poor welfare and economic performance (Petherick, 1983a). For instance, Anil *et al*., (1998a) have reported that a reduction in space may cause an increase in agonistic behavior in grow-finish pigs.

Petherick and Baxter (1981) related space requirement to live weight of the pig by a mathematically defined biological (allometric) relationship, considering size and shape of the pig and its behavior relative to the manner in which the space is utilized. This in turn was used to calculate the total static space occupied by a group of pigs. However, additional space is required to allow animals to perform various behaviors. Based on allometric relationships, Petherick (1983b) calculated the area (A) using a formula $A (m^2) = k \times W^{0.667}$, where 'k' is a constant and W is the body weight of the pig in kg. Baxter (1984) suggested that space allowances for pigs on fully slatted floors should be calculated using a factor of 0.034. Similarly Edwards *et al*., (1988) suggested a value of 0.03 for 'k' for grow-finish pigs in commercial farms in fully slatted floors. However, all these studies have used only production performance in the evaluation, and not other welfare indicators.

The advantage of using allometric measurements to calculate space requirements is that the space requirement at any particular body weight or stage of growth can be determined. Allometric expression can be applied over a wide range of weights and allows comparison of studies involving different weight end points (Gonyou *et al.,* 2005). Baxter (1992) proposed that space available for movement in groups is shared so that if most animals are resting, an active animal will get more space than when it is housed individually. The number of pigs occupying a given size pen and the manner in which pigs utilize that area will determine the amount of free space available in the pen. McGlone and Newby (1994) have also hypothesized that when a fixed total space is provided per pig, a direct relationship exists between group size and amount of free space. However, how much extra space can be taken away to minimize cost and to ensure efficient space utilization without adversely affecting well-being and production has not yet been well understood. Similarly, when the space needed for a group of pigs is calculated allometrically, based on average body weight of the pigs in the group, a group with heavier and lighter pigs may get more available space than a group with uniform sized pigs.

When pigs are given a fixed space, the method of calculating space requirement using 'k' for the final anticipated weight will ensure that pigs get adequate space during the early stages. However, depending on the value of 'k', pigs will have to compromise in space at later stages of growth. Pigs provided with space based on the ideal 'k' value at exit will not be required to compromise at any stage before attaining market weight, those with 'k' less than the ideal at exit will have to compromise at some point towards later stages of growth . The stage of growth at which pigs in pens with a lesser 'k' will be compromised depends up on the actual space availability (dependent on the 'k' value) and whether the weight of pigs in the group is uniform or varying, as a smaller animal will require less space than a larger pig. A group of pigs with varying body weights may thus be benefited when the space needed is calculated considering the average anticipated final weight of the pig in the group in comparison to a group of pigs with uniform body weight. However, the manner in which the group of pigs with uniform and varying initial body weights performs in terms of production and welfare at different space allowances at different stages of growth needs to be studied so that the space requirement for a fixed group size with pigs of similar or varying initial body weight can be determined to minimize the cost and improve pig welfare.

There are three major issues associated with previous studies on space allowance for pigs; (a) basis for space allowance calculation (allometrically or weight-based), (b) confounding of space allowance with group size and (c) effect of body weight composition of the group. In some previous studies where space allowance was calculated allometrically (Edwards *et al*., 1988; Gonyou and Stricklin, 1998; Spoolder *et al*., 2000), the space allowance was maintained constant throughout the trial period by adjusting pen space weekly, based on body weight measurements. Though this approach provides more accurate values for any particular stage during growth, it is not feasible at the producer level to change pen size at frequent intervals. On the other hand, in those studies where space allowance was not based on allometric measurements (Meunier-Salaun *et al*., 1987; Randolph *et al*., 1981), the allotment of fixed area throughout the trial resulted in pigs having extra space early in the trial and relatively less space towards the end of the trial.

The effect of stocking density is mediated through area allocation and group size. However, in previous studies often these two factors were confounded (Anil *et al*., 1998b; Edmonds *et al*., 1998; Mitchell *et al*., 1983; Wolter *et al*., 2000) and consequently were unable to determine whether differences in performance were due to space or due to the number of pigs in the group. Similarly, effect due to stocking density was found to be influenced by factors such as type of building, floor type (Jensen *et al*., 1973; Spoolder *et al*., 2000), feed additives (Brumm and Miller 1996; Ferguson *et al*., 2001; NCR-89 Committee on confinement management of swine, 1986), feeders (Hyun and Ellis, 2002; Nielsen *et al*., 1995) environmental enrichment (Beattie *et al*.,1996; Pearce and Paterson, 1993) and sex (Jensen *et al*., 1973; Hsia and Lu, 1985).

Avoiding weight variation at marketing is essential to minimize discounts for pigs which weigh more or less than slaughter house- defined ideal (Payne *et al*., 1999). The effect of rearing pigs of unequal weights together on the final weight of pigs and how space allowance can reduce final weight variation are elusive. Studies on the impact of reducing variability in body weight on performance during the growing period by removal and remixing of the light-weight pigs are limited. Brumm, *et al*., (2002) reported that removal of light weight pigs and remixing of removed pigs into pens of similar weight pigs was ineffective in improving overall performance of a population of pigs during post-weaning period, based on sorting and remixing at 70kg body weight or at 3 weeks post weaning. Further, this practice involves additional mixing and associated welfare issues along with extra labor.

The present study was designed to assess the welfare and production performance of grow-finishers while considering the limitations in previous studies and accounting for the feasibility of adoption at the producer level. This study evaluated welfare and performance of grow-finisher pigs in groups composed of 19 barrows of either uniform or varying initial body weight composition. Groups were provided with one of four levels of floor space allowances calculated allometrically using the 'k' value recommended by Baxter (1984) and values 10 and 20 % lower and 10% higher than the recommended value (0.034, 0.031, 0.027 and 0.037 respectively).

Objectives

1. To measure following parameters of grow-finish pigs in combinations of four stocking densities and groups of similar and varying body weight compositions,
   a. Behavior
   b. Injury levels of pigs
   c. Stress hormone (cortisol) concentrations
   d. Diseases and mortality
   e. Production parameters such as ADG and pen efficiency

2. To compare the benefits in terms of above variables between combinations of four stocking densities and groups of similar and varying body weight compositions.

Materials and methods

Experimental design and housing

The trial was conducted in a commercial farm in Eastern Minnesota, following a 4 x 2 factorial design (4 space allowance and 2 types of body weight compositions) across 32 pens. Each pen had fully slatted flooring, a 5-place dry wean to finish feeder and 2 cup waterers. Barrows (Yorkshire X Landrace X Hampshire X Duroc commercial crosses) of 30 kg (30.56 $\pm$0.15) were randomly allocated to 4 floor space treatments based on 4 values of 'k' (0.037, 0.034, 0.031 and 0.027) calculated for the final anticipated weight of 116 kg and maintained up to a market weight of 116 kg. The four final space allowance treatments based on 'k' for the anticipated 116 kg body weight were 0.88 , 0.81, 0.74 and 0.64 m^2 per pig respectively and these treatments were designated as SA0.88, SA0.81, SA0.74 and SA0.64 respectively. The group composition treatments included pigs of uniform (pigs of body weight above 25 and below 75 percentiles) or varying body weights (pigs of body weight below 25 and above 75 percentiles) and the group sizes were kept constant as 19 pigs per pen. The size of the pen was altered to achieve the proposed 'k' value in each case by adjusting the gating. In the event of pig death or removal, pen size was adjusted to maintain the proposed 'k' values. The experiment was replicated four times using 608 individually identified (ear-tagged) pigs, in two identical environmentally controlled barns on the same site with fully slatted-floor pens. The pigs received a corn-soybean meal based diet. All pigs had *ad libitum* access to feed and water. Paylean (ractopamine hydrochloride, Elanco Animal Health; a repartitioning agent to improve the performance by increasing ADG) was added (9g /ton) to the feed during last week (14^{th} week) of the trial. The actual 'k' value for each pen was recorded every week based on average body weight of the pigs in the pen. Five focal pigs were randomly identified from each pen at the start of the trial for behavior, injury and cortisol assessment. The same focal pigs were followed through out the trial.

Measurements

Salivary cortisol: Saliva samples were collected using a salivette with cotton wool swab (SARSTEDT, Aktiengesellschaft and Co, Numbrecht, Germany). Saliva collection started when pigs reached body weight of 75 kg in any one of the pens and at weekly intervals thereafter. Saliva was collected from the same pigs in all weeks. Pigs were allowed to chew the cotton wool swab clipped to a flexible thin metal rod until the swab was thoroughly moistened. Care was taken to keep the pigs minimally disturbed to avoid activity during saliva collection. Saliva samples were collected between 7-11am on all collection days. Approximately 3 minutes were needed to collect saliva from a pig. The Salivette with moistened cotton swabs were centrifuged at 400 X g for five minutes to extract saliva and kept frozen at –20 ^{0}C until radioimmunoassay. Approximately 0.5 ml saliva was obtained from each swab. The solid phase cortisol radioimmunoassy kit, (Coat-A-Count TKCO, Diagnostic Products Corporation, Los Angels, U.S.A) was modified (Ruis *et al.,* 1997) to measure cortisol concentrations in saliva. Phosphate buffered solution (0.01M and 7.2pH) was used to dilute the supplied human serum based calibrators to final cortisol concentrations of 0.000 (maximum binding or B0), 0.3125, 0.625, 1.25, 2.5, 5, 10, 20, and 40 ng/ ml. Saliva samples and calibrators were analyzed in duplicate aliquots of 200µl. After adding ^{125}I cortisol, tubes were mixed and incubated for 45 minutes at 37^{o}C. Following incubation, unbound ^{125}I cortisol was aspirated and remaining radioactivity was counted using a gamma counter (Packard instrument company). The recovery rate of calibrator cortisol added to porcine saliva was determined by adding calibrator solutions to saliva containing both relatively high and low concentrations of endogenous cortisol. The recovery percentage of cortisol from the saliva was 102%. The assay was conducted in three runs. The intra-assay coefficient of variation calculated from duplicate low medium and high cortisol saliva pools were 6.9, 8.9 and 6.6 % respectively for the three assays. The inter-assay coefficient variation was 6.0 %. Different amounts of calibrators added to the saliva samples gave a slope similar to that of the calibrator added to the buffer solution. The minimal detectable sensitivity (concentration at 92.4 % of the maximum binding) of the assay was 0.31ng/ml.

