Performance, milk fatty acid composition and behaviour of high-yielding Holstein dairy cows given a limited grazing period

by Atkins, N.E., Cianchi, C., Rutter, S.M., Williams, S.J., Gauld, C., Charlton, G.L. and Sinclair, L.A.

DOI: https://doi.org/10.1111/gfs.12471

Atkins, N.E., Cianchi, C., Rutter, S.M., Williams, S.J., Gauld, C., Charlton, G.L. and Sinclair, L.A. Performance, milk fatty acid composition and behaviour of high-yielding Holstein dairy cows given a limited grazing period. *Grass and Forage Science*.
3 April 2020

Performance, milk fatty acid composition and behaviour of high-yielding Holstein dairy cows given a limited grazing period

Running title: Grazing high-yielding cows

N. E. Atkins, C. Cianchi, S. M. Rutter, S. J. Williams, C. Gauld, G. L. Charlton and L. A. Sinclair[1]

Department of Animal Production, Welfare, and Veterinary Sciences, Harper Adams University, Newport, Shropshire, TF10 8NB, United Kingdom

[1]*Correspondence:* Liam A. Sinclair, Department of Animal Production, Welfare, and Veterinary Sciences, Harper Adams University, Newport, Shropshire, TF10 8NB, United Kingdom.

E-mail: lsinclair@harper-adams.ac.uk

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of the Harper Adams University farm staff, laboratory technicians and students. We are also grateful for the assistance of Dr Bob Mayes, James Hutton Institute, for the n-alkane analysis. The financial support from AHDB Dairy is gratefully acknowledged.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this article.

ORCID

Norton E. Atkins http://orcid.org/0000-0002-7414-6956

Liam A. Sinclair http://orcid.org/0000-0002-8543-0063

Abstract

The effects of a limited grazing period on the performance, behaviour and milk composition of high-yielding dairy cows was examined. A total of 56 Holstein cows yielding 44.7 ± 0.42 kg/d were allocated to one of four treatments in one of two, 4-week periods. Treatments were: Control (**C**) - cows housed and offered TMR *ad libitum*; Early Grazing (**EG**) - cows grazed for 6 hr after morning milking then housed; Delayed Grazing (**DG**) - cows returned to housing for 1 hr after morning milking followed by grazing for 6 hr, then housed; Restricted TMR (**RT**) - cows grazed for 6 hr after morning milking then housed and fed TMR at 75% of *ad libitum*. Intake of TMR was highest in cows receiving C, intermediate in EG and DG, and lowest in RT at 26.9, 23.6, 24.7 and 20.3 kg DM/d respectively. Pasture intake was similar in cows receiving EG or DG, but was higher in RT at 2.4, 2.0 and 3.5 kg DM/d respectively. Milk yield was similar between cows receiving C, EG or DG, but lowest in RT at 45.7, 44.2, 44.9 and 41.7 kg/cow respectively, whilst milk fat content of C18:3 n-3 was increased by grazing. Cows in C spent more than 55 min/d longer lying and had three additional lying bouts/d, whilst lying bouts were shorter than for cows receiving EG, RT or DG. It is concluded that high-yielding cows can be grazed for 6 hr/d with little impact on performance, provided TMR is available *ad-libitum* when housed.

Keywords: behaviour, fatty acid, grazing, intake, milk production

1 | INTRODUCTION

Grazing lactating dairy cows in many Western countries is decreasing as milk production per cow increases, resulting in the greater use of summer housing and total mixed ration (TMR) feeding (March et al., 2014; Wolf et al., 2015). Increasing the proportion of grazed pasture in the diet of dairy cattle can however, offer economic, environmental, milk quality and animal welfare benefits (Hennessy et al., 2015). For example, grazing dairy cows for part of the day can lower farm expenses and increase profit in scenarios with high feed costs and low milk prices (Tozer et al., 2003), and reduce the methane output of animals (Dall-Orsoletta et al., 2016; Mufungwe et al., 2014). Grazing may also increase the concentration of fatty acids (FA) in milk that are beneficial to human health (Barca et al., 2018; Mufungwe et al., 2014) and, because cows can exhibit motivation to be outside at pasture (Motupalli et al., 2014), pasture access allows natural behaviour to be expressed which may potentially improve animal welfare. Some farmers in European countries such as the United Kingdom (UK), the Netherlands and Germany are currently incentivised by milk companies to graze milking cows for a minimum of 6 hr per day, while in Scandinavia, legislation requires cows to have outdoor access for at least 6 hr per day during the summer months. Providing pasture on its own however, is insufficient to meet the nutrient requirements of high yielding dairy cows, limiting their daily milk production to below 30 kg/cow (Kolver & Muller, 1998). Alternating grazing with TMR feeding between the am and pm milking intervals has also been reported to lower milk yield compared with housed and TMR fed cows (Bargo et al., 2002; Soriano et al., 2001), unless TMR was provided in the field (Mufungwe et al., 2014). Recently it has been reported that limiting the time cows have at pasture to 6 hr per day allows cows in mid to late lactation to graze pasture and consume sufficient TMR to maintain milk yield in comparison with housed and TMR fed cows (Dall-Orsoletta et al., 2016).

Despite the potential benefits from grazing, little is known about the effects of the length or timing of a grazing period on the performance and behaviour of high yielding cows. Behavioural studies have revealed that cows with free access to pasture and housing, rapidly consume a meal of TMR following milking before going out to pasture (Charlton et al., 2011; Motupalli et al., 2014), a strategy that was able to maintain milk yield but limited pasture intake to less than 2 kg DM/cow per d. The diurnal response of cows to consume feed around dawn/morning milking (Gregorini, 2011) may also be used to increase the pasture intake of high yielding cows receiving limited access to pasture and fed a TMR when housed. Additionally, restricting the access of cows to TMR prior to grazing, or restricting the allowance of TMR when housed may promote grazing and pasture intake, although few studies have been conducted in this area. The primary objective of this study was to determine the effects of giving high yielding cows a 6 hr grazing period compared with continuously housed cows on feed intake, milk yield, milk composition, and behaviour, and to determine the effects of delaying the 6 hr grazing period or restricting TMR allowance with a 6 hr grazing period. It was hypothesised that total feed intake and milk yield would be unaffected by a 6 hr grazing period, but grazing behaviour, grass intake and milk composition would alter.

2 | MATERIALS AND METHODS

The study was conducted at Harper Adams University, Newport, Shropshire, UK (52°780´N, 2°434´W). Experimental work took place from the 12th May to 14th July 2015, with all procedures involving animals, conducted in accordance with the UK Animals (Scientific Procedures) Act 1986 (amended 2013).

2.1 | Experimental design and routine

2.1.1 |Animals and treatments

Fifty-six dairy cows with previous experience of grazing that were (mean ± SE) 89 ± 5.3 days post-partum, yielding 44.7 ± 0.42 kg milk/d, with a live weight (LW) of 644 ±7.7 kg and a body condition score (BCS scale 1-5; Ferguson et al., 1994) of 2.78 ± 0.029 were used. Twenty-eight cows were allocated to one of four groups of seven cows for a period of 28 d duration. Another 28 cows were allocated in the same way, in a consecutive period of 28 d. Period 1 occurred during May and June, and period 2 during June and July 2015. At the start of each period, the cows were stratified according to their milk yield, LW, feed intake and milk fat content measured in the week prior to allocation, and randomly allocated to one of four treatments. The treatments were; Control (**C**) - cows were continuously housed and offered a TMR *ad libitum*; Early grazing (**EG**) - cows grazed for 6 hr directly post am milking and then housed and offered TMR *ad libitum*; Delayed Grazing (**DG**) - cows were returned to housing for 1 hr post am milking before being grazed for 6 hr and then housed and offered TMR *ad libitum*; Restricted TMR (**RT**) - cows were grazed for 6 hr directly post morning milking then housed and offered TMR that was restricted to 75% of *ad libitum* intake. Cows remained on treatment for four weeks with measurements undertaken during the final week.

