Grass and Forage Science
The Journal of the British Grassland Society | The Official Journal of the European Grassland Federation

# Effect of feed space allowance and period of access to food on dairy cow performance

**C. P. Ferris*, D. C. Patterson*, C. S. Mayne* and N. E. O'Connell†**
*Agri-Food and Biosciences Institute, Large Park, Hillsborough, UK and †School of Biological Sciences, Medical Biology Centre, Queen's University Belfast, Belfast, UK

## Abstract

Two experiments were conducted to examine the 'long-term' effect of feed space allowance and period of access to feed on dairy cow performance. In Experiment 1, three horizontal feed space allowances (20, 40 and 60 cm cow$^{-1}$) were examined over a 127-d period (14 cows per treatment). In Experiment 2, 48 dairy cows were used in a continuous design (10-week duration) 2 × 2 factorial design experiment comprising two horizontal feed space allowances (15 and 40 cm cow$^{-1}$), and two periods of access to feed (unrestricted and restricted). With the former, uneaten feed was removed at 08·00 h, while feeding took place at 09·00 h. With the latter, uneaten feed was removed at 06·00 h, while feeding was delayed until 12·00 h. Mean total dry-matter (DM) intakes were 19·0, 18·7 and 19·3 kg cow$^{-1}$ d$^{-1}$ with the 20, 40 and 60 cm cow$^{-1}$ treatments in Experiment 1, and 18·1 and 18·2 kg cow$^{-1}$ d$^{-1}$ with the 'restricted feeding time' treatments, and 17·8 and 18·1 kg d$^{-1}$ with the 'unrestricted feeding time' treatments (15 and 40 cm respectively) in Experiment 2. None of milk yield, milk composition, or end-of-study live weight or condition score were significantly affected by treatment in either experiment ($P > 0{\cdot}05$), while fat + protein yield was reduced with the 15-cm treatment in Experiment 2 ($P < 0{\cdot}05$). When access to feed was restricted by space or time constraints, cows modified their time budgets and increased their rates of intake.

***Keywords:*** dairy cattle, feed barrier, feed space allowance, feed access time

*Correspondence to:* C. P. Ferris, Agri-Food and Biosciences Institute, Large Park, Hillsborough, Co. Down, BT26 6DR, UK.
E-mail: conrad.ferris@afbini.gov.uk

*Received 13 May 2013; revised 9 October 2013*

## Introduction

Achieving high nutrient intakes is generally recognized as a key management requirement for dairy cows of high yield potential. While dietary strategies such as improving forage quality or increasing concentrate feed levels can promote food intake (Ferris *et al.*, 2001), non-nutritional strategies such as optimizing the cow–feed interface may also have a role in promoting intake. In particular, ensuring that cows have an adequate feed space allowance and adequate access times to feed are often highlighted as important non-nutritional strategies to maximize intake. Regarding horizontal feed space, Grant and Albright (2001) have mentioned a 'traditional recommendation' of 0·6 m cow$^{-1}$, while an allowance of 0·65–0·67 m for a 600-kg cow has been made by Defra (2006). The rationale for these recommendations appears to be that this is the space occupied by one cow when feeding and that all cows should be able to feed at any one time. However, feed space allowances of more than 0·6 m cow$^{-1}$ have recently been suggested as a means of reducing the frequency of aggressive behaviours (DeVries and von Keyserlingk, 2006). In relation to feed access time, it is normally suggested that the period during which cows do not have access to feed should be minimized. Indeed, the relationship between available feed space and feed access time was highlighted by Albright (1993), who suggested that the critical length of manger space below which competition occurs depends on the time that feed is in the manger.

While a number of dairy cow studies have examined different feed space allowances and feed access times, the primary objective of most of these studies was to examine cow behaviour rather than animal performance. Indeed, a number of studies examining different feed space allowances make no mention of cow performance (DeVries *et al.*, 2004; DeVries and von Keyserlingk, 2006). However, in the majority of studies where information on cow performance has been presented, measurement periods were normally short, typically 1 week (Friend *et al.*, 1977; Collis *et al.*,

doi: 10.1111/gfs.12098
 

1980). In addition, a number of studies examining the impact of competition at feeding have involved increasing the number of cows sharing each 'feed space' (Olofsson, 1999; Elizalde and Mayne, 2009), while most studies examining the impact of feed access time have involved cows confined in individual tie stalls (Collings *et al*., 2011). Unfortunately, neither of these scenarios are directly applicable to group-housed cows accessing feed from an 'open' feed barrier. Indeed, remarkably few studies have examined the impact of feed space allowance or period of access to feed on cow performance over a reasonable time scale using typical commercial feeding systems.

With this in mind, DeVries and von Keyserlingk (2006) concluded that work is required to understand the long-term implications of increasing feed access and reducing competition at the feed bunk on dry-matter intake, milk production and health of lactating dairy cows, particularly those in early lactation. Thus, the experiments presented within this study were conducted with the primary objective of examining the impact of feed space allowance and period of access to feed on cow performance.

## Material and methods

Two experiments were conducted to examine the effect of feed space allowance per cow (Experiment 1), and the interaction between feed space allowance per cow and period of access to feed (Experiment 2), on dairy cow performance and behaviour.

### Experiment 1

This three-treatment continuous-design experiment involved forty-two Holstein–Friesian dairy cows, comprising fifteen primiparous cows (five per treatment) and twenty-seven multiparous cows (nine per treatment). Cows calved between 20 November and 10 February and had a mean calving date of 1 January (s.d. 25·5 d). Cows were blocked according to calving date (primiparous and multiparous cows blocked separately) and allocated to one of three treatment groups, with groups balanced for genetic merit for milk production (predicted transmitting ability for milk yield and fat + protein yield) and for live weight, condition score, cow height and cow girth diameter (measured approximately 2 weeks pre-calving). In addition, multiparous cows were balanced for lactation number and previous-lactation milk composition.

