The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK

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Space needs of broilers

EAM Bokkers*†, IJM de Boer† and P Koene‡

† Animal Production Systems Group, Wageningen Institute of Animal Sciences, Wageningen University, PO Box 338, 6700 AH, Wageningen, The Netherlands
‡ Livestock Research, Wageningen University and Research Centre, PO Box 65, 8200 AH, Wageningen, The Netherlands
* Contact for correspondence and requests for reprints: eddie.bokkers@wur.nl

Abstract

There is continuing debate about the space needs and requirements of broiler chickens, The aims of this study were to measure the amount of floor area a six-week-old broiler occupies for different behaviours and to use the obtained results in two models to estimate the number of birds that can be kept per m² in large flocks simulating different levels of behavioural synchronisation. Photographs were taken of overhead projections of broilers (2.468 kg on average) kept in floor pens of 1 m² with either eight (low density) or 16 birds (high density) per pen. Individual body space was measured from these photographs for seven behaviours. Posture and density affected body space of the behaviours idle, drinking, and ground pecking. The first model, computing space needed per bird performing a behaviour in relation to flock size, showed that 15.3–15.7 birds m⁻² (37.8–38.7 kg m⁻²) can be housed maximally, based on low density measurements and 18.5–19.4 birds m⁻² (45.7–47.9 kg m⁻²) based on high density measurements. The second model, computing stocking density based on synchronisation of behaviour and body space, showed that 13.7–15.9 birds m⁻² (33.8–39.2 kg m⁻²) can be housed maximally based on low density measurements and 15.4–18.6 birds m⁻² (38.0–45.9 kg m⁻²) based on high density measurements. Results based on high density measurements implied that birds are compressed. Given the restrictions of a limited number of behaviours and no inclusion of movement and social interactions in the models of this study, stocking density in large flocks should not exceed 16 birds m⁻² (39.4 kg) because that would lead to compression of birds which will suppress opportunities for behavioural expression and therefore impair welfare.

Keywords: *animal welfare, behaviour, broiler chicken, modelling, space occupation, synchronisation*

Introduction

Space allowance is often mentioned as a cause of welfare problems in broiler chicken production (Brambell 1965; EU 2000; Hall 2001). Recommendation guidelines and current commercial practice concerning stocking densities vary greatly (Estevez 2007). In Europe, fast growing broilers are generally kept in a large flock (10.000–30,000 birds per house) with a stocking density of 18 to 22 birds m⁻². High stocking density in combination with increasing bodyweight during the fattening period of approximately six weeks is related to issues such as reduced litter quality, heat stress, and reduced health which are also recognised as relevant for broiler welfare (Dawkins *et al* 2004; Bessei 2006; Febrer *et al* 2006; Estevez 2007; Gouveia *et al* 2009; Villagrá *et al* 2009). For a long time, the number of birds per square meter was determined by the farmer or by companies in the poultry industry and based mainly on economic gains as regulations for space requirement in broilers did and do not exist in most countries.

In June 2010, the European Union (EU) laid down space requirements for broilers in a directive (Directive 2007/43/EC) establishing a maximum stocking density of 33 kg m² (EU 2007). A derogation of this rule can be granted by member states if, for example, extra measures are taken that are in favour of ambient conditions at animal level. In such cases a maximum stocking density of 39 kg m⁻² is allowed (EU 2007). A further increase in stocking density of 3 kg m⁻² is allowed when extra criteria are met (EU 2007). These include monitoring by a competent authority, good management practices, a cumulative daily mortality rate below 1 (± 0.06)% multiplied by the slaughter age of the flock in days of the last seven flocks (EU 2007). According to these rules, the number of birds that may be kept per square meter is, therefore, dependant on slaughter weight. Commonly, this means that, for birds of average slaughter weight (2.0 to 2.5 kg per bird), a stocking density of 17 to 21 birds per square meter is permitted, with 42 kg m⁻² the upper limit in the regulations. The question is whether this new EU Directive ignores the space needs of broilers, because under certain circumstances it permits stocking densities above those recommended by scientists, eg Appleby (2004) who suggested that 34 kg m⁻² unacceptably

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restricts freedom of movement, Estevez (2007) who suggested a density of between 34–38 kg m^{-2}, and the Scientific Committee of the EU (2000) suggesting that stocking density must be equal or below 25 kg m^{-2}.

The space an individual animal needs can be separated into three factors (Petherick 1983). First, body space which is the static space needed for the body itself. Second, behavioural space which is the space an animal needs to express behaviour in an individual context. Third, social space — the space needed to allow animals to interact or avoid interactions with conspecifics. These three factors were combined in a model by Petherick (1983) to determine the total space per animal that is needed. When exploring the space needs of a flock, individual space measurement might be useful. It is important, however, to consider that animals living in a social group tend to synchronise their behaviour due to social facilitation (Rook & Penning 1991).