Cows were milked twice daily at approximately 06:30 and 16:30 h. Immediately following morning milking, treatments C and DG were allowed to return to the free-stall housing and feeding area, while treatments EG and RT were separated as they left the milking parlour and moved to the pasture. After 1 hr, cows receiving treatment DG were separated and moved to the pasture. After 6 hr at pasture, cows were gathered and returned inside (approximately 12:30 and 13:30 h for treatments EG/RT, and DG respectively). All cows had continuous access to water when indoors and at pasture.

2.2 | Grazing and pasture allocation

The grazing area consisted of a 3 ha paddock composed predominately of perennial ryegrass (*Lolilum perenne*), sown in spring 2011. The paddock had received 50 kg/ha N and 20 kg/ha S fertiliser, and was grazed once that grazing season with dairy cows before the beginning of the study. The area was subdivided with temporary electric fences to allow flexible rotational grazing. Cows were given a fresh strip of grass each day in blocks of three days, and then that block was back fenced and allowed to regrow. Each daily grass strip was further split into three parts of equal area and randomly allocated to the treatment groups who grazed independently. Grazing was counter balanced so that no group grazed the same area twice over a three-day block. Allocation of the grazing area was determined from herbage mass (HM), estimated daily prior to grazing by walking the paddock in a 'W' pattern and taking 30 random measurements using a rising plate meter (Jenquip, Fielding, New Zealand).

Daily fresh pasture allowance was initially set at 12 kg DM/d above a 4 cm base, but during the first 10 d of the study it became apparent that cows were consuming considerably less, and the daily amount was reduced to 6 kg DM/cow/d above a 4 cm base (8 kg DM on day one and 5 kg DM in each subsequent day of a 3 d block), plus the residual herbage from the previous days grazing during days two and three of each block. Post-grazing herbage mass was also recorded daily for each group using a rising plate meter. Target pre-grazing herbage mass was 2700-3000 kg DM/ha above ground level, with a mean of 2842 ± 89.2 kg DM/ha during the collection period. A group of non-lactating cows were used to graze residual herbage to 1500-1600 kg DM/ha above ground level, and mechanical topping was used to maintain pasture quality when necessary.

2.3 | Housing and TMR feeding

When housed, the cows were located together in the same portion of a free-stall building containing Super Comfort cubicles fitted with foam mattresses (IAE, Stoke-on-Trent, United Kingdom). Fresh TMR was delivered at approximately 08:00 h daily using a forage mixer wagon (Hi-spec Engineering Ltd, Bagenalstown, Ireland) calibrated to ± 0.1 kg, and was composed of maize silage, lucerne silage and straight feeds, formulated according to Thomas (2004; Table 1). The TMR was accessed via 30 electronic roughage intake control (RIC) bins (Insentec, Marknesse, The Netherlands). Cows were trained to use the bins at least one week prior to each study period. Cows receiving treatments C, EG or DG received *ad-libitum* access to the TMR, with those receiving RT were restricted to 75% of the DM intake of their corresponding pair in treatment C.

2.4 | Experimental measurements

2.4.1 | Feed intake milk yield, composition and live weight

Grass and TMR samples were collected during the final five days of each period. Samples of the TMR were collected within 10 min of feeding, and grass 'pluck' samples were taken at approximately 07:30 and 11:30 h as described by Smit et al. (2005) to represent the herbage in the grazed horizon, and stored at -20°C prior to subsequent analysis. Individual grass intake was estimated using the n-alkane method as described by Mayes et al. (1986). For the final 12 d of each period, a daily dose of C32 alkane (dotriacontane) was thoroughly incorporated into the TMR at 2.0 g/cow/d. Briefly; alkane powder (56 g) was mixed with 1 kg of the straight feeds mix, and the straight feeds plus alkane mix was then scattered across the TMR and mixed for 10 minutes. The daily TMR intake was then used to calculate the quantity of n-alkane consumed by each cow. Faecal samples for each cow were collected during the final 5 d of each period between 04:00 – 06:00 and 16:00 – 18:00 h from naturally voided faecal deposits of certain origin at the time of deposition, and frozen at -20°C. Milk yield was recorded at each milking for all cows during the collection period, with sub-samples collected on four separate occasions (2 x am and 2 x pm) during week 4 of each period for subsequent analysis. Cow LW was measured (Trutest, Auckland, New Zealand) and BCS (Ferguson et al., 1994) recorded at the start and end of each four-week treatment period at approximately 16:30 h.

2.4.2 | Visual and automatic behaviour recording

On days 4 and 7 of week 3 of each experimental period, visually observed behaviour was recorded for cows receiving treatments EG, DG and RT for the 6 hr whilst they were at pasture. Every 5 min during each observational period the posture (lying, standing, walking) and jaw activity (grazing, ruminating, drinking, idling) of each cow was recorded. Binoculars were used when necessary for accurate identification of each cow and to maintain a distance from the cows to prevent disturbance. Prior to the study each cow had an accelerometer (IceQube, IceRobotics Ltd, Edinburgh, UK) attached to their hind left leg. The sensors recorded lying time (LT min/d), frequency of lying bouts (LB/d), average lying bout duration (LBD; min/bout) and step count (steps/d). All data were stored within the accelerometer device and subsequently uploaded each time the cows walked past a reader (CowAlert system, IceRobotics Ltd, Edinburgh, UK), at the entrance to the milking parlour. Time spent eating TMR was determined using the data recorded by the RIC feeders for each cow during the final week of each period.

2.5 | Chemical analysis

Grass and TMR samples were bulked by period, and a sub-sample of grass was freeze dried (Edwards Modulyo, Bolton, UK) and TMR oven dried to constant weight and analysed (AOAC, 2012) for ash (942.05) and crude protein (CP; 990.03) content. Faecal samples were bulked within cow and a sub-sample freeze dried for subsequent analysis. Fibre content of the TMR and grass was assessed according to the method of Van Soest et al. (1991), and water soluble carbohydrate (WSC) according to Thomas (1977). Grass metabolisable energy content (ME; MJ/kg DM) was predicted from the concentration of modified acid detergent fibre (MADF; Givens et al., 1990). Milk samples were analysed for fat, protein and lactose content using a Milkoscan Minor (FOSS, Warrington, UK) calibrated according to AOAC (2012), and energy corrected milk yield (ECM) calculated using milk yield, milk fat, protein and lactose content (Sjaunja et al., 1990). Fatty acid methyl esters (FAME) in hexane were prepared from milk fat by the method of Feng et al., (2010) and from feeds by the method of Jenkins (2010). Individual FAME were determined by GLC (Hewlett Packard 6890, Wokingham, UK) fitted with a CP-Sil 88 column (100 m x 0.25 mm i.d. x 0.2 μm film). Hydrogen was used as the carrier gas and a programmed temperature sequence was used; further details and conditions have been described previously (Lock et al., 2006). Grass, TMR and faecal samples were analysed for n-alkanes and grass intake for each cow calculated from the concentrations of the naturally occurring odd-chain (C33) and the dosed even-chain (C32) n-alkane using the method described by Mayes et al. (1986). Alkane analysis was conducted on a GLC (Phillips PU 4500; Phillips, Surrey, UK), fitted with a 30 m x 0.32 mm 0.25μm fused silica capillary column (Restec Corporation, Bellefonte, USA) using helium as the carrier gas. Oven temperature was programmed at 190°C for 3 min and then increased by 6°C per min until 316°C.

