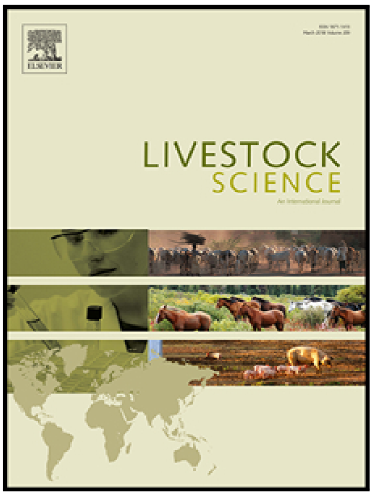
# Accepted Manuscript

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**Highlights**

- Grazing behavioural indicators of restricted grass availability were identified
- Grazing bite frequency of cows increased with restricted grass availability
- Cow rumination time/day and rumination chews/bolus were reduced
- Potential to use grazing behavioural indicators to optimize pasture management

# Identification of possible cow grazing behaviour indicators for restricted grass availability in a pasture-based spring calving dairy system

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Abstract

Precision livestock farming uses biosensors to measure different parameters of individual animals to support farmers in the decision making process. Although sensor development is advanced, there is still little implementation of sensor-based solutions on commercial farms. Especially on pasture-based dairy systems, the grazing management of cows is largely not supported by technology. A key factor in pasture-based milk production is the correct grass allocation to maximize the grass utilization per cow, while optimizing cow performance. Currently, grass allocation is mostly based on subjective eye measurements or calculations per herd. The aim of this study was to identify possible indicators of insufficient or sufficient grass allocation in the cow grazing behaviour measures. A total number of 30 cows were allocated a restricted pasture allowance of 60 % of their intake capacity. Their behavioural characteristics were compared to those of 10 cows (control group) with pasture allowance of 100 % of their intake capacity. Grazing behaviour and activity of cows was measured using the RumiWatchSystem for a complete experimental period of 10 weeks. The results demonstrated that the parameter of bite frequency was significantly different between the restricted and the control groups. There were also consistent differences observed between

the groups for rumination time per day, rumination chews per bolus and frequency of cows standing or lying.

Keywords: grass allocation, grazing management, decision support tool, sensor technology, RumiWatch, grazing bites

## 1. Introduction

The primary goal of precision livestock farming (PLF) is to generate reliable data using biosensors and process it to create added value for the farmer, the environment and the animal (Neethirajan et al., 2017). Although the development and accuracy of sensor technology has improved rapidly in recent years, the interpretation and implementation of measured data are still not fully adopted for decision making processes at farm level (Rutten et al., 2013). Currently, there are many relevant technologies available, but their value for farmers is not clear or recognized (Steeneveld et al., 2015). This is particularly true on pasture-based milk production systems where the progress in implementing PLF is slower than in indoor housed dairying. This may be explained by the smaller market potential for technology for pasture-based grazing systems (French et al., 2015).

Pasture-based systems of milk production are often associated with more positive characteristics than high-input confinement systems (Dillon et al., 2005) such as greater global sustainability, improved product quality, better animal welfare and increased labour and economic efficiency (Dillon et al., 2008; O'Brien et al., 2012; Hofstetter et al., 2014). Efficient and profitable milk production from pasture centres around the utilisation of grazed grass (Shalloo et al., 2011) as this is the cheapest home produced feedstuff on dairy farms (Finneran et al., 2010). Consistent allocation of sufficient pasture on a daily basis can result in ~ 10 % higher milk yield (Fulkerson et al., 2005). Pasture allocation is dependent on a number of factors such as the assessment of the quantity of biomass, animal requirements which can be influenced for example by stage of lactation and the quality of the pasture, but the primary determinant is available biomass. Therefore, to achieve a maximum utilization of grazed grass, dairy farmers need an accurate real-time measurement of pasture biomass and quality to optimise grazing management (French et al., 2015).

A combination of grass height measurements and estimations and grass quality estimations is presently used to allocate the appropriate pasture biomass for the herd. These measurements can vary from experience-based eye estimation (O'Donovan et al., 2002) to automated measurement using precision tools such as the Grasshopper device (McSweeney et al., 2015). A mostly subjective determination of the correct allocation of grass to the herd is most common as quantitative measurement tools are not routinely used on a widespread basis. Even when quantitative measurements are used, absolute accuracy in allocating the total maximum amount that the dairy herd will consume is extremely difficult. Optimum accuracy is necessary to prevent wastage of grass or poor subsequent growth rates. However, pasture is allocated on a herd basis rather than an individual animal which can result in competition for feed and difficulty in regulating the feed allowance to individual animals. There is also great variability in grazing efficiency between cows. This may be due to genetic potential or individual traits (Prendiville et al. (2010). Cows can change their grazing behaviour based on vegetative status of the grass and the decline of grass quality (O'Driscoll et al., 2010) as well as adapt their behaviour to restricted pasture access over different time periods (Kennedy et al., 2011). Thus a precise indicator of grass availability and consequently, the appropriate time to deliver additional allocation would be a powerful tool particularly in a grass-based system. Potentially, it could be incorporated into a grassland based decision support tool, such as PastureBase Ireland (Hanrahan et al., 2017). Detailed information regarding cow's grazing behaviour using measures such as number of grazing bites or rumination chews may be possible indicators of correct allocation of pasture biomass or the suitability of the pasture, essentially including the individual animal in the decision making process of grass allocation.

The objective of this paper represents a relatively novel concept of using animal behaviour characteristics recorded automatically to correctly manage herbage allowance per individual animal. Combined with appropriate decision support tools this may be a useful approach for improving animal performance and grass utilisation simultaneously. As a first step of the development process, it is crucial to determine potential indicators of cow grazing behaviour or activity that are influenced by pasture allowance. While most previous measurements of cow behaviour were based on laborious visual observations or short-term automated measurements, e.g. for 24-hours, the RumiWatchSystem (noseband sensor and pedometer) was used in this study and provides a very robust automated solution to monitor detailed grazing behaviour and activity over a period of 10 weeks. Therefore the key aim of this study was to identify cow grazing behavioural parameters that are influenced by grass availability and therefore may potentially be used to inform on correct grass allocation or optimum availability of grass to cows.