Several studies have been conducted to measure body space and behavioural space in laying hens, pigs, and cattle. The basic method is to take overhead photographs and calculate the occupied area (Bogner *et al* 1979; Freeman 1983; Dawkins & Hardie 1989; Hurnik & Lewis 1991a; Ellerbrock & Knierim 2002). Another method to determine body space is to derive it from bodyweight or body dimensions (Esmay 1969; Klatt *et al* 1975; Petherick & Baxter 1981; Petherick 1983; Hurnik & Lewis 1991a; Hurnik & Lewis 1991b; Ekkel *et al* 2003; Petherick & Phillips 2009), but this method cannot be used to distinguish between behaviours. Nevertheless, the use of digital images proved to be useful in estimating bodyweight in broilers (De Wet *et al* 2003).

The aim of this study was to investigate how individual body space measurements for different behaviours can be used to model the number of broilers that can be kept per square meter in large flocks taking different levels of behavioural synchronisation into consideration.

Materials and methods

The established principles of laboratory animal use and care were followed, as well as the Dutch law on animal experiments, which complies with the ETS123 (Council of Europe 1985) and the 86/609/EEC Directive. The Wageningen University Committee on Animal Care and Use approved this experiment.

Determination of individual space requirements

Fast growing broilers (48 Ross 308 birds and 48 Cobb 500 birds) were housed in eight floor pens with either 8 or 16 birds per pen (one breed per pen; half male, half female) from 1 to 42 days of age. Floor pens measured 1.25 × 0.80 m (length × width) and were covered with wood shavings. In the pens with eight individuals, each bird had 1,250 cm^2 pen surface (ie 8 m^{-2}), which was expected to be enough space to perform behaviour without being limited by space (low density). In the pens with 16 individuals, each bird had 625 cm^2 pen area (ie 16 birds m^{-2}), which was expected to restrict behavioural expression (high density). In every pen, each bird was coloured on the back of the head and back with a grease pencil (blue, green, red, and purple) for individual recognition. Feed was *ad libitum*, consisting of a standard commercial diet (Research Diet Services BV, Wijk bij Duurstede, The Netherlands) provided in an open-through feeder with a grid that was placed in front of the pen (0.8 m-wide). Drinking water was *ad libitum*, provided via four drinking nipples with a cup beneath located along one side of the pen. Pen space available for the birds was not reduced by the feeding or drinking system. The lighting schedule was 16 h light (20 lux): 8 h darkness to give the birds a natural day:night rhythm. Temperature was maintained at 32 (± 1)°C at the beginning of the experiment, and gradually decreased by 1° every three days to a constant temperature of 21 (± 1)°C. Each bird was weighed weekly.

Two adjacent pens were recorded at the same time from above with a colour camera (Panasonic WV-CP460, Panasonic Corporation, Japan) (2.3 m above floor level). All four cameras were connected to a video recorder (Panasonic AG-6124, Panasonic Corporation, Japan) via a video switch. We recorded 4-min of each pen successively every 30 min during the lighting period, providing 32 video samples of 4 min per pen per day. Recordings were made during four consecutive days when the birds were six-weeks old. The age of six weeks was taken because broilers tend to be slaughtered around this age. These video samples were played and when dustbathing, walking, stretching, idle, drinking, ground pecking, and preening were observed (see Bokkers & Koene 2003 for behavioural definitions), a screenshot was taken. In this way, we aimed for at least eight independent screenshots per behaviour, posture, gender, and density. Of each 4-min video sample only one screenshot was taken. This screenshot was digitised (TV player 6.2, ATI Technologies Inc, Markham, Canada) and saved as a digital photograph with a title that included relevant information about, eg individual, pen, behaviour, and posture.

The amount of floor area the body occupied was measured using Photoshop® (version 5.5, Adobe® Systems Inc, USA). With the programme tool *lasso* a line was drawn exactly around the bird. A histogram in the menu *image* gave the number of pixels within the selected area. The number of pixels within the total pen area was measured also. Knowing the total pen area in cm^2, we converted the occupied floor area expressed in pixels to occupied floor area in square cm, which is the body space measurement.

Taking overhead screen shots can give some distortion to the edges of the pictures, but due to the high position of the camera and the fact that a broiler has more or less the shape of a ball the small change in angle to the edges therefore was assumed to have a minimal effect on the measured body space for the different behaviours.

Space occupation at flock level — model 1

Based on the work of Petherick (1983), we defined a model which describes the total space needed per bird performing a behaviour in relation to the total number of birds in a flock:

$$S = A_0 + (A_1 - A_0)e^{-k(n-1)}$$

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S = total space (cm^2) required per bird, n = number of birds in the flock; A_0 = body space for 'sitting idle' (cm^2) averaged over gender. Sitting is the most observed posture in broilers. It is performed more than 70% at daytime in broilers (Bokkers & Koene 2003) but will obviously be close to 100% during dark periods. Amount of space, therefore, must allow at least all birds to sit undisturbed at the same time. A_1 = body space (cm^2) for any other behaviour averaged over gender; k = fraction (between 0 and 1) of current area required per animal that is shared by adding an extra individual. High values for k, therefore, relate to a low level of synchronisation, whereas low values for k relate to high values of synchronisation.