Throughout the experiment, cows were housed in a cow shed, in one of three adjacent pens, with the layout of pens 1 and 3 being identical, while pen 2 was a mirror image of pens 1 and 3. Each pen (dimensions: 855 × 1306 cm) was fitted with sixteen cubicles configured in three rows. The layout of each pen (from the front to the back of the pen) was as follows: a feed barrier (with a potential feed space allowance of 845 cm), a standing passage (375 cm wide), two rows each of five cubicles (cubicle dimension: 220 × 122 cm) arranged 'head to head', a second standing passage (246 cm wide) and a row of six cubicles (cubicle dimension: 246 × 122 cm) facing the back wall of the pen. Cows moved between the front and back of the pen via a 244-cm-wide 'cow pass' and exited the pen via a cow pass located in the back wall. Each pen was fitted with a drinker and an out-of-parlour feeder (not in use), while each standing passage was scraped by an automatic scraper which operated six times daily. A plan of the pen layout has already been presented by O'Connell *et al.* (2010). Cubicles were fitted with rubber-filled cow mats, approximately 6·0 cm deep. The divisions between pens were solid from 60 cm to 185 cm above floor level, thus visually isolating cows from those in adjacent pens. Feed barriers in all pens were 'post and rail' design and comprised a 10-cm-wide concrete wall (inside pen height of 45 cm, outside pen height 40 cm), with the vertical feeding space defined by an upper and lower horizontal bar (6·0 cm diameter).

Treatments examined comprised three horizontal feed-space allowances, namely 20, 40 and 60 cm cow$^{-1}$, with each treatment located in a separate pen. These different feed-space allowances were achieved by 'blocking off' sections of the feed barriers within the 20 and 40 cm cow$^{-1}$ treatment pens with wooden sheeting (so that cows were unable to feed from these areas) so that the length of accessible horizontal barrier space remaining within these pens was 280 and 560 cm respectively. With the 60 cm cow$^{-1}$ treatment, the full 845 cm of horizontal feed barrier space within the pen was left available. With the 20 and 40 cm cow$^{-1}$ treatments, the boundary of the feed space on the inside of the pen was defined by a 'divider' positioned at 90° to the feed barrier, with this extending 95 cm into the pen. This divider restricted access to the feed barrier so that only cows standing directly behind the available barrier space were able to gain access to feed. This was unnecessary with the 60 cm cow$^{-1}$ treatment, as the side walls of the pen achieved this function. On the outside of the pens, feed was prevented from 'spilling' beyond the end of each feeding area by a wooden 'retainer' wall. With the 40 and 60 cm cow$^{-1}$ treatments, the 560 and 845 cm of available feed space was 'interrupted' by either one or two vertical steel bars (10 × 10 cm), respectively, with these bars part of the internal infrastructure of the house. The space occupied by these bars was included within the 'available' feed space described earlier.

The experiment commenced with each treatment pen occupied by fourteen late-lactation non-experimental cows, with each group of non-experimental cows balanced for milk yield and live weight. Each experimental cow was transferred into its appropriate treatment group within 24 h of calving, and a non-experimental cow removed. This process was repeated until each group comprised fourteen experimental cows. By adopting this approach, experimental cows were subject to the designated feed space allowance (20, 40 and 60 cm cow$^{-1}$) from the point of calving, including the time prior to the full experimental group being established. Experimental cows remained on the treatment regimes until 9 May, a mean of 127 d, with the period from the last cow calved, until the end of the study being 88 d.

Cows were offered fresh feed between 09·30 and 10·00 h approximately, with the ration offered comprising grass silage and concentrates (65:35 DM ratio). The silage offered was produced from a perennial ryegrass-based sward (primary regrowth), which was harvested on 8 August after a period of field wilting of approximately 36 h. The concentrate component of the diet was in the form of a meal and had an ingredient composition (on a kg t$^{-1}$ air-dry basis) as follows: barley 140; wheat 140; unmolassed sugar-beet pulp 95; citrus pulp 95; maize gluten feed 100; maize distillers grains 100; soya bean meal 165; rape meal 100; megalac 12; minerals 23; molasses 30. Sufficient silage for all three treatments was placed in a complete diet mixer wagon and mixed for 3–4 min. Sufficient concentrates for all three treatments were then added, and mixing continued for a further 7–8 min. An appropriate quantity of this mix was then offered to cows within each of the three treatment groups, with feed being offered to each group at proportionally 1·05 of the previous day's intake. The order in which feed was offered to each of the three treatment groups was changed daily. Uneaten feed was 'pushed up' to the barrier by hand on four occasions during each 24-h period, at approximately 12·00, 15·30 h (after cows were removed for evening milking), 21·00 h and at 06·30 h (after cows were removed for morning milking). Uneaten feed was removed at approximately 09·00 h the following day, and the weight of uneaten feed recorded for each pen. In addition, 1·0 kg of a commercial concentrate was offered in the parlour during milking (0·5 kg at each milking) to all cows. Artificial lighting was maintained in the cow house throughout the duration of the experiment.

## Experiment 2

Forty-eight Holstein–Friesian dairy cows were used in a continuous 2 × 2 factorial design experiment of 10-week duration. Thirty-two cows were multiparous (mean lactation number, 3·5), while the remaining cows were primiparous. Cows were a mean of 141 (s.d., 31·1) days calved when the study commenced, with cows having a mean pre-experimental milk yield of 31·1 (s.d., 6·86) kg d$^{-1}$. Cows were allocated to one of four treatment regimes during the week prior to the start of the study, with treatments balanced for calving date, lactation number, milk yield, milk fat and milk protein content, live weight, condition score, height and girth measurements (the latter seven parameters measured during the week of allocation). Eight multiparous cows and four primiparous cows were allocated to each treatment.

Throughout the experiment, cows were kept in four adjacent pens (as described in Experiment 1), with pens 1 and 3 being a mirror image of pens 2 and 4. Treatments examined comprised two horizontal feed space allowances (15 and 40 cm cow$^{-1}$) and two periods of access to feed (restricted and unrestricted). The feed barriers were as described in Experiment 1, with total available feed space within the 40 and 15 cm cow$^{-1}$ treatment pens of 480 and 180 cm respectively. With the 40 cm cow$^{-1}$ treatments, the feed space was interrupted by a vertical steel bar (10 cm × 10 cm), with the space occupied by this bar included within the space allowance. With all treatments, the boundary of the feed space on the inside of the pen was defined by a 'divider', which extended 95 cm into the pen, as described in Experiment 1. On the outside of the pens, feed was prevented from spilling beyond the end of each feeding area by a wooden retainer.