## 2. Materials and methods

This study was part of a larger overall experiment, which was conducted at Teagasc, Moorepark Dairy Research Farm, Animal & Grassland Research and Innovation Centre, Fermoy, Co. Cork, Ireland. Ethical approval was received from the Teagasc Animal Ethics Committee (TAEC; TAEC100/2015) and procedure authorisation was granted by the Irish Health Products Regulatory Authority (HPRA) (AE19132/P045). Experiments were undertaken in accordance with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012). A permanent grassland site was used with pastures contained 70 % perennial ryegrass and 30 % annual meadow grass. The research was carried out in springtime which coincided with the early lactation stage of cows in a spring calving herd. The overall experiment examined the effects of restricted pasture allowance on milk production, immunology and indicators of reproductive health of grazing dairy cows. This provided a platform for the current study aiming to analyse potential indicators in cow grazing behaviour to identify insufficient grass allocation.

### 2.1 Experimental design

2.1.1 Animals:

The overall experiment had 105 spring calving dairy cows which were blocked and randomly assigned to one of 7 experimental herds contained 15 animals. Of the total number of animals, forty (21 Holstein-Friesian and 19 Holstein-Friesian x Jersey crossbred) cows were stratified across the 7 experimental groups and were monitored in this current study. Cows were balanced on parity (30 multiparous and 10 primiparous cows), milk production from the two weeks prior to the start of the experiment (25.3 ± 4.3 kg/cow/day), average body weight (BW) (460 ± 77 kg) and days in milk (34 ± 12 days). All cows followed a similar milking schedule; milked twice daily at 07:00 h and 15:30 h with approximately 1.5 - 2.0 hours per milking away from the paddock.

2.1.2 Treatments:

Cows were offered a pasture allowance of either 100 % of their intake capacity (IC) or 60 % IC. Intake capacity was calculated according to the equation of Faverdin et al. (2011) and was dependent on age, parity, days in milk, stage of pregnancy, BW, Body Condition Score (BCS) and potential milk yield. In the overall experiment, there were seven individual herds of 15 cows per herd; six of these herds were assigned to restricted pasture allowance (PA) during the early lactation period in spring. The remaining herd functioned as a control group (0) offered 100 % IC. To maintain a post-grazing sward height of 3.5 cm for the control group the PA was adjusted daily, thereby catering for the increasing demand of the cows due to stage of lactation, consequently all other treatments increased proportionately (e.g. if the control group were offered 18 kg DM/cow/day, the restricted groups were offered 10.8 kg DM/cow/day).

In this study, 5 cows were randomly selected within each of the 6 restricted groups and 10 cows were randomly selected in the control group. The 40 selected focal cows were subjected to behaviour recordings. The six restricted treatment groups had different durations of restricted pasture allowance, either 2 weeks (2) or 6 weeks (6). The experimental period of 10 weeks was divided into five 2-week blocks (A-E). Separate groups of cows commenced their PA restriction period (either 2 or 6 weeks) at one of three time points in early lactation (S=Start), mid (M=mid) (2 weeks after the S restriction commenced) or late (L=late) (4 weeks after the S restriction commenced). The behaviour of the non-restricted herd (Control) was monitored over a 10-week period (Figure 1). The 3 cow groups on the 2-week restricted treatment had their behaviour recorded during the full 2-week periods, whereas the 3 cow groups on the 6-week restricted treatment had their behaviour recorded during the last 2 weeks of their 6-week treatment period. All herds grazed individually but adjacent to one another. Herds were separated using a temporary electric fence.  A fresh grass allocation was allocated after each milking access to water was provided at all times. Pasture allowances were calculated above 3.5 cm. Cows received a grass only diet with no additional concentrate.

Periods of high rainfall were encountered during the experimental period, during this time cows were offered restricted access to pasture (removed from pasture after 3 hours grazing and housed until the following milking) in accordance with the guidelines outlined by Kennedy et al. (2009); Kennedy et al. (2011). During this period they had access to water and cubicle accommodation but had no access to feed. The weather conditions, especially high rainfall, caused an ON/OFF grazing situation on 1 of 14 days for Period A and 10 of 14 days for Period B.

**2.2 Data collection**

**2.2.1 Weather**

A weather station situated at the Moorepark research farm was used to monitor weather during the experiment. Maximum distance between the weather station and the pasture was 1.0 km. The station measured air temperature using a platinum resistance thermometer (Sensing Devices, US) placed 1 m above the soil. A tipping bucket rain gauge (Casella, UK) was used to monitor rainfall. All sensors were connected to a data logger (CR series, Campbell Scientific, US) that processed all the readings and transmitted them to the Irish National Meteorological Service (Met Éireann) server via a broad-band connection.

### 2.2.2 Grass measurements

Pre- and post-grazing sward height measurements were taken daily using a rising plate meter (diameter 355 mm and 3.2 kg/m$^2$; Jenquip, Fielding, New Zealand); approximately 40 heights per treatment across the two diagonals of each paddock were taken. Pasture offered to each treatment group was sampled weekly with Gardena hand shears (Accu 60, Gardena International GmbH, Ulm, Germany) to the post-grazing sward height of each individual treatment in order to represent the grass defoliated by the cows. A subsample was stored at –20°C before being freeze dried and milled through a 1-mm sieve before chemical analysis. Herbage samples were analysed for dry matter (DM), crude protein (CP), Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) by wet chemistry in a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY, USA).