2.6 | Statistical analysis

Data were evaluated by ANOVA in Genstat v.17 (VSN International 2015). Feed intake, milk production, fatty acid, LW and BCS variables were tested for normality and fitted to the model:

$$y_{ijk} = \mu + P_i + B_j + T_k + \epsilon_{ijk}$$

where y_{ijk} = dependent variable; μ = overall mean; P_i = random effect of period; B_j = random effect of block; T_k = effect of treatment; ε_{ijkw} = residual error. Measurements of feed intake, milk production, LW and BCS taken prior to allocation were used as covariates in the model if appropriate. Behaviour data were evaluated using the same model for the individual animals. Differences were considered significant at $p < 0.05$ and a least significant difference test was conducted post hoc.

3 | RESULTS

3.1 | Chemical analysis of the diets

The DM content of the TMR was more than double that of the grazed grass (Table 1), but the ME and CP content was similar in both feeds, with a mean value of 12.2 MJ/kg DM and 176 g/kg DM respectively. The WSC and NDF concentration was 121 and 61 g/kg DM higher in the grazed grass than the TMR respectively. Total FA content was 8 g/kg DM higher in the TMR than the grass. The major FA in grass was C18:3 n-3, which contributed 41g/100g FA, whereas in the TMR C16:0, C18:1n-9 and C18:2n-6 were the major FA, each contributing approximately 28 g/100g FA.

3.2. | Intake and performance

Intake of TMR was highest ($p < 0.05$) in cows offered C, and was approximately 3 kg DM/d higher than in cows offered EG or DG, which did not differ ($p > 0.05$; Table 2). The lowest intake of TMR was in cows receiving RT, which was 75% of the value of cows receiving the Control. In contrast, grass intake was highest ($p < 0.05$) in cows receiving RT at 3.5 kg DM/d compared to the mean value of 2.2 kg DM in those receiving EG or DG. In the 6 hr prior to grazing, cows receiving DG had the highest ($p < 0.05$) TMR intake, at 7.6 kg DM, whilst those in C, EG and RT were similar at 4.5 kg DM (Figure 1). In the 6 hr following grazing, cows receiving EG, DG and RT had a similar ($p > 0.05$) intake, with a mean of 10.6 kg DM, whilst the TMR intake of those receiving C was the lowest ($p <$

0.05) at 7.4 kg DM. Total DM intake was similar in cows receiving C, EG or DG (mean value of 26.5 kg/d), and was approximately 2.7 kg DM/d higher than cows receiving RT ($p < 0.05$; Table 2). Milk yield was similar in cows receiving C, EG or DG, with a mean value of 44.9 kg/d, but was lower ($p < 0.05$) in cows fed RT compared to C or DG. However, ECM was similar ($p > 0.05$) between treatments, with a mean value of 37.6 kg/d. There was no effect ($p > 0.05$) of treatment on milk fat or protein content, whereas milk protein and lactose yield were higher ($p < 0.05$) in cows receiving C compared to RT. Cows receiving C also had a higher LW and greater LW gain than those receiving RT ($p < 0.05$), with EG and DG being intermediate. There was no effect ($p > 0.05$) of treatment on BCS or BCS change.

3.3 | Milk fatty acid profile

Milk fat content of C10:0 and C14:0 were lowest ($p < 0.05$) in cows receiving RT and highest in EG (Table 3). The odd-chain FA C15:0 was lowest in milk from cows fed RT and highest in C ($p < 0.05$), whereas C17:0 was lowest in cows receiving C and highest in those offered DG ($p < 0.05$). There was no effect ($p > 0.05$) of treatment on the trans FA content of milk, except C18:1 t12, which was lower in C than any of the treatments that received access to pasture. Milk content of C18:1 c9 was highest ($p < 0.05$) in cows offered RT and lowest in cows offered EG. There was an effect of the inclusion of access to pasture on the milk fat content of C18:3 n-3, which was approximately one-third higher in cows receiving any of the grazing treatments (EG, DG or RT) compared to those receiving C ($p < 0.001$). Cows receiving RT had a lower content of saturated and a higher content of MUFA compared to those offered EG ($p < 0.05$). Similarly, milk FA of <C16 was lowest ($p < 0.05$) in cows receiving RT compared to EG, whereas milk FA >C16 was highest ($p < 0.05$) in cows receiving RT compared to C.

3.4 | Behavioural measurements

When visually observed, cows that had access to pasture spent on average 42.9% of their time at pasture grazing, 32.7% ruminating, 1.4% drinking and 22.9% idle, which was not affected by treatment ($p > 0.05$; Table 4). There was also no difference ($p > 0.05$) in jaw activity (grazing, ruminating, drinking and idling) between cows receiving EG, DG or RT. Whilst at pasture, cows spent on average 42.2% of their time lying, and 55.7% standing, which was not affected by treatment ($p > 0.05$). In contrast, there was a difference ($p < 0.01$) in the proportion of time spent walking at pasture; cows receiving EG spent a greater proportion of their time walking than either DG or RT, which did not differ.

When activity was recorded over 24 h/d (during pasture access and indoors) using accelerometers, there was a difference ($p < 0.001$) between cows receiving C compared to those receiving EG, RT or DG in all behavioural activities. Cows receiving C spent at least 55 min/d longer lying and had three additional LB/d, whilst lying bouts were shorter than for cows receiving EG, RT or DG ($p < 0.001$; Table 4). Cows in C also took less steps/d compared to EG, RT or DG ($p < 0.001$). There were no differences ($p > 0.05$) in behavioural activity, measured using the accelerometers, between cows receiving treatments EG, RT or DG. When recorded by the RIC system, time spent feeding on TMR was highest ($p < 0.05$) in C (191 ± 11.1 mins/d), lowest in RT (124 ± 10.8 mins/d) and intermediate in EG and RT (both 152 ± 10.8 mins/d).

4 | Discussion

4.1. | Intake and performance

The current study was conducted over the summer months when the reproductive growth of pasture can reduce its feed quality compared to earlier in the grazing season (Givens et al., 1993). Summer grazing is, however, common practice on many dairy systems, with approximately 92% of dairy farms in Britain grazing for at least part of the day during summer (March et al., 2014). Typical values for pasture ME on commercial farms in the UK are less than 12 MJ ME/kg DM over the summer (Wilkinson et al., 2014). In comparison, the grass used in the current study, at 12.5 and 12.0 MJ ME/kg DM in the first and second periods respectively, was above average, and similar to the TMR.

Similarly, NDF and ADF content of the pasture was low (Wilkinson et al., 2014), indicative of a leafy well-managed pasture (Dale et al., 2018), although the pasture contained a moderate concentration of CP, but CP was similar to the TMR and sufficient for animal performance (Sinclair et al., 2014). The cows in the current study grazed laxly, with post-grazing HM of approximately 2400 kg DM/ha above ground level, and the high-quality pasture was maintained using hard grazing with dry cows following the experimental cows, then mechanical topping if still required for an even sward. Commercially, following grazing with dry cows may be insufficient to maintain pasture quality, as dry cows may be too few in number on a commercial farm to keep up with a grazing rotation and greater use of mechanical topping may be required with an associated increase in pasture wastage.