Cows were offered the experimental ration for a 2-week period prior to the start of the experiment. The experimental ration comprised forage and concentrates (60:40 DM basis), with the forage component of the diet comprising grass silage and maize silage (60:40 DM basis). The grass-silage component of the diet was produced from secondary regrowth herbage (harvested on 4–6 October from predominantly perennial ryegrass-based swards), while the maize silage offered was harvested on 1 November. The ingredient composition of the concentrate feed stuff was as described in Experiment 1, while 1·0 kg d$^{-1}$ of a commercial concentrate was offered to each cow during milking (0·5 kg at each milking).

With the restricted access time treatment, uneaten feed was removed from the feed barriers when cows were removed for morning milking (at approximately 05·30 h). With the unrestricted access time treatment, uneaten feed was removed from the feed barriers between 08·00 and 08·30 h. The weight of uneaten feed removed from each pen was recorded daily. Cows on the unrestricted and restricted access time treatments were offered fresh feed at 09·00 and 12·00 (±10 min).

Rations were prepared as follows: sufficient grass silage for all four treatments was added to the mixer wagon and mixed for approximately 5 min, with sufficient silage for the restricted access-time treatment then deposited on a clean floor in a roofed silo. The required quantities of maize silage and concentrates for the unrestricted access-time treatments were then added to the wagon, mixing continued for a further 7–8 min, with this feed being offered to the non-restricted feeding treatment. After 11·00 h, the remainder of the silage was placed back in the wagon, and the appropriate quantity of maize silage and concentrate added, and mixed as above, and subsequently fed. Ration preparation with this treatment was delayed until after 11·00 h to maintain the 'freshness' of the ration offered. Maize silage for the restricted and non-restricted feeding treatments was removed from adjacent positions in the silo to ensure similar composition. Feed was offered to each treatment group at proportionally 1·1 of the previous day's intake. The order in which feed was offered to the two space allowance treatments within the restricted and unrestricted access time treatments was alternated daily. Uneaten feed was pushed up to the barrier at 12·00 h (unrestricted access time only), at 15·30 h (after cows were removed for evening milking), at 21·00 h and at 06·30 h (after cows were removed for morning milking: unrestricted access time only). During the first few days of the experiment, it was discovered that cows with the 15 cm space allowance tended to push feed out during the night (between 21·00 and 06·30 h) so that a significant proportion of feed was beyond the reach of cows. To overcome this problem, a wooden shield was placed along the front of the feed barriers with these treatments at 21·00 h to maintain feed within the reach of the cows. This problem did not arise with the 40 cm feed space allowance treatments.

## Measurements

Cows were milked twice daily, between 05:30 and 06·30 h and between 14:30 and 16:30 h, with milk yields recorded automatically at each milking. The order in which each group of cows was removed for milking, milked and returned to their pen post-milking was maintained throughout the study, thus ensuring that each treatment group was away from feed for a similar period of time. Throughout the experiments, milk samples were collected from each individual cow during two consecutive milkings each week, with each sample analysed for fat, protein and lactose concentrations using a Milkoscan FT120 (Foss Electric, Hillerød, Denmark). A weighted mean milk composition for each animal was subsequently calculated. Cow live weights were recorded weekly throughout each experiment. Feed intakes (group basis) were recorded daily throughout each experiment, as the difference between feed offered to each group and feed refused, with the calculation assuming no preferential selection of individual feed ingredients from the mixtures offered. The oven dry matter (ODM) of silages offered was determined daily, while a fresh sample of each of the silages offered was analysed weekly throughout the study for nitrogen, pH, ammonia nitrogen, lactic acid and volatile components. In addition, dried silage samples were bulked over each 2-week period and analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF) and ash concentrations, and in the case of maize silage, for starch. A bulked sample of the concentrate offered during each 4-week period was analysed for ODM, with the dried sample subsequently milled and analysed for nitrogen, NDF, ADF and ash concentrations.

Within each experiment, each pen was video recorded (in 24-h time lapse mode) continuously for a number of 24-h periods (weekly during the final 12 weeks during Experiment 1) and twice weekly (during two consecutive 24-h periods during Experiment 2). Tapes were scanned at 30-min intervals to determine the total number of animals 'feeding', standing in the passageway behind the feed barrier and lying (Experiment 1), and the total number of animals feeding and standing in the passageway behind the feed barrier (Experiment 2). An animal was defined as 'feeding' if its head was through, or in contact with the barrier, or if the cow was part of a row of animals feeding at the barrier. The mean number of animals involved in each activity was averaged over the two observation periods each hour, and weekly data averaged over each experiment and subsequently used to plot diurnal activity patterns.

On 1 d each week during the final 12 weeks of Experiment 1 (after all cows on the study had calved), cows feeding at the feed barrier within each treatment group were video recorded in real time for 30 min immediately after fresh feed was offered in the morning, and again for 30 min after cows accessed fresh feed after returning from evening milking. The number of butting (defined as 'butting' another cow through the upswing of the head as an isolated incident: not part of a fight) and pushing (defined as pushing another cow with the head, head to head or perpendicular as an isolated incident: not part of a fight) incidents observed among cows at the feed barrier were recorded continually during six 5-min periods. The mean frequency of butting and pushing behaviours were then calculated per animal at the feed barrier during each 5-min period, and the mean frequency across the six 5-min observation periods subsequently determined. The number of cows present at the barrier during each 5-min observation period was calculated as the mean of the number of cows present at the start and at the end of each 5-min period.

## Statistical analysis

Feed intake data for Experiment 1 relate to the period between the removal of the last non-experimental cows from the groups and the end of the study (i.e. intakes for experimental cows only), while those for Experiment 2 are for the entire experimental period. As feed intakes were recorded on a group-intake basis, it was not possible to undertake a statistical analysis of intake data in either experiment. In view of the resources (animal and building) required to establish the long-term measurement periods within these experiments (an unique aspect of this work), and the need to have group sizes which were sufficiently large so as not to result in abnormal behavioural patterns, a replicated pen study with sufficient replication to identify relatively small potential treatment differences was impossible. Consequently, data describing milk production and 'end-of-study' body tissue reserves were analysed using individual cow data as the experimental unit. Milk production data analysed were the mean performance data for the entire experimental period. Performance data in Experiment 1 were analysed using ANOVA according to the three treatment design, with blocking included in the analysis. In addition, predicted transmitting ability for milk, for fat and protein percentage deviations, and for fat + protein yield, and condition scores and live weights recorded approximately 2 weeks pre-calving, were used as covariates in the analysis of milk yield, milk fat and milk protein content, milk fat + protein yield and end-of-study condition score and live weight respectively. In addition, milk yield data were tested for an interaction between treatment and lactation number (primiparous vs multiparous), with predicted transmitting ability for milk yield used as a covariate.

