Performance and welfare of steers housed on concrete slatted floors at fixed and dynamic (allometric based) space allowances

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ABSTRACT: The objectives of the study were to determine whether allometric equations are suitable for estimating the space requirements of finishing beef cattle housed on concrete slatted floors (CSF) and to examine the effect of fixed and dynamic space allowances on the performance and welfare of these cattle. Continental crossbred steers [$n = 120$: mean initial live weight, 590 (SD 29.8) kg] were blocked by breed, weight, and age and assigned to 1 of 5 space allowance treatments (3 fixed and 2 dynamic) on CSF: 1) 2.0 m² per animal, 2) 2.5 m² per animal, 3) 3.0 m² per animal, 4) Equation 1 (E1); $y = 0.033w^{0.667}$, where $y = \text{m}^2$ per animal and $w = \text{body weight}$, and 5) Equation 2 (E2); $y = 0.048w^{0.667}$. The length of the feed face was 3.0 m for all treatments. Steers were offered grass silage and concentrates ad libitum. DMI was recorded weekly on a pen basis. Steers were weighed and dirt scored every 14 d. Blood samples were collected every 28 d, and analyzed for complete cell counts. Behavior was recorded using closed-circuit infrared cameras. Steers’ hooves were inspected for lesions at the beginning of the study and post-slaughter. Slaughter weight and ADG were lowest, and feed conversion ratio (FCR) was poorest, for steers accommodated at 2.0 m², and

slaughter weight and ADG were greatest, and FCR was the best, for steers accommodated at E2 ($P < 0.05$); steers accommodated at 2.5 m² were intermediate ($P > 0.05$) to those accommodated at 2.0 m² and both 3.0 m² and E1, whereas steers accommodated at 3.0 m² and E1 were intermediate ($P > 0.05$) to 2.5 m² and E2. Carcass weight of steers housed at 2.0 m² was lower ($P < 0.05$) than all other treatments. Steers housed at 2.5 m² had lower carcass weights ($P < 0.05$) than those with accommodated at E1 and E2, whereas the carcass weight of steers accommodated at 3.0 m² was intermediate. Carcass fat scores and hide weights were lower ($P < 0.05$) in steers accommodated at 2.0 m² than those housed at E2 with other treatments being intermediate. The number of steers lying at any one time and the number of steers observed grooming themselves was lower ($P < 0.05$) at 2.0 m² than any other treatment. Dirt scores, hoof lesion number, and hematological measurements were not affected by treatment. It was concluded that 2.0 m² per animal was an insufficient space allowance for housing finishing beef steers and that the equation $y = 0.033w^{0.667}$ is sufficient for estimating the space required by finishing beef cattle housed on CSF.

Key words: allometric equations, beef cattle, concrete slats, performance, space allowance, welfare

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INTRODUCTION

Concrete slatted floors (CSF) are the predominant housing system used for finishing beef cattle in European countries (SCAHAW, 2001). Due to high construction costs it is desirable to operate this housing system with relatively low space allowances per animal; however, animal live weight varies between studies, therefore it is difficult to conclude, from the literature, what space allowance (m^2 per animal) finishing beef cattle should be provided with. One way of possibly determining the optimal space for finishing cattle, irrespective of their weight, is through the use of allometric equations (Baxter 1992; Petherick 2007; Petherick and Baxter 1981; Peterwick and Phillips, 2009). Instead of allocating a fixed space allowance per animal, allometric equations use the progressing weight of an animal to estimate the space that they require during housing. Petherick and Phillips (2009) concluded that beef cattle should be housed at a space allowance defined by the formula $y = 0.033w^{0.667}$, where $y = \text{m}^2$ per animal and w is body weight. Furthermore, SCAHAW (2001) recommended that beef cattle expected to reach 500 kg should be provided with 3.0 m^2 per animal, $\pm 0.5 \text{ m}^2$ for every 100 kg above or below this level. In allometric terms, the SCAHAW (2001) recommendation equates to a space allowance defined by the formula $y = 0.048w^{0.667}$. To date, no study has evaluated the use of these equations, using dynamic space allowances, for housing beef cattle on CSF.

Thus, the objective of this study was to compare the performance and welfare of beef cattle housed on CSF at 2 different dynamic space allowances, defined by Petherick and Phillips (2009) and SCAHAW (2001), to that of cattle housed at 3 different fixed space allowances. Our study hypothesis was that providing finishing beef cattle with dynamic space allowances, defined by allometric equations, would be more beneficial, for performance and welfare, than providing them with a fixed space allowance per animal.

MATERIALS AND METHODS

All animal procedures performed in this study were conducted under experimental license AE19132/P035 from the Health Products Regulatory Authority, Ireland and the Teagasc Animal Ethics Committee.

