Animal (2020), **14:12**, pp 2503–2510
doi:10.1017/S1751731120001251

animal

A comparison of two rotational stocking strategies on the foraging behaviour and herbage intake by grazing sheep

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(Received 5 March 2018; Accepted 22 May 2020; First published online 16 June 2020)

An understanding of the processes involved in grazing behaviour is a prerequisite for the design of efficient grassland management systems. The purpose of managing the grazing process is to identify sward structures that can maximize animal forage daily intake and optimize grazing time. Our aim was to evaluate the effect of different grazing management strategies on foraging behaviour and herbage intake by sheep grazing Italian ryegrass under rotational stocking. The experiment was carried out in 2015 in southern Brazil. The experimental design was a randomized complete block with two grazing management strategies and four replicates. The grazing management treatments were a traditional rotational stocking (RT), with pre- and post-grazing sward heights of 25 and 5 cm, respectively, and a 'Rotatinuous' stocking (RN) with pre- and post-grazing sward heights of 18 and 11 cm, respectively. Male sheep with an average live weight of 32 ± 2.3 kg were used. As intended, the pre- and post-grazing sward heights were according to the treatments. The pre-grazing leaf/stem ratio of the Italian ryegrass pasture did not differ between treatments ($P > 0.05$) (~2.87), but the post-grazing leaf/stem ratio was greater ($P < 0.001$) in the RN than in the RT treatment (1.59 and 0.76, respectively). The percentage of the non-grazed area was greater ($P < 0.01$) in post-grazing for RN compared with RT treatment, with an average of 29.7% and 3.49%, respectively. Herbage nutritive value was greater for the RN than for the RT treatment, with greater CP and lower ADF and NDF contents. The total time spent grazing, ruminating and resting did not differ between treatments ($P > 0.05$), with averages of 439, 167 and 85 min, respectively. The bite rate, feeding stations per min and steps per min by sheep were greater ($P < 0.05$) in the RN than in the RT treatment. The grazing time per hour and the bite rate were greater ($P < 0.05$) in the afternoon than in the morning in both treatments. The daily herbage intake by sheep grazing Italian ryegrass was greater ($P < 0.05$) in the RN than in the RT treatment (843.7 and 707.8 g organic matter/sheep, respectively). Our study supports the idea that even though the grazing time was not affected by the grazing management strategies when the animal behaviour responses drive management targets, such as in 'Rotatinuous' stocking, the sheep herbage intake is maximized, and the grazing time is optimized.

Keywords: grazing behaviour, grazing management, intake rate, Italian ryegrass, sward structure

Implications

In the traditional rotational stocking, the behavioural responses of animals are not considered when establishing grazing management targets. Pre-grazing sward structure is variable and is indirectly defined by the pasture resting period, which focuses on maximum herbage growth. Post-grazing sward height targets are defined for maximum herbage harvesting efficiency. However, the 'Rotatinuous' stocking strategy, which is based on optimal sward structure represented by pre- and post-grazing heights that maximize intake rate, resulted in a greater daily intake of a high-quality diet. 'Rotatinuous' stocking has the potential to be used as a grazing management strategy to improve animal performance in grassland ecosystems.

Introduction

There is a need to know the processes involved in livestock production systems, in particular, grazing ecosystems, which are the basis of ruminant production in the world, to propose clear management strategies to improve high-quality human

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food production. Therefore, grazing management strategies that are based on the understanding of the grazing process have an essential role in fostering productive, competitive and sustainable livestock systems.

The grazing process consists of searching and handling of forage by the animal (Ungar and Noy-Meir, 1988), which uses different foraging strategies in the pastoral environment to optimize the intake of nutrients (Forbes and Gregorini, 2015). Foraging behaviour is both the cause and the consequence of sward structure as indicated by Carvalho (2013): 'defoliation provokes differential tissue removal, altering vegetation competition and plant growth patterns; thus, sward structure is altered by defoliation. At the same time, sward structure determines defoliation patterns and forage intake, ultimately determining body condition and fitness of animals'.