Injury scores: Injuries of all focal pigs were scored after saliva collection. Injuries on various body parts such as ear (right and left), snout, face, forehead, shoulder (right and left sides), forelimb (right and left), neck (right and left sides), thorax (right and left sides), flank (right and left sides), top of the back (dorsum), udder, croup-hind quarters (right and left sides), hind limb (right and left), tail and vulva were recorded (Anil et al., 2003). If the depth of a wound was > 0.5 cm, it was considered a deep wound. A score of zero was given for no injury, 1 for mild injury (< 5 superficial wounds), 2 for obvious injury (5 to 10 superficial wounds, $\leq$ 3 deep wounds, or both), and 3 for severe injury (> 10 superficial wounds, > 3 deep wounds, or both). Total injury score (TIS) was calculated by adding injury scores for individual sites. The same individual did scoring on all days.

Behavior: Behavior of the pigs was recorded using a time-lapse video recorder (Lorex SG7964, Strategic Vista International Inc. 300 Alden Road, Markham, Ontario, Canada L3R 4C1) and high resolution bullet cameras with 3.6mm lenses (123 CCTV Security Camera, PO Box 41855, Bakersfield, CA 93389) for 8 hours (8 day-light hours from 8 am to 4 pm) at 30H speed (12 fields/seconds). Behavior recording started when pigs reached body weight of 75 kg in any one of the pens (at 8^{th} week after beginning of the experiment) and continued at bi-weekly intervals thereafter. Pigs were individually identified by large numbers marked on their back using a livestock marker. The cameras were fixed on the ceiling of the pen in such a way to view a pen completely. The frequency and duration of behaviors of focal pigs for the first 10 minutes of every hour for the 8 h period were analyzed from the videotape using 'The Observer' software (version 4.1. Noldus Information Technology Inc, Leesburg, USA). Video tapes were analyzed for various behaviors as described in the ethogram in Table 1.

Table 1: Behavioral ethogram for pig housed in pens with 4 space allowances following behavioral definitions from Jensen (1980), Baxter, (1984), Jensen *et al*., (1995), Pearce and Paterson, (1993) and Morrison *et al*., (2003).

Behavior	Definition
Agonistic	Performed and received such as parallel pressing (two pigs standing side-by-side in the same direction, pressing against each other's shoulder, with one throwing its head against the head or the neck of the other pig), inverse parallel pressing (two pigs standing side-by-side in opposite directions, pressing against each other's shoulder/croup), head-to-head knock (a rapid thrust upward or sideways with the head or snout against the neck, head or ears of another pig), levering (the pig puts its snout under the body of another pig from behind or from the side and lifts the other pig up into the air) and biting on any part of the body.
Postures	Standing (the pig is upright on all four legs). Lying in preferred area: Lying near the walls and away from feeder and central area to avoid disturbances while resting. Lying in lateral recumbency: the pig lies flat on one side of its body, not supported by legs. Lying on sternum: lying on sternum with one or more legs tucked under the body. Lying in isolation: body is not in contact with another pig Lying in cluster: body is in contact with another pig Sitting: body is supported by one or two front legs.
Feeding	Head contained within the feeder
Non-social physical interactions (exploration)	Pigs nosing, chewing, licking or sniffing floor or any inanimate object in the pen
Social tactile interactions	Nose-to-body and nose-to-nose interactions performed and received.
Locomotion	Walking or running

ADG and pen efficiency: Pigs were individually weighed at the start, bi-weekly up to 6 weeks and weekly thereafter up to 14th week of the trial. ADG was determined from weekly weights and pen efficiency was determined by calculating daily gain per square meter of floor space.

Diseases and mortality: Incidence of morbidity and mortality observed during the study period was recorded.

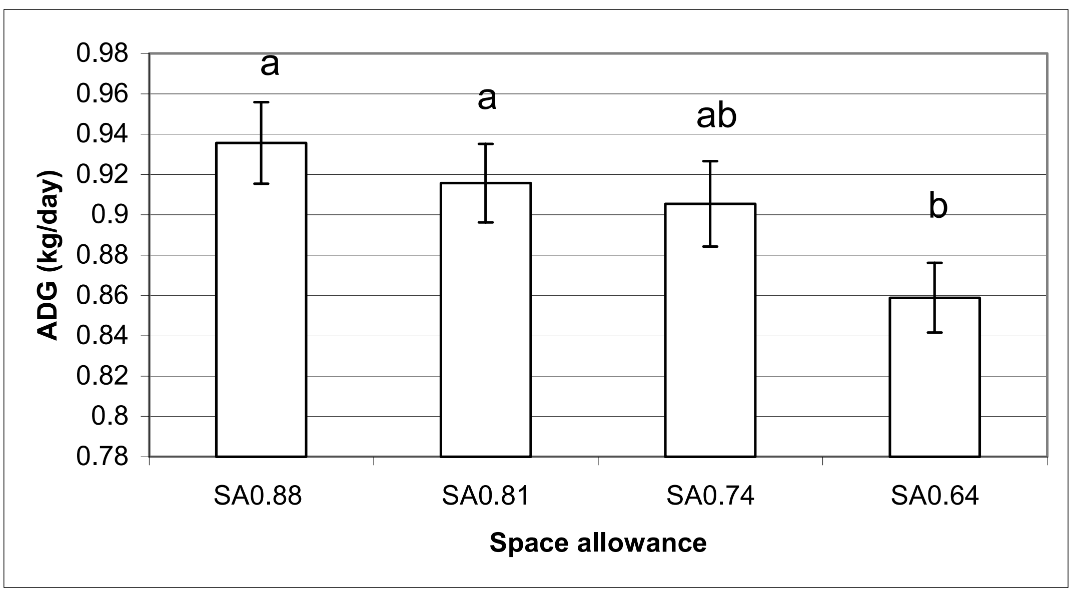
Statistical analysis: The pen was considered as the experimental unit. Data collected were described using mean and SE. All agonistic interactions and social tactile interactions (received or performed for both) were added together and expressed as total aggressions and total non-agonistic social interactions respectively for behavior analysis. The proportion of time spent on a specific behavior was expressed as percentage of observation time and the number of occurrences in observation time was expressed as frequency of behavior. Actual k experienced by the pigs at different time periods was calculated based on weekly body weight and pen area. The calculated k values were split into 5 categories: $\leq$ 0.030 (k1), 0.0301-0.0320 (k2), 0.0321-0.0340 (k3), 0.0341-0.360 (k4) and >0.0360(k5). In the present longitudinal data, repeated measurements were recorded on individual subjects over a period of time. Thus, there were 'between-subject' (those whose values change only from subject to subject and remain the same for all observations on a single subject) and 'within-subject' (those whose values differing from measurement to measurement) effects. In the present analysis repeated measures of ANOVA (Proc Mixed) with data collection time as 'within subject factor' and treatments as 'between subject factor' was performed for ADG, pen efficiency, injury levels, cortisol concentrations and behavior. Since measurements on the same experimental unit were correlated, first-order autoregressive covariance structure was used to account for that correlation. In all the analyses, interactions between weight categories and space allowance per pig were included. Means were compared using Tukeys pairwise comparison with probability difference option (PDIFF). ANOVA (Proc ANOVA) was performed for comparing coefficient of variation (CV%) of weight at different time points and ADG, cortisol, injuries and behavior at different k categories. A linear regression model was fitted to analyze the association of ADG with the five k categories, body weight (kg), weight categories (uniform and variable), Paylean (fed or not) and barns (barn-1 and barn-2). All the analyses were performed using SAS (version 9.1, 2003). A *P* value of $\leq$ 0.05 was considered significant for all comparisons.

Results

Average daily gain

Figure 1 and Fig 2 show the effects of space allowance per pig and time periods on ADG. Barn and interaction of space allowance per pig and weight had no (p>0.05) effect on ADG.