Animals, management, and study design

The study was conducted at the Teagasc, Animal & Grassland Research and Innovation Centre in

Grange, Co. Meath, Ireland, coordinates $53^{\circ}30'N$, $6^{\circ}40'W$, from November 2016 until February 2017. One hundred and twenty continental crossbred steers, either Charolais or Limousin [mean initial live weight on day (d) 0, 590 (SD 29.8) kg], were sourced from commercial beef farms throughout Ireland and assembled at Teagasc, AGRIC, Grange. On arrival, they were treated for the control of ecto- and endoparasites using Closamectin (Norbrook Laboratories, Co., Monaghan, Ireland), were immunized against bovine respiratory syncytial virus (BRSV), parainfluenza-3 virus (PI3V), and bovine viral diarrhoea (BVD) using Rispoval3 (Pfizer Animal Health, Co., Cork, Ireland), infectious bovine rhinotracheitis virus using Rispoval-IBR marker live (Pfizer Animal Health, Co., Cork, Ireland), and against clostridial diseases using Tribovax 10 (Intervet, Tallaght, Ireland). Steers remained outdoors grazing at pasture prior to housing for 14 d. When they were housed, steers were allowed an adaptation period of 21 d during which the concentrate proportion of the diet was increased daily until the stage was reached where the animals no longer consumed all of the concentrates offered. Grass silage was offered *ad libitum* throughout the adaptation period. After 21 d, steers were weighed on 2 consecutive days, then blocked by breed, live weight, and age, and assigned, from within block, to 1 of 5 space allowance treatments (3 fixed and 2 dynamic) on CSF: fixed; 1) 2.0 m^2 per animal, 2) 2.5 m^2 per animal, 3) 3.0 m^2 per animal, and dynamic; 4) Equation 1 (E1) $y = 0.033w^{0.667}$ (Petherick and Phillips, 2009), where $y = \text{m}^2$ per animal and $w = \text{body weight}$, and 5) Equation 2 (E2) $y = 0.048w^{0.667}$ (SCAHAW, 2001). The study duration was 105 d. The health status of the steers was inspected daily.

Experimental pens

Each treatment consisted of 6 pens, with each pen containing 4 steers. All pens were located in the same housing facility. The experimental pens were distributed evenly throughout the house. To achieve the respective treatment space allowances the dimensions of the pens were $3.0 \text{ m} \times 2.67 \text{ m}$ for treatment 1, $3.0 \text{ m} \times 3.33 \text{ m}$ for treatment 2, and $3.0 \text{ m} \times 4.0 \text{ m}$ for treatment 3. The initial dimensions of the pens for treatment 4 were $3.0 \text{ m} \times 3.1 \text{ m}$ and for treatment 5 were $3.3 \text{ m} \times 4.2 \text{ m}$. The pen size for treatment 4, and 5, was increased every 14 d. To facilitate this, portable gates were fitted at the back of the pens, for treatment 4 and at the side of the pens for treatment 5. In order to achieve this,

pens in treatment 5 were adjacent to an empty pen to facilitate the extension of the width of the pen. The average body weight (kg) per m² for each treatment at the beginning and end of the experiment is shown in Table 1. For treatment 4, and 5, the space allowance per animal increased from 2.3 m² at the start of the experiment to 2.6 m² at the end of the experiment, and from 3.4 to 3.9 m², respectively. The feed face length was fixed at 3.0 m for all pens for the duration of the study. The floor of each pen was fitted with concrete gang slats with the following dimensions: slat length 3.5 m, slat width 1.18 m, slat rib width 170 mm, void space 40 mm. The concrete slats were in good condition with no obvious defects. Adjacent pens were separated by a metal bar design that prevented physical contact but permitted visual contact between animals. The average daily ambient temperature inside the housing shed for the duration of the study was 7.8 (SE $\pm$ 1.2) °C (min: 3.9 °C; max: 14.0 °C).

Animal diet and composition

Steers were offered grass silage and concentrates (860 g/kg rolled barley, 60 g/kg soya bean meal, 50 g/kg molasses, and 30 g/kg minerals and vitamins) ad libitum and had free access to clean, fresh drinking water. Feeding took place once daily at 0800 h. DMI was calculated on a pen basis. Feed was weighed into each pen on Monday, Tuesday, Wednesday, and Thursday, and refusals were weighed on Friday. Refusals were discarded on Monday and Friday. Representative samples of the grass silage and concentrates offered were taken twice weekly and stored at -20 °C pending laboratory analysis. These samples were subsequently pooled on a weekly basis for DM determination and on a 3-wk basis for chemical analysis. The DM of the concentrate samples was determined after drying, in an oven with forced-air circulation, at 98 °C for 16 h. A separate sample was dried at 40 °C for 48 h for chemical analysis. Grass silage samples