According to Chapman *et al.* (2007), when searching costs are low, the animal consumes a greater proportion of preferred feed. Searching costs are low when ideal sward structures are offered that maximize bite mass (Carvalho, 2013) and may reduce the eating time and consequently the total daily grazing time. The maximum short-term intake rate by sheep and cattle is strongly related to the ideal sward height that maximizes bite mass (Laca *et al.*, 1994; Gonçalves *et al.*, 2009; Mezzalira *et al.*, 2014). For example, extremely short or tall swards of *Cynodon* sp. and *Avena strigosa* resulted in lower animal intake rates (Mezzalira *et al.*, 2014). In addition, to maintain the greater intake rate in rotational stocking, the level of grazing down should not exceed 40% of the optimal pre-grazing sward height (Fonseca *et al.*, 2012; Mezzalira *et al.*, 2014).

These behavioural responses of animals to sward structure (e.g. herbage intake per unit of time) are not considered by the traditional grazing management strategies that target maximum herbage mass accumulation. For example, in rotational stocking, pre-grazing sward height is variable and indirectly defined by the pasture resting period. Additionally, post-grazing sward height is defined by an intended maximum herbage harvesting efficiency. Thus, animal intake is only a consequence of sward growth and utilization targets. In this proposition, from the economic perspective, herbage intake per unit of the area must have greater priority than the intake per animal (see Romera and Doole, 2015). Conversely, Carvalho (2013) argued that grazing management targets must consider the animal behavioural responses to sward structure. Conceptually, offering the animals an optimal sward structure should then promote greater intake per unit of grazing time, so sward structure represented by pre- and post-grazing sward heights should maximize intake rate rather than pasture growth and utilization. From this, an innovation in grazing management, called 'Rotatinuous' stocking, was proposed as a new strategy that considers the animal response to sward structure as the main factor driving grazing management (Carvalho, 2013).

In the context of these contrasting grazing management strategies, we hypothesized that 'Rotatinuous' stocking (RN) strategy would allow sheep grazing Italian ryegrass pastures to optimize grazing time and increase daily herbage intake compared to the traditional rotational stocking (RT). We aimed to evaluate the effect of two grazing management strategies on foraging behaviour and daily organic matter (**OM**) intake by sheep grazing Italian ryegrass pastures.

Material and methods

Experimental conditions and treatments

The experiment was conducted at the experimental station of the Federal University of Rio Grande do Sul, Eldorado do Sul city, Rio Grande do Sul State, Brazil (30°05′ S, 51°39′ W), between April and September 2015.

The climate zone is the humid subtropics. During the experimental period, average ambient temperature was 18°C and rainfall was 980 mm (National Institute of Meteorology, INMET, Brazil).

The experimental design was a randomized complete block with two grazing management strategies and four replicates (paddocks). The grazing management treatments were a traditional rotational stocking (RT), with pre- and post-grazing target heights of 25 and 5 cm, respectively (Mittelmann, 2017), and a 'Rotatinuous' stocking (RN) (Carvalho, 2013) with pre- and post-grazing target heights of 18 and 11 cm, respectively, for Italian ryegrass pastures (Amaral *et al.*, 2013).

In the RT treatment, the pre- and post-grazing sward heights were designed to achieve maximum herbage accumulation and pasture utilization, respectively (Mittelmann, 2017). The RN treatment used optimal pre-grazing sward heights to achieve the maximum herbage intake rate (Amaral *et al.*, 2013) and a post-grazing height that allowed the animals to graze only the top 40% of the sward to maintain a greater intake rate (Fonseca *et al.*, 2012; Mezzalira *et al.*, 2014); we proposed that the animal is the main agent that dictates the rules, that is, animal responses to sward structure, such as the forage intake per unit grazing time, constitute the core of the proposition.