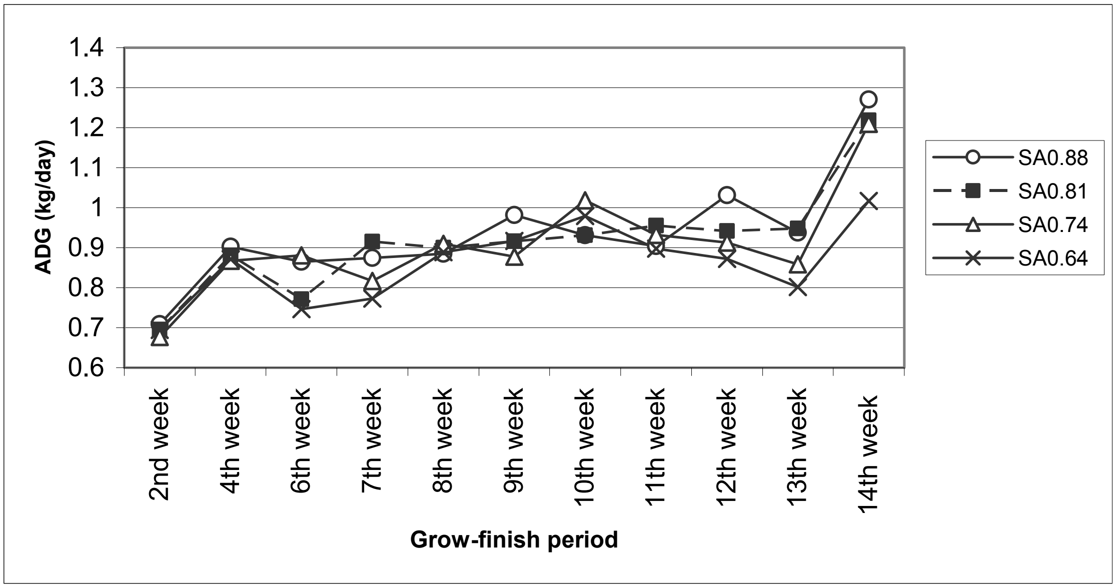
Figure 1: Effect of four space allowances, 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64), on ADG of grow-finish pigs.



The pigs in SA0.64 had lower (P<0.05) ADG than those in SA0.88 and SA0.81 whereas pigs in SA0.64 and SA0.74 did not differ (P>0.05) in ADG.

ADG (average of four space allowances) was the lowest at 2[nd] week (0.694 $\pm$0.013) and gradually increased from 4th week onwards, the highest (1.179$\pm$0.03) at 14[th] week (P<0.05 for both) (Figure 2).

Figure 2: ADG of pigs in space allowances of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) or 0.64 m^2/pig (SA0.64) at different time points during grow-finish period.



Body weight of pigs before first removal of pigs also followed the same trend as that of ADG, with higher ($P<0.05$) body weight for pigs in SA0.88 (121.14 $\pm$0.806) than in SA0.64 (114.66$\pm$0.898). However, body weight of pigs in SA0.81 (118.73$\pm$1.356) and SA0.74 (117.64 $\pm$1.079) did not differ ($P>0.05$) from that in SA0.88 or SA0.64. Weight categories did not differ ($P>0.05$) in body weight at 14th week, before first removal of pigs.

A linear regression model was fitted to assess the association of ADG with body weight (kg), weight categories (uniform and variable), 'k' categories (5 levels), Paylean (fed or not) and barns (barn-1 and barn-2). ADG had a positive association ($P<0.05$) with body weight and use of Paylean. The category k1 had a negative effect ($P<0.0001$) on ADG (R^2 0.38) (Table2).

Table 2: Association of ADG with calculated 'k' values of $\leq$ 0.030 (k1), 0.0301-0.0320 (k2), 0.0321-0.0340 (k3), 0.0341-0.0360 (k4) and >0.036 (k5), body weight, weight categories barn and Paylean feeding.

Variables	Parameter estimate	SE	P
Intercept	0.59140	0.03622	<0.0001
Body weight (kg)	0.00352	0.00046012	<0.0001
Uniform weight category	0.01494	0.01568	0.3411
k1	-0.15632	0.03646	<0.0001
k2	-0.01935	0.03494	0.5800
k3	-0.04813	0.03228	0.1369
k4	-0.04813	0.02913	0.1366
Barn-1	0.01152	0.01569	0.4635
Paylean	0.20760	0.03205	<0.0001

Base parameters: k5, barn-2, variable weight group and no Paylean feeding.

A lower ($P<0.05$) ADG of 0.865$\pm$0.0103 was observed for k5 than other k categories with the exception of k1. The ADGs for k2 (1.011$\pm$0.042), k3 (0.973$\pm$0.043), k4 (1.043$\pm$0.034) and k1 (0.918$\pm$0.038) were not different ($P>0.05$).

There was clear indication that ADG increased with space allowance. The highest space allowance of SA0.88 provided in this study was based on a 'k' value of 0.037. This space allowance treatment had the highest ADG of 0.94 kg/day. Although pigs in all space allowance treatments had more space at the start of the trial, they all reached a space allowance per pig corresponding to a 'k' value of 0.037 at different stages of grow-finish period depending on the respective space allowance treatment. Figures 3,4,5 and 6 present the ADG plotted against 'k' calculated based on weekly weights at different space allowance treatments and the points at which different space allowance treatments reach a 'k' value of 0.037 are also marked. Pigs in SA0.88 reached 0.037k only at 13-14 weeks after the start of the trial at an ADG of 1.08. Pigs in SA0.64, SA0.74 and SA0.81 reached the same point at 7-8, 10, and 12 weeks after the start of the trial with corresponding ADGs of 0.83, 1.0 and 0.94 respectively.

Figure 3: Point of attaining 0.037k and the corresponding ADG in 0.64 m^2/pig (SA0.64).

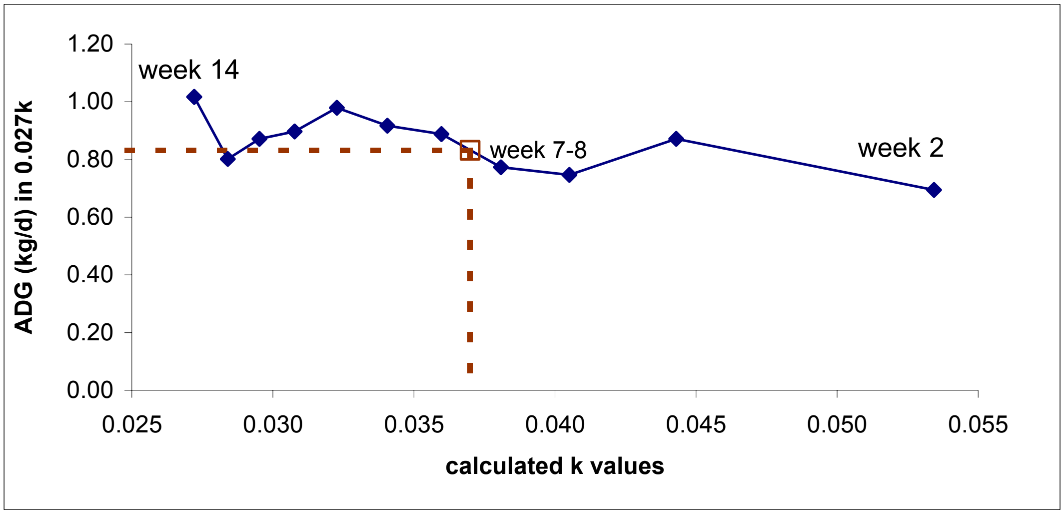


Figure 4: Point of attaining 0.037k and the corresponding ADG in 0.74 m^2/pig (SA0.74).

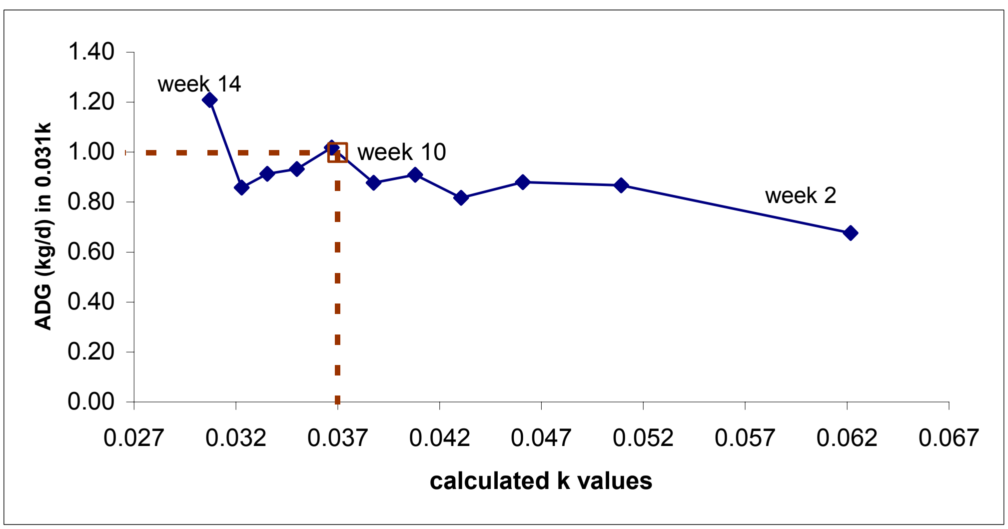


Figure 5: Point of attaining 0.037k and the corresponding ADG in 0.81 m^2/pig (SA0.81).