were dried at 40 °C for 48 h for DM determination and the samples were subsequently used for chemical analysis as described by Owens et al. (2008). Both grass silage and concentrate samples were then ground through a 1-mm screen (Willey mill, Arthur H. Thomas, Philadelphia, PA, USA) and analyzed for ADF and NDF using the Ankom method (F57 Ankom Technology, Macedon, NY, USA), for in vitro DM digestibility (DMD) using the method of Tilley and Terry (1963) and for ash content by combustion at 550 °C for 5 h. The CP content was determined, as N $\times$ 6.25, using a LECO FP 428N analyzer (LECO Corporation, St. Joseph, MI, USA). The mean (and corresponding SEM values) for DM, in vitro DMD, and chemical composition of the grass silage offered was: DM: 208 (7.1) g/kg, DMD: 744 (6.3) g/kg, CP: 153 (1.6) g/kg DM, ADF: 332 (2.1) g/kg DM, NDF: 538 (3.0) g/kg DM, and ash: 86 (0.8) g/kg DM. Corresponding values for the concentrates were: 794 (17.4) g/kg, (5.7) g/kg, 135 (2.1) g/kg DM, 55 (0.7) g/kg DM, 195 (1.2) g/kg DM, and 62 (0.5) g/kg DM.

Animal measurements

Steers were weighed, before feeding, on d -2 and -1 before assignment to treatment on d 0, and at 14-d intervals (d 14, 28, 42, 56, 70, 84, and 98) throughout the study period, and additionally on the day preceding and the day of slaughter (d 105). From these weights ADG was determined by linear regression. Post-slaughter, carcass weight, kill-out proportion, and hide weights were determined. Carcasses were graded mechanically for conformation and fat scores according to the EU beef carcass classification scheme (EC, 2006) on a continuous 15-point scale. Feed conversion ratio (FCR) was expressed as kilograms of DMI/pen/d divided by kilograms of live weight gain/pen/d.

Animal cleanliness

Steers were dirt scored, at the same time as weighing, on d -1, 14, 28, 42, 56, 70, 84, 98, and 105. Dirt scoring, as described by Earley et al. (2015), was carried out blind to treatment assignment by the same experienced person on each occasion. Using this system, the entire left side of each steer was diagrammatically divided into 16 body segments and each segment was assigned a score between 1 (very clean) and 5 (very dirty) levels of intensity. Each animal was then given an overall dirt score, between 16 and 80, which was equal to the sum of the scores for each of the 16 body segments.

Table 1. Average stocking rate (kg/m²) for each of the space allowances

	Space allowance, m ² /steer				
	2.0	2.5	3.0	E1	E2
Day 0	295	237	197	257	173
Day 105	333	275	235	270	183
Mean	314	256	216	263	178

E1 = space allowance per animal (m²) = 0.033W^{0.667}, space allowance per animal ranged from 2.3 to 2.6 m²; E2 = space allowance per animal (m²) = 0.048W^{0.667}, space allowance per animal ranged from 3.4 to 3.9 m².

Assessment of hoof lesions

Using the method of [Greenough and Vermunt \(1991\)](#), all 4 hooves of each steer were inspected for the presence of lesions, by the same person, on d -1 and again on retrieval of the 4 hooves post-slaughter. The dorsal area was examined for equal and unequal size, and the plantar area for heel erosion, under run sole, digital dermatitis, inter-digital dermatitis, and white line damage. The total number of lesions that each steer obtained during the study was calculated.

Hematological sample collection

Steers were blood sampled via jugular venepuncture on d -1 and at 28-d intervals; therefore, each steer was blood sampled 5 times over the course of the study. Blood samples were collected into 1 × 6 mL K₃ethylene diamine tetra-acetic acid (K₃EDTA) tube (Vacuette, Cruinn Diagnostics, Ireland) for hematological analysis. Unclothed K₃EDTA whole blood samples were analyzed using an ADVIA hematology analyzer (ADVIA 2120, Bayer Healthcare, Siemens, UK) equipped with software for bovine blood. White blood cell, total leukocyte, neutrophil, lymphocyte, eosinophil, monocyte, basophil, red blood cell and platelet numbers, hemoglobin concentration, mean cell hemoglobin concentration (MCHC), mean corpuscular hemoglobin (MCH), mean corpuscular volume (MCV), and hematocrit (HCT) percentage were measured.

Animal behavior

Animal behavior in each pen was recorded continuously throughout the study using Hikvision (High Definition, EXIR Dome 3.6 mm) infrared cameras (Lynx Security, Co., Meath, Ireland). One camera was positioned in front of 2 pens which provided a clear view of both pens. The video cameras were connected to a network video recorder (Hikvision DS-9608/9616/9632NI-ST). The pictures from all cameras were calibrated with date and time settings. For the purposes of data analysis, individual animal behavior was recorded by scan sampling the video footage every 10 min ([Fregonesi et al., 2004](#)) for 24 h at 3 different occasions, d 12, d 43, and d 78. At each scan sampling, the number of steers lying, standing, eating (head down, actively biting feed), drinking, grooming itself, grooming another steer, or head-butting was recorded ([Earley et al., 2015](#)).