Pasture

The experimental area of 1.76 ha was divided into eight equal paddocks (experimental units), that is, four paddocks per treatment. Each paddock was divided by strips that had variable size during the stocking cycle to accomplish sward height treatments requirement. The pastures consisted of pure stands of Italian ryegrass (*Lolium multiflorum* Lam.). Italian ryegrass was sown in April 2015 (35 kg of seed/ha).

Three hundred kilograms per hectare of fertilizer (NPK, 5-30-15) and 140 kg N/ha as urea were applied at seeding and before the beginning of the stocking season, respectively. The stocking season started on 25 May 2015.

Sward management

The grazing management was based on a 1-day strip-grazing regime. The animals were moved into a new strip between 1400 and 1500 h every day for both treatments. The sheep were given access to a fresh strip-grazing in the afternoon to synchronize with their natural response of grazing longer and more intensely before sunset (Orr *et al.*, 1997).

Each stocking cycle started when the first strip had reached the target height for each treatment. The stocking season lasted 155 days (13 stocking cycles with 12 days each (12 strips)) and 146 days (4 stocking cycles with 36 days each (36 strips)) for the RN and RT treatments, respectively.

Sward measurements

One hundred random readings of the sward height were taken per strip before (pre-grazing, 1300 h), during (mid-grazing, 1900 h) and after grazing (post-grazing, 1500 h) using a sward stick (Barthram, 1985). Mid- and post-grazing sward readings were recorded as either grazed or non-grazed condition.

Herbage mass was measured by cutting three herbage samples (0.25 m^2) at ground level in each strip (pre- and post-grazing). These samples were oven-dried at 55°C for 72 h, and a sub-sample was taken and separated to estimate the leaf/stem ratio.

Hand-plucked herbage samples (Johnson, 1978) were taken in each strip on two occasions: after the strip allocation at 1600 h (afternoon) and the following morning at 0900 h, in August and September. This sampling was done together with each measurement of animal herbage intake, resulting in a total of 32 herbage samples.

These hand-plucked herbage samples represented the consumed herbage by the animals. The samples were then oven-dried at 55°C for 72 h and ground with a centrifugal mill (1-mm screen). Near-infrared reflectance spectroscopy was used to determine herbage OM, NDF, ADF and CP contents. These predictions were performed by The Walloon Agricultural Research Centre, Belgium (*sensu* Decruyenaere *et al.*, 2009).

Animals

The experimental animals were crossbred Texel and Polwarth growing lambs. The animals had an average age of 12 months and an average live weight (**LW**) of 32 ± 2.3 kg. Each paddock had three test animals (permanent animals over the whole stocking season) and adjustment animals (Mott and Lucas, 1952). The stocking rate adjustment was performed whenever necessary (one or two times a week) to maintain the sward height targets, and the animals used for it were similar to the test animals in age, LW and breed.

Behaviour measurements

The animal behaviour measurements were taken during the stocking season (after 60 days of the beginning of the experiment) in all paddocks for both treatments on two occasions: August and September. Each animal behaviour variable was measured for 1 day (in a single strip-grazing), starting when the animals changed strips at 1400 h, and continued until dusk (approximately 1900 h), then it resumed the following day after dawn (approximately 0600 h) and continued until 1400 h. The animals were not evaluated at night, between 1900 and 0600 h.

Measurements were always performed per block (one block included two paddocks), with one or two blocks evaluated on the same day and the other blocks evaluated the following days.

The behavioural activities (grazing, ruminating and resting) were assessed visually and recorded every 5 min (Hirata *et al.*, 2002) for all animals in each paddock; a total of 57 sheep were evaluated (48 test animals plus 9 adjustment animals), for both treatments in 2 months (August and September). Grazing time per hour was then calculated as the time in minutes that the animal grazed in each hour of the day.