The major limiting factor for production in pasture-based systems for dairy cows is often not grass quality, but DM intake (Kolver, 2003). The current study aimed to maintain overall DM intake, with TMR offered *ad libitum* while housed, except for cows in RT that were restricted to 75% of *ad-libitum* intake, and the provision of sufficient grass HM to facilitate a high rate of intake while at pasture. A feeding bout was expected immediately following morning milking, therefore moving the cows receiving EG to pasture at this point was hypothesised to promote a greater desire to consume grass, and therefore increase grass intake. Delaying access to pasture for cows in DG following milking was hypothesised to reduce grass intake as a result of increased TMR intake prior to grazing. The DMI results for the 6-hr period prior to grazing indicate that cows in DG did consume the greatest quantity of TMR during this period, however, grass intake of cows in EG or DG was similar (mean of 2.2 kg DM/cow/d, or 8.2% of total DMI). Approximately 40% of the time at pasture for cows in EG or DG was spent grazing, and therefore the rate of intake at pasture was low in comparison with predominately pasture-fed dairy cows. For example, in cows with unrestricted access to pasture the mean rate of intake of grass ranged from 16.2 to 44.8 g of DM/min (Pérez-Prieto & Delagarde, 2013), and at these values, the 6 kg DM/d offered in the current study could have been consumed between 2.2 and 6.2 hr at pasture. Low intakes of grass in TMR-fed dairy cows offered pasture has also been reported in previous work, with Motupalli et al. (2014) reporting a grass intake of only 0.8 to 1.6 kg

DM/cow/d when cows had free access to pasture and TMR. Similarly, in a study comparing continuous housing with daytime or night time grazing, either with or without TMR access at pasture, Mufungwe et al. (2014) reported grass intakes of 1.1 kg DM/cow during the day, or 0.7 kg DM/cow at night, when cows had access to TMR while at pasture. When TMR was not provided in the field, Mufungwe et al. (2014) reported that grass intake increased to 2.6 kg DM/cow, but total DMI was decreased. The continuously housed cows in the current study were able to consume more feed (8.5 kg DM), during the 6 hr following the morning milking, which corresponds to the grazing period of the other treatments. Despite this, cows in both EG and DG achieved a similar total DMI to C cows, which was a consequence of the grazing groups increasing the duration and intensity of TMR feeding at other times of the day.

It was hypothesised that the intake of grass would be highest in cows receiving RT, as these animals would be hungrier and have a greater drive to consume grass, which would compensate for the restriction of the TMR. Although the intake of grass for RT cows was higher than DG or EG, it was still only 3.5 kg DM/cow, approximately 14.7% of total DMI for these cows, and the time spent grazing (47.7% of time at pasture) was not different to cows in either of the other two grazing groups. Previous research has reported a longer grazing time when TMR was more severely restricted. For example, Fajardo et al. (2015), reported that when cows were offered 50% of the TMR of continuously housed cows and had 6 hr/d of grazing, they spent 64% of their time at pasture grazing, whilst cows with 9 hr/d of pasture access, grazed for 52% of the time, with a similar grazing duration for both groups. In combination, these results suggest that when TMR is the major component of a cows DM intake, their preference may be to wait for the TMR if it is not immediately available, even if this results in a reduced total DMI. Alternatively, evidence suggests that grazing is a partially learned behaviour (Charlton & Rutter, 2017), and thus limited early grazing exposure or limited incentive to graze may limit the intake of grass, although all the cows in the current study had extensive access to pasture prior to the study.

Milk yield reflected the pattern of DM intake, with a similar yield in cows receiving C, EG or

DG (mean of 44.9 kg/d), and was 3.2 kg/d lower in cows receiving RT. In contrast, previous research has reported that cows fed TMR alone had a higher milk yield than those receiving a combination of grazing and TMR (Bargo et al., 2002; Mufungwe et al., 2014; Soriano et al., 2001). However, these studies had a longer grazing period (7-12 hr/d), suggesting that the 6 hr/d used in the current study was within the ability of cows yielding 45 kg/d to compensate for a period without access to TMR. Although DMI from grass was low, this small amount may have had a positive impact on the overall nutrient digestibility of the diet, and it is also possible that there was increased mobilisation of adipose tissue in cows that grazed grass which may have supported the high level of milk production, as LW gain was lower in cows receving EG or RT compared to C. Chapinal et al. (2010) reported that early lactation cows could be grazed for approximately 10.5 hr overnight from 20:00 h without a reduction in TMR intake or milk production. However, both the TMR intake and milk yield were lower in the study of Chapinal et al. (2010) at 15.5 kg DM/d and 38.3 kg milk/d, and the cows may therefore have been able to consume sufficient TMR before overnight grazing with less reliance on the pasture. Other studies have observed negative production responses in early lactation when pasture has been a major component of the diet. For example, Fajardo et al. (2015), restricted the TMR of cows to 50% with either a 6 or 9 hr of grazing per day for 13 weeks from calving, and reported a milk yield of 33.8 kg/d, which was approximately 91% of the continuously housed cows. In the current study, with a 75% TMR allowance, the cows receiving RT did not fully compensate for their reduced DM intake when at pasture, despite sufficient time and HM allowance, with the consequence that their yield was reduced.

No difference was observed in milk fat or protein concentration in the current study, although milk fat content was nominally higher in RT and subsequently ECM was similar in all treatments. Lower milk yield of cows receiving RT compared to C resulted in a lower daily yield of protein, but not fat. Milk fat concentration has previously been reported to increase (Fajardo et al., 2015), decrease (Dall-Orsoletta et al., 2016; Morales-Almaráz et al., 2010), or remain unaffected (Soriano et al., 2001; Vibart et al., 2008) when grazing was included in the diet of TMR-fed cows. These differences may be a function of NDF intake, as pasture is typically higher in NDF than the TMR, which may be expected to increase milk fat concentration (Sutton, 1986). In the current study, the NDF content of the grass was approximately 20% higher than the TMR, but the intake of the grass was low and the subsequent effects on total NDF intake small. Additionally, other factors of the TMR, such as particle length and physically effective NDF content, may also have a large influence on milk fat content (Tayyab et al., 2018, 2019).

4.2. | Milk fatty acid profile

Increasing forage intake has the potential to improve the FA profile of milk by increasing unsaturated and decreasing saturated FA, with increases in beneficial long chain and reductions in medium chain fatty acids (Dewhurst et al., 2006; Elgersma, 2015). For example, pasture-fed vs. maize silage-based TMR-fed cows generally produce milk fat with increased concentrations of 18:3 n-3, C18:2 c9,t-11, C18:1 t11, C18:1 n-9, and C18:0, with decreasing concentrations of C12:0, C14:0 and C16:0 (Dewhurst et al., 2006). Other studies that have also incorporated a period of grazing with TMR feeding have also reported increases in the C18:3 n-3 concentration of milk fat (Barca et al., 2018; Morales-Almaráz et al., 2010; Vibart et al., 2008). In the current study, there was an increase of C18:3 n-3 by approximately 29% in the milk fat of cows with a 6-hr grazing period compared to TMR-only cows, although the amount was still comparatively small at less than 0.5% of the total fat content. The major source of C18:3 n-3 was from the grass, which contained 41g/100g FA compared with only 2.8 g/100g FA in the TMR. Despite the low intake of grass of cows receiving EG, DG or RT, the intake of C18:3 n-3 was calculated to be increased by approximately 43, 36 and 64 g/cow/d, respectively, compared to C. Approximately 90% of C18:3 n-3 would be expected to be biohydrogenated in the rumen (Sinclair et al., 2005), but would still result in a net absorption of between 4 and 6 g/d, and may explain the increase of this FA in milk of the grass-fed cows.