Clinical assessment of lungs

On d 36 and d 83, all steers were assessed for the presence of bovine respiratory disease (**BRD**) using the Whisper Veterinary Stethoscope System (MSD Animal Health, Ireland). This system incorporates an electric stethoscope, with computer-aided analytics to determine the severity of an animal's lung condition. The stethoscope was placed over the animals' lung to capture the sound frequencies and the device then assigns an objective score between 1 and 5 (1 = normal, 5 = chronic) to each animal. Rectal temperatures were also recorded on d 36 and d 83.

Statistical analysis

All statistical analyses were performed using SAS software version 9.3 (SAS Institute Inc., Cary, NC, USA). Pen was the experimental unit for all variables. Data were checked for normality and homogeneity of variance by histograms, q-q plots, and formal statistical tests as part of the UNIVARIATE procedure. Data that were not normally distributed were transformed by raising the variable to the power of lambda. The appropriate lambda value was obtained by conducting a Box-Cox transformation analysis using the TRANSREG procedure. Data subjected to transformation were used to calculate *P*-values. Data were analyzed using a mixed model ANOVA with the MIXED procedure to examine the effect of treatment on intake, performance traits, hoof lesion scores, and behavioral data. The statistical model included the fixed effect of treatment. Data with multiple observations, such as dirt scores, hematological variables, and metabolites, were analyzed using a repeated measures ANOVA (MIXED procedure). Terms for treatment, day, and their interaction were included in the model. If the interaction term was not significant (*P* > 0.05), it was subsequently excluded from the final model. The Tukey test was applied as appropriate to evaluate comparisons between the group means and the associated *P*-values were derived. Data were considered statistically significant when *P* < 0.05. Least square means (LS-means) are reported with the pooled SEM.

RESULTS

Intake, growth, and carcass characteristics

Animal DMI and performance data are shown in [Table 2](#). Treatment had no effect on grass silage

Table 2. Effect of space allowance on intake, performance characteristics, and number of hoof lesions of finishing beef steers over a 105-d study period

	Space allowance, m ² /steer					SEMp	P-value
	2.0	2.5	3.0	E1	E2		
Grass silage DMI, kg/steer/d	1.2	1.2	1.2	1.2	1.1	0.02	>0.10
Concentrate DMI, kg/steer/d	8.8	9.2	9.6	9.4	9.8	0.21	0.07
Total DMI, kg/steer/d	10.0	10.4	10.8	10.6	10.9	0.2	0.06
Initial weight, kg	589	593	590	590	589	2.9	>0.10
Slaughter weight, kg	665 ^a	688 ^{ab}	705 ^{bc}	701 ^{bc}	713 ^c	8.1	0.038
ADG, kg	0.76 ^a	0.88 ^{ab}	1.05 ^{bc}	1.09 ^{bc}	1.14 ^c	0.066	0.041
FCR ^a	13.7 ^a	12.0 ^{ab}	10.3 ^{bc}	10.1 ^{bc}	9.4 ^c	0.69	0.016
Carcass weight, kg	389 ^a	401 ^b	409 ^{bc}	411 ^c	417 ^c	4.9	0.01
Kill-out proportion, g/kg	586	581	583	588	583	3.6	>0.10
Carcass conformation score ^b	9.2	9.4	9.8	9.8	9.8	0.28	>0.10
Carcass fat score ^c	7.9 ^a	8.7 ^{ab}	8.9 ^{ab}	8.9 ^{ab}	9.3 ^b	0.38	0.042
Hide weight, kg	49.1 ^a	50.2 ^{ab}	52.1 ^{ab}	50.5 ^{ab}	54.7 ^b	1.35	0.049
Hoof lesions obtained, number per animal	3.1	2.5	3.5	2.9	3.6	0.35	>0.10

Values are expressed as least square means $\pm$ SEMP. SEMP = pooled SEM; E1 = space allowance per animal (m²) = 0.033w^{0.667}, space allowance per animal ranged from 2.3 to 2.6 m²; E2 = space allowance per animal (m²) = 0.048w^{0.667}, space allowance per animal ranged from 3.4 to 3.9 m².

^aKilograms of DMI divided by kilograms of live weight gained.

^bEU beef carcass classification scheme, scale 1 (poorest) to 15 (best).

^cEU beef carcass classification scheme, scale 1 (leanest) to 15 (fattest).

^{a,b,c}Least squares means within a row without a common superscript letter differ ($P < 0.05$).

DMI; however, there was a statistical tendency for concentrate DMI ($P = 0.07$) and total DMI ($P = 0.06$) to be lower for steers accommodated at 2.0 m² than those at 3.0, E1, and E2.

Slaughter weight and ADG were lowest, and FCR was poorest, for steers accommodated at 2.0 m², and slaughter weight and ADG were greatest, and FCR was the best, for steers accommodated at E2 ($P < 0.05$); steers accommodated at 2.5 m² were intermediate ($P > 0.05$) to those accommodated at 2.0 m² and both 3.0 m² and E1, whereas steers accommodated at 3.0 m² and E1 were intermediate ($P > 0.05$) to 2.5 m² and E2.