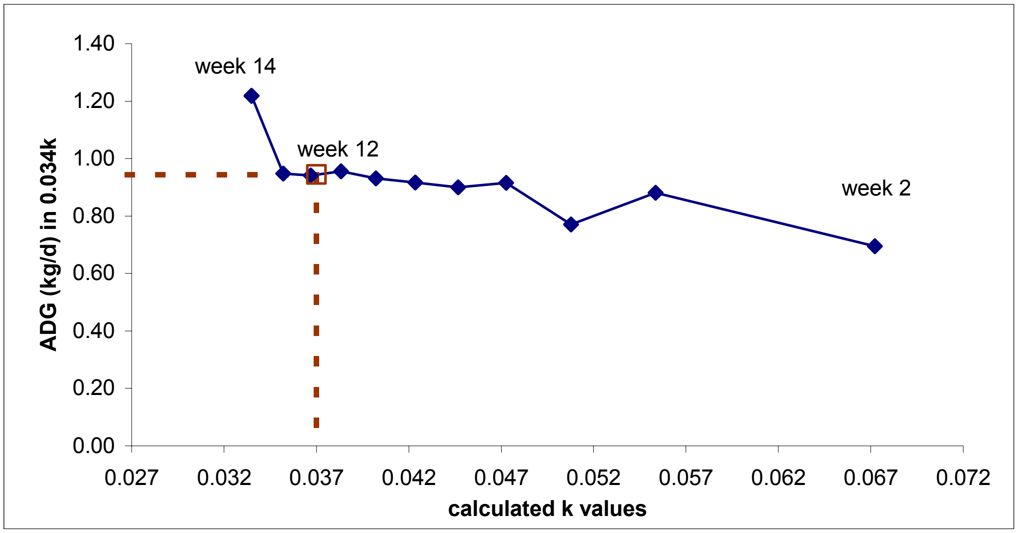


Figure 6: Point of attaining 0.037k and the corresponding ADG in 0.88 m^2/pig (SA0.88).

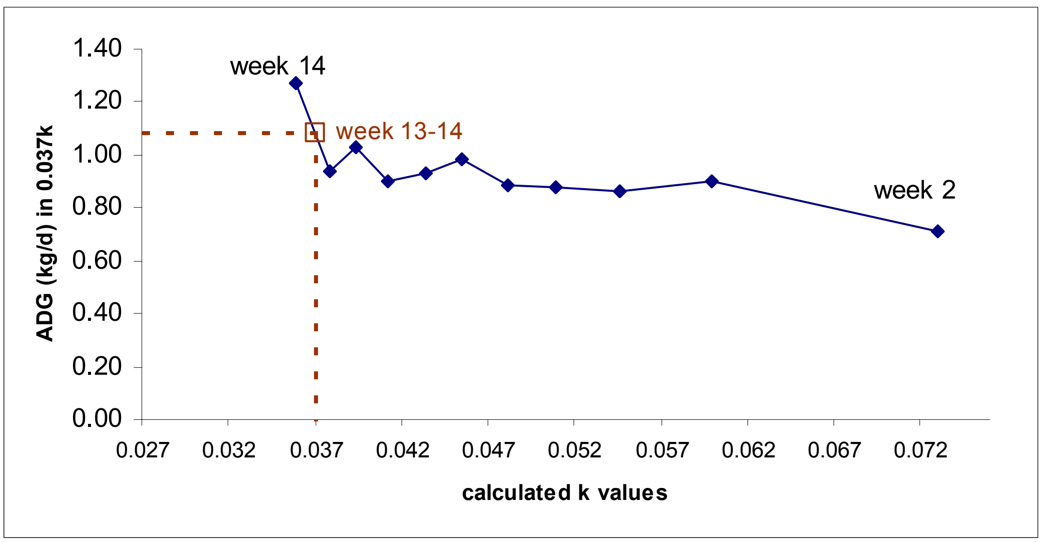


Table 3 presents the coefficients of variation (CV%) of body weight of pigs in uniform and varying weight groups at the start and end of the trial in different space allowance treatments.

Table 3: Coefficients of variation (CV%) of body weights of pigs in uniform and varying weight groups at the start and end of the of the trial in space allowance of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64).

Space allowance	CV% of body weight at the start		P	CV% of body weight at the end		P
	Uniform	Varying		Uniform	Varying	
SA0.88	4.61±0.19^a	16.12±0.67^b	0.0001	9.42±1.24	13.26±2.06	NS
SA0.81	4.77±0.17^a	16.11±0.18^b	0.0001	10.78±1.15	12.08±2.11	NS
SA0.74	4.5±0.07^a	15.90±0.43^b	0.0001	6.73±0.93^a	13.49±1.2^b	0.0043

SA0.64	5.98$\pm$0.81[a]	15.9$\pm$0.29[b]	0.0001	9.25$\pm$0.89	15.95$\pm$1.38	0.0066

The results indicated that pigs in both uniform and varying groups in SA0.88 and SA0.81 did not differ in CV% body weight at market weight.

Pen efficiency

Figure 7 shows that pigs in SA0.64 had higher overall pen efficiency (Kg daily gain/ m^2 space) than in other space allowance treatments. Pen efficiency was different ($P<0.05$) at different time periods (Figure 8) with minimum of 0.916 $\pm$ 0.0251 at 2nd week and maximum at 14th week with Paylean feeding (1.543$\pm$ 0.0365). Weight groups, barns or interaction of weight with space allowance had no significant effect on pen efficiency. Even though there was significant difference in pen efficiency at different time periods, these differences were not significant ($P>0.05$) among the 4 space allowance treatments during the last 3 weeks (Figure 8).

Figure 7: Pen efficiency in space allowances of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64).

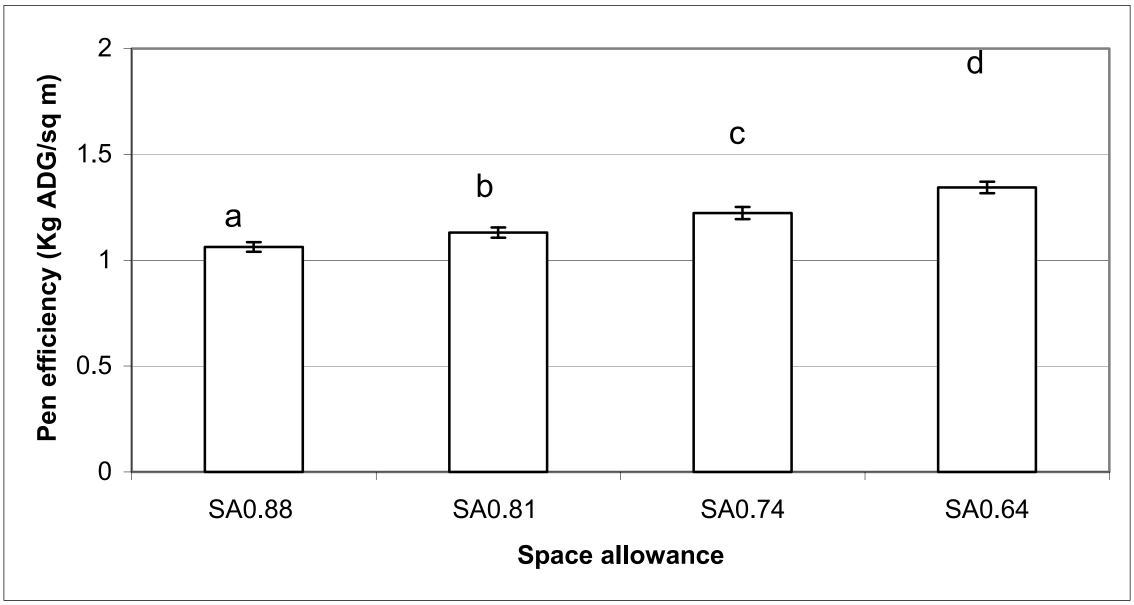
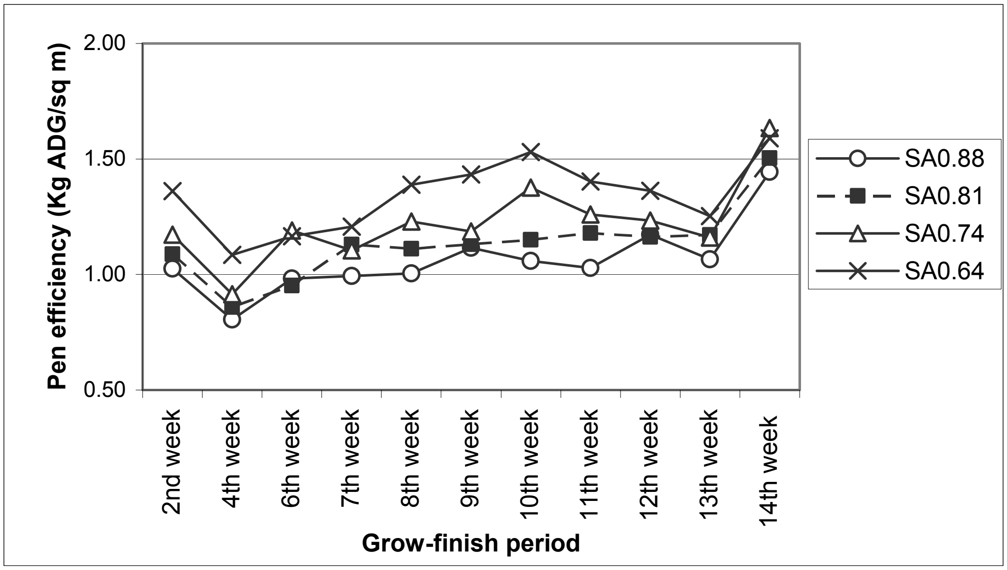


Figure 8: Pen efficiency in space allowances of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64) at different time points during grow-finish period.