The majority of C18:3 n-3 is biohydrogenated in the rumen to c18:1t-11 and then C18:0, with the mammary gland desaturating the majority of C18:t-11 to C18:2 c9,t11, or C18:0 to C18:1 c9

(Elgersma, 2015). An increase in these intermediaries may also have been expected with the inclusion of grass in the diet, but no differences were observed in the milk from the cows receiving the 6 hr grazing compared to continuously housed cows, although C18:1 t-12 was higher and C18:2 t-10,c12 tended to be higher in cows in grazing treatments compared to C. The FA C18:2 t-10,c12 is a potent inhibitor of milk fat synthesis (Lock et al., 2006), and although not statistically significant, milk fat content was numerically lowest in C and was relatively low overall, with a mean of 32.1 g/kg across all treatments. Factors other than the proportion of grass in the diet can also affect the concentration of these FA in milk fatty acids, with for example basal forage and concentrate composition and ratio, pasture composition and vegetative state, rumen pH and animal factors playing an important role (Dewhurst et al., 2006).

Overall, none of the grazing treatments substantially affected total SAT, MUFA or PUFA content of the milk compared with continuously housed cows, although restricting TMR allowance did result in a lower SAT, higher MUFA, less *de novo* synthesised FA and more preformed FA in milk than unrestricted, early-grazed cows. Some of the differences in the milk FA composition between grazing treatments may be explained by the higher grass intake in RT compared to EG, and potentially less selective grazing or grazing to a lower sward horizon altering the FA profile, as grazing intensity has been shown to alter the chemical composition of grass (Dale et al., 2018).

4.3. | Behaviour

Lying is a high-priority activity for dairy cows, and is essential for health, welfare and productivity (Charlton & Rutter, 2017). When soil conditions are dry, and temperature and humidity temperate, cows have been reported to show a preference for lying outside (Krohn et al., 1992; Legrand et al., 2009). The cows that received 6 hr/d of grazing in the current study spent approximately 42% of their time at pasture lying down, compared with 38% of their time indoors lying. Continuously housed cows spent just over one hr/d more lying than those grazing, although the lying bouts were shorter in the continuously housed cows. This reduced lying time of the grazed cows is likely to be due to the additional time required for grazing. Previous studies have found that continuously housed cows will spend an average of 3 to 6 hr/d feeding (Charlton & Rutter, 2017). Although cows in C had a high DMI, which they were able to achieve in a relatively short feeding time of 191 min, cows in EG and DG achieved a similar DMI but in 298 minutes of feeding plus grazing. Interestingly, cows in RT spent a similar total time feeding and grazing (296 min), whilst total lying time was also similar between the grazing groups (566 min). There may therefore have been a conflict between lying and feeding/grazing, with the grazed cows in the current study perhaps reaching a minimum acceptable lying time, or maximum feeding time with the conditions presented to them. Alternatively, social interactions may have moderated the grazing behaviour of cows receiving RT, although each treatment grazed in an independent area. Variation in grazing behaviour has been observed to be related to milk yield, which influences appetite (Rind and Phillips, 1999) and the similarity in grazing time between groups may be due to the lower milk yield of RT cows rather than social influence from the adjacent groups.

5 | CONCLUSIONS

For cows with a milk yield of approximately 45 kg/d, providing access to pasture for 6 hr per day did not have a major effect on intake or milk performance, with grass only contributing approximately 8% of DMI. In contrast, having access to pasture for 6 hr/d and restricting TMR intake to 75% of *ad libitum* resulted in the highest grass intake, but this was not sufficient to compensate for the lower TMR intake, and milk performance was reduced. Providing access to pasture can increase the milk content of C18:3 n-3 but values were still low, at under 0.5% of the total fat. Having access to pasture also resulted in cows spending more time feeding and spending less time lying, but when they did lie, they did so for a longer period of time.

REFERENCES

AOAC. (2012). *Official Methods of Analysis of the Association of Official Analytical Chemistry*

(19th ed.). Washington, USA: AOAC International.

Barca, J., Carriquiry, M., Olazabal, L., Fajardo, M., Chilibroste, P., & Meikle, A. (2018). Milk fatty acid profile from cows fed with mixed rations and different access time to pastureland during early lactation. *Journal of Animal Physiology and Animal Nutrition*, *102*(3), 620–629. https://doi.org/10.1111/jpn.12826

Bargo, F., Muller, L. D., Delahoy, J. E., & Cassidy, T. W. (2002). Performance of high producing dairy cows with three different feeding systems combining pasture and total mixed rations. *Journal of Dairy Science*, *85*(11), 2948–2963. https://doi.org/10.3168/jds.S0022-0302(02)74381-6

Chapinal, N., Goldhawk, C., de Passillé, A. M., von Keyserlingk, M. A. G., Weary, D. M., & Rushen, J. (2010). Overnight access to pasture does not reduce milk production or feed intake in dairy cattle. *Livestock Science*, *129*(1–3), 104–110. https://doi.org/10.1016/J.LIVSCI.2010.01.011

Charlton, G. L, Rutter, S. M., East, M., & Sinclair, L. A. (2011). Effects of providing total mixed rations indoors and on pasture on the behavior of lactating dairy cattle and their preference to be indoors or on pasture. *Journal of Dairy Science*, *94*(8), 3875–3884. https://doi.org/10.3168/jds.2011-4172

Charlton, G. L., & Rutter, S. M. (2017). The behaviour of housed dairy cattle with and without pasture access: A review. *Applied Animal Behaviour Science*, *192*(April 2018), 2–9. https://doi.org/10.1016/j.applanim.2017.05.015

Dale, A. J., Laidlaw, A. S., McGettrick, S., Gordon, A., & Ferris, C. P. (2018). The effect of grazing intensity on the performance of high-yielding dairy cows. *Grass and Forage Science*, *73*(3), 798–810. https://doi.org/10.1111/gfs.12350

Dall-Orsoletta, A. C., Almeida, J. G. R., Carvalho, P. C. F., Savian, J. V., & Ribeiro-Filho, H. M. N. (2016). Ryegrass pasture combined with partial total mixed ration reduces enteric methane emissions and maintains the performance of dairy cows during mid to late lactation. *Journal of*

Dairy Science, *99*(6), 4374–4383. https://doi.org/10.3168/jds.2015-10396

Dewhurst, R. J., Shingfield, K. J., Lee, M. R. F., & Scollan, N. D. (2006). Increasing the concentrations of beneficial polyunsaturated fatty acids in milk produced by dairy cows in high-forage systems. *Animal Feed Science and Technology*, *131*(3–4), 168–206. https://doi.org/10.1016/J.ANIFEEDSCI.2006.04.016

Elgersma, A. (2015). Grazing increases the unsaturated fatty acid concentration of milk from grass-fed cows: A review of the contributing factors, challenges and future perspectives. *European Journal of Lipid Science and Technology*, *117*(9), 1345–1369. https://doi.org/10.1002/ejlt.201400469