A total of 48 observations (3 animals per paddock, 8 paddocks and 2 months (August and September)) were used to evaluate the time spent per bite (Laca *et al.*, 1992) (time to take 20 bites) and per feeding station (time per 10 feeding stations) as well as the number of steps taken per feeding station; these measurements were performed during the afternoon and morning. Each animal was evaluated at least twice each day shift for these behaviour measurements, then an average per animal was done.

Bites occurred between 1 and 2 s and were defined by the jaw, tongue and neck movements. The feeding station was defined by the actions such as bites taken by the animals without moving their front feet (Bailey *et al.*, 1996). A feeding station was composed of at least one bite.

The data were then used to calculate the time per feeding station (min), bite rate per min and the total number of bites per day. These visual measurements were performed by trained observers.

Herbage intake

The faecal CP technique (Penning, 2004) was used to estimate daily OM intake. Herbage intake was estimated using the equation proposed for Italian ryegrass pastures by Azevedo *et al.* (2014): OM intake (g/sheep per day) = 111.33 + 18.33 × faecal CP (g/sheep per day).

The measurements were performed twice during the stocking season, in August and September, after the animal behaviour measurements.

Faecal collection bags were fitted to 3 test animals per paddock, that is, the same 48 observations used for animal behaviour measurements; 3 animals per paddock, with a total of 8 paddocks and 2 months (August and September). This measurement lasted five consecutive days; the bags were emptied once a day and the faeces were weighed and homogenized.

A faecal sample per animal composing 20% of the total faecal collection was then taken and oven-dried at 55°C for 72 h. The dried samples were then ground with a knife mill using a 1-mm screen. The daily samples were then pooled per animal totalizing 48 faecal samples, and analysed for DM, OM and total N (AOAC, 1975).

Statistical analysis

Before the analysis, all data were checked for normality and homogeneity of variance using histograms and QQ plots. Data were a log, cube or square root transformed according to the Box-Cox transformation procedure when necessary. Data were analysed using ANOVA at a 5% level of significance. The analysis was performed using R software for statistical computing, version 2.12.0 (R Development Core Team, 2010). Linear models and linear mixed-effects models (lme) were used, and the best model was selected by the likelihood ratio test and Akaike's information criterion. For the animal and sward analysis, treatments were considered as a fixed effect, and measurements performed (August and September), paddocks and animals (only for animal analysis) were considered as random effects. The time of day (afternoon and morning) was considered as a fixed effect. The measurement periods (August and September) were considered to be repeated measures on time, where each month represented the measurement of the same paddock (experimental unit) under a different condition.

Results

Sward characteristics

As intended, the pre-grazing sward height (Table 1) of the RT was greater ($P < 0.001$) than that of the RN treatment, averaging of 26.1 and 17.2 cm, respectively. However, the mid-grazing sward heights did not differ between treatments ($P > 0.05$) (~13.2 cm). Post-grazing sward heights were lower ($P < 0.001$) for the RT than for the RN treatment (7.8 and 11.9 cm, respectively). Pre-grazing herbage mass (Table 1) was greater ($P < 0.001$) for the RT than for the RN treatment. However, the post-grazing herbage mass did not differ between treatments ($P > 0.05$) (~1319 kg DM/ha).

The pre-grazing leaf/stem ratio of the Italian ryegrass pastures (Table 1) did not differ between treatments ($P > 0.05$) (~2.87), but the post-grazing leaf/stem ratio was greater ($P < 0.001$) for the RN than for the RT treatment (1.59 and 0.76, respectively). The percentage of the non-grazed area was greater ($P < 0.01$) in mid- and post-grazing for RN compared to RT treatment (Table 1). The average non-grazed area was 42.2% (RN) and 22.9% (RT) in the mid-grazing, and 29.7% (RN) and 3.49% (RT) in the post-grazing.

The herbage CP content was greater ($P < 0.001$) and both ADF and NDF contents were lower ($P < 0.001$) for the RN than for the RT treatment. However, the herbage OM content did not differ between treatments ($P > 0.05$) (Table 2). The herbage ADF and NDF contents were lower ($P < 0.001$) in the afternoon than in the morning for both treatments. Yet, there was a significant interaction between treatment and time of the day for the herbage CP content. In the RN treatment, CP content did not differ ($P > 0.05$) between the afternoon and the morning, but in the RT treatment, the CP content was lower ($P < 0.05$) in the morning than in the afternoon.