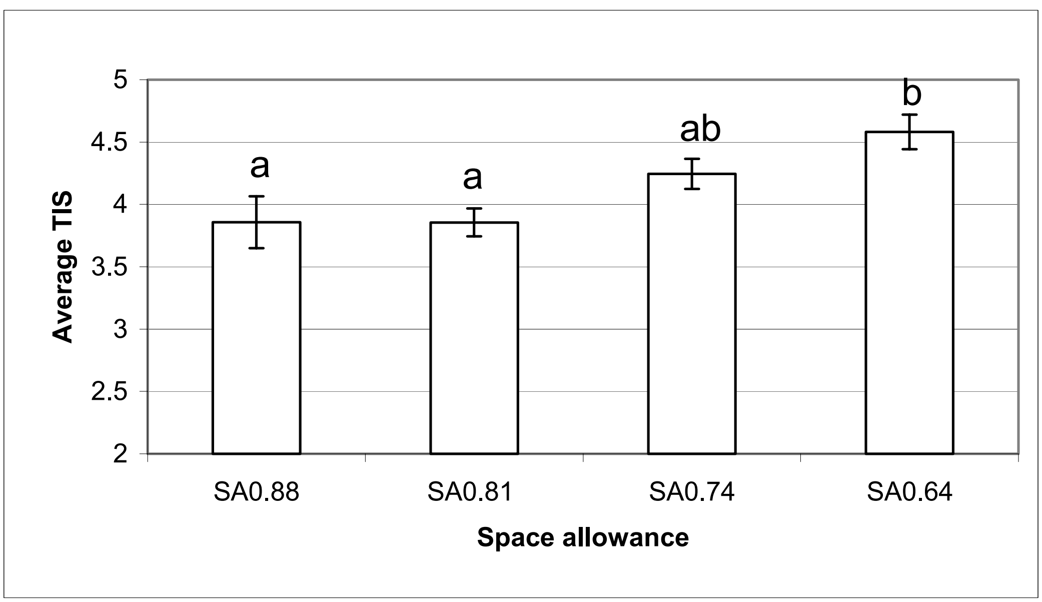


Pen efficiency was lower (P<0.05) at k5 (1.096 ± 0.013) than at other k categories. Pen efficiency for k1 (1.423± 0.0559), k2 (1.486±0.0533), k3 (1.331± 0.0497) and k4 (1.381± 0.0427) were not different (P>0.05).

Injury levels

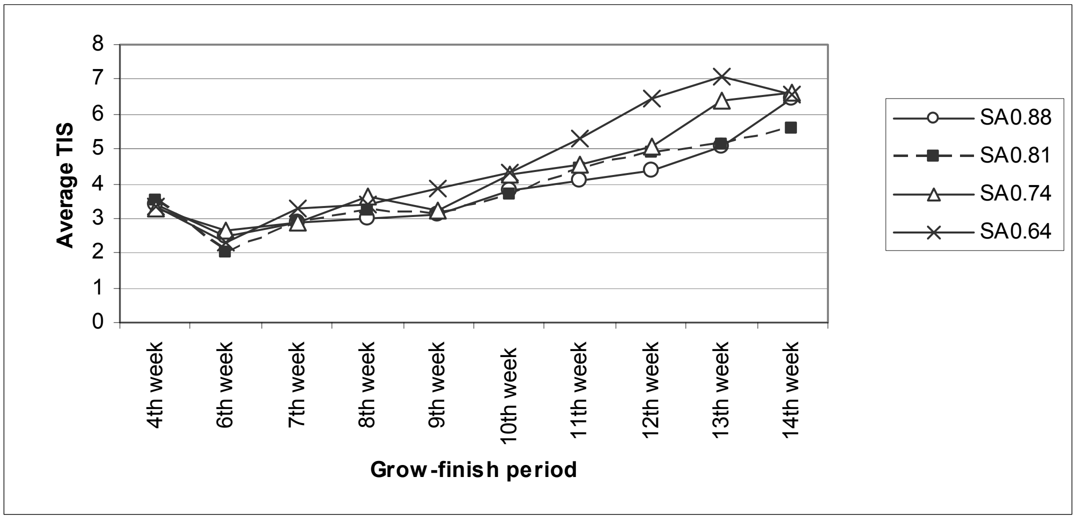
The injury levels of pigs were related to space allowance treatments, time period and barn. Weight categories or its interaction with space allowance treatment had no effect on injury levels. Pigs in SA0.64 had higher (P<0.05) injury scores than those in SA0.88 and SA0.81 (Figure 9).

Figure 9: Total injury scores of pigs in space allowance of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) or 0.64 m^2/pig (SA0.64)



Injury scores were different (P<0.05) at different time points also (Figure 10). The lowest average injury score was noticed at 14 days after the start of the trial (2.37±0.129) and injury scores gradually increased towards the end of grow-finish period, reaching a maximum score of 6.31±0.179. The average injury scores were different among pigs housed in two barns with pigs in barn-1 having higher ($P<0.05$) injury scores (4.27 ± 0.121) than those in barn-2 (4.0 ± 0.119).

Figure 10: Total injury scores of pigs in space allowance of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64) at different time points during grow-finish period.

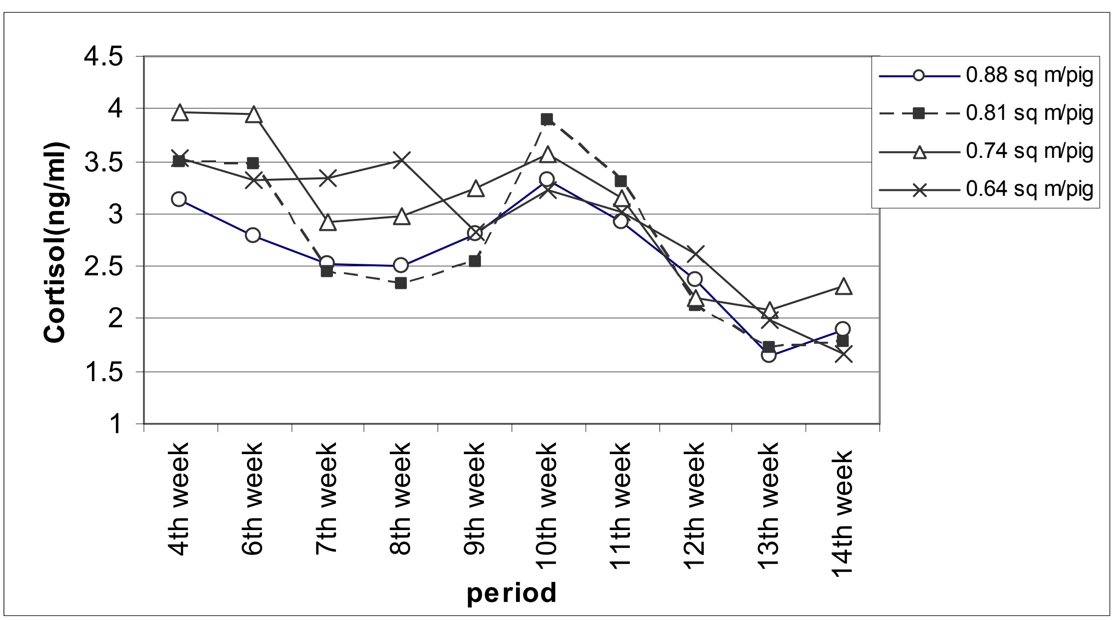


Injuries scores were different (P<0.05) among 'k' categories; pigs in k5 had the lowest (3.42±0.08) and pigs in k1 had the highest injury scores (6.69±0.17). Injury scores were not different (P>0.05) for k2 (5.63±0.26), k3 (5.11±0.22) and k4 (4.92±0.23) categories.

Salivary cortisol concentration

Cortisol concentrations (ng/ml) did not differ (P>0.05) with space allowance treatments (2.59± 0.093; 2.71±0.132; 3.04±0.134 and 2.90±0.128 respectively for SA0.88, SA0.81, SA0.74 and SA0.64), or with weight groups (2.70±0.08 and 2.92±0.09 respectively for uniform and varying groups). There was no interaction effect of weight groups or space allowances or barn with respect to cortisol concentration. However, cortisol concentration varied with time periods (Figure 11). The final stages (12^{th}, 13^{th} and 14^{th} week) had lower (P<0.05) cortisol concentrations than other stages.

Figure 11: Cortisol concentration (ng/ml) of pigs in space allowances of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64) at different time points during grow-finish period.



Though space allowance treatments had no effect on salivary cortisol concentration, pigs in k5 had higher ($P<0.05$) cortisol concentration (2.91 ± 0.08) compared to pigs in k1 (2.19 ± 0.16). Cortisol concentrations at k2 (2.67 ± 0.18), k3 (2.37 ± 0.16) and k4 (2.55 ± 0.17) were not different from that in both k1 and k5.