Carcass weight of steers housed at 2.0 m² was lower ($P < 0.05$) than all other treatments. Steers housed at 2.5 m² had lower carcass weights ($P < 0.05$) than those accommodated at E1 and E2, whereas the carcass weight of steers accommodated at 3.0 m² was intermediate. There was no difference in the kill-out proportion or carcass conformation score between treatments. Carcass fat scores and hide weights were lower ($P < 0.05$) in steers accommodated at 2.0 m² than those housed at E2 with other treatments being intermediate.

Hoof lesions and dirt scores

Treatment had no effect on the number of hoof lesions that steers gained during the study ($P > 0.10$) (Table 2). The results for dirt scores are presented in Fig. 1. There was no treatment $\times$ day or treatment

effect on the dirt scores of steers. Dirt scores were affected by day ($P < 0.001$) whereby they decreased initially until d 14, before increasing until d 42. After this point, dirt scores decreased consistently until slaughter.

Hematological variables

The results for white blood cell differential counts and hematological variables are presented in Tables 3 and 4, respectively. There was no treatment or treatment $\times$ day interaction for any of white blood cell populations or hematological variables measured. Day had an effect ($P < 0.05$) on the hematological variables measured.

Animal behavior

The results for animal behavior are shown in Table 5. The mean lying time and mean number of animals lying simultaneously was lower ($P < 0.05$) for steers accommodated at 2.0 m² than any of the other treatments. There was no difference in lying behavior between the remaining treatments. The number of steers observed self-grooming was lower ($P < 0.01$) for those accommodated at 2.0 m² than any other treatment. There was no difference in self-grooming behavior between the remaining treatments. Space allowance had no effect on eating, drinking, allogrooming, or head-butting.

Figure 1. Effect of space allowance on dirt scores (1–80) of beef steers over a 105-d finishing period. E1 = space allowance per animal (m^2) = $0.033w^{0.667}$, space allowance per animal ranged from 2.3 to 2.6 m^2 ; E2 = space allowance per animal (m^2) = $0.048w^{0.667}$, space allowance per animal ranged from 3.4 to 3.9 m^2 .

Table 3. Effect of space allowance on white blood differential cell counts of beef steers during a 105-d finishing period

Blood variable	Space allow- ance, m^2/steer	Day					SEMp	<i>P</i> -value		
		0	28	56	84	105		Treatment	Day	Treatment × day
White blood cells, $\times 10^3$ cells/ μL	2.0	8.3 ^{ab}	8.7 ^{ab}	9.1 ^b	8.7 ^{ab}	8.0 ^a	0.41	0.635	0.0001	0.062
	2.5	8.3	9.0	9.3	9.1	8.5	0.41			
	3.0	8.3	9.1	9.2	8.7	8.9	0.41			
	E1	9.1	8.8	9.3	9.8	9.0	0.41			
	E2	8.3	8.3	8.7	9.0	8.1	0.41			
Neutrophils, $\times 10^3$ cells/ μL	2.0	2.2 ^a	2.7 ^{ab}	2.9 ^b	2.7 ^{ab}	2.4 ^{ab}	0.22	0.487	0.0236	0.234
	2.5	2.1	2.5	2.7	2.3	2.3	0.22			
	3.0	2.1	2.5	2.5	2.3	2.3	0.22			
	E1	2.5	2.3	2.7	2.6	2.3	0.22			
	E2	2.4	2.0	2.2	2.5	2.1	0.22			
Lymphocytes, $\times 10^3$ cells/ μL	2.0	5.9 ^a	5.5 ^{ab}	5.6 ^{ab}	5.2 ^{ab}	5.1 ^b	0.29	0.444	0.0006	0.191
	2.5	6.1	6.0	6.0	6.0	5.7	0.29			
	3.0	6.0	6.2	6.1	5.6	6.0	0.29			
	E1	6.5	6.1	6.1	6.1	6.1	0.29			
	E2	5.7	5.9	5.8	5.7	5.6	0.29			
Basophils, $\times 10^3$ cells/ μL	2.0	0.10 ^{ab}	0.10 ^{ab}	0.11 ^a	0.08 ^{bc}	0.07 ^c	0.007	0.808	<0.0001	0.215
	2.5	0.09	0.10	0.09	0.08	0.08	0.007			
	3.0	0.10	0.10	0.10	0.08	0.09	0.007			
	E1	0.11 ^a	0.11 ^a	0.10 ^{ab}	0.08 ^b	0.08 ^b	0.007			
	E2	0.10	0.10	0.10	0.08	0.09	0.007			
Monocytes, $\times 10^3$ cells/ μL	2.0	0.35	0.41	0.36	0.43	0.39	0.033	0.645	<0.0001	0.680
	2.5	0.32 ^a	0.43 ^b	0.40 ^{ab}	0.40 ^{ab}	0.39 ^{ab}	0.033			
	3.0	0.31 ^a	0.39 ^{ab}	0.36 ^{ab}	0.44 ^b	0.42 ^b	0.033			
	E1	0.31 ^a	0.39 ^{ab}	0.32 ^a	0.37 ^{ab}	0.42 ^b	0.033			
	E2	0.26 ^a	0.40 ^b	0.34 ^{ab}	0.37 ^b	0.37 ^b	0.033			