Chemical composition of Italian ryegrass pastures grazed by sheep over the stocking season (July, August and September) is shown in Figure 1. The herbage CP content was greater in the RN over the stocking season (July, $P < 0.001$; August, $P < 0.001$; September, $P < 0.05$), and the RN treatment presented lower herbage NDF and ADF contents in July ($P < 0.05$ and $P < 0.001$, respectively) and August ($P < 0.01$), but not in September ($P > 0.05$).

Table 1 *Characteristics of Italian ryegrass pastures grazed by sheep under different grazing management strategies (RN and RT)*

Variables	RN	RT	SEM	*P*-values
Sward height (cm)				
Pre-grazing	17.2	26.1	0.16	***
Mid-grazing[1]	12.6	13.9	0.12	ns
Post-grazing	11.9	7.8	2.07	***
Herbage mass (kg DM/ha)				
Pre-grazing	2011	2532	107	***
Post-grazing	1376	1262	68.9	ns
Leaf/stem ratio				
Pre-grazing	3.11	2.64	0.26	ns
Post-grazing	1.59	0.76	0.12	***
Non-grazed area (%)				
Mid-grazing[1]	42.3	22.9	3.95	**
Post-grazing	29.7	3.49	3.88	***

RN = 'Rotatinuous' stocking; RT = traditional rotational stocking.
[1]Measurements taken before dusk.
**$P < 0.01$, ***$P < 0.001$, ns $P > 0.05$.

Stocking rate, animal behaviour and intake

The stocking rate was greater ($P < 0.001$) for the RT than for the RN treatment, with an average of 993 and 681 kg LW/ha, respectively.

The total time spent grazing, ruminating and resting (Table 3) did not differ between treatments ($P > 0.05$), with averages of 439, 167 and 85 min, respectively. The RN treatment resulted in greater bite rate ($P < 0.05$), feeding stations per min ($P < 0.001$) and steps per min ($P < 0.05$) in comparison to the RT treatment (Table 3).

The time per bite and time per feeding station were greater ($P < 0.05$ and $P < 0.001$, respectively) for the RT than for the RN treatment. The steps per feeding station (Table 3) did not differ between treatments ($P > 0.05$).

Grazing time per hour was greater ($P < 0.05$) for the RN than for the RT treatment, with an average of 41.5 and 38.7 min, respectively. The grazing time per hour and the bite rate were greater ($P < 0.001$) in the afternoon than in the morning for both treatments. The ruminating time and the resting time per hour were greater ($P < 0.001$) in the morning than in the afternoon for both treatments (Table 4).

Daily OM intake was greater ($P < 0.001$) in the RN than in the RT treatment, with an average of 843.7 and 707.8 g OM/sheep, respectively (Table 3). This difference was also confirmed when expressed as a percentage of LW ($P < 0.01$), with averages of 2.53% and 2.25% for the RN and RT treatments, respectively.

Discussion

This study showed that the grazing management did not affect total grazing time, but it did affect others foraging

Table 2 *Chemical composition (% DM) of Italian ryegrass pastures grazed by sheep under different grazing management strategies (RN and RT) and time of day (afternoon and morning)*

Variables	RN		RT		SEM	P_T	P_{AM}	$P_{T\times AM}$
	Afternoon	Morning	Afternoon	Morning				
OM	87.1	86.6	87.5	87.1	1.22	ns	ns	ns
CP	24.9[a]	24.8[a]	20.2[b]	17.4[c]	0.72	***	***	***
ADF	20.7	22.8	23.8	27.2	0.48	***	***	ns
NDF	41.0	43.1	43.6	46.9	0.53	***	***	ns

RN = 'Rotatinuous' stocking; RT = traditional rotational stocking; OM = organic matter; P_T = probability for treatment (RN and RT); P_{AM} = probability for time of day (afternoon and morning); $P_{T\times AM}$ = probability for interaction between treatment and time of day.
[a,b,c]Values within a row with different superscript letters differ by the Tukey test.
***$P < 0.001$, ns$P > 0.05$.