Total space occupied per bird was computed by first determining the space occupied to perform the behaviour sitting idle (A_0). Second, the additional space occupied for other behaviour was computed ($A_1 - A_0$). Third, the additional space occupied per bird was taken to decrease exponentially as the number of birds increases (the exponential part is based on the model of Petherick [1983]). Factor k, which reflects a certain synchronisation of A_1 affects the strength of exponential decrease. When k is equal to 0, there is a maximal synchronisation for the behaviour A_1, meaning additional space needed for A_1 is as much as the number of birds times the additional space plus the space occupied for A_0 (sitting idle). When k is equal to 1 there is no synchronisation at all for the behaviour A_1 and space occupied is totally determined by A_0.

Data obtained from the individual body space measurements were used to run this model.

Space occupation at flock level — model 2

In the previous model, the different values for factor k cannot be validated for different synchronisation levels. In addition, the model is applicable for only two behaviours and cannot deal with a larger number of behaviours and their synchronisation in a large flock. Therefore, we built another model based on the work of Rook and Penning (1991). This model gives the density of broilers dependent on the synchronisation of one behaviour and body space per behaviour.

$D_i = n / \sum^{b}_{i=1} n_1 \times A_i$

D_i = density of ith behaviour (birds per m^2); n_i = number of birds in the flock performing i^{th} behaviour; A_i = body space for i^{th} behaviour (in m^2); b = total number of behaviours; n = total number of birds.

To run this model, body space measurements for each of the seven behaviours were averaged over posture and gender. In accordance with the first model, the assumed flock size was 20,000 birds. Next, we assumed that birds not performing the target behaviour evenly distributed the other six behaviours. In this way, the synchronisation per behaviour, ie the percentage of animals performing that behaviour, was computed. Finally, the maximum number of birds that could occupy one m^2 (maximum density) was computed based on the body space measurements in the low and high density situation.

Statistical analysis

In all cases where more than one body space measurement of an individual bird performing a particular behaviour in a particular posture was included in the database, the average of these body space measurements was taken before the actual statistical analysis. Body space data met assumptions of normality. Analysis of variances was applied to examine if body space measurements were affected by breed (Ross vs Cobb), gender (male vs female), posture (sit vs stand), density (high vs low) nested within pen, and the interaction between gender and density. This analysis was performed with and without bodyweight as co-variable. Breed was removed from the final model because no significant breed effects were found. Slopes of the linear relation between bodyweight and body space of each behaviour were determined and tested for a density effect with an analysis of variance. Data were analysed using SAS software package (SAS Institute Inc, Cary, USA, version 9.1.3, 2002–2003).

Results

Individual body-space measurements

In Table 1, body space measurements are shown per behaviour, posture, density, gender. It can be seen that we did not succeed in collecting at least eight screenshots for all behaviours, per posture, and gender.

Males had a higher bodyweight than females at six weeks of age (2,674.4 [± 31.0] vs 2,261.9 [± 23.6] g; $F_{1,93} = 115.22$, $P < 0.001$). Except for dustbathing, body space of females was significantly smaller than body space of males (in all cases, $P < 0.05$). However, when bodyweight was included as co-variable in the analysis of variance, only for the behaviour idle (LSmean [± SEM]: male 615.6 [± 10.6], female 575.3 [± 12.7]) g a gender effect was found (Table 2). No interaction effect was found between gender and density for any of the behaviours. Body spaces for idle, drinking, ground pecking and preening were significantly smaller for birds performing this in a sitting posture than in a standing posture. Figure 1 demonstrates that when birds were idle, stretching, drinking or preening they occupied less space when sitting than standing, but when ground pecking the reverse was true. Body spaces for these behaviours were also significantly smaller for the high density than for the low density situation. Figure 2 demonstrates the effect of density on body-space measurements. No significant effect of posture was found for stretching and no significant effect of density was found for stretching, dustbathing, and walking (Table 2).

Analysing the slopes of the linear relation between bodyweight and body space of the different behaviours in the two densities, it was found that slopes were significantly higher for the low density (2.78 [± 0.29]) than for the high density (1.64 [± 0.28]; $F_{1,20} = 7.64$, $P < 0.05$).

Space occupation at flock level — model 1

The mean body space over gender for sitting idle was set as A_0, which was 636 cm^2 for the low density situation, and 514 cm^2 for the high density situation. Furthermore, body

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Table 1 Body space measured in female and male broilers in standing and sitting body posture kept at a stocking density of 8 (low density) and 16 birds m^{-2} (high density).