Values are expressed as least square means $\pm$ SEMP. SEMP = pooled SEM; E1 = space allowance per animal (m^2) = $0.033w^{0.667}$, space allowance per animal ranged from 2.3 to 2.6 m^2 ; E2 = space allowance per animal (m^2) = $0.048w^{0.667}$, space allowance per animal ranged from 3.4 to 3.9 m^2 .

^{a,b,c}Least squares means within a row without a common superscript letter differ ($P < 0.05$).

Table 4. Effect of space allowance on hematological variables of beef steers during a 105-d finishing period

Blood variable	Space allow- ance, m ² / steer	Day					SEMp	P-value		
		0	28	56	84	105		Treatment	Day	Treatment × day
Red blood cells, ×10 ⁶ cells/μL	2.0	7.8 ^a	8.2 ^{ab}	8.6 ^{bc}	8.7 ^{bc}	9.0 ^c	0.16	0.240	<0.0001	0.440
	2.5	8.1 ^a	8.4 ^{ab}	8.7 ^{abc}	8.8 ^{bc}	9.2 ^c	0.16			
	3.0	7.9 ^a	8.1 ^{ab}	8.6 ^{bc}	8.7 ^{bc}	9.2 ^c	0.16			
	E1	8.2 ^a	8.4 ^{ab}	8.8 ^{abc}	9.0 ^{bc}	9.2 ^{bc}	0.16			
	E2	8.0 ^a	7.9 ^a	8.5 ^{ab}	8.5 ^{ab}	8.9 ^b	0.16			
Hemoglobin, g/dL	2.0	12.53 ^a	13.65 ^b	14.00 ^{bc}	13.85 ^{bc}	14.48 ^c	0.208	0.470	<0.0001	0.238
	2.5	12.78 ^a	13.83 ^b	14.25 ^b	14.15 ^b	14.97 ^c	0.208			
	3.0	12.35 ^a	13.70 ^b	14.13 ^b	14.17 ^b	15.25 ^c	0.208			
	E1	12.82 ^a	13.85 ^b	14.47 ^{bc}	14.35 ^{bc}	14.87 ^c	0.208			
	E2	12.38 ^a	13.30 ^b	14.08 ^{bc}	13.87 ^b	14.70 ^c	0.208			
Platelets, ×10 ³ cells/μL	2.0	668.8 ^a	659.5 ^a	520.0 ^{ab}	470.3 ^b	384.8 ^b	36.41	0.342	<0.0001	0.594
	2.5	679.8 ^a	649.3 ^a	483.7 ^{bc}	532.8 ^{ab}	342.7 ^c	36.41			
	3.0	705.2 ^a	702.0 ^a	509.5 ^b	494.0 ^{bc}	358.2 ^c	36.41			
	E1	640.3 ^a	563.3 ^a	499.3 ^a	519.7 ^a	348.5 ^b	36.41			
	E2	688.0 ^a	710.8 ^a	534.7 ^b	526.0 ^b	358.5 ^c	36.41			

Values are expressed as least square means ± SEMp. SEMp = pooled SEM; E1 = space allowance per animal (m²) = 0.033w^{0.667}, space allowance per animal ranged from 2.3 to 2.6 m²; E2 = space allowance per animal (m²) = 0.048w^{0.667}, space allowance per animal ranged from 3.4 to 3.9 m².

^{a,b,c}Least squares means within a row without a common superscript letter differ ($P < 0.05$).

Clinical assessment of lungs

Space allowance had no effect on the Whisper score or rectal temperature of steers (Table 6). No “severe acute” or “chronic” Whisper scores were detected.

DISCUSSION

The space allowance that finishing cattle require will vary depending on body weight, therefore, allometric equations are useful for estimating the space that an animal requires as it uses body weight to estimate an animal's space requirements, returning the formula $y = kw^{0.667}$, where y = surface area, w = body weight, and k = a space allowance

coefficient (Petherick, 1983). In the current study, using allometric equations to determine the space requirements of cattle required that pen size had to be increased in line with body weight gain. In a commercial setting, projecting the potential growth rate of cattle and providing younger animals with sufficient space for their estimated final weight may be a more attainable method of using allometric principles. Removing an animal in a commercial setting is not realistic but it could be in a practical “drafting for slaughter” situation.