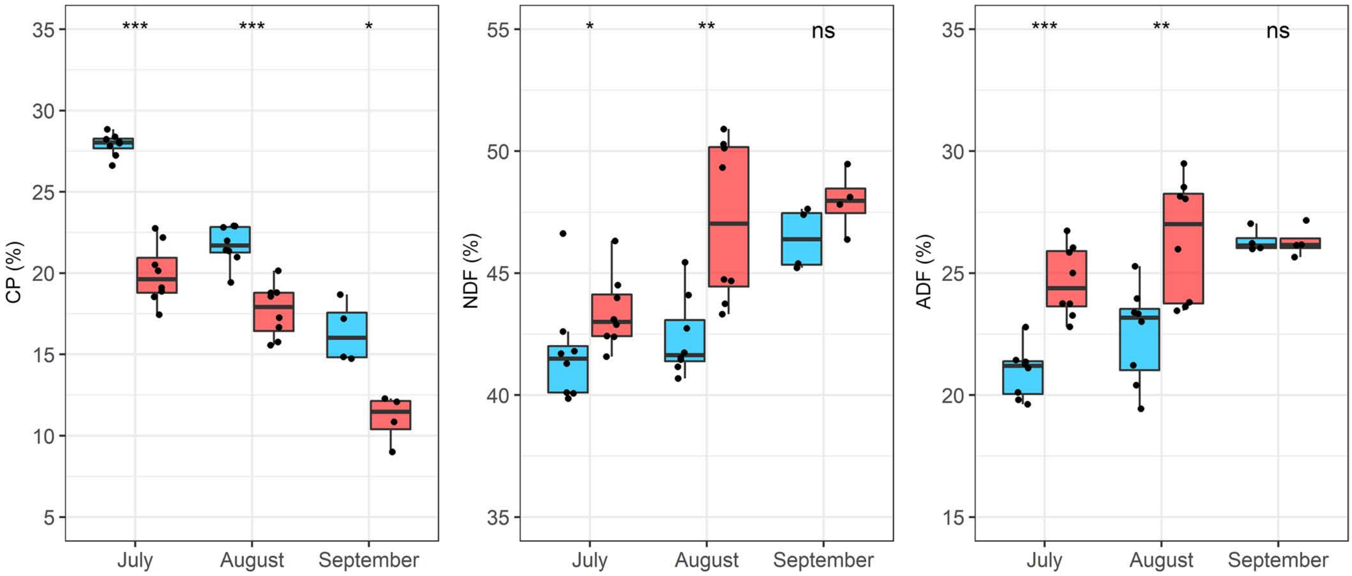

Figure 1 (colour online) Chemical composition of Italian ryegrass pastures grazed by sheep under different grazing management strategies (RN: 'Rotatinuous' stocking, blue; RT: traditional rotational stocking, red) over the 2015 stocking season. Treatment comparisons were made within each month. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns$P > 0.05$.

behavioural measures (e.g. bite rate and time per feeding station). In addition to that, the grazing management based on the optimal sward structure represented by pre- and post-grazing sward heights, called 'Rotatinuous' stocking, resulted in greater herbage nutritive value and daily herbage intake by sheep grazing Italian ryegrass than the traditional rotational stocking (RT).

Sward structure and herbage chemical composition

The pre- and post-grazing heights defined in the different grazing management treatments had a direct influence on the herbage mass and morphological composition (Table 1). This was previously reported by Amaral *et al.* (2013) for Italian ryegrass pastures managed under different grazing intensities. Consequently, as hypothesized, the chemical composition of the herbage (Table 2 and Figure 1) was also affected, which is a common response observed under different level of pasture depletion (see Benvenutti *et al.*, 2016).