In Experiment 2, effects on cow performance of feed space allowance, period of access to feed, and their interactions, were examined using ANOVA according the 2 × 2 factorial design nature of the experiment. Milk yield, milk fat, protein and lactose content, milk fat + protein yield, live weight and condition score data recorded during the week prior to the start of the experiment were used as covariates when analysing milk yield, fat, protein and lactose content, milk fat + protein yield and end-of-study live weight and condition scores respectively. In addition, milk yield data were tested to see whether there was an interaction between feed space allowance and lactation number (primiparous vs multiparous), and period of access to feed and lactation number, with predicted transmitting ability for milk yield used as a covariate. All data were analysed using Genstat v12.1 (VSN International, 2009). Video analysis data relating to aggression and activity patterns were not analysed statistically as the weekly observations did not represent true replication. Rather, mean data over all observation days have been presented.

## Results

The grass silages offered in Experiments 1 and 2 (Table 1) were both well fermented, with ammonia nitrogen concentrations of 52 and 79 g kg total nitrogen$^{-1}$, respectively, and crude protein concentrations of 166 and 171 g kg DM$^{-1}$ respectively. While the maize silage offered in Experiment 2 had a high DM content (343 g kg$^{-1}$), its starch content was low (216 g kg DM$^{-1}$).

While a statistical comparison of treatment effects on feed intake was not possible, total daily DM intake

**Table 1** Chemical composition of silages (g kg corrected DM$^{-1}$, unless stated otherwise) and concentrates (g kg DM$^{-1}$, unless stated otherwise) offered during Experiments 1 and 2.

| | Experiment 1 | | Experiment 2 | | | | Experiments 1 and 2 | |
|---|---|---|---|---|---|---|---|---|
| | Grass silage | s.d. | Grass silage | s.d. | Maize silage | s.d. | Concentrate | s.d. |
| Oven dry matter (g kg$^{-1}$) | 377 | 62·4 | 264 | 23·9 | 329 | 23·5 | 880 | 7·7 |
| Corrected dry matter (g kg$^{-1}$) | 387 | 61·5 | 280 | 26·4 | 343 | 22·9 | | |
| Ammonia N (g kg total N$^{-1}$) | 52 | 10·0 | 79 | 8·0 | 104 | 9·1 | | |
| pH | 4·05 | 0·164 | 3·80 | 0·126 | 3·65 | 0·038 | | |
| Crude protein | 166 | 20·3 | 171 | 21·5 | 77 | 4·4 | 211 | 14·6 |
| Lactic acid | 74 | 35·6 | 170 | 36·0 | 61 | 13·4 | | |
| Ash | 110 | 7·1 | 107 | 9·8 | 38 | 13·8 | 77 | 4·0 |
| Acid detergent fibre | 303 | 13·5 | 305 | 9·3 | 286 | 18·7 | 114 | 10·8 |
| Neutral detergent fibre | 506 | 19·8 | 518 | 21·2 | 525 | 30·4 | 262 | 16·4 |
| Starch | | | | | 216 | 28·8 | | |

s.d., standard deviation.

with the 20 cm treatment in Experiment 1 was numerically 0·3 kg higher than for the 40 cm treatment, and 0·3 kg lower than for the 60 cm treatment (Table 2). In Experiment 2, total daily DM intakes with the 15 cm treatments were on average 0·2 kg lower than with the 40 cm treatments, while intakes with the restricted and unrestricted feed access time treatments both averaged 18·2 kg DM $cow^{-1}$ $d^{-1}$. Feed space allowance (20, 40 or 60 cm $cow^{-1}$) had no effect on daily milk yield, or milk composition throughout the experimental period in Experiment 1 (Table 2), or on end-of-study body condition score or live weight ($P > 0·05$). In addition, there was no interaction between feed space allowance and lactation number for daily milk yield ($P > 0·05$), with daily milk yield for the 20, 40 and 60 cm treatments being 24·1, 25·6, 23·1 kg for primiparous cows and 36·1, 34·3 and 36·3 kg, respectively, for multiparous cows (s.e.m., 2·29). Neither feed space per cow nor period of access to feed had a significant effect on daily milk yield or milk composition during Experiment 2 (Table 3), or on end-of-study live weight or body condition score ($P > 0·05$). However, fat + protein yield was significantly lower ($P < 0·05$) with cows with a feed space allowance of 15 cm cow. There were no significant interactions between feed space allowance and period of access to feed for any of the parameters examined ($P > 0·05$). In addition, there was no significant interaction ($P > 0·05$) between feed space allowance and parity, or between period of access to feed and parity, for milk yield.

There were clear trends for the number of incidences of aggression (both butting and pushing) observed during the 30-min period after fresh feed was offered, and post-access to feed following pm milking, to decrease with increasing feed space allowance in Experiment 1 (Table 4). The mean number of cows feeding (Figure 1), standing behind the feed barrier (Figure 2) and lying (Figure 3) is presented at hourly intervals over a 24-h period within Experiment 1. During the 1-h period after fresh feed was offered, approximately 9, 7 and 4 cows were observed at the feed barrier with treatments 20, 40 and 60 cm respectively. While numbers feeding decreased over the 7-h period after fresh feed was offered with the 40 and 60 cm treatments, the number of cows feeding with 20 cm treatment remained relatively constant during

**Table 2** Effect of feed space allowance per cow on dairy cow performance (Experiment 1).

| | Feed space per cow | | | | |
|---|---|---|---|---|---|
| | 20 cm | 40 cm | 60 cm | s.e.m. | Significance |
| Total DM intake (kg $d^{-1}$) | 19·0 | 18·7 | 19·3 | | |
| Milk yield (kg $d^{-1}$) | 31·9 | 31·3 | 31·5 | 1·11 | NS |
| Milk fat (g $kg^{-1}$) | 42·3 | 42·0 | 42·4 | 0·72 | NS |
| Milk protein (g $kg^{-1}$) | 31·3 | 31·2 | 32·3 | 0·49 | NS |
| Milk lactose (g $kg^{-1}$) | 48·6 | 48·2 | 48·8 | 0·35 | NS |
| Fat + protein yield (kg $d^{-1}$) | 2·33 | 2·28 | 2·38 | 0·076 | NS |
| End-of-study condition score | 2·6 | 2·6 | 2·6 | 0·05 | NS |
| End-of-study live weight (kg) | 585 | 595 | 608 | 8·8 | NS |

DM, dry matter; s.e.m., standard error of the mean; NS, non-significant.