### 2.2.3 Grazing and activity behaviour

The RumiWatchSystem (Itin+Hoch GmbH, Liestal, Switzerland) was used for measuring grazing behaviour and activity of the cows. It incorporated the RumiWatch noseband sensor and the RumiWatch pedometer. Both sensors were validated in a pasture based milking system against visual observation (Werner et al., 2017). Raw data were recorded in a 10 Hz resolution. In the current study, the RumiWatch Manager 2 (V.2.1.0.0) was used to manage time synchronization and raw data recording of the devices. The RumiWatch Converter (V.0.7.3.36) was used for analysing the raw data. Further technical information about the

RumiWatchSystem is reported by Alsaaod et al. (2015) and Zehner et al. (2017). The RumiWatch noseband sensor is capable to record grazing behaviour in a detailed manner. In Table 1, there are the grazing behaviour parameters and the corresponding RumiWatch output variables listed which are included in the analysis of this experiment. After two weeks of continuous recording the raw data were downloaded and the sensors were applied to the cows again on the following morning. Only complete daily records were included in the analysis. All relevant data regarding cow performance were merged together in an electronic spread sheet (Microsoft Excel, Version 2010, USA).

### 2.2.4 Intake estimation

The n-alkane technique was used to estimate grass dry matter intake (DMI) (Dillon and Stakelum, 1988) on the last two weeks of the treatment periods in each of the 6 restricted groups. The control treatment was divided into two subgroups and grass DMI was estimated every two weeks on alternative groups. As part of the n-alkane technique cows were dosed twice daily with a paper filter (Carl Roth, GmbH and Co. KG, Karlsruhe, Germany) containing an indigestible marker (C32) by a trained member of staff for 12 days. From day seven of dosing, faecal samples were collected in the paddocks twice daily, before both a.m. and p.m. milking for the remaining 6 days. On occasion, faecal grab samples were obtained manually from the cow. Based on the marker amount in the faeces, it was possible to estimate the amount of grass the cow was ingesting. Further information about the method can be found in Kennedy et al. (2011).

### 2.2.5 Animal performance

Milk yield was measured individually (kg) twice daily at each milking (Dairymaster, Tralee, Co. Kerry, Ireland). Milk fat, protein, lactose, casein, dry matter, urea and somatic cell count (SCC) was determined once weekly. The concentrations of these components were measured using Milkoscan 203 (Foss Electric-DK-3400, Hillerød, Denmark). All cows were weighed weekly. Bodyweight was recorded weekly using a portable weighing scale and

Winweigh software package (Tru-test Limited, Auckland, New Zealand). BCS measurements were conducted every second week by two alternating trained observers during the study on a 1 to 5 point scale (1 = emaciated, 5 = extremely fat; Lowman et al. (1976))

**2.3 Statistical analysis**

The data were analysed using the Mixed procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). As control animals were measured repeatedly, the resultant correlations were included in the modelling as a covariate structure in the residual error. There were a number of combinations of measurement period (A-E) and restriction treatment (2 weeks or 6 weeks) in the experiment. However, a complete factorial set for all combinations of period and restriction was incomplete. Therefore a linear model was used to fit a one-way classification where each measured combination of period and restriction was fitted as a separate treatment. These combinations were analysed using the following model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

where $\mu$ = mean, $T_i$ = Treatment (combination of period and restriction), $e_{ij}$ = residual error term.

Within the set of treatment combinations there were subsets of measurement period and restriction (either 2 week or 6 week) with complete factorial structure. Interaction and main effects (measurement period or restriction) were examined in these subsets using contrasts of the coefficients from the one-way analysis. These contrasts were equivalent to fitting the following factorial model to the subsets:

$$Y_{ijk} = \mu + P_i + R_j + PR_{ij} + e_{ijk}$$

where $Y_{ijk}$ = response; μ = mean, $P_i$ = measurement period, $R_j$ = restriction, $e_{ijk}$ = residual error term.

Comparisons of means were made with adjustment for multiplicity using the Multtest procedure. Residual checks were made to ensure that the assumptions of the analysis were met. Boxplot figures were created with the Sqplot procedure and means were calculated with the means procedure in SAS 9.4.

# 3. Results

### 3.1 Sward measurements

The sward measurements indicated that each restricted group had similar pre-grazing sward heights to its comparable control group in the respective measurement period (Table 2). However, the post-grazing height was always lower for restricted groups compared to the control group. Cows assigned to the control treatment had a post-grazing height above 3.5 cm (range: 3.6 – 4.7 cm); alternatively cows offered 60 % IC grazed below the 3.5 cm horizon (range: 2.5 – 3.1 cm). There was no difference in the chemical composition of swards offered to all groups. Focal cows in all restricted groups showed a higher individual grass DMI compared to the calculated daily herbage allowance.

### 3.2 Behavioural measurements

The results of the behavioural measurements (means and standard deviation) of cow groups per period and statistically significant effects are presented in Table 3-5. Overall, the results demonstrated that there were only a few very distinguishable effects of the restricted pasture allocation on cow grazing behaviour. There was also a strong effect of the measured period on some parameters.

#### 3.2.1 <u>Grazing</u>

The effects of restriction in pasture allocation and measurement period on grazing behaviour are displayed in Table 3. Bite frequency was consistently affected by the restriction, with the measured parameter being significantly higher for the restricted cow groups compared to the control groups for the 2-week and 6-week restricted cows as presented in Table 3 and Figure 2. Cows on the restricted allocation generally recorded a numerically lower number of grazing bouts/day within each period, except for cow group M2 during Period B. The lower number of grazing bouts/day was associated with extended length of the grazing bouts for the restricted cows in comparison to the control cows. However, while this trend was observed, it was not statistically significant. All grazing parameters measured (other than bite frequency) were significantly influenced by the effect of the measurement period. The number of grazing bites/day recorded in Period B was significantly reduced compared to Periods A and C. Meanwhile the occurrence of grazing bouts/day was significantly lower during Period B compared to Periods A and C and higher for Period D compared to C and E.

### 3.2.2 Rumination

The effects of restricted pasture allocation and measurement period on rumination behaviour parameters are displayed in Table 4. Cows with a restricted pasture allocation generally recorded a significantly shorter duration of rumination time/day and less rumination chews/day except during Period A, where no significant effect was found. Restricted pasture allocation also significantly reduced the mean length of rumination bouts of the restricted cows compared to control cows for both the 2-weeks and 6-weeks restriction. However, within Periods A-C, there was also a significant decrease in mean rumination bout length detected for Period B compared to Period A and C. The restriction also significantly affected the number of rumination chews/bolus, which was lower for the restricted cows compared to the control groups for the 6-week restriction. With regard to the mean number of rumination bouts/day, there was no significant effect found for either the restriction or the measurement period.