In the RN treatment, the sward height reduction was not severe, since the key objective was to defoliate approximately 40% of the initial sward height. In contrast, the RT treatment achieved greater levels of sward defoliation, with more than 70% of the sward height removed (Table 1). This resulted in a lower residual leaf/stem ratio than in the RN treatment (Table 1).

Amaral *et al.* (2013) observed the same response in Italian ryegrass pastures when the sward height was reduced from 17.3 to 10.7 cm, the leaf/stem ratio decreased from 1.05 to 0.69, and when the sward height was grazed from 26.0 to 8.2 cm, the leaf/stem ratio decreased from 0.85 to 0.34. Fonseca *et al.* (2012) also reported that in *Sorghum bicolour* pastures the post-grazing leaf mass decreased from 388 to 29 kg DM/ha when the intensity of defoliation (i.e. the level of grazing down) increased from 36% to 63% of the pre-grazing sward height.

In general, the animals always started grazing a new strip in the afternoon with greater CP content in the RN treatment and maintained this good quality until the end of their grazing the following morning, which may be explained by the greater post-grazing leaf/stem ratio. This result supports

Table 3 *Stocking rate, foraging behaviour and daily herbage intake by sheep grazing Italian ryegrass pastures under different grazing management strategies (RN and RT)*

Variables	RN	RT	SEM	*P*-values
Stocking rate (kg LW/ha)	681	993	67.6	***
Diurnal animal activity (min)				
Grazing time	454	425	14.6	ns
Ruminating time	159	175	7.81	ns
Resting time	79.3	90.7	5.50	ns
Bite and feeding station behaviour				
Bite rate per min	49.7	27.7	11.0	*
Time per bite (s)	1.35	2.39	0.52	*
Feeding station per min	8.92	6.04	1.44	***
Time per feeding station (s)	6.96	10.4	1.71	***
Steps per feeding station	1.69	1.88	0.10	ns
Steps per min	15.6	10.7	2.46	*
Daily organic matter intake				
g/sheep	843.7	707.8	19.6	***
% LW	2.53	2.25	0.04	**

RN = 'Rotatinuous' stocking; RT = traditional rotational stocking; LW = live weight.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns$P > 0.05$.

the argument that the animals in the RN treatment mainly had access to the top grazing stratum composed mainly of leaves, which is consistent with the animal strategy of maximizing diet quality and intake rate (Baumont *et al*., 2004). It seemed that in the RT treatment the animals had access to the lower grazing strata composed of leaves and stems, with lower nutritive value. This response was described by Benvenutti *et al.* (2016), who showed that the CP content in *Axonopus catarinensis* pastures decreased from the top to the bottom stratum of the sward. Therefore, the greater nutritive value of herbage (e.g. CP content) is consequently achieved in a specific grazing period (Table 2) and over the stocking season (Figure 1) situations when the animals have access to greater pasture allocations, such as occurs in 'Rotatinuous' stocking, resulting in greater OM matter and nutrient intake.

Sheep behaviour and intake

Previous studies (Tharmaraj *et al.*, 2003; Champion *et al.*, 2004; Pérez-Prieto *et al.*, 2011; Gonçalves *et al.*, 2018) have reported that different grazing management strategies did not affect grazing time. Despite the large difference in pasture height between treatments, the same response also was observed in our study (Table 3). This indicates that sheep used different strategies to graze the pasture and achieve greater daily herbage intake in the RN treatment (Table 3). The animals started grazing a new strip in the afternoon, continuing until dusk with longer grazing time per hour and low ruminating and resting times (Table 4). In both treatments, the grazing time per hour was lower the following day between dawn and the allocation of the next strip. This response was expected because when the animals started grazing a new strip in the afternoon, the grazing time was longer and more intensive, especially in the afternoon/evening when the herbage had greater DM content (Orr *et al.*, 1997) and nutritive value (Gregorini *et al.*, 2007).