**Table 3** Effect of feed space allowance and period of access to feed on dairy cow performance (Experiment 2).

| | Restricted access time | | Unrestricted access time | | | Significance | | |
|---|---|---|---|---|---|---|---|---|
| | 15 cm | 40 cm | 15 cm | 40 cm | s.e.m. | Feed space | Access time | Interaction |
| Total DM intake (kg $d^{-1}$) | 18·1 | 18·2 | 17·8 | 18·1 | | | | |
| Milk yield (kg $d^{-1}$) | 29·8 | 30·7 | 29·2 | 29·5 | 0·61 | NS | NS | NS |
| Milk fat (g $kg^{-1}$) | 39·4 | 41·0 | 40·5 | 41·2 | 0·68 | NS | NS | NS |
| Milk protein (g $kg^{-1}$) | 32·9 | 32·6 | 32·5 | 33·6 | 0·42 | NS | NS | NS |
| Milk lactose (g $kg^{-1}$) | 47·3 | 47·7 | 46·6 | 46·9 | 0·59 | NS | NS | NS |
| Fat + protein yield (kg $d^{-1}$) | 2·13 | 2·25 | 2·12 | 2·19 | 0·043 | * | NS | NS |
| End-of-study condition score | 2·5 | 2·5 | 2·6 | 2·5 | 0·06 | NS | NS | NS |
| End-of-study live weight (kg) | 620 | 618 | 636 | 628 | 9·2 | NS | NS | NS |

*, $P < 0·05$; DM, dry matter; s.e.m., standard error of the mean; NS, not significant.

 

**Table 4** Effect of feed space allowance per cow on the average frequency of aggressive behaviours recorded (per cow at the feed barrier, per 5-min period) during the 30-min period after fresh feed was offered, and during the 30-min period after cows had access to feed following pm milking (Experiment 1).

| | Feed space per cow | | |
|---|---|---|---|
| | 20 cm | 40 cm | 60 cm |
| After fresh feed was offered | | | |
| Butting | 0·052 | 0·028 | 0·012 |
| Pushing | 0·059 | 0·045 | 0·042 |
| Post-access to feed following pm milking | | | |
| Butting | 0·026 | 0·015 | 0·016 |
| Pushing | 0·090 | 0·056 | 0·041 |

this period. A similar trend, although of a shorter duration (approximately 2 h), was observed after cows returned following evening milking. During the remainder of the 24-h period, the number of cows feeding was relatively similar with all three treatments. Relatively few cows were observed standing throughout the measurement period in Experiment 1. However, with the 20 cm treatment, there was an obvious peak in the number of cows standing during the 2-h period after fresh food was offered. The number of cows lying peaked prior to fresh feed being offered, falling during the hour after fresh feed was offered to approximately 6, 4 and 2 cows with treatments 60, 40 and 20 cm respectively.

Mean feeding time per cow (4·6, 5·8 and 6·0 h $cow^{-1}$ $d^{-1}$ for treatments 20, 40 and 60 cm $cow^{-1}$, respectively) was calculated by summing the average number of cows at the feed barrier each hour (during a 24-h period) and dividing by the total number of cows in the group. Intake rates, calculated by dividing total average daily DM intake per cow by the mean feeding time per cow, were 4·17, 3·24 and 3·33 kg DM $cow^{-1}$ $h^{-1}$, for the 20, 40 and 60 cm treatments.

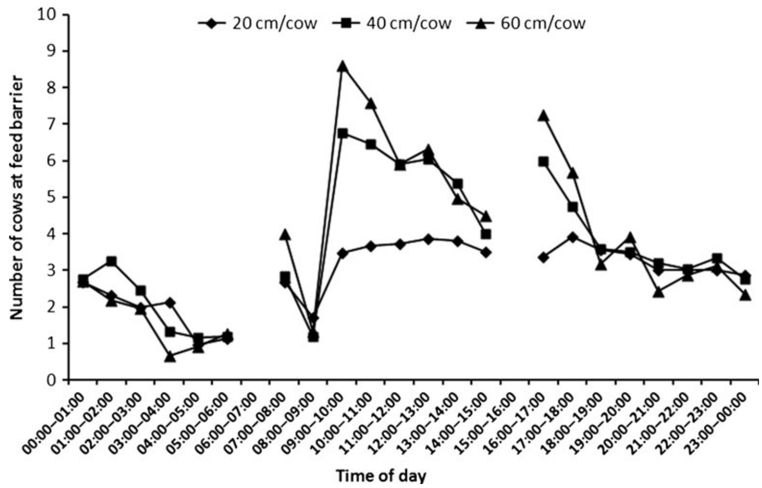


**Figure 1** Effect of feed space allowance on the mean number of cows feeding throughout a 24-h period (Experiment 1).

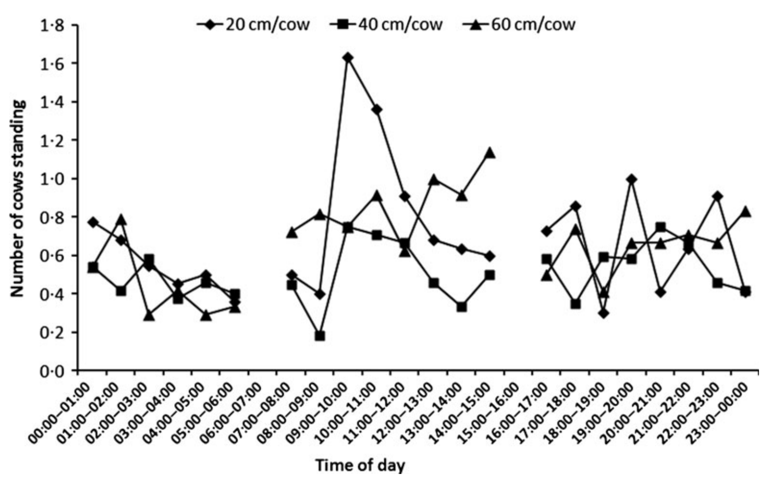


**Figure 2** Effect of feed space allowance on the mean number of cows standing in the feed passage throughout a 24-h period (Experiment 1).