### 3.2.3 Activity

Restriction in pasture allocation had no clear effect on cow activity (Table 5). Cows on the restricted allocation spent similar time durations in lying and standing positions compared to the control group within each period. Statistically, there was a significant difference observed among measurement Periods A-C on standing and lying time. Significant differences also occurred with respect to time spent walking by cows. But a clear pattern was not observed across measurement periods throughout the experiment. The number of standing and lying events during the day numerically differed between the restricted cows and the control cows. The restricted cows changed from a standing to a lying position on fewer occasions than the control cows in all measurement periods. This was statistically different for just the 2-week restricted groups.

## 4. Discussion

The results of this study showed that bite frequency was consistently affected by the restricted pasture allowance. Furthermore, there were some parameters which were consistently numerically lower for the restricted cows, such as rumination time/day, mean rumination bout length and rumination chews/bolus. However, there was no clear significant effect of restriction for those parameters over all experimental periods. This may be either due to the stronger effect of measuring period or the small sample size of cows.

Even though new technologies were used in the current study to monitor cow grazing behaviour continuously over prolonged periods, the results are comparable to previous studies when cow grazing behaviour was studied over 24-h periods under restricted access times to pasture (Kennedy et al., 2011). Kennedy et al. (2009) reported that cows with full time access to pasture showed a higher number of grazing bouts of shorter duration than that of restricted access groups. A study of Soca et al. (2014) confirmed that restricted pasture access resulted in a longer initial grazing bout for those cows, but the overall grazing time was longer for cows with unlimited access to pasture. Thus, those studies showed that the cows restricted in either time on pasture or as in the current study in grass availability spent a longer time grazing per bout and engaged in fewer grazing bouts. It is likely that cows alter their grazing behaviour to compensate for the restriction, e.g they graze more efficiently with a higher bite rate or bite frequency (Patterson et al., 1998; Gregorini et al., 2009). Chilibroste et al. (2015) explained the increased bite rate and adaption to restricted grazing conditions with decreasing sward heights as being associated with reduced bite mass. As a response to reduced bite mass, cows increase their bite rate, as a compensatory mechanism to maintain their intake. This is also represented in the results of the current study, as bite frequency was significantly higher for all restricted groups in all periods.

With regards to rumination behaviour, Chilibroste et al. (2007) indicated that increases in intake rates, based on bite rate and bite mass, occur at the expense of rumination time, which they demonstrated in various studies (Chilibroste et al., 1997; Soca et al., 2014). Contrary to the current study, Kennedy et al. (2011) found longer rumination times for the cows with restricted access to pasture compared to cows with full-time access. Those cows also showed a higher number of rumination bouts as well as longer bouts. However in the current study, the restricted cows recorded a lower total rumination time and also the length of rumination bouts was shorter compared to the control group. This might be explained by the fact that the cows in the study of Kennedy et al. (2011) were restricted by access to pasture contrary to the current study where the cows were restricted in grass availability in the paddock. Therefore, when cows had no access to pasture and were housed, they adapted their rumination times to compensate for a reduction in available grazing time (Gregorini et al., 2012). The reduced rumination time associated with restricted cows in the current study may be due to the fact that there is less material in the rumen to digest or the grass pieces in the rumen might be already sufficiently reduced for digestion as a consequence of a shorter grass sward (Kennedy et al., 2009). Gregorini et al. (2012)

explained reduced rumination times of cows with restricted access to pasture as a compensatory mechanism to enhance rumen digestion.

There are only a few comparable studies in the literature with analysed activity behaviour during a period of restriction in pasture access or grass availability. However a study of O'Driscoll et al. (2015) demonstrated that the extent of lying bouts was also affected by restriction of pasture. Restricted cows had a smaller number of lying bouts, which is in accordance with the current study when restricted cows showed less events of lying or standing. The differing number of occasions when cows were lying down/standing up might be also due to a more consistent lying behaviour of the restricted cows due to reduced grass availability. After entering the fresh paddock, there were longer initial grazing bouts and once they depleted the grass allocation the restricted cows rested for longer periods. Considering the results of activity measurements, there was just a small degree of difference shown within the treatments. All cows spent a similar amount of time either standing or lying. This may be due to the paddock sizes, which are constrained in strip grazing rotational management. Similar walking times, which are more affected by the measurement period than the restriction may be explained by the fact, that all cows, either restricted or control groups, were grazed in paddocks with similar distances to the milking parlour. Therefore the amount of walking to the grazing paddocks was comparable.

The measured DMI based on the n-alkane method, showed that the restricted individual cows consumed more grass than was allocated to them based on a calculated intake capacity. These cows grazed lower than the 3.5 cm sward height, which was used as the basis for the herbage allowance calculations. This may have influenced restriction somewhat, as cows may not have experienced a restriction of 60 % in reality. However, even with an actual restriction of approximately 80 %, a strong effect on bite frequency was still detected. Some cows in both the control and restricted herds may have had a lower DMI than that which would be associated with the calculated herbage allocation, as the calculated allocation is conducted at a herd or group level, and high ranking cows could potentially increase their intake at the expense of low ranking cows. With automated sensors, it is possible to gain feedback per individual cow and this could be used to improve grazing management at an individual animal level. Individual cow data for grazing behaviour and possible grazing efficiency may be then also used for automated phenotyping for breeding purposes.

Bite frequency was significantly affected in all restricted groups. Furthermore, rumination parameters such as rumination time/day, rumination chews/bolus and rumination bout length were also continuously of shorter duration for the cows in restricted groups compared to the control group, but not statistically significant for both restriction treatments or over all measurement periods. Caution may need to be exercised in relation to the importance of statistically significant effects with a small sample size of 5 animals per group. Alternatively, it may be considered that an effect detected even with a small sample size of individual animals strengthens the importance of the parameters, such as bite frequency. The effects of restriction may also be influenced by the fact that cows received two pasture allocations per day.