Behaviour	Posture	Body space (± SEM) (cm^2)			
		Low density		High density	
		Male (n)	Female (n)	Male (n)	Female (n)
Idle	Stand	687.3 (± 31.7) (6)	589.5 (± 14.5) (9)	628.4 (± 18.2) (10)	525.3 (± 18.9) (5)
	Sit	667.2 (± 16.5) (14)	605.1 (± 12.2) (12)	541.3 (± 11.8) (9)	487.4 (± 19.9) (7)
Stretching	Stand	814.0 (± 15.0) (11)	718.4 (± 22.7) (9)	733.6 (± 27.2) (9)	680.3 (± 33.7) (6)
	Sit	671.8 (± 17.8) (9)	603.8 (± 7.0) (3)	601.5 (± 68.4) (2)	549.7 (±14.7) (4)
Drinking	Stand	687.0 (± 21.8) (9)	597.6 (± 12.9) (8)	584.8 (± 21.4) (8)	567.3 (± 9.2) (10)
	Sit	659.3 (± 27.0) (7)	571.0 (± 10.8) (6)	557.3 (± 16.6) (7)	509.7 (± 19.4) (6)
Ground pecking	Stand	653.8 (± 19.6) (6)	564.9 (± 20.0) (7)	548.8 (± 36.9) (6)	495.4 (± 20.5) (3)
	Sit	698.0 (± 17.4) (9)	628.1 (± 15.5) (7)	546.7 (± 21.0) (8)	555.0 (± 16.8) (3)
Preening	Stand	703.6 (± 15.5) (5)	632.5 (± 16.7) (10)	613.2 (± 17.9) (9)	601.9 (± 19.9) (6)
	Sit	657.4 (± 13.8) (9)	613.8 (± 22.3) (7)	588.6 (± 30.9) (8)	505.0 (± 18.6) (4)
Dustbathing	Sit	762.4 (± 14.8) (4)	694.0 (± 42.9) (3)	665.2 (1)	630.0 (1)
Walking	Stand	681.7 (± 22.2) (10)	614.6 (± 17.9 (5)	623.2 (± 33.0) (6)	583.5 (± 11.2) (8)

Table 2 Effect of gender, posture, and density controlled for bodyweight of seven different behaviours in broilers.

Behaviour	N	Gender		Posture		Density	
		F-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Idle	72	4.26	0.043	4.70	0.034	18.65	0.005
Stretching	40	1.11	0.302	0.57	0.457	3.24	0.122
Drinking	60	1.14	0.291	6.85	0.012	9.34	0.022
Ground pecking	49	0.24	0.630	8.04	0.007	34.20	0.001
Preening	58	0.39	0.536	7.57	0.009	22.30	0.003
Dustbathing	9	NE*		NA**		53.28	0.087
Walking	29	0.36	0.554	NA**		0.18	0.684

* NE: not estimable; ** NA: not applicable.

space for stand stretching was the behaviour with largest measured body space and therefore covered all other measured body spaces of the different studied behaviours. Stand stretching was set as A_1. The mean of stand stretching over gender was 763 cm^2 for the low density situation and 707 cm^2 for the high density situation.

Figure 3 shows the space a six-week old broiler occupied to perform stand stretching with 1 to 20,000 conspecifics in the flock. Estimations have been computed with different levels of behavioural synchronisation, determined by the factor *k*.

Similar estimations have been conducted based on measurements of the high density situation (Figure 4). In both figures it can be seen that only with a very high synchronisation level (a low value for *k*) of stand stretching more space (ie 653 cm^2 per bird) is occupied than for only sitting idle (636 cm^2 per bird). When all birds perform sitting idle at the same moment 15.7 and 19.4 birds m^{-2} can be kept in the low and the high density situation according to the model calculations. This equates to 38.7 kg m^{-2} in the low density situation and 47.9 kg m^{-2} in the high when the average bird weight at six weeks of age (2,468 g) of the current experiment is used for this calculation. When virtually all birds perform stand stretching the maximum number of birds that can be kept is 15.3 m^{-2} in the low density situation and 18.5 m^{-2} in the high. These results corresponded to 37.8 and 45.7 kg m^{-2} again using the average bodyweight of the current experiment for the calculation.

Space occupation at flock level — model 2

The consequences of synchronisation of behaviour for the number of birds that can be kept per m^2 are shown in Figures 5 and 6. Figures are based on the body-space measurements of the low and high density situation. When

Figure 1

Body space for different behaviours (LSmeans [± SEM]) in standing and sitting posture.