Behaviors

Behaviors were assessed after the pigs attained 75 kg body weight (at 8th week) at bi-weekly intervals until the first removal of pigs from the trial. The time points of behavior measurement represented 'k' values of 0.042 (8th week), 0.038 (10th week), 0.035 (12th week) and 0.032 (14th week).

Average number of aggressive interactions were higher ($P<0.05$) in SA0.64 compared to that in SA0.88 and SA0.81 (Table 4). Average number of aggressive interactions was the highest ($P<0.001$) at 10th week (Table 5). Barn, weight groups, or weight group interaction with space allowance treatments had no effect on average number of total aggression. Average number of non-agonistic social interactions and average number of feeder visits were not different ($P>0.05$) among the four space allowance treatments (Table 4), at different time points (Table 5), or in different weight groups (Table 6) or in different barns. There was no interaction between weight groups and space allowance treatments.

The proportion of time spent sitting varied with time points during grow-finish period with higher proportion at last 2 week than at 8th and 10th weeks (Table 4).

Pigs in SA0.64 spent a lower ($P<0.05$) proportion of time lying in preferred areas (body supported on side walls of the pen rather than at the central area or near the feeder) than pigs in SA0.88 and SA0.81 (Table 4). Pigs spent a higher ($P<0.05$) proportion of time lying at 8th week and 10th week compared to 12th and 14th weeks (Table 5). Pigs in varying weight group spent higher proportion of time lying in preferred area ($P<0.05$) than pig in the uniform weight group (Table 6). The proportion of time spent on lateral recumbency was lower ($P<0.05$) at 12th week and 14th week than at the other 2 time points (Table 5). Space allowance, weight group, their interaction, and barn had no effect on the proportion of time spent in lateral recumbency.

Space allowance and time point had influence on the proportion of time spent lying isolated. Pigs in SA0.74 and SA0.64 spent less time ($P<0.05$) lying isolated than pigs in SA0.81 (Table 4). Pigs spent a lower ($P<0.05$) proportion of time lying isolated at the last 2 time points than at 8th and 10th week (Table 5). The proportion of time spent lying (irrespective of location, type of recumbancy and lying pattern) varied with time points; the lowest proportion ($P<0.05$) at 14th week and highest ($P<0.05$) at 8th week (Table 5).

The proportion of time spent standing was higher ($P<0.05$) at 12th and 14th week than that at 10th week (Table 5). Exploratory behavior was higher ($P<0.05$) at 14th week than at other time points (Table 5). Uniform weight group showed higher ($P<0.05$) proportion of time spent on exploratory behavior than varying weight group (Table 6). Space allowance, interaction of space allowance with weight groups, and barn had no effect on proportion of time spent on exploratory behavior. Proportion of time spent walking was different ($P<0.05$) at different time points (Table 5) and was higher ($P<0.05$) in uniform weight group than in varying group (Table 6).

Table 4: Average number and proportion of time (% of observation time) spent on various behaviors by pigs in space allowances of 0.88 m^2/pig (SA0.88), 0.81 m^2/pig (SA0.81), 0.74 m^2/pig (SA0.74) and 0.64 m^2/pig (SA0.64).

Behavior	SA0.88	SA0.81	SA0.74	SA0.64	P
Average number of social interaction	9.69±0.698	9.94±0.637	9.86±0.632	11.32±0.580	NS
Average number of aggressions	1.08±0.212^{a}	1.24±0.238^{a}	1.56±0.242^{ab}	1.94±0.286^{b}	0.05
Average number of feeder visits	3.77±0.24	3.28±0.2	3.78±0.25	3.94±0.30	NS
Proportion of time spent lying	77.04±1.138	77.16±1.356	75.78±1.209	74.68±1.198	NS
Proportion of time spent sitting	1.62±0.236	1.72±0.184	2.36±0.271	2.08±0.235	NS
Proportion of time spent lying in isolation	3.26±0.717^{ab}	4.52±0.467^{a}	2.76±0.441^{b}	2.18±0.372^{b}	0.004
Proportion of time spent lying in preferred area	61.02±1.203^{a}	59.77±1.417^{a}	57.61±1.333^{ab}	55.22±1.644^{b}	0.015
Proportion of time spent lying in lateral recumbancy	57.83±1.345	58.76±1.727	55.72±1.930	56.44±1.712	NS
Proportion of time spent standing	20.97± 1.076	20.51±1.22	21.43±1.23	22.84±1.14	NS
Proportion of time spent on exploration	7.29±0.534	8.32±0.617	7.89±0.546	8.67±0.642	NS
Proportion of time spent walking	2.26±0.288	2.36±0.270	1.83±0.229	1.75±0.185	NS

Table 5: Average number and proportion of time spent on various behaviors (% of observation time) by pigs at 8, 10, 12 and 14th weeks.

Behavior	At 75 kg (8th week)	10th week	12th week	14th week	P
Average number of social interaction	9.28±0.494	10.79±0.791	10.06±0.573	10.68±0.662	NS
Average number of aggressions	0.69±0.118^{a}	2.58±0.253^{b}	1.11±0.216^{ac}	1.43±0.260^{c}	<0.0001
Average number of feeder visits	3.43±0.26	3.88±0.32	3.68±0.18	3.75±0.24	NS
Proportion of time spent lying	76.79±1.144^{ab}	79.38±1.343^{a}	75.74±1.123^{b}	72.74±1.028^{c}	0.0012
Proportion of time spent sitting	1.47±0.187^{a}	1.61±0.188^{a}	2.15±0.235^{ab}	2.55±0.283^{b}	0.0032
Proportion of time spent lying in isolation	3.54±0.439^{a}	5.32±0.729^{b}	2.01±0.320^{a}	1.85±0.285^{a}	<0.0001
Lie isolation pro of lying	0.045±0.005^{ab}	0.068±0.009^{b}	0.027±0.005^{a}	0.026±0.004^{a}	<0.0001
Proportion of time spent lying in preferred area	60.06±1.528^{ab}	62.71±1.055^{b}	57.15±1.331^{ac}	53.71±1.375^{c}	0.0213
Proportion of time spent lying in lateral recumbancy	59.28±1.538^{ab}	63.80±1.519^{a}	54.05±1.178^{bc}	51.63±1.643^{c}	<0.0001
Proportion of time spent standing	21.37± 1.15^{ab}	18.46±1.23^{a}	21.74±1.03^{ab}	24.19±1.05^{b}	0.0042
Proportion of time spent on exploration	7.66±0.428^{a}	6.59±0.458^{a}	8.06±0.560a^{b}	9.85±0.726^{b}	0.0009
Proportion of time spent walking	2.09±0.149^{a}	3.01±0.389^{b}	1.53±0.131^{a}	1.56±0.120^{a}	<0.0001

Table 6:Average number and proportion of time spent on various behaviors (% of observation time) by pigs in uniform and varying weight groups.

Behavior	Uniform	Varying	P
Average number of social interaction	10.49±0.486	9.92±0.419	NS
Average number of aggressions	1.53±0.197	1.38±0.155	NS
Average number of feeder visit	3.82±0.20	3.6+0.16	NS
Proportion of time spent lying	75.09±0.894	77.24±0.825	NS
Proportion of time spent sitting	2.18±0.174	1.71±0.156	NS
Proportion of time spent lying in isolation	3.37±0.373	2.98±0.382	NS
Proportion of time spent lying in preferred area	57.08±1.078	59.73±0.942	0.046
Proportion of time spent lying in lateral recumbancy	56.60±1.190	57.78±1.197	NS
Proportion of time spent standing	22.28±0.085	20.59±0.78	NS
Proportion of time spent on exploration	8.83±0.448	7.25±0.356	0.024

Proportion of time spent walking	2.34+0.213	1.75+0.117	0.0215

Proportion of time spent sitting, lying isolated, lying in preferred area, lateral recumbancy and walking were different at various 'k, categories (Table 7). Pigs at k1 spent higher (P<0.05) proportion of time sitting than those at k5. Proportions of time spent on lateral recumbancy and walking were lower (P<0.05) at k1 than at k5. Pigs at k5 spent higher (P<0.05) proportion of time lying isolated than pigs at other 'k' categories. Proportion of time spent lying in preferred area was lower (P<0.05) at k1 when compared to k3, k4 and k5.

Table 7: Average number and proportion of time spent on various behaviors (% of observation time) by pigs at 'k' categories of <0.03 (k1), 0.0301-0.0320 (k2), 0.0321-0.0340 (k3), 0.0341-0.036 (k4) and >0.036 (k6).