The results emphasised that further research should focus on parameters such as bite frequency and rumination time/day, rumination chews/bolus or mean rumination bout length. These may then be used as potential indicators in decision support tools to help farmers improve grazing management. A huge variability among individual animals as well as among days or even hours may mean that an extension of this study with more individual animals would be required. Also the variability of individual cows compared to the herd needs to be analysed to develop thresholds for insufficient grass allocations. These thresholds at individual animal levels could be integrated in the decision support tool to give farmers feedback on their grazing management. Based on this feedback, new grass allocations could be adapted to improve grazing efficiency and productivity in a pasture-based milk production system.

## 5. Conclusion

The study demonstrated that the parameter bite frequency was significantly affected by the restricted pasture allowance regardless of the duration of restriction. The restricted cows had a higher bite frequency in all measurement periods. A significantly lower number of rumination chews/bolus was detected for the 6-week restricted groups compared to the control groups, but not for the restricted groups experiencing a 2-week restriction. Furthermore, other rumination parameters such as rumination time/day and mean rumination bout duration were generally reduced for the restricted groups compared to the control groups. However, there was also an influence of the measurement period detected. The activity behaviour was significantly different between the control group and the restricted groups with respect to occasions of standing and lying for the groups with a two week restriction but not for the groups with a six week restriction. However, most measurable parameters of grazing behaviour or activity behaviour were not detected to be suitable as an indicator for insufficient grass allocation, as they were not strongly influenced by restricted pasture allowance. This might be due to the significant interaction between measured period and restriction, or the fact that the restricted groups grazed below 3.5 cm thus negating some of the restriction. Further research should focus on identifying the thresholds of grazing behaviour parameters, such as bite frequency, rumination time/day, rumination chews/ bolus or mean rumination bout length, which may represent insufficient grass allocation. These thresholds could then be integrated and implemented within a decision support tool for farmers and could potentially optimize the grazing management for dairy cows.

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## Figure captions

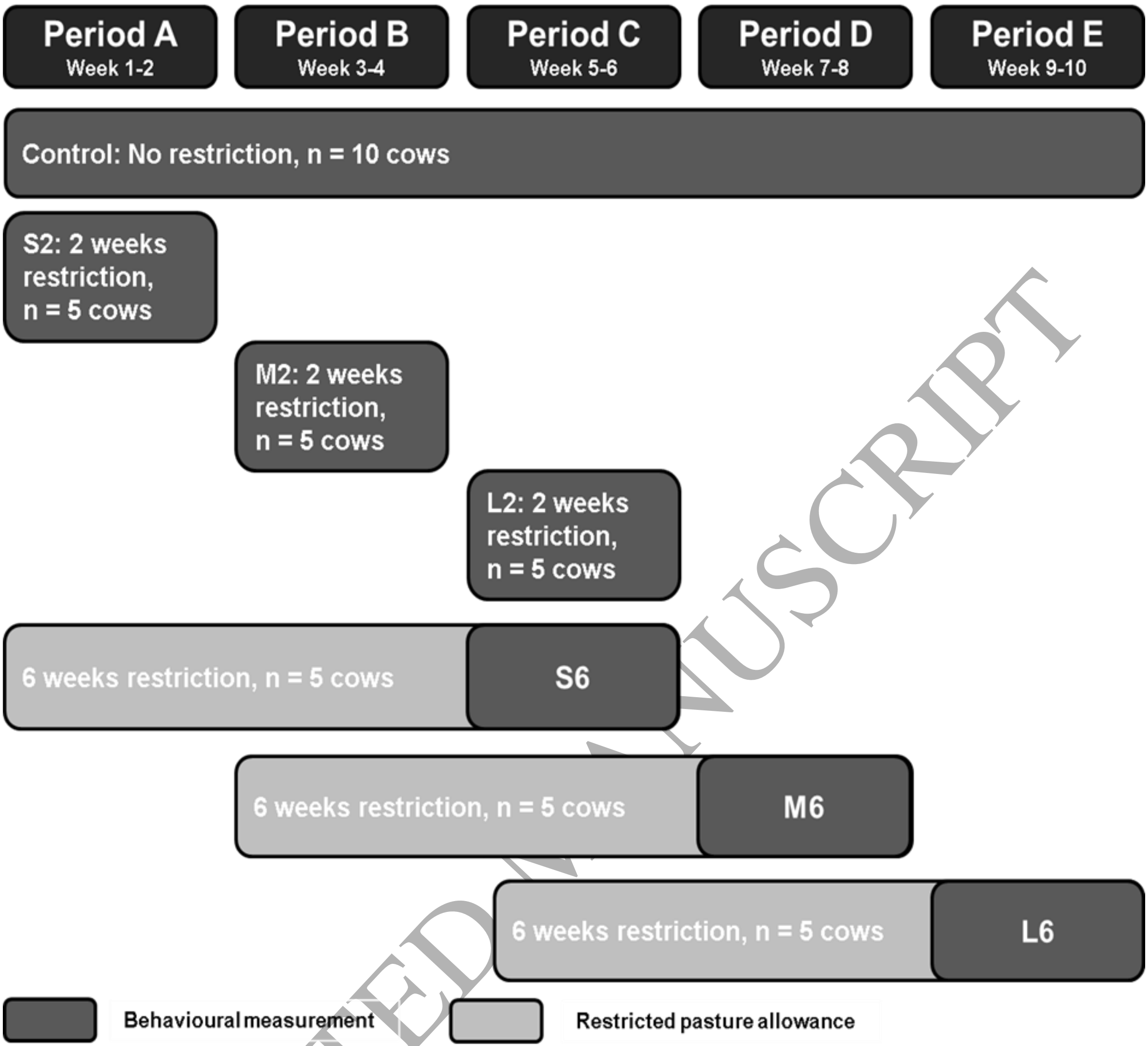


Figure 1: Study design for assessing the effect of restricted (60 %) pasture allowance compared to control (100 %) pasture allowance on cow behaviour with two different durations of restriction (2 week s (2) and 6 weeks (6)) and three different commencement periods during spring lactation (S=Start, M=Mid, L=Late); before and after the 60 % restriction cows were offered a 100 % intake capacity.