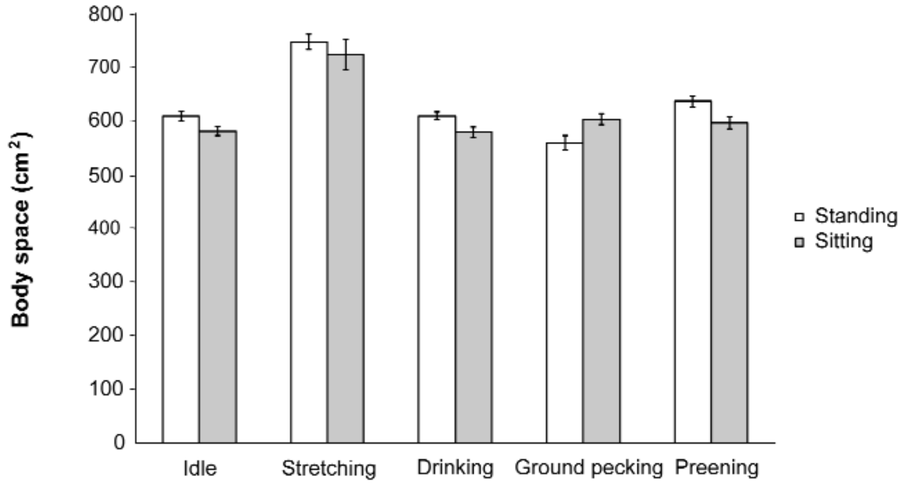

Figure 2

Body space for different behaviours (LSmeans [± SEM]) in low and high density conditions (dustbathing is not shown because it was not estimable).

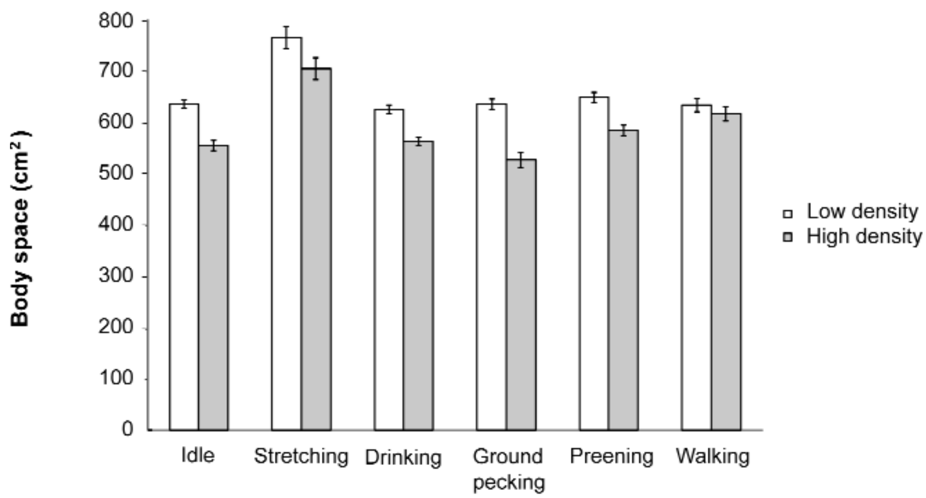

Figure 3

Space occupied per animal for groups of 1 to 20,000 six-week old broilers modelled for different levels of behavioural synchronisation based on body-space measurements in a low density situation. This figure is based on sitting idle (setting a minimum limit of 636 cm²) and stand stretching (setting a maximum limit of 763 cm²). The lower *k* the higher is the synchronicity in the flock.