Behavior	<0.03	0.0301-0.0320	0.0321-0.0340	0.0341-0.0360	>0.036	P
Average number of non-agonistic social interaction	10.87+0.734	12.16+1.396	9.19+0.607	10.08+1.054	10.00+0.442	NS
Average number of aggressions	2.13+0.432	2.40+0.425	1.46+0.333	1.15+0.291	1.20+0.157	NS
Proportion of time spent lying	72.68+1.309	73.11+2.442	77.32+1.327	74.95+1.328	77.59+0.909	NS
Proportion of time spent sitting	2.67+0.377[a]	2.32+0.465[ab]	1.96+0.314[ab]	2.13+0.356[ab]	1.65+0.143[b]	0.05
Proportion of time spent lying in isolation	1.56+0.348[a]	2.43+0.629[ab]	1.96+0.518[a]	2.15+0.343[a]	4.30+0.430[b]	0.0004
Proportion of time spent lying in preferred area	49.94+1.695[a]	57.60+2.573[ab]	58.03+1.730[b]	57.02+1.658[b]	61.18+0.923[b]	0.0001
Proportion of time spent lying in lateral recumbancy	52.03+2.094[a]	56.01+3.988[ab]	54.59+2.198[ab]	56.10+2.201[ab]	59.66+1.075[b]	0.0232
Proportion of time spent standing	24.29+1.36	24.15+2.39	20.02+1.29	22.55+1.22	20.33+0.86	NS
Proportion of time spent on exploration	9.75+0.992	9.28+1.251	7.81+0.541	8.00+0.817	7.46+0.377	NS
Proportion of time spent walking	1.23+0.129[a]	1.89+0.241[ab]	1.79+0.329[ab]	1.90+0.269[ab]	2.39+0.198[b]	0.0261

There were no recorded abnormal behaviors or vices such as tail biting or ear chewing. The feeding frequencies were also similar among k categories and time periods. However, it was observed that 7 pigs from SA0.64 and 4 pigs from SA0.74 jumped out of their pen into the alleyway during the trial and none from other space allowance treatments.

Mortality

Out of 608 pigs allotted, 19 pigs died and 2 were euthanized during the trial period (before first pull) resulting in a mortality of 3.45 %. Numbers of dead pigs were 7, 2, 6 and 6 respectively for SA0.88, SA0.81, SA0.74 and SA0.64. Based on weight categories, 13 pigs from uniform and 8 pigs from varying groups died during the course of the trial.

Discussion

A lower ADG at lower space allowance per pig (Figure 1) as observed in this study agrees with several previous reports (Heitman,et al., 1961; Jensen, 1973; Ford and Teague, 1978; Randolph *et al.,* 1981; Edmonds *et al*., 1998; Harper and Kornegay, 1983; Kornegay and Notter, 1984;NCR-89 Committee on confinement management of swine, 1993). However, in most of those studies group size has been confounded with space allowance. Studies that have eliminated the problem of confounding space and group size by allometric calculation of space allotment to treatment groups have also indicated the benefit of higher space allowance on daily gain in grow-finishers. In the present study, though the space allowances were based on final 'k' values, results have been analyzed based on both space allowances and 'k' values at different time points. In a trial with four 'k' values (0.024, 0.027, 0.03 and 0.034 with weekly pen adjustment), Edwards *et al*., (1988) reported that increasing space allowance increased live weight gain. Although the present results are in agreement with that of Edwards *et al*., (1988), it differed from that of Edwards *et al*., (1988) in the range of 'k' values and also in that the space allowances were calculated based on anticipated 'k' value at a market weight of 116 kg, resulting in a gradual reduction in 'k' from start to end of the trial. The initial 'k' values were 0.091, 0.084, 0.076 and 0.067 for the space allowances allotted based on final 'k' values of 0.037, 0.034, 0.031 and 0.027 respectively. Gonyou *et al*., (2005) analyzed previously reported data and suggested a critical 'k' value range of 0.0317-0.0348, below which ADG appeared to decrease. Similarly, Gonyou and Stricklin (1998) have reported that decreasing floor area allowance below a 'k' value of 0.030 resulted in 5% reduction of ADG compared to a 'k' value of 0.039. Other studies without confounding of space and group size (Pearce and Paterson, 1993, 'k' 0.048 vs. 0.025; Moser *et al*., 1985, 'k' 0.034, 0.031 and 0.026; Meunier-Salaun *et al*., 1987, 'k' 0.032 vs. 0.047; Matthews *et al*., 2001, 'k' 0.025 vs. 0.035) have also indicated lower ADG when 'k' value was small. Different 'k' values have been suggested to be optimum for maximum gain: 0.04 (NCR committee-89, 1993), 0.029 (McGlone and Newby, 1994), and 0.032- 0.038 (Brumm *et al*., 1996). The present trial indicated that SA0.81 and SA0.88 (0.034k and 0.037k respectively) ensured higher ADG which are comparable to the range of 'k' suggested by Brumm *et al*., (1996). However, ADG corresponding to SA0.74 (0.031k), lower than that suggested by Brumm *et al.,* (1996), was not different from the ADG of higher space allowances in this trial.

Sorting by weight is suggested to minimize dominance related variation in production. However, it has also been reported that it is effective only if resources (such as feed) are limited and easily defendable and therefore grow-finish pigs fed *ad-libitum* may not be benefited from sorting by weight (Gonyou, 2003). A lack of difference in performance among pigs grouped with varying degrees of weight variation has been reported by McGlone *et al*., (1987). This finding also supports present observation though it was based on a 28 day trial. However, unlike in the present study, Tindsley and Lean (1984) and Francis *et al*., (1996) have reported that even-weight groups of pigs had significantly higher live weight gain than mixed-weight groups of pigs.

The increase in ADG at the last week despite a reduction in space (Figure 2) could be associated with the repartitioning effect of ractopamine on nutrients (Watkins *et al*., 1990; Crome *et al*., 1996). Brumm *et al*., (2004) reported a higher ADG for ractopamine-fed pigs in comparison to no ractopamine feeding. Brumm *et al*., (2004) also reported that response to ractopamine feeding was similar in both crowded and uncrowded pigs. However, in the present study, response to ractopamine feeding at different space allowances was not assessed.

Since the 'k'values were fixed for the final anticipated weight of 116 kg, all groups in this study experienced higher 'k'values during early stages of grow-finish period. The reduction in ADG during early stages of growth (despite higher k), commonly referred to as growth lag (Mahan and Lepine, 1991) is not necessarily dependent on space allowance alone. Comparison of ADG at different stages during the grow-finish period (Figure 2) also showed that ADG was lower at early stages of growth and higher at the end of the grow-finish stage. However, the effect of space restriction was evident in the significant difference between ADG levels at calculated 'k' value of <0.03 and 0.034-0.036. A reduction in ADG at a calculated 'k'value of $\leq$0.03 was also evident in the regression analysis (Table 2).

Although, it has been acknowledged that pigs in crowded groups experience space restriction, the point at which it begins is often not clear (Gonyou and Stricklin, 1998). The present study shows that pigs in the lower space allowance of SA0.64 arrived at a space allowance corresponding to 'k' 0.037 in 7 weeks time (Figure 3) whereas pigs in SA0.88 reached this stage only a few days before the end of grow-finish period (Figure 6). Given the relationship between space allowance and ADG, these results explain the lower ADG in SA0.64 compared to the ADG in SA0.81 and SA0.88.

Minimizing variation in the weight of market pigs has great economic advantage (Brumm *et al*., 2002) and variation in performance has been suggested to be an important hidden cost that is difficult to quantify (Payne *et al*., 1999). The finding that pigs allotted to varying weight groups did not differ from pigs in uniform weight group at market in terms of CV% of weight (Table 3) is suggestive of the benefit of higher space allowance in ensuring uniformity in market weight. This finding agrees with that of Tindsley and Lean (1984) that weight range at allocation had no effect on final range of weight though it disagrees with Kornegay *et al*., (1985) who reported a lack of effect of space allowance on variation in piglet body weight.

Pen efficiency indicates the amount of body mass gain per unit area and the maximum utilization of pen space is an important economic variable. Higher pen efficiencies at lower space allowance as observed in this study (Figure 7) has been reported previously (Powell and Brumm, 1992). Lower pen efficiency at earlier stages is due to higher space availability since space allocation was fixed based on market weight. The higher pen efficiency in the last week of grow-finish period (Figure 8) could be associated with ractopamine feeding and its effect on ADG. Time periods represent the actual 'k' available to pigs in the pen. However, the lack of difference in pen efficiency among different space allowances in the last 3 weeks of the grow-finish stage indicated that pen efficiency was not adversely affected by an increase in space, since the ADG was also high at higher space allowances. This suggests that provision of higher space allowance may not have a financial effect.

Studies analyzing the effect of space allowance on injury levels in pigs are limited. An increase in frequency of lesions may indicate inadequate environment (de Koning, 1984) such as limited space. The increase in injury levels at lower space allowances is mediated through an increase in agonistic behaviors at lower space allowances. Decreasing space allowance has been reported to increase agonostic behaviour (Ewbank and Bryant, 1972; Meunier-Salaun *et al*. 1987). A high correlation between observed incidence of play/fight behavior and lesion scores has also been observed (Francis *et al*., 1996). Weng *et al*., (1998) reported that though a reduction in space may inhibit initial aggression, it may increase aggression later on in stable groups. The present result of higher injury scores at lower spaces of SA0.64 and SA0.74 (Figure 9) agrees with these reports. Although overall injury levels decreased with increase in space allowance, an increase in space allowance from SA0.64 to SA0.74 did not result in significant reduction in injury. Higher injury score in the later grow-finish period (Figure 10) is associated with a progressive reduction in available space within the pen. Jensen (1984) has reported that frequency of interactions such as those involving bites increased significantly at lower space allowances. There are two probable reasons for higher injury scores when space is reduced. When space is less, there will be increased competition for resting place causing aggression and injuries. Also, when animals grow in size there may be difficulty for all pigs to simultaneously occupy the feeder though the amount of feeder space remains the same. Competition to gain access to the feeder and maintain it may be a cause for aggression. Even if feeding is *ad-libitum*, social facilitation may motivate pigs to eat simultaneously resulting in competition and aggression. The difference in injury levels of pigs in different barns could be due to the minor variation in the pen fixtures.