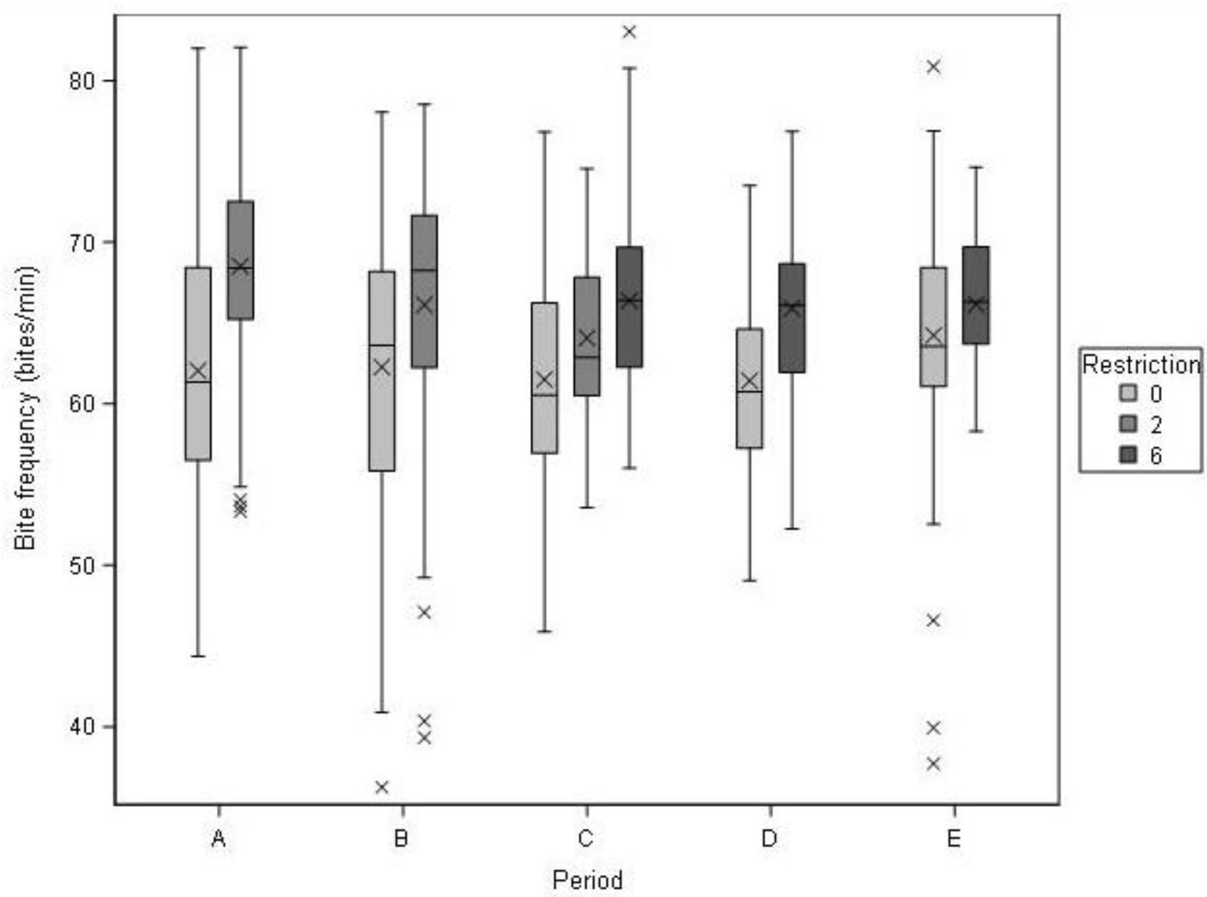


Figure 2: Effect of treatment (2-week restricted PA (2) and 6-week restricted PA (6)) versus control group (0) in bite frequency. Data are presented as box plots indicating observed median, first and third quartiles and absolute range of data with outliers, displayed as crosses, as well as observed mean displayed within boxes as crosses.

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Table 1: Grazing behaviour parameters measured by the RumiWatch noseband sensor.

| Parameter | RumiWatch output | Definition |
|---|---|---|
| Grazing time (min/day) | EAT1TIME | Grazing time with head position down |
| Grazing bouts (n/day) | GRAZINGSTART | Number of grazing bouts started per day<br>(Definition grazing bout = minimum duration of 7 min and intra-bout interval is smaller than 7 min, Werner et al. 2017) |
| Time of feeding (min/day) | GRAZINGTIME | Duration (in min) of feeding (head position up or down) with time totalled for all grazing bouts per day |
| Grazing bout length (min/bout) | GRAZINGTIME/<br>GRAZINGSTART | Calculated value for mean grazing bout length |
| Grazing bites (n/day) | GRAZINGBITES | Number of jaw movements (prehensions) for ripping of grass |
| Bite frequency (n/min) | GRAZINGBITES/<br>EAT1TIME | Calculated value for grazing bites per min |
| Rumination time (min/day) | RUMINATETIME | Total rumination time per day |
| Rumination chews/bolus (n/bolus) | RUMINATECHEWS/BOLUS | Calculated value for mean number of rumination chews per bolus |
| Rumination bouts (n/day) | RUMIBOUTSTART | Number of rumination bouts started per day (Definition rumination bout = minimum duration of 3 min and intra-bout interval is smaller than 1 min; Werner et al. 2017) |
| Time of rumination within all rumination bouts (min/day) | RUMIBOUTTIME | Duration (in min) of rumination behaviour with time totalled for all rumination bouts per day |
| Rumination bout length (min/bout) | RUMIBOUTTIME/<br>RUMIBO | Calculated value for mean rumination bout length per day |

| | | |
|---|---|---|
| | UTSTAR T | |

Table 2: Sward measurements, grass quality, dry matter intake of individual cows and calculated daily herbage allowance for experimental periods per group (mean and standard deviation).