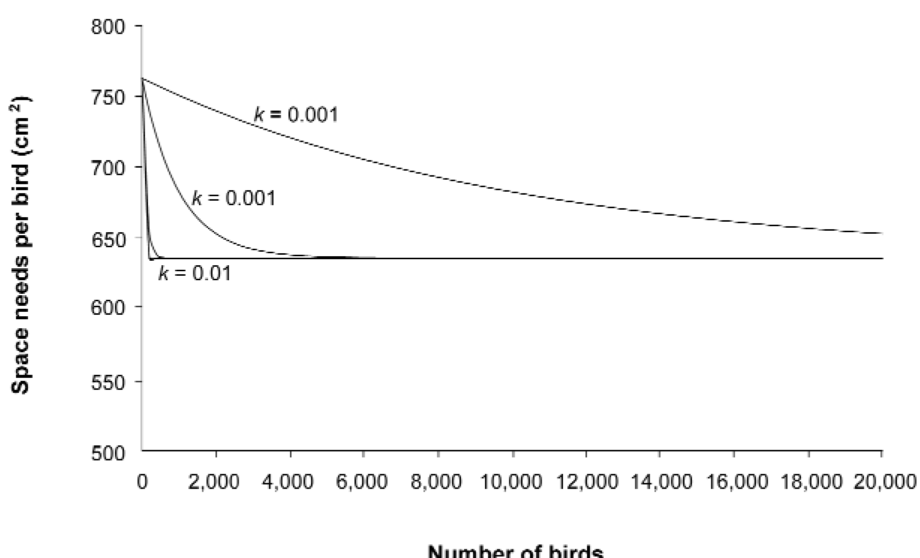

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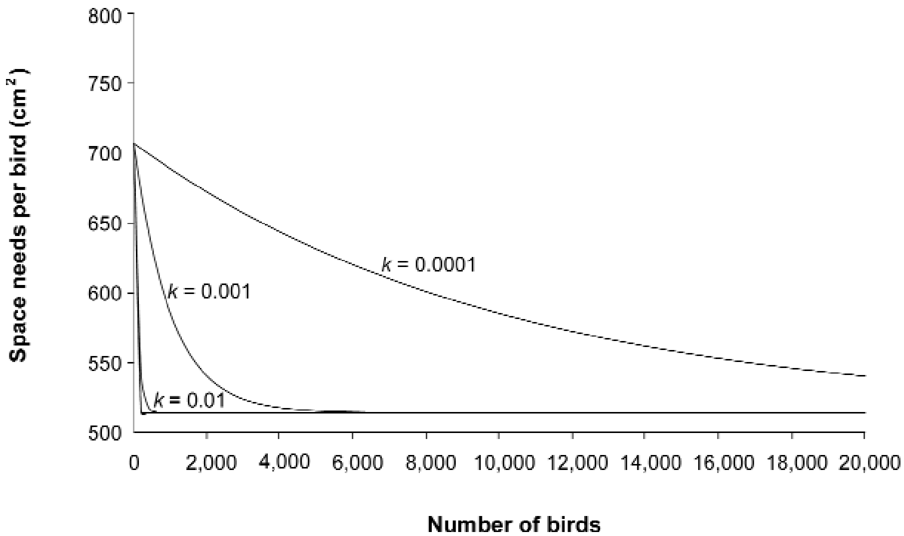
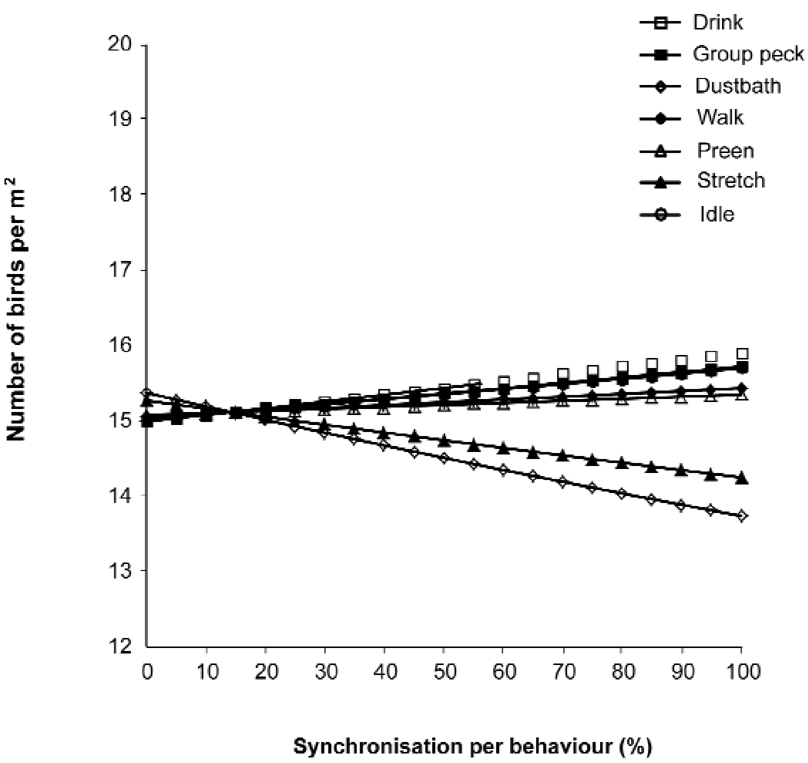
Figure 4



Space occupied per animal for groups of 1 to 20,000 six-week old broilers modelled for different levels of behavioural synchronisation based on body-space measurements in a high density situation. This figure is based on sitting idle (setting a minimum limit of 514 cm^2) and stand stretching (setting a maximum limit of 707 cm^2). The lower *k* the higher is the synchronicity in the flock.

Figure 5



The relationship between stocking density (birds m^{-2}) and synchronisation of different behaviours based on body-space measurements of broilers kept at 8 birds m^{-2}.

broilers are highly synchronised the maximum density of broilers based on the low density situation body-space measurements ranged from 13.7 birds m^{-2} for dustbathing to 15.9 birds m^{-2} for drinking (Figure 5). With an average weight of 2,468 g per bird this means 33.8–39.2 kg m^{-2}. Based on the high density body-space measurements, the maximum density of highly synchronised birds ranged from 15.4 birds m^{-2} for dustbathing to 18.6 birds m^{-2} for ground pecking (ie 38.0 to 45.9 kg m^{-2}) (Figure 6). Obviously, when synchronisation of a behaviour is lower than 100% the maximum density changes accordingly. This change has a turning point at 14.3% synchronisation (due to the seven behaviours). At this turning point, no synchronisation takes place other than by chance, which equals to 15 birds m^{-2}