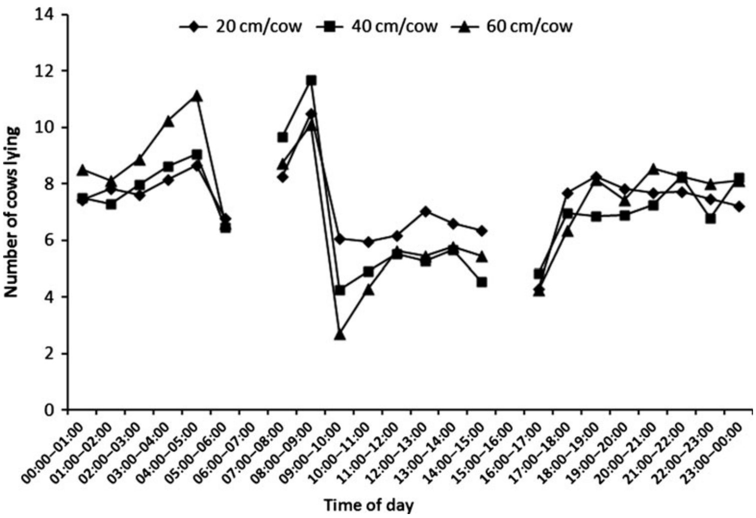


**Figure 3** Effect of feed space allowance on the mean number of cows lying throughout a 24-h period (Experiment 1).

The frequency of butting and pushing during the 30 min after fresh feed was offered in the morning and during the 30-min period after cows had access to feed following evening milking tended to decrease with increasing feed space allowance (Table 4).

The effect of treatment on the mean number of cows feeding and the mean number of cows standing behind the feed barrier during a 24-h period is presented in Figures 4 and 5 respectively (Experiment 2). With the unrestricted access time treatments, a maximum of six animals were observed feeding with the 40 cm treatment immediately after cows were given access to fresh feed, with this number declining to approximately four cows at approximately 5 h post-feeding. With the 15 cm treatment, 2–3 cows were observed to be feeding during the 5-h period following access to fresh feed. Following evening milking, the number of cows feeding tended to remain higher with the 40 cm treatment, compared with the 15 cm treatment until approximately 22·00 h, with only relatively small differences observed thereafter. The number of cows standing tended to be higher with the 15 cm treatment from the time fresh feed was offered, until midnight. This was particularly evident with the restricted access time treatment, especially around the time fresh feed was offered. Mean feeding times were 2·9, 3·6, 4·2 and 5·1 h for the 15 cm restricted and unrestricted treatments, and the 40 cm restricted and unrestricted treatments, respectively, while the associated intake rates were 6·25, 4·89, 4·37 and 3·56 kg DM cow$^{-1}$ h$^{-1}$ respectively.

## Discussion

### Feed space allowance and cow performance

Experiments 1 and 2 clearly demonstrate that milk yield was unaffected when feed space allowance was reduced from either 60 to 20 cm per cow, or from 40 to 15 cm per cow, although there was a small reduction

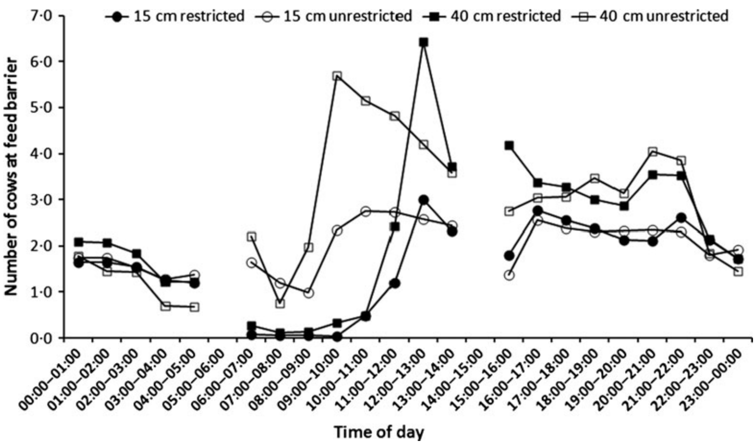


**Figure 4** Effect of feed space allowance and period of access to feed on the mean number of cows feeding throughout a 24-h period (Experiment 2).

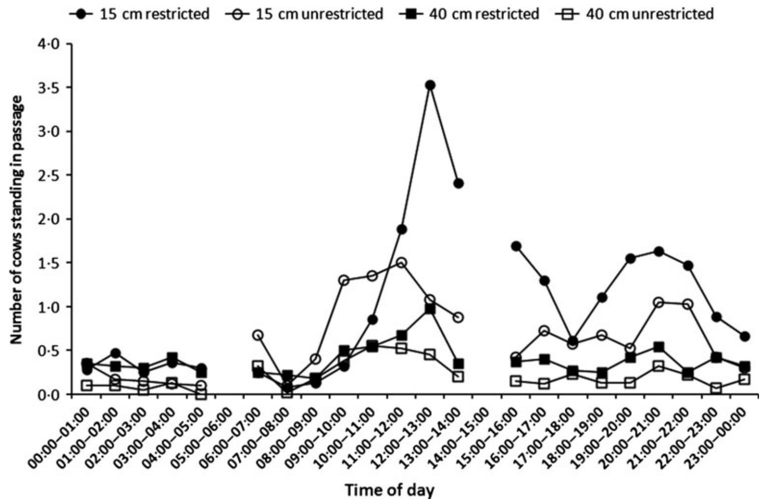


**Figure 5** Effect of feed space allowance and period of access to feed on the mean number of cows standing in the passage throughout a 24-h period (Experiment 2).

in fat + protein yield with the 15 cm per cow space allowance in Experiment 2. It is unlikely that such a small difference could have been identified as being significant in a study involving a small number of replicated 'group treatments'. In addition, although group intake data preclude a statistical comparison of differences in intakes between treatments, the numerical difference in intake between the 20 and 60 cm treatment in Experiment 1 was 0·3 kg DM cow$^{-1}$ d$^{-1}$, while in Experiment 2, the difference between the 15 and 40 cm cow$^{-1}$ treatments was 0·2 kg DM cow$^{-1}$ d$^{-1}$. These differences represent <1·5 and 1·1% of total feed intake with the high feed space allowance treatments in Experiments 1 and 2 respectively.