Fajardo, M., Mattiauda, D. A., Motta, G., Genro, T. C., Meikle, A., Carriquiry, M., & Chilibroste, P. (2015). Use of mixed rations with different access time to pastureland on productive responses of early lactation Holstein cows. *Livestock Science*, *181*, 51–57. https://doi.org/10.1016/j.livsci.2015.09.023

Feng, S., Lock, A. L., & Garnsworthy, P. C. (2010). Technical Note: A Rapid Lipid Separation Method for Determining Fatty Acid Composition of Milk. *Journal of Dairy Science*, *87*(11), 3785–3788. https://doi.org/10.3168/jds.s0022-0302(04)73517-1

Ferguson, J. D., Galligan, D. T., & Thomsen, N. (1994). Principal descriptors of body condition score in Holstein cows. *Journal of Dairy Science*, *77*(9), 2695–2703. https://doi.org/10.3168/jds.S0022-0302(94)77212-X

Givens, D. I., Everington, J. M., & Adamson, A. H. (1990). The nutritive value of spring-grown herbage produced on farms throughout England and wales over 4 years. III. The prediction of energy values from various laboratory measurements. *Animal Feed Science and Technology*, *27*(3), 185–196. https://doi.org/10.1016/0377-8401(90)90081-I

Givens, D. I., Moss, A. R., & Adamson, A. H. (1993). Influence of growth stage and season on the energy value of fresh herbage. 1. Changes in metabolizable energy content. *Grass and Forage Science*, *48*(2), 166–174. https://doi.org/10.1111/j.1365-2494.1993.tb01849.x

Gregorini, P. (2011). Diurnal grazing pattern: its physiological basis and strategic management. *Animal Production Science*, *52*(7), 416–430. https://doi.org/10.1071/AN11250

Hennessy, D., Delaby, L., Van den Pol-van Dasselaar, A., & Shalloo, L. (2015). Possibilities and constraints for grazing in high output dairy systems. *Grassland Science in Europe, 20*, 151–162.

Jenkins, T. C. (2010). Technical note: Common analytical errors yielding inaccurate results during analysis of fatty acids in feed and digesta samples. *Journal of Dairy Science*, *93*(3), 1170–1174. https://doi.org/10.3168/jds.2009-2509

Kolver, E. S., & Muller, L. D. (1998). Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science*, *81*(5), 1403–1411. https://doi.org/10.3168/jds.S0022-0302(98)75704-2

Kolver, E. S. (2003). Nutritional limitations to increased production on pasture-based systems. *Proceedings of the Nutrition Society*, *62*(02), 291–300. https://doi.org/10.1079/PNS2002200

Krohn, C. C., Munksgaard, L., & Jonasen, B. (1992). Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments I. Experimental procedure, facilities, time budgets — diurnal and seasonal conditions. *Applied Animal Behaviour Science*, *34*(1–2), 37–47. https://doi.org/10.1016/S0168-1591(05)80055-3

Legrand, A. L., von Keyserlingk, M. A. G., & Weary, D. M. (2009). Preference and usage of pasture versus free-stall housing by lactating dairy cattle. *Journal of Dairy Science*, *92*(8), 3651–3658. https://doi.org/10.3168/JDS.2008-1733

Lock, A. L., Teles, B. M., Perfield, J. W., Bauman, D. E., & Sinclair, L. A. (2006). A Conjugated Linoleic Acid Supplement Containing trans-10, cis-12 Reduces Milk Fat Synthesis in Lactating Sheep. *Journal of Dairy Science*, *89*(5), 1525–1532. https://doi.org/10.3168/jds.s0022-0302(06)72220-2

March, M. D., Haskell, M. J., Chagunda, M. G. G., Langford, F. M., & Roberts, D. J. (2014). Current trends in British dairy management regimens. *Journal of Dairy Science*, *97*(12), 7985–

7994. https://doi.org/10.3168/jds.2014-8265

Mayes, R. W., Lamb, C. S., & Colgrove, P. M. (1986). The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *The Journal of Agricultural Science*, *107*(1), 161–170. https://doi.org/10.1017/S0021859600066910

Morales-Almaráz, E., Soldado, A., González, A., Martínez-Fernández, A., Domínguez-Vara, I., de la Roza-Delgado, B., & Vicente, F. (2010). Improving the fatty acid profile of dairy cow milk by combining grazing with feeding of total mixed ration. *Journal of Dairy Research*, *77*(02), 225. https://doi.org/10.1017/S002202991000004X

Motupalli, P. R., Sinclair, L. A., Charlton, G. L., Bleach, E. C., & Rutter, S. M. (2014). Preference and behavior of lactating dairy cows given free access to pasture at two herbage masses and two distances. *Journal of Animal Science*, *92*, 5175–5184. https://doi.org/10.2527/jas.2014-8046

Mufungwe, J., Rutter, S. M., Birch, S., Huntington, J. A., Wilkinson, R. G., & Sinclair, L. A. (2014). The influence of time of access to pasture and provision of a total mixed ration on the intake, milk fatty acid profile and methane production of high yielding dairy cows. *Advances in Animal Biosciences*, *5*, 96. https://doi.org/10.1017/S2040470014000028

Pérez-Prieto, L. A., & Delagarde, R. (2013). Meta-analysis of the effect of pasture allowance on pasture intake, milk production, and grazing behavior of dairy cows grazing temperate grasslands. *Journal of Dairy Science*, *96*(10), 6671–6689. https://doi.org/10.3168/jds.2013-6964

Rind, M.I., & Phillips, C.J.C. (1999). The effects of group size on the ingestive and social behaviour of grazing dairy cows. *Animal Science*, *68*(4), 589–596. doi:10.1017/S135772980005061X.

Sinclair, L. A., Cooper, S. L., Chikunya, S., Wilkinson, R. G., Hallett, K. G., Enser, M., & Wood, J. D. (2005). Biohydrogenation of n-3 polyunsaturated fatty acids in the rumen and their effects on microbial metabolism and plasma fatty acid concentrations in sheep. *Animal Science*, *81*(2), 239–248. https://doi.org/10.1079/asc50040239

Sinclair, K. D., Garnsworthy, P. C., Mann, G. E. and L.A. Sinclair. 2014. Reducing dietary protein in dairy cow diets: implications for nitrogen utilization, milk production, welfare and fertility. *Animal, 8*, 262–274. http://doi.org/10.1017/S1751731113002139.

Smit, H. J., Taweel, H. Z., Tas, B. M., Tamminga, S., & Elgersma, A. (2005). Comparison of techniques for estimating herbage intake of grazing dairy cows. *Journal of Dairy Science*, *88*(5), 1827–1836. https://doi.org/10.3168/jds.S0022-0302(05)72857-5

Sjaunja, L.O., Baevre, L., Junkkarinen, L. Pedersen, J., Setälä, J. (1990). A Nordic proposal for an energy corrected milk (ECM) formula. In: Twenty seventh Session of the International Committee of Recording and Productivity of Milk Animals. Paris, pp. 156–157.

Soriano, F. D. D., Polan, C. E. E., & Miller, C. N. N. (2001). Supplementing pasture to lactating Holsteins fed a total mixed ration diet. *Journal of Dairy Science*, *84*(11), 2460–2468. https://doi.org/10.3168/jds.S0022-0302(01)74696-6

Sutton, J. D. (1986). Milk composition. In W. H. Broster, R. H. Phipps, & C. L. Johnson (Eds.), *Principles and Practice of Feeding Dairy Cows* (Technical, pp. 203–218). Reading, UK.: National Institute for Research in Dairying.