Analysis of the effect of time period on cortisol concentration (Figure 11) indicated lower cortisol concentrations at later stages of growth. Increased activity levels have been reported to be associated with changes in corticosteroid concentrations (Davies and Few, 1973; Selye, 1976). Though the activity levels at different stages were not compared in this study, it is likely that pigs were more active during early stages when they were smaller in size and there was more space in all space allowance treatments. Young pigs are reported to spend 40-60% of time resting (Kuipers and Whatson, 1979; Blackshaw, 1981) while pigs of 100 kg body weight may spend up to 87.5% of their time lying Ekkel, *et al*., (2003). Though the time spent lying was lower at later stages of grow-finish period in this study, it was mostly due to lack of space and not due to engagement in other activities. The reduction in activity could have lowered the cortisol level at lower space allowances. This may also explain the higher levels of cortisol when actual space allowance experienced by pigs based on calculated 'k' value was higher though it disagrees with previous reports of elevation in plasma cortisol in space restricted pigs (Warnier and Zayan, 1985, Hemsworth *et al*., 1986; Barnett *et al*., 1992). Basal cortisol concentrations were not elevated by space restriction in studies reported by Pearce and Paterson, (1993) and Meunier-Salaun *et al*., (1987) which agrees with the present result of no difference in cortisol concentrations among pigs in various space allowance treatments.

Pigs involved in this study were in static groups and therefore, postural and locomotion behaviors were also analyzed in addition to social behavior to assess the welfare of pigs in the treatment groups. Pigs in groups require space to occupy their bodies in different postures as well as for postural changes. Additional social space is also needed in groups to exhibit normal behavior and interactions (Baxter, 1984). The finding of higher number of aggressions (Table 4) and higher levels of injuries (Figure 9) in SA0.64 compared to SA0.88 and SA0.81 is in line with the finding that reducing space allowance below pigs' spatial preference can cause behavioral changes indicative of compromised welfare (Pearce and Paterson, 1993). However, an increase in space allowance from SA0.64 to SA0.74 did not result in significant benefit. Randolph *et al*., (1981) have also reported that there were only less number of attacks, threats and displacements when floor space was more. The present findings are also supported by other previous studies wherein increased agonistic behavior has been reported to be associated with decreasing space allowance (Ewbank and Bryant, 1972). However, a higher number of aggressions and higher cortisol concentration observed at 10^{th} week compared to other time points (Table 5) could not be explained.

A higher proportion of time spent sitting when space availability was less (Table 4 and Table 7) could be due to increased body mass making it difficult to get involved in activities in limited space, and is suggested to be a coping mechanism of pigs to an unsuitable environment (Wood-gush *et al*., 1983) and thus may be indicative of reduced welfare (Pearce and Paterson, 1993). Based on study in group housed sows, Weng *et al*., (1998) have reported that the time spent sitting was higher at lower space allowance of $2m^2$/sow than 3.6 or $4.8m^2$/sow. Pearce and Paterson (1993) have also reported more time spent sitting in crowded than in uncrowded groups.

Baxter (1984) has reported that pigs in groups prefer to lie down close to the side walls or at the corners rather than at the center of the pen or near the feeder to avoid disturbance from other pigs. Lack of space appeared to influence the ability of pigs to occupy preferred resting places. In the present study also, pigs in the lower space allowance treatments were only able to spend a lesser proportion of time lying in the preferred areas (Table 4 and Table 7). However, an increase in space allowance from SA0.64 to SA0.74 did not result in significant increase in proportion of time spent lying in preferred areas. Pigs in the varying weight group were able to spend more time lying in preferred locations which appeared to be due to a clear dominance hierarchy in that group compared to the uniform weight group.

Lack of space with pigs growing in size could have also reduced the available space and opportunities for activities and proportion of time spent lying (Table 4). Physical dimensions of the animal and its behavior are the primary determinants of space. For lateral and sternal recumbencies pigs require spaces corresponding to 'k' values of 0.047 and 0.019 respectively (Petherick and Baxter, 1981). Full recumbency is reported to be the most preferred lying position (Ekkel et al., 2003). Huynh et al., (2005) observed that more than 70% of pigs lie on their lateral side. Increased body mass and consequent reduction in space could have resulted in a higher proportion of time spent lying in sternal recumbancy than in lateral recumbency towards later stages of grow-finish period (Table 5 and Table 7). The space available in terms of 'k' value at the last 4 weeks was clearly lower than that suggested by Petherick and Baxter (1981) required for lateral recumbency. Muener-Salaun *et al*., (1987) has reported that sternum resting was more frequent than resting the side when body weight reached 60-70 kg. A higher proportion of time spent on lateral recumbency in uncrowded groups of pigs has also been reported by Pearce and Paterson (1993). Lack of space, especially at later stages could have been a reason for the lower proportion of time spent lying isolated in lower space allowance treatments (Table 4) and at later stages of grow-finish period (Table 5 and Table 7). It has been reported that when provided with a reasonable amount of space, pigs prefer to lie down with their limbs extended and with only some contact with pen mates (Ekkel *et al*., 2003). The lower proportion of time spent lying, irrespective of location and lying posture at later stages could also be due to lack of space at that stage. Pigs exhibit long periods of rest or inactivity (Hafez and Signoret 1969, Ruckbusch, 1972, Fraser and Broom, 1990, Tober, 1996) and therefore the reduction in proportion of time spent lying, due to the physical inability to do so, can be a welfare concern.

Bryant and Ewbank (1974) and Heitman *et al*., (1961) have observed that increased stocking rate increases the amount of time spent standing or walking. This increase in time spent standing could have resulted in higher proportion of time spent on exploration, as observed in this study (Table 4), because it is more likely for pigs to explore their environment when they are standing or walking rather than when they are lying down. This also explains the higher proportion of time spent on exploration in the uniform weight group where the proportion of time spent walking and standing is higher than that in varying group (Table 6). However, this finding is not in accordance with that of Weng *et al*., (1998), who found that frequency of rooting, an important exploratory behavior, was lower at low space allowance. Similarly, Pearce and Paterson (1993) observed higher frequency of explorative behavior in uncroweded than in crowded groups of pigs. Exploratory behavior is viewed as an important component of pig welfare (Wood-Gush and Vestergaard 1993). However an increase in time spent on exploratory behavior, observed in this study may not be indicative of better welfare of pigs. This is because the pigs in lower space allowance treatment had only less space and were spending more time standing or walking, thus increasing the chance of exploration. Also, the behavior measurements were started only in the later stages of the trial when the available space in the pen had become less due to the growth of the pigs and it is not clear whether the proportion of time spent on exploration was similar during the early stages when the space availability was more with the pigs being small in size. Further, exploration alone is not an adequate indicator of welfare. It has been reported that an increased stocking rate may decrease the amount of time spent sleeping and resting (Heitman *et al*., 1961) which in turn may increase the time spent walking or standing and consequently on exploration, as observed at later stages in the present study (Table 5).

The overall mortality rate observed in this study was not high. Gastro-intestinal problems and rectal prolapse were the major removal reasons. The numbers of deaths in different k-categories were not sufficient to permit a statistical comparison.

Lay interpretation

There was significant difference in ADG among pigs in various space allowance treatment groups, with lower ADG at SA0.64 compared to that at SA0.81 and SA0.88. Barring the initial period of growth lag, a difference in ADG between higher and lower ‘k’ values experienced was also evident. Pigs in the lowest space allowance treatment had to spend the longest period of time below a 0.037k with respect to ADG in the trial whereas pigs in the highest space allowance treatment had to spend only a few days under that space allowance. Though the performance and welfare of pigs in SA0.81 and SA0.88 were comparable, pigs in SA0.081 were compromised in space earlier than those in SA0.88 with respect to ADG suggesting that SA0.88 would be the ideal space allowance to be provided for a market weight of 116 kg. Comparing pen efficiency among all the space allowance treatments indicated that increasing space allowance may not necessarily take away economic benefit and that it rather minimizes variation in market weight. In addition, the results also suggested welfare benefits in terms of postural behavior, lower injuries and aggression associated with higher space allowance. Allotting grow-finishers according to uniformity or variation in body weight may not provide any differential benefit in ADG or overall welfare. Although a beneficial effect was observed in terms of ADG, injury scores, aggression and lying behavior by increasing space allowance, the difference in results by an increase in space allowance from 0.64 m^2/pig to 0.74 m^2/pig was not significant. Similarly reducing space allowance from 0.81 to 0.74 m^2/pig also did not cause further disadvantages in terms of ADG, lying behavior, injuries and aggression. It may be concluded that in fully slatted floor, space allotted considering the final market weight of barrows, corresponding to ‘k’ values of 0.037 (0.88 m^2/pig) and 0.034 (0.81 m^2/pig) appear to be acceptable when compared to a ‘k’ value of 0.27 in production and welfare terms. A ‘k’ value of 0.031 (0.74 m^2/pig) was intermediate to higher (0.037 and 0.34) and lower (0.027) ‘k’ values.

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