While the effect of feed space allowance has been examined in a number of experiments, most of these have been designed with cow behaviour as the primary focus. This is highlighted in that a number of experiments examining the effects of feed space allowance make no mention of cow performance. These include studies by DeVries *et al.* (2004) and DeVries and von Keyserlingk (2006) which compared feed space allowances of 50 and 100 cm cow$^{-1}$, and 64 and 92 cm cow$^{-1}$ respectively. However, other studies in which animal performance data were presented have significant limitations due to performance being examined over short measurement periods. For example, Friend *et al.* (1977) and Collis *et al.* (1980) progressively reduced the feed space available for a group of cows on a weekly basis (decreasing incrementally from 50 to 10 cm cow$^{-1}$, and from 105 to 15 cm cow$^{-1}$ respectively). In the former study, intake 'appeared' to decrease at the 10 cm space allowance, although milk yield was unaffected, while in the latter study, milk yield was unaffected by feed space allowance. In one of the few studies in which feed space allowance was examined over a reasonable time period (5-week periods), O'Connell *et al.* (2010) found that neither feed intake nor milk production performance differed between a feed space allowance of either 20 or 56 cm cow$^{-1}$.

While each of these experiments examined the effect of linear feed space allowance per cow, a number of other studies have reduced the 'feed space allowance' per cow by increasing the number of animals sharing individual feeding places. These include studies by Olofsson (1999) (either one or four cows per feed box), Elizalde and Mayne (2009) (either one, three, five, seven or nine cows per Calan gate) and Collings *et al.* (2011) (either one or two cows per feed bin). Neither feed intake nor milk production was affected by treatment in any of these studies.

In summary, the results of the current experiments, together with evidence from the literature, provide relatively little evidence that restricted feed space allowances (except when severely restricted: 15 cm cow$^{-1}$) have a negative effect on cow performance. Thus, the recommendation of a feed space allowance of at least 60 cm cow$^{-1}$, or that all cows should be able to feed simultaneously, is not supported by data relating to milk production performance. Although many earlier studies involved low-yielding cows, the results from Experiment 1, together with the findings of O'Connell *et al.* (2010), demonstrate that milk production performance can be maintained at feed space allowances as restrictive as 20 cm cow$^{-1}$ with groups of cows with a mean milk yield of approximately 30 kg d$^{-1}$. While there appear to be no controlled studies in which the performance of very-high-yielding cows have been compared across a range of feed space allowances, in a field trial by Menzi and Chase (1994) rolling herd averages of 10 000 kg of milk per annum (40 L d$^{-1}$) were observed with space allowances of between 37 and 40 cm cow$^{-1}$. Thus, this study highlights that high levels of performance can be achieved with feed space allowances considerably lower than the 60 cm cow$^{-1}$ frequently recommended. Nevertheless, the small reduction in fat + protein yield observed with the 15 cm cow$^{-1}$ space allowance in Experiment 2 demonstrates that at dramatically reduced feed space allowances, production is likely to be compromised.

Within the current experiment, all of the diet (with the exception of 1·0 kg concentrate cow$^{-1}$ d$^{-1}$ offered in-parlour) was offered at the feed barrier in the form of a total mixed ration. This feeding practice was adopted so as to put maximum pressure on the available feed space. However, on many farms, a considerable proportion (if not all) of the total daily concentrate allowance may be offered via in-parlour or out-of-parlour concentrate feeding systems. Thus, in these situations, the pressure on feed barrier space would be expected to be much reduced compared with that within the current experiments.

While restricted feed space allowances (down to 20 cm cow$^{-1}$) appear to be possible from a cow performance point of view, severe feed space restrictions create very practical difficulties. For example, when feed was offered once-daily with the 15 and 20 cm cow$^{-1}$ treatments (Experiments 2 and 1, respectively), the quantity of feed in front of the feed barrier was such that it tended to spill out over the feed passage, while it was also easier for cows to pull feed into and onto the floor of the pen, thus causing wastage.

## Access time to feed and cow performance

As with feed space allowance, information on the impact of restricted access times to feed on cow performance is limited, with most published studies having been designed primarily to examine cow behaviour, rather than cow performance. In addition, most studies examining the impact of restricted access time to feed have involved cows confined in individual tie stalls, a situation that is quite different to that within a group-housed environment. In one such study, Erdman *et al.* (1989) observed that neither DM intake (per unit of live weight) nor milk yield differed when cows housed in individual tie stalls accessed feed for 8, 12, 16 or 20 h d$^{-1}$. Similarly, using animals in tie stalls, Munksgaard *et al.* (2005) found that neither intake nor milk yield was affected when period of access to feed was reduced from 24 to 12 h d$^{-1}$. In a separate study, these same authors observed a reduction in both milk yield and intake when period of access to feed, lying and social contact was reduced from 23 to 12 h d$^{-1}$ and suggested that time constraints on lying behaviour will have more severe consequences than time constraints on eating.

In a study similar to Experiment 2, Collings *et al.* (2011) examined the relationship between space allowances (one vs two cows per feed bin) and duration of access to feed (14 h vs 24 h). While milk yield was unaffected by treatment, intakes were lower with the restricted access time treatment ($P < 0{\cdot}06$), although there was no interaction between access time and 'feeding density'. Nevertheless, cows were only on each treatment for a 7-d period. Similarly, Chapinal *et al.* (2011) imposed a restriction on access time to a total mixed ration by putting cows overnight at pasture and found no effect on feed intake during the course of the day. Thus, the results of the current study are largely in agreement with those cited in the literature, namely that cows are able to adapt to a period of restricted access to feed without any detrimental effects on performance, even at very low feed space allowances.