In the current study, there was a tendency for steers accommodated at 2.0 m² to have a lower DMI than those accommodated at 3.0 m², E1, and E2, which may explain the greater ADG and carcass weight observed for steers on the latter 3 space

Table 5. Effect of space allowance on the percentage occurrence of behavioral parameters in steers during a 105-d finishing period

Parameter	Space allowance, m ² /steer					SEMp	P-value
	2.0	2.5	3.0	E1	E2		
Lying	54.6 ^a	59.5 ^b	59.1 ^b	59.3 ^b	58.8 ^b	0.96	0.035
Mean no. lying simultaneously ^a	2.19 ^a	2.39 ^b	2.36 ^b	2.39 ^b	2.39 ^b	0.05	0.014
Eating	9.1	9.5	9.4	9.5	10.1	0.47	0.586
Drinking	2.1	1.7	1.7	1.7	2.1	0.22	0.502
Grooming self	1.7 ^a	2.7 ^b	2.9 ^b	2.6 ^b	2.7 ^b	0.14	0.002
Allogrooming	1.3	1.2	1.2	1.2	1.2	0.15	0.981
Head-butting	1.2	1.1	1.2	1.3	1.2	0.21	0.992

Values are expressed as least square means ± SEM. SEMp = pooled SEM; E1 = space allowance per animal (m²) = 0.033w^{0.667}, space allowance per animal ranged from 2.3 to 2.6 m²; E2 = space allowance per animal (m²) = 0.048w^{0.667}, space allowance per animal ranged from 3.4 to 3.9 m².

^aMean number (no.) of animals lying simultaneously per pen.

^{a,b}Least squares means within a row without a common superscript letter differ ($P < 0.05$).

Table 6. Effect of space allowance on Whisper scores and rectal temperature of beef steers during a 105-d finishing period

	Space allowance, m ² /steer	Day		SEMp	P-value		
		36	83		Treatment	Day	Treatment × day
Whisper score (1–5) ^a	2.0	1.7	1.6	0.18	0.749	0.111	0.671
	2.5	1.5	1.6	0.18			
	3.0	1.7	1.4	0.18			
	E1	1.9	1.6	0.18			
	E2	1.7	1.4	0.18			
Rectal temperature (°C)	2.0	39.1	38.9	0.09	0.904	0.612	0.309
	2.5	39.2	38.9	0.09			
	3.0	39.2	39.1	0.09			
	E1	39.1	39.0	0.09			
	E2	39.1	39.0	0.09			

Values are expressed as least square means ± SEMP. SEMP = pooled SEM; E1 = space allowance per animal (m²) = 0.033w^{0.667}, space allowance per animal ranged from 2.3 to 2.6 m²; E2 = space allowance per animal (m²) = 0.048w^{0.667}, space allowance per animal ranged from 3.4 to 3.9 m².

^aWhisper lung scoring system, scale 1 (normal) to 5 (chronic).

allowances. The differences in DMI may be due to steers at the lowest space allowance having restricted access to the feed face. The results of the present study are consistent with Hickey et al. (2003) who reported that steers accommodated at 2.0 m² had lower intakes than those at 3.0 m² and that feed intake was not affected when space allowance was increased above 3.0 m² per animal. On the contrary, however, Fisher et al. (1997) found no difference in intake between heifers housed at 2.0, 2.5, and 3.0 m². This may be due to the fact that Fisher et al. (1997) used lighter animals than those used in the current study, therefore occupying less space in the pen, and making it easier for all animals to access the feed face. There was no difference in ADG or carcass weight between steers accommodated at 2.5 and 3.0 m² in the current study, which is consistent with the findings of Fisher et al. (1997). However, in contrast to Fisher et al. (1997), the current study reported a greater ADG and carcass weight for steers accommodated at 3.0 m² than those at 2.0 m². Again, the discrepancies between the present study and that of Fisher et al. (1997) may be due to the heavier animals used in the current study. For example, the average *k*-values for cattle accommodated at 2.0 and 3.0 m² in the current study were 0.027 and 0.040, respectively, whereas the corresponding *k*-values in the study by Fisher et al. (1997) were 0.032 and 0.047, respectively. Additionally, Hickey et al. (2003) also reported a greater ADG for steers accommodated at 3.0 than 2.0 m² (average *k*-values of 0.044 and 0.030, respectively), but no difference between steers housed at 3.0 and 4.0 m² (average *k*-values of 0.044 and 0.058, respectively). Similarly, Gupta et al. (2007) reported a greater ADG for bulls housed at 2.7 m² than those at 1.2 m² (average

k-values of 0.046 and 0.021, respectively) but no difference between bulls accommodated at 2.7 and 4.2 m² (average *k*-values of 0.046 and 0.071, respectively). Consequently, this evidence, combined with the findings of the present study, would suggest that a *k*-value of 0.033 is sufficient for estimating the space allowance requirements of finishing beef cattle.

The lower carcass fat scores observed in steers housed at 2.0 m² (*k*-value = 0.027) than those with a space defined by E2 (*k* = 0.048) in the current study may be due to the heavier slaughter weights observed in steers on the latter treatment. The greater hide weights recorded for steers with a space allowance defined by E2 compared to steers accommodated at 2.0 m² may be due to heavier slaughter weights, as there was no difference in dirt scores between the 2 treatments.