| Period | A | | B | | C | | | D | | E | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cow group* | Control | S2 | Control | M2 | Control | L2 | S6 | Control | M6 | Control | L6 |
| Pregrazing height in cm | 7.2 ± 1.7 | 6.9 ± 1.3 | 7.5 ± 1.4 | 7.4 ± 1.6 | 7.4 ± 1.3 | 7.1 ± 0.7 | 7.3 ± 1.6 | 9.9 ± 1.6 | 10.1 ± 1.2 | 12.5 ± 2.5 | 11.9 ± 2.1 |
| Postgrazing height in cm | 3.6 ± 0.2 | 2.5 ± 0.4 | 4.0 ± 0.5 | 3.0 ± 0.5 | 3.7 ± 0.3 | 2.8 ± 0.5 | 2.8 ± 0.3 | 4.0 ± 0.4 | 3.1 ± 0.5 | 4.7 ± 0.6 | 3.0 ± 0.5 |
| Daily herbage allowance above 3.5 cm in kg/cow/day[a] | 14.1 ± 0.5 | 8.5 ± 0.4 | 15.3 ± 0.2 | 9.2 ± 0.1 | 15.9 ± 0.2 | 9.6 ± 0.1 | 9.6 ± 0.1 | 15.8 ± 0.8 | 9.9 ± 0.7 | 16.1 ± 1.4 | 9.7 ± 0.8 |
| DryMatter Intake[b] (kg/cow/day) | 11.1 ± 1.8 | 10.3 ± 0.6 | 13.7 ± 1.6 | 9.7 ± 1.9 | 17.5 ± 2.3 | 20.1 ± 2.1 | 17.2 ± 3.7 | 20.0 ± 2.1 | 17.7 ± 2.0 | 16.4 ± 3.6 | 15.0 ± 2.2 |
| Drymatter above 3.5 cm in kg DM/ha | 1371 ± 475 | 1296 ± 193 | 1129 ± 351 | 1063 ± 367 | 1110 ± 237 | 1056 ± 312 | 971 ± 321 | 1769 ± 292 | 1743 ± 310 | 1766 ± 383 | 1690 ± 357 |
| Crude protein (%) | 19.9 ± 0 | 19.1 ± 0.1 | 20.0 ± 3.4 | 20.4 ± 3.0 | 22.4 ± 2.5 | 20.3 ± 2.7 | 21.9 ± 3.7 | 20.5 ± 1.6 | 18.6 ± 0.1 | 21.2 ± 1.2 | 22.9 ± 0.1 |
| ADF (%) | 27.1 ± 0.8 | 25.3 ± 1.2 | 24.7 ± 0.8 | 25.7 ± 5.1 | 22.7 ± 2.0 | 24.0 ± 1.0 | 21.3 ± 3.3 | 22.3 ± 1.6 | 21.0 ± 0.7 | 22.4 ± 0.5 | 23.7 ± 0.2 |
| NDF (%) | 45.0 ± 0.8 | 44.5 ± 0.5 | 39.2 ± 3.8 | 38.6 ± 3.2 | 37.8 ± 2.2 | 37.7 ± 2.2 | 35.9 ± 3.0 | 38.4 ± 2.2 | 38.0 ± 1.9 | 40.8 ± 0.1 | 40.6 ± 0.2 |

[a] Daily herbage allowance was offered to the experimental herds based on calculation of intake capacity

[b] Intake estimation of dry matter intake (kg/cow/day) based on individual focal cows chosen for behavioural measurements

* Cow group: Control cow group received a 100% pasture allocation, all other treatment groups commenced their restriction period (either 2 or 6 weeks) at one of three time points in early lactation (S=Start), mid (M=mid) (2 weeks after the S restriction commenced) or late (L=late) (4 weeks after the S restriction commenced).

Table 3: Effects of restriction or period on grazing behaviour parameters, behavioural measurements are displayed as means with standard deviation and significance of effects.

| Period | A | | B | | C | | | D | | E | | Significant effects[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cow group* | Control | S2 | Control | M2 | Control | L2 | S6 | Control | M6 | Control | L6 | |
| Grazing time (min/day) | 504 ± 67 | 510 ± 74 | 425 ± 103 | 384 ± 86 | 531± 71 | 576 ± 58 | 545 ± 82 | 511 ± 67 | 506 ± 54 | 531 ± 72 | 469 ± 109 | Period A-C *p <.0.001* |
| Grazing bites (n/day) | 31302 ± 6044 | 35046 ± 6157 | 26520 ± 7344 | 25497 ± 6700 | 32769 ± 6080 | 36981 ± 5019 | 36233 ± 6637 | 31486 ± 5524 | 33468 ± 5157 | 34258 ± 6037 | 31364 ± 8697 | Period A-C *p <.0.001* |
| Bite frequency (bites/min) | *62.0 ± 7.9* | *68.5 ± 3.8* | *62.2 ± 8.0* | *66.1 ± 8.3* | *61.5 ± 6.5* | *64.1 ± 4.5* | *66.4 ± 5.8* | *61.4 ± 5.3* | *65.9 ± 5.3* | *64.2 ± 6.6* | *66.2 ± 4.0* | *Restriction 0/2 p = 0.022* *Restriction 0/6 p = 0.038* |
| Grazing bouts (n/day) | 9.3 ± 2.6 | 8.4 ± 2.6 | 6.5 ± 2.4 | 6.5 ± 2.3 | 8.4 ± 1.8 | 8.0 ± 2.5 | 8.0 ± 2.1 | 9.5 ± 2.0 | 9.0 ± 2.6 | 7.8 ± 1.8 | 7.7 ± 2.1 | Period A-C *p <.0001* Period C-E *p = 0.001* |
| Grazing bout length (min/bout) | 67.5 ± 14.7 | 73.6 ± 17.7 | 85.3 ± 32.5 | 81.5 ± 31.5 | 74.9 ± 17.8 | 87.0 ± 25.9 | 82.8 ± 23.9 | 65.3 ± 16.7 | 74.9 ± 20.5 | 80.7 ± 19.7 | 82.7 ± 24.2 | Period A-C *p = 0.002* Period C-E *p = 0.009* |

Italics = parameter is consistently numerically higher for restricted groups compared to the control group
[a] Significant effects are reported, either significant effect among Period A-C or C-E, significant effect between restriction 0/2 or 0/6 or significant interactions between period x restriction
* Cow group: Control cow group received a 100% pasture allocation, all other treatment groups commenced their restriction period (either 2 or 6 weeks) at one of three time points in early lactation (S=Start), mid (M=mid) (2 weeks after the S restriction commenced) or late (L=late) (4 weeks after the S restriction commenced).