Within the current study, cows on the restricted access treatments soon became accustomed to the fact that fresh feed was not offered at 09·30 h, when cows on the unrestricted access treatment were fed. Indeed, it was observed that after a period of time, these cows no longer came to the feed barrier when the latter group's feed was being dispensed from the mixer wagon. In this situation, where an access time restriction was imposed on a daily basis, it is likely that cows suffer relatively little stress when feed is not present at the barrier. Indeed, Erdman *et al.* (1989) concluded that when enough feed is offered for *ad libitum* consumption, and timing of feeding is consistent from day to day, access to feed can be limited to 8 h d$^{-1}$ with no adverse effects. However, it is suggested that in a situation where cows have restricted access to feed on an erratic basis, for example when feeding times are variable or when feed runs out at various intervals prior to fresh feed being offered, cows are more likely to experience stress, than during a regular period without access to feed.

## Feeding, standing and lying patterns

The diurnal patterns of feed barrier occupancy observed within Experiments 1 and 2 are similar to those reported previously (DeVries *et al.*, 2003; O'Connell *et al.*, 2010), with the greatest level of occupancy observed during the day, especially after fresh feed was offered, and after evening milking. However, with the high feed-space allowance treatments, a greater number of animals were able to feed immediately after fresh feed was offered, while only 3–4 cows were able to feed simultaneously with the 20 cm cow$^{-1}$ treatment. This difference remained evident during the 5-h period after fresh feed was offered, and during the 2-h period after cows returned following evening milking. Thereafter, the number of cows feeding remained relatively constant with all three treatments.

In contrast, there was a trend for a greater number of cows to be observed standing in the feed passage, especially around the time that fresh feed was offered, with the restricted access treatments. A similar effect was observed by Huzzey *et al.* (2006) and DeVries and von Keyserlingk (2006), with the latter suggesting that while these cows were motivated to feed at this time, they had to wait for feed space to become available. However, their numbers were relatively small. In contrast, in Experiment 1, there was a trend for a greater number of cows to be observed lying during the 5-h period after fresh feed was offered with the 20 cm cow$^{-1}$ treatment. This might indicate that less dominant cows simply waited for the feed barrier to become less crowded, before attempting to access feed. However, the impact of diet sorting on the quality of diet being consumed by these later feeding cows has been highlighted by DeVries and von Keyserlingk (2006), with these authors suggesting that cows feeding later in the day are likely to consume a diet of a lower quality. Thus, the results of these two experiments provide clear evidence that cows modify their time budgets to deal with restrictions in feed access. Munksgaard *et al.* (2005) noted that changes in time budget may reflect adaptation to a specific environment without having any negative consequences for the welfare of animal.

That similar intakes were observed with restricted and unrestricted space allowance treatments, despite the mean number of cows feeding at any one time being quite different demonstrates that cows were able to modify their intake rates to maintain food intake. Intake rates calculated within these experiments, together with evidence from the literature, confirm that dairy cows have a high capacity to modify their feeding behaviour so as to maintain intakes when access to feed is restricted. For example, when the number of cows sharing each feed space was increased from 1 to 9, Elizalde and Mayne (2009) observed that the number of meals per day increased, while mean duration of each meal and total feeding time per day decreased. However, cows were able to maintain their daily intakes by increasing their mean daily intake rates from 29 to 96 g DM min$^{-1}$. Similarly, Munksgaard *et al.* (2005) using animals in tie stall barns found that neither intake nor milk yield was affected when period of access to feed was reduced from 24 to 12 h d$^{-1}$, although cows with restricted access time to feed spent less time eating (243 vs 293 min d$^{-1}$) but had an increased rate of feed intake (0·104 vs 0·086 kg min$^{-1}$).

There is also evidence that when access to feed is restricted, submissive cows will increase their intake rates to a greater extent than dominant cows (Harb *et al.*, 1985). While it has been suggested that this increase in intake rate, which has been observed previously after restricted cows are given access to fresh food (Collings *et al.*, 2011), could have a detrimental effect on rumen function, cow performance data within the current experiments suggest that rumen function was not impaired, despite the increase in intake rates calculated. Similarly, neither ruminating time nor total chewing time was affected when feed access time was reduced from 20 to 8 h d$^{-1}$ (Erdman *et al.*, 1989).

## Impact of feed space allowance and restricted access to feed on aggression

While the primary aim of Experiment 1 was to examine the effect of feed space allowance on cow performance, frequency of aggressive interactions was also recorded during the 30-min period after cows had access to fresh feed, and after cows returned from evening milking. In common with the findings of previous studies (DeVries *et al.*, 2004; DeVries and von Keyserlingk, 2006; O'Connell *et al.*, 2010), the frequency of aggressive interactions tended to increase as feed space allowance decreased. In addition, DeVries and von Keyserlingk (2006) observed that when feed space was increased, cows with lower social status at the feed bunk experienced the greatest decrease in the number of times they were displaced each day. DeVries and von Keyserlingk (2006) concluded that from a behavioural point of view, there were benefits in increasing feed space allowances beyond the recommended allowance of approximately 60 cm cow$^{-1}$.

While the frequency of aggressive interactions were only observed for 30-min periods after cows had access to fresh feed, and after cows returned from evening milking, these coincided with periods of maximum feed barrier occupancy with all treatments. Feed barrier occupancy decreased rapidly with the higher feed-space allowance treatments during the subsequent hours, and while not measured, it is likely that the number of aggressive interactions also decreased. While occupancy with the lowest space-allowance treatment remained high for much longer periods of time, it is unclear whether the trend for higher levels of aggression observed during the two 30-min focus periods continued longer term. Despite these trends towards differing levels of aggression between treatments, these were not associated with any reduction in cow performance. In addition, while it might be expected that heifers will suffer most at a restricted feed space allowance, there was no indication of an interaction between either feed space allowance or period of access to feed, and parity, for milk yield, in either experiment. Nevertheless, von Keyserlingk *et al.* (2009) have highlighted that although it is often assumed that poor welfare will be reflected in low milk production, and *vice versa*, a high level of milk production is no guarantee of high welfare, nor is a low level of production to be taken as an automatic sign of poor welfare.

## Conclusions

Cow performance was unaffected by period of access to feed or by a feed space allowance of 20 cm $cow^{-1}$, while fat + protein yield was reduced at a space allowance of 15 cm $cow^{-1}$. When access to feed was restricted by space or time constraints, cows modified their time budgets and intake rates so as to maintain intakes.

## Acknowledgments

Thanks are due to the Dairy Unit staff at AFBI Hillsborough for care of the experimental animals and for assisting with experimental measurements. This study was co-funded by the Department of Agriculture and Rural Development (DARD) in Northern Ireland and by AgriSearch (farmer levy).

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