The cleanliness of animals presented for slaughter is becoming an area of major concern (EFSA, 2006, 2009). Studies have shown that concrete slats are an acceptable floor type for ensuring that cattle are kept clean during the finishing phase (Scott and Kelly, 1989; Lowe et al., 2001; Keane et al., 2015). Space allowance had no effect on dirt scores in the present study which is consistent with the findings of Fallon and Lenehan (2003). By the end of the present study, steers were cleaner, which is consistent with Keane et al. (2015) and (2017), and may be due to the shedding of the winter coat as suggested by Scott and Kelly (1989).

The hoof health of intensively housed cattle on CSF is an area of concern (SCAHAW, 2001). However, Hultgren and Bergsten (2001) have shown that housing cattle on CSF reduces the risk of hygiene-related diseases such as interdigital

dermatitis and heel horn erosion. The abrasiveness of the floor can affect hoof growth, wear, and conformation, therefore having an effect on the animals' susceptibility to hoof lesions (Telezhenko et al., 2009). The number of hoof lesions in the present study was similar to that recorded by Keane et al. (2017) but lower than the number recorded by Earley et al. (2015) and Keane et al. (2015) where the study durations were much greater than the present study.

Blood cell profiles are sensitive indicators of the physiological response of cattle to stress (Radostits et al., 2006) and they have proven extremely useful as indicators of bovine stress during housing (Eicher et al., 2013; Sutherland et al., 2014). In the present study, space allowance had no effect on the white blood cell population of steers, which is consistent with the findings of Fisher et al. (1997) and Hickey et al. (2003). Similarly, Gupta et al. (2007) reported no difference between the white blood cell populations of bulls housed at 1.2, 2.7, and 4.2 m² (*k*-values of 0.021, 0.046, and 0.062, respectively); however, they did report neutrophilia and lymphopenia across all 3 space allowances for the first 36 d immediately after housing indicating the presence of a stress response. In the present study, red blood cell number and hemoglobin concentration did increase after assignment to treatment and remained elevated throughout the study. In the present study, absolute values and changes were within the normal physiological ranges of cattle (Radostits et al., 2006) which would suggest that hemostasis was not compromised.

Normal lying duration for confined cattle has been defined as lying for between 12.5 and 14.5 h/d (Wechsler, 2011) and any deviations from this may indicate suboptimal animal welfare conditions. In the current study, the lying behavior of steers accommodated at each space allowances was within the normal range, although those housed at 2.0 m² (*k*-value = 0.027) lay down for less time than steers at any other space allowance. Similarly, Ruis-Heutinck et al. (2000) reported longer lying durations when space allowance per animal was increased from 2.0 to 4.2 m². There was no difference in lying behavior of cattle accommodated at 2.5 m², 3.0 m², E1, or E2 in the present study, which is in agreement with Wechsler (2011) who proposed that lying time was only affected when space allowance was very low (<2.5 m² per animal). This is further supported by Hickey et al. (2003) who observed a reduced lying time for steers housed at 1.5 m² per animal (*k*-value = 0.023) compared to those at 2.0 m² (*k*-value = 0.030), 3.0 m² (*k*-value = 0.044), and 4.0 m²

per animal (*k*-value = 0.058), with no difference in the lying time of steers at the latter 3 space allowances. Space allowance had no effect on aggressive behavior or allogrooming in the present study, which is consistent with the findings of Hickey et al. (2003). Although there is evidence to suggest that aggressive behavior increases when space allowance per animal is low (SCAHAW, 2001), the lack of a difference in aggressive behavior in the current study may be due to the fact that the feed face was the same length for all of the treatments. Kohari et al. (2007) reported that healthy steers generally spend 2% of a 24-h period self-grooming. Steers accommodated at 2.0 m² in the current study groomed themselves less than this which would suggest that 2.0 m² per animal is insufficient space for allowing steers to express their natural grooming repertoire.

The use of the Whisper Veterinary Stethoscope System (MSD Animal Health) has proven successful in the early detection of BRD in steers (Mang et al., 2015). Steers are classified as having BRD if they have a Whisper score greater than 2 (Mang et al., 2015) and a rectal temperature greater than 39.7 °C (Duff and Galyean, 2007). In the present study, no steer presented with a Whisper score of 2, or a rectal temperature greater than 39.7 °C.

In conclusion, the present study found that 2.0 m² per animal (*k*-value of 0.027) is an insufficient space allowance for finishing continental crossbred beef steers. It is also concluded that using *k*-values to estimate the space cattle require is more appropriate than providing them with a certain space (m²) per animal. The results demonstrated that the equation $y = 0.033w^{0.667}$, as suggested by Petherick and Phillips (2009), is sufficient for estimating the space requirements of finishing beef cattle on CSF.

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