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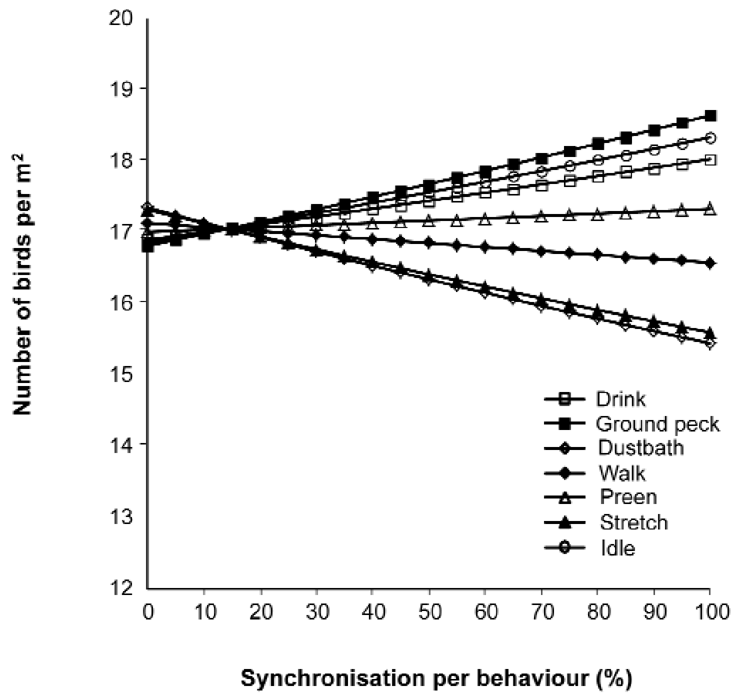
Figure 6

The relationship between stocking density (birds m^2) and synchronisation of different behaviours based on body space measurements of broilers kept at 16 birds m^{-2}.



(low density) to 17 birds m^{-2} (high density) assuming 20,000 birds in the flock. These results corresponded to 37.0 and 42.0 kg m^{-2} based on the average weight of 2,468 g per bird in the current experiment.

Discussion

This study showed that basic measurements of body space and modelling can be helpful gaining insight into space needs at flock level and numbers of birds that can be housed maximally per square meter. We measured body space of seven behaviours and found that stand ground pecking occupied the least space and stand stretching occupied the most. Posture (stand vs sitting) affected body-space occupation for idle, drinking, ground pecking and preening, but not for stretching. Except for the behaviour idle, gender effects could be attributed to bodyweight differences.

Keeping birds in a relatively high stocking density resulted in — not always significant — lower body space measurements than when birds were kept in a low stocking density. This might be an indication that birds were compressed by each other in terms of their body surface, most probably due to feather and soft tissue compression. Such a compression of birds was confirmed by the difference in slopes of the relationship between bodyweight and occupied area of the different behaviours in the two densities. In a high density situation, birds with a certain bodyweight occupied less area than birds with a similar bodyweight in a low density situation. This illustrates heavier birds occupied more space but also, due to the high density, birds do not have required space. Additionally, birds in a high density situation might express behaviour to a lesser extent because birds do have less space. A lower behavioural expression might result in lower body space measurements.

As mentioned previously, not all differences between densities were significant. For dustbathing, the low number of observations probably meant that body space only tended to be higher in low density. For walking, it could be expected that density did not have much effect because during the act of walking there is little to no contact with conspecifics and therefore no compression will take place. For stretching, it is less clear why no difference was found between low and high density. The variation of these measurements is high compared to the other body-space measurements. Perhaps, independently of density, stretching was not always performed to a maximal degree in the observations upon which we based our body-space measurements.

These basic body-space measurements lead to the conclusion that whenever birds are kept at more than 15.7 birds m^{-2}, which is the number of birds that can be kept based on measurements on sitting idle, compression will happen. This is because: i) complete synchronisation is unlikely in large commercial flocks, not even for the behaviour 'sitting idle' which is generally the most frequently observed behaviour in broiler studies; ii) most behaviours take more body space than is needed for sitting idle; iii) for most other behaviours than sitting idle body movements are needed and therefore additional space is needed to be able to perform the behaviour. In lower stocking densities compression may still be unavoidable but to a lesser extent.

This result of 15.7 birds m^{-2} (38.7 kg m^{-2}) approaches the final conclusion in a review of Estevez (2007) about stocking density for broilers which states:

> science consistently indicates that the health and welfare of broilers can be achieved at a range of densities (rather than at a single density) between 34 to 38 kg/m.

This corresponds to 13.8 to 15.4 birds m^{-2} when taking the average bodyweight of this experiment (2,468 kg per bird).

Both results, however, are above the norms as described in the EU Directive concerning broilers (EU 2007). That regulation states that birds may be kept with a maximum of 33 kg m^{-2}. The derogation of the EU regulation (39–42 kg m^{-2}), however, permits stocking densities at levels that our results suggest may cause problems, and higher than those recommended by Estevez (2007).

Although the first model could only model the body space of two behaviours, it showed clearly the effect of group size and synchronisation of a behaviour other than sitting on space needs. The simulations showed that the larger the group the higher the synchronisation must be to have an effect on space need. Space needs of a large group are therefore different than for a small group. The simulations also showed the higher synchronisation of A_1 the more additional space to the space for sitting idle (A_0) is needed. Obviously, the different input for the model of low and high density body-space measurements affected the final result. But, since compression takes place in the high density situation, the low density situation should be taken as a criterion. The weakness of the first model is that there is no biological validation for factor k. Only for the extremes 0 (maximum synchronisation) and 1 (no synchronisation) is it clear what the situation would be in practice. Between 0 and 1, however, it cannot be related to, for example, a percentage of synchronisation. This was different in the second model.