Table 4: Effects of restriction or period on rumination behaviour parameters, behavioural measurements are displayed as means with standard deviation and significance of effects.

| Period | A | | B | | C | | | D | | E | | Significant effects[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cow group* | Control | S2 | Control | M2 | Control | L2 | S6 | Control | M6 | Control | L6 | |
| Rumination time (min/day) | **456 ± 69** | **456 ± 73** | **431 ± 86** | **327 ± 90** | **490 ± 78** | **395 ± 85** | **383 ± 70** | **504 ± 72** | **446 ± 61** | **491 ± 66** | **430 ± 59** | **Restriction 0/6** ***p <.0001*** **Period C-E** ***p = 0.013*** **Period A-C x restriction 0/2** ***p = 0.001*** |
| Rumination chews (n/day) | **30387 ± 5290** | **28676 ± 5227** | **27841 ± 6667** | **20313 ± 6524** | **32343 ± 5775** | **24236 ± 5050** | **23061 ± 4408** | **33985 ± 5902** | **29520 ± 4991** | **32192 ± 5072** | **26202 ± 3825** | **Restriction 0/6** ***p <.0001*** **Period C-E** ***p = 0.002*** **Period A-C x restriction 0/2** ***p = 0.008*** |
| Rumination chews/bolus (n/bolus) | **56.8 ± 6.0** | **55.5 ± 4.3** | **55.6 ± 5.7** | **52.7 ± 5.2** | **56.2 ± 5.7** | **51.5 ± 5.0** | **47.7 ± 4.1** | **55.3 ± 5.9** | **51.7 ± 5.0** | **54.1 ± 5.4** | **49.1 ± 4.2** | **Restriction 0/6** ***p = 0.018*** |
| Rumination bouts (n/day) | 12.8 ± 2.7 | 13.4 ± 2.1 | 13.1 ± 2.4 | 12.3 ± 2.6 | 12.8 ± 2.5 | 12.3 ± 2.0 | 13.7 ± 2.6 | 13.7 ± 2.5 | 14.8 ± 2.4 | 13.2 ± 5.4 | 14.8 ± 2.7 | No significant effect |
| Rumination bout length (min/bout) | **37.5 ± 8.3** | **34.0 ± 6.3** | **34.0 ± 8.3** | **27.1 ± 6.7** | **39.9 ± 8.8** | **32.6 ± 6.2** | **28.9 ± 5.9** | **38.4 ± 7.8** | **31.5 ± 6.9** | **38.9 ± 8.3** | **30.2 ± 6.9** | **Restriction 0/2** ***p = 0.006*** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | **Restriction 0/6** ***p <.0001*** **Period A-C** ***p = 0.003*** |

Bold= parameter is consistently numerically lower in restricted groups compared to the control group
[a] Significant effects are reported, either significant effect among Period A-C or C-E, significant effect between restriction 0/2 or 0/6 or significant interactions between period x restriction
* Cow group: Control cow group received a 100% pasture allocation, all other treatment groups commenced their restriction period (either 2 or 6 weeks) at one of three time points in early lactation (S=Start), mid (M=mid) (2 weeks after the S restriction commenced) or late (L=late) (4 weeks after the S restriction commenced).

Table 5: Effects of restriction or period on activity parameters, measurements are displayed as means with standard deviation and significance of effects.

| Period | A | | B | | C | | | D | | E | | Significant effects[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cow group* | Control | S2 | Control | M2 | Control | L2 | S6 | Control | M6 | Control | L6 | |
| Lying time (min/day) | 477 ± 170 | 485 ± 140 | 428 ± 117 | 428 ± 126 | 566 ± 92 | 583 ± 98 | 535 ± 85 | 565 ± 102 | 556 ± 100 | 569 ± 95 | 603 ± 84 | Period A-C *p <.0001* |
| Standing time (min/day) | 873 ± 158 | 873 ± 136 | 921 ± 110 | 911 ± 118 | 800 ± 83 | 791 ± 87 | 823 ± 78 | 785 ± 96 | 782 ± 91 | 788 ± 93 | 749 ± 75 | Period A-C *p <.0001* |
| Walking time (min/day) | 90 ± 32 | 83 ± 20 | 90 ± 21 | 102 ± 35 | 75 ± 18 | 667 ± 22 | 82 ± 35 | 91 ± 19 | 102 ± 26 | 83 ± 15 | 89 ± 18 | Period A-C *p <.0001*<br>Period C-E p = 0.001 |
| Standing up/lying down events (n/day) | **8.4 ± 3.2** | **6.4 ± 2.6** | **9.1 ± 3.1** | **6.7 ± 2.1** | **9.0 ± 2.7** | **7.6 ± 2.0** | **7.7 ± 2.7** | **9.2 ± 3.6** | **7.8 ± 2.4** | **7.9 ± 2.0** | **7.0 ± 2.2** | **Restriction 0/2 *p = 0.004*** |
| Strides (n/day) | 2792 ± 952 | 2550 ± 596 | 2832 ± 680 | 3069 ± 899 | 2268 ± 534 | 2002 ± 270 | 2483 ± 970 | 2870 ± 521 | 3141 ± 675 | 2654 ± 469 | 2794 ± 524 | Period A-C p <.0001<br>Period C-E p <.0001 |

Bold= parameter is consistently numerically lower in restricted groups compared to the control group

[a] Significant effects are reported, either significant effect among Period A-C or C-E, significant effect between restriction 0/2 or 0/6 or significant interactions between period x restriction

* Cow group: Control cow group received a 100% pasture allowance, all other treatment groups commenced their restriction period (either 2 or 6 weeks) at one of three time points in early lactation (S=Start), mid (M=mid) (2 weeks after the S restriction commenced) or late (L=late) (4 weeks after the S restriction commenced).