Tayyab, U., Wilkinson, R. G., Charlton, G. L., Reynolds, C. K., & Sinclair, L. A. (2019). Grass silage particle size when fed with or without maize silage alters performance, reticular pH and metabolism of Holstein-Friesian dairy cows. *Animal*, *13*(3), 524–532. https://doi.org/10.1017/S1751731118001568

Tayyab, Usama, Wilkinson, R. G., Reynolds, C. K., & Sinclair, L. A. (2018). Particle size distribution of forages and mixed rations, and their relationship with ration variability and performance of UK dairy herds. *Livestock Science*, *217*(September), 108–115. https://doi.org/10.1016/j.livsci.2018.09.018

Thomas, C. (2004). *Feed into Milk: An Advisory Manual* (1st ed.). Nottingham, UK: Nottingham University Press. Retrieved from http://www.bsas.org.uk/wp-content/uploads/2012/09/FiM-Book.pdf

Thomas, T. A. (1977). An automated procedure for the determination of soluble carbohydrates in herbage. *Journal of Agricultural Science*, *28*, 639–642. https://doi.org/10.1002/jsfa.2740280711

Tozer, P. R., Bargo, F., & Muller, L. D. (2003). Economic Analyses of Feeding Systems Combining Pasture and Total Mixed Ration. *Journal of Dairy Science*, *86*(3), 808–818. https://doi.org/10.3168/jds.S0022-0302(03)73663-7

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, *74*(10), 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vibart, R. E., Fellner, V., Burns, J. C., Huntington, G. B., & Green, J. T. (2008). Performance of lactating dairy cows fed varying levels of total mixed ration and pasture. *Journal of Dairy Research*, *75*(04), 471. https://doi.org/10.1017/S0022029908003361

Wilkinson, J. M., Allen, J. D., Tunnicliffe, R., Smith, M., & Garnsworthy, P. C. (2014). Variation in composition of pre-grazed pasture herbage in the United Kingdom, 2006–2012. *Animal Feed Science and Technology*, *196*, 139–144. https://doi.org/10.1016/J.ANIFEEDSCI.2014.07.001

Wolf, P., Prochnow, A., & Berg, W. (2015). Changes in land use resulting from diet modifications related to increasing milk yields. *Grassland Science in Europe, 20,* 493–496.

TABLE 1 Ingredient (kg/kg DM) and chemical composition of a TMR and pasture offered to dairy cows that were continuously housed or receiving TMR and grazed pasture

	TMR	Pasture
Ingredient		
Maize silage	0.416	
Lucerne silage	0.117	
Sweetstarch[a]	0.129	
Rapeseed meal	0.074	
Wheat distillers dark grains	0.074	
Pot ale syrup[b]	0.061	
Soya hulls	0.035	
Hipro soyabean meal	0.031	
Palm kernel meal	0.021	
Rumen protected fat[c]	0.018	
Molasses	0.006	
Minerals[d]	0.006	
Limestone flour	0.005	
Feed grade urea	0.003	
Buffer[e]	0.002	
Yeast[f]	0.002	
Chemical composition		
DM (g/kg)	482	206
ME (MJ/kg DM)	12.2	12.3
OM (g/kg DM)	930	895
Ash (g/kg of DM)	70	105
CP (g/kg of DM)	176	175
WSC (g/kg DM)	81	202
NDF (g/kg of DM)	329	390
ADF (g/kg of DM)	196	210
Hemicellulose (g/kg DM)	133	180
Fatty acids (g/kg DM)	52.6	44.6
Fatty acids (g/100 g FA)		
C16:0	29.9	11.7
C18:0	4.2	0.3
C18:1 c9	28.9	1.5
C18:2 c9 c12 (n-6)	26.7	10.3
C18:3 c9 c12 c15 (n-3)	2.8	41.0

[a]KW Alternative Feeds, Andover, UK; g/kg 360 cake products, 140 breakfast cereals, 140 cocoa hulls, 140 wheat feed, 70 sugar confectionery, 140 flour.

[b]Spey syrup, KW Alternative Feeds, Andover, UK.

[c]Megalac, Volac International Limited, Royston, UK.

[d]Contained the following macro minerals (g/kg) 210 Ca, 100 Mg, 50 Na, 30 P and trace minerals (mg/kg) 6000 Zn, 5000 Mn, 2500 Cu, 400 I, 70 Co, 40 Se.

[e]Acid Buff, AB Vista, Wiltshire, UK.

[f]Vistacell Ultra, AB Vista, Co. Antrim, Ireland.

TABLE 2 Performance of dairy cows that were continuously housed or received 6 hr of access to pasture.

	C[1]	EG	DG	RT	SED	*p-value*
TMR intake (kg DM/d)	26.9[c]	23.6[b]	24.7[b]	20.3[a]	0.698	<0.001
Pasture intake (kg DM/d)	---	2.35[a]	1.98[a]	3.48[b]	0.449	0.006
Total intake (kg DM/d)	26.9[b]	26.0[b]	26.7[b]	23.8[a]	0.524	<0.001
Milk yield (kg/d)	45.7[b]	44.2[ab]	44.9[b]	41.7[a]	0.993	<0.001
ECM[2] (kg/d)	38.2	37.8	37.8	36.5	1.32	0.588
Milk fat (g/kg)	30.6	32.7	31.3	33.7	0.18	0.293
Milk protein (g/kg)	29.7	29.1	28.9	29.4	0.56	0.492
Milk lactose (g/kg)	44.2	43.8	44.5	44.2	0.57	0.686
Milk fat (kg/d)	1.44	1.44	1.36	1.39	0.088	0.769
Milk protein (kg/d)	1.36[b]	1.29[ab]	1.29[ab]	1.23[a]	0.032	0.002
Milk lactose (kg/d)	2.01[b]	1.93[ab]	2.00[b]	1.84[a]	0.051	0.005
Live weight (kg)	668[b]	653[a]	656[ab]	647[a]	4.9	<0.001
Live weight change (kg/d)	0.86[b]	0.31[a]	0.41[ab]	0.09[a]	0.177	<0.001
Body condition	2.87	2.83	2.76	2.76	0.058	0.186
Body condition change, units 28 d	0.086	0.047	-0.021	-0.021	0.0549	0.185

[1]C = cows that were continuously housed and offered a TMR *ad libitum*; EG = cows that were grazed for 6 hr directly post am milking and then housed and offered a TMR *ad libitum*; DG = cows that were returned to housing for 1 hr post am milking before being grazed for 6 hr and then housed and offered a TMR *ad libitum*; RT = cows that were grazed for 6 hr directly after morning milking then housed and offered a TMR restricted to 75% of *ad libitum* intake.
[2]Energy corrected milk yield.

TABLE 3. Milk fatty acid composition of dairy cows that were continuously housed or received 6 hr of access to pasture.