The simulations of the second model showed the effects of different percentages of synchronisation for one behaviour while assuming that the other six behaviours were performed equally distributed. This model showed that the number of birds per square meter depended on the behaviour that was synchronised in the model, and on the input of the different body-space measurements of the low and high density situations. When there was no synchronisation at all for one of the seven behaviours, 15 (low density) or 17 (high density) birds per square meter can be housed. In the high density situation, it implied that birds are compressed. When one behaviour was synchronised more than randomly, the number of birds per square meter that can be housed is dependent on the nature of the behaviour selected.

Our models considered a limited number of behaviours. Our method worked well for relatively static behavioural elements, such as sitting idle and standing idle. Obviously, most behaviours include a certain degree of movement and it can be expected that more space is needed when movement is involved. The true space requirement, therefore, is larger than calculated from overhead projections which capture only one moment of time in the course of an activity (Keeling 1995). Animals can, however, use parts of the total space available at different times (time-sharing) (Petherick 1983). To a certain extent, it reduces the body space per animal when the number of animals per area is increased as shown in Figures 3 and 4. Although body space for walking was measured, we did not measure the actual space needed for walking. Walking from one position to another implies that the first position is free and can be used by another bird. According to computer simulations, Stricklin *et al* (1995) suggested that the degree of freedom of movement per animal remains relatively constant across increasing group sizes when group size is large. Nevertheless, the average distance travelled by individual birds in an experimental setting increased by 20% when space increased from 660 to 1,320 cm^2 per bird (Lewis & Hurnik 1990). This was confirmed by Mallapur *et al* (2009) and Leone *et al* (2010) who found that space use and moving through space was affected more by enclosure size than group size.

Both behavioural space and social space requirements vary almost from minute-to-minute (Keeling 1995). In the model of Petherick (1983), space for social behaviour is increasing exponentially when the number of animals is increasing. Obviously, the required space for social behaviour will not increase endlessly because there will be a point that the number of animals will become so large that it will be impossible to interact with all group members. We did not collect data on social space needed for different behaviours. Social space, therefore, was not included in the models we used.

Broilers have the motivation to be active but the barren environment and physical limitations inhibit activity (Bokkers & Koene 2004; Bokkers *et al* 2007). Providing a large amount of space is not sufficient to stimulate activity (Stricklin *et al* 1995; Arnould & Faure 2003) but a rich environment can stimulate activity (Kells *et al* 2001; Bizeray *et al* 2002; Shields *et al* 2005). In addition, it is important to realise that broilers do not use their space evenly; they tend to stay close to the walls (Newberry & Hall 1990; Cornetto & Estevez 2001). Fewer disturbances in that area and staying close to the location of food and water might be motivations for the birds (Arnould & Faure 2003; Collins & Sumpter 2007). This has consequences for the behavioural opportunities for the birds. Huddling may restrict those birds that lie in the middle of a group. They may be unable to stand up and walk away or perform any behaviour other than sitting or standing.

The expression of stocking density as kg per square meter, disregards the individual animal with its own behavioural expressions and needs. A regulation based on kg per square meter may lead to a high number of birds per square meter when the birds are young and have a low bodyweight. This results in a decrease of available space per bird which can be detrimental to their behavioural and physical ontogeny and therefore for their welfare. Laying down a maximum number of birds per square meter in a regulation can assure an adequate amount of space during the first weeks of life.

However, birds grow and become larger with age. A prescribed space based on number of birds per square meter therefore may turn out negatively for the birds. In the latter case, a maximum stocking density based on kilograms per square meter might be better because such a prescribed space requirement assures a certain amount of space when birds become heavier.

Not only our conclusions but also those of the EU Directive (EU 2007), and Estevez (2007) are, on the face of things, not in agreement with the overall conclusion of the Scientific Committee (EU 2000) saying that stocking density must be 25 kg m^{-2} or lower to prevent serious welfare problems. However, bearing in mind that a limited number of behaviours were included in our study and movements within a behaviour and the social context of space needs were not included at all, the conclusion of the Scientific Committee would appear quite reasonable.

Animal welfare implications and conclusion

Individual body-space measurements are useful to model space needs of larger flocks and to determine the maximum number of birds that can be kept per square meter. Space occupation differed per behaviour and is dependent upon bodyweight, flock size and synchronisation of behaviour.

Given the restrictions of a limited number of behaviours and no inclusion of movement and social interactions in the models of this study, stocking density in large flocks should not exceed 16 birds m^{-2} (39.4 kg) since that would lead to compression of birds suppressing opportunities for behavioural expression and ultimately impairing welfare.

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