	C[1]	EG	DG	RT	SED	*p*-value
Fatty acid (g/100g)						
C4:0	5.45	5.34	5.31	5.27	0.202	0.830
C6:0	2.62	2.69	2.41	2.44	0.131	0.115
C8:0	1.33^{b}	1.41^{ab}	1.20^{a}	1.22^{ab}	0.079	0.040
C10:0	2.69^{ab}	2.91^{b}	2.43^{a}	2.42^{a}	0.177	0.025
C12:0	3.11^{bc}	3.25^{c}	2.80^{ab}	2.68^{a}	0.173	0.006
C14:0	9.63^{ab}	9.88^{b}	9.33^{ab}	8.80^{a}	0.341	0.018
C14:1 c9	1.06	0.88	0.94	0.91	0.097	0.321
C15:0	0.89^{b}	0.84^{ab}	0.91^{b}	0.75^{a}	0.051	0.015
C16:0	28.2^{b}	27.6^{ab}	26.1^{a}	26.8^{ab}	0.56	0.004
C16:1 c7	1.66	1.48	1.66	1.82	0.163	0.253
C17:0	0.46^{a}	0.48^{ab}	0.52^{b}	0.50^{ab}	0.019	0.009
C18:0	7.16	7.55	7.40	7.41	0.446	0.851
C18:1 t9	0.53	0.51	0.55	0.57	0.040	0.562
C18:1 t11	0.65	0.68	0.64	0.74	0.086	0.638
C18:1 t12	0.96^{a}	1.24^{b}	1.22^{b}	1.24^{b}	0.086	0.004
C18:1cis 9	21.5^{ab}	21.1^{a}	23.1^{ab}	23.3^{b}	0.93	0.044
C18:1 c9, c12 (n-6)	2.61	2.45	2.53	2.58	0.107	0.457
C18:2 c9 t11	0.69	0.78	0.78	0.82	0.052	0.123
C18:2 t10 c12	0.12	0.07	0.07	0.05	0.027	0.084
C18:3 c9 c12 c15 (n-3)	0.31^{a}	0.40^{b}	0.40^{b}	0.41^{b}	0.022	<0.001
C22:0	0.09	0.05	0.04	0.06	0.019	0.057
C20:5 c7 c8 c11 c14 c17 (n-3)	0.02	0.03	0.03	0.02	0.008	0.506
Other	7.04	7.07	8.24	7.57	0.687	0.274
Summation by degree of saturation						
SAT	61.6^{ab}	62.0^{b}	58.5^{a}	58.4^{a}	1.29	0.008
MUFA	26.9^{ab}	26.5^{a}	28.6^{ab}	29.3^{b}	0.99	0.016
PUFA	4.53	4.51	4.68	4.74	0.161	0.397
Summation by length						
<C16	26.8^{ab}	27.2^{b}	25.3^{ab}	24.5^{a}	0.09	0.020
C16:0 and C16:1	30.2^{b}	29.5^{ab}	28.2^{a}	29.1^{ab}	0.58	0.012
>C16	36.0^{a}	36.2^{ab}	38.2^{ab}	38.8^{b}	1.12	0.032

[1]C = cows that were continuously housed and offered a TMR *ad libitum*; EG = cows that were grazed for 6 hr directly post am milking and then housed and offered a TMR *ad libitum*; DG = cows that were returned to housing for 1 hr post am milking before being grazed for 6 hr and then housed and offered a TMR *ad libitum*; RT = cows that were grazed for 6 hr directly after morning milking then housed and offered a TMR restricted to 75% of *ad libitum* intake.

TABLE 4 Behaviour of dairy cows that were continuously housed or received 6 hr of access to pasture.

	C[1]	EG	DG	RT	*p*-value
Behaviour at pasture, % of time visually observed					
Grazing	---	40.9 ± 4.3	40.2 ± 3.4	47.7 ± 3.2	0.292
Ruminating	---	33.7 ± 2.3	32.7 ± 1.8	31.7 ± 2.3	0.792
Drinking	---	1.5 ± 0.2	1.7 ± 0.2	1.1 ± 0.2	0.108
Idling	---	23.8 ± 3.4	25.4 ± 2.7	19.6 ± 2.2	0.318
Lying	---	41.5 ± 3.5	45.8 ± 3.8	39.2 ± 4.0	0.462
Standing	---	55.2 ± 3.5	52.5 ± 3.6	59.3 ± 3.9	0.433
Walking	---	3.4 ± 0.4	1.7 ± 0.3	1.5 ± 0.4	0.003
Behavioural measurements (grazing and housed) measured automatically					
Lying time (min/d)	630 ± 13.0[b]	563 ± 15.4[a]	574 ± 11.7[a]	560 ± 10.7[a]	<0.001
Lying bouts (per d)	12.8 ± 0.35[b]	9.6 ± 0.31[a]	9.6 ± 0.30[a]	9.9 ± 0.32[a]	<0.001
Lying bout duration (min/bout)	53.5 ± 1.23[b]	61.4 ± 1.66[a]	64.9 ± 2.19[a]	60.1 ± 1.54[a]	<0.001
Steps (per d)	1137 ± 65.3[b]	1592 ± 48.8[a]	1592 ± 34.6[a]	1563 ± 28.7[a]	<0.001

[1]C = cows that were continuously housed and offered a TMR *ad libitum*; EG = cows that were grazed for 6 hr directly post am milking and then housed and offered a TMR *ad libitum*; DG = cows that were returned to housing for 1 hr post am milking before being grazed for 6 hr and then housed and offered a TMR *ad libitum*; RT = cows that were grazed for 6 hr directly after morning milking then housed and offered a TMR restricted to 75% of *ad libitum* intake.

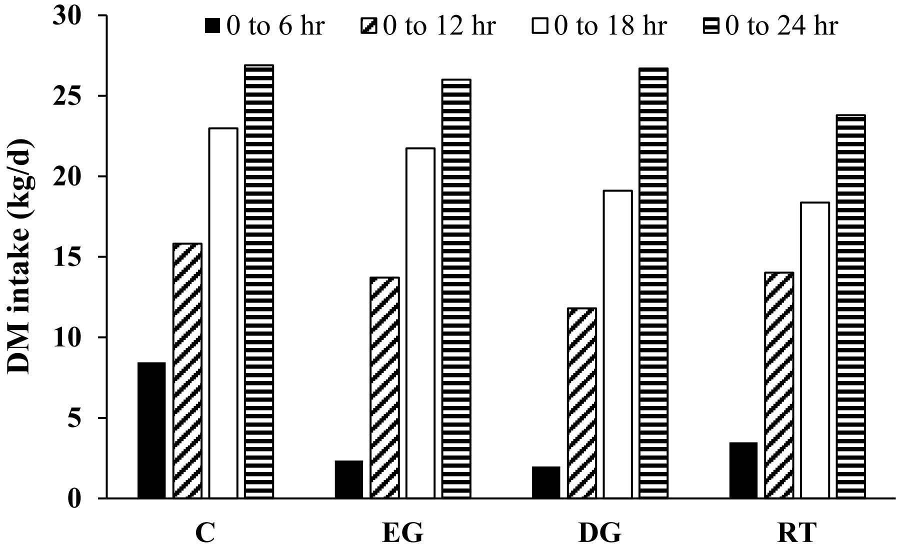

FIGURE 1 Cumulative DM intake in cows that were continuously housed and offered a TMR *ad libitum* (C); grazed for 6 hr directly post am milking and then housed and offered a TMR *ad libitum* (EG); returned to housing for 1 hr post am milking before being grazed for 6 hr and then housed and offered a TMR *ad libitum* (DG); grazed for 6 hr directly after morning milking then housed and offered a TMR restricted to 75% of *ad libitum* intake (RT). Hours 0 to 6 relate to the grazing period. For cows that were continuously housed the 6 hr blocks relate to the same period as EG and RT. Treatment $p < 0.001$; SED 0.86, Time $p < 0.001$; SED 0.39, Treatment x Time $p < 0.001$; SED 1.09.