According to Gregorini (2012), the dusk grazing event seems to be an adaptive feeding strategy to maximize energy acquisition, which is then used during the night. Bite mass and intake rate were found to be greater in the afternoon/evening than in the morning for both sheep (Orr *et al.*, 1997) and cows (Gibb *et al.*, 1998). In addition, Abrahamse *et al.* (2009) also observed that grazing time, bites and chews were greater in the period immediately after moving the dairy cattle to a fresh paddock of grass, which according to Meuret and Provenza (2015) may be related to the motivation to graze.

A mechanism that can help us to explain the greater intake for RN is the greater bite rate compared to the RT treatment on both shifts of the day, even with a reduction from afternoon to morning (Table 4). The grazing down dynamics, concurrent with changes in sward structure along the occupation period, may explain these results. At the beginning of the strip utilization, the animals face taller swards on RT treatment and need a longer time to manipulate leaf gathering (non-biting jaw movements) during grazing (Nadin *et al.*, 2012). Also, the animals might be spending more time searching at the end of strip utilization,

Table 4 *Animal activity (time per hour) and bite rate by sheep grazing Italian ryegrass pastures under different grazing management strategies (RN and RT) and time of day (afternoon and morning)*

Variables	RN		RT		SEM	P_T	P_{AM}	$P_{T\times AM}$
	Afternoon	Morning	Afternoon	Morning				
Diurnal animal activity (min/h)[1]								
Grazing time	52.5	30.4	52.0	25.5	1.26	*	***	ns
Ruminating time	3.64^b	19.9^a	2.25^b	22.3^a	0.92	ns	***	**
Resting time	4.33	8.66	4.95	9.35	0.47	ns	***	ns
Bite rate per min	54.8	44.2	29.7	24.5	0.83	**	***	ns

RN = 'Rotatinuous' stocking; RT = traditional rotational stocking; P_T = probability for treatment (RN and RT); P_{AM} = probability for time of day (afternoon and morning); $P_{T\times AM}$ = probability for interaction between treatment and time of day.
[a,b]Values within a row with different superscript letters differ by the Tukey test.
[1]Grazing, ruminating and resting time per hour were calculated as the time in minutes that the animal grazed in each hour of the day.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns$P > 0.05$.

as post-grazing leaf/stem ratio on RT treatment was very low. In fact, Nadin *et al.* (2012) showed that the bite rate of calves grazing oat pastures was greater for medium (26 cm) than tall (52 cm) or short (15 cm) sward heights.

Another factor that probably determined the differences in intake between treatments was bite fracture force that was likely to be greater for the RT treatment. As the stem proportion (post-grazing) was greater for the RT treatment, it is to be expected that the animals needed more force per bite, resulting in a lower bite rate, as reported by Tharmaraj *et al.* (2003). Moreover, older plants in RT treatment can present a greater fracture force than younger plants in RN treatment, based on greater content of sclerenchyma (Wright and Illius, 1995).

In addition, during the grazing down of swards, the bite rate was reduced from the previous afternoon to the morning (Table 4) in both treatments. This response was also observed by Gonçalves *et al.* (2018) for sheep grazing Italian ryegrass pastures. This was likely due to the reduction of the leaf/stem ratio in the treatments, which may have impaired the animals' manipulation of the plant material, resulting in more time spent per bite. Benvenutti *et al.* (2008) found that when the stem density of the canopy increased, the animals spent more time manipulating the herbage; consequently, the time per bite was also greater. Fonseca *et al.* (2013) also found that when more than 40% of the pre-grazing height of the herbage was depleted, such as in the RT treatment, the bite rate decreased linearly. As a result, the animals spent more time per feeding station (Table 3).

According to the foraging theory (Charnov, 1976), the greater the amount of available biomass in the feeding station, the longer the time per feeding station. This scenario is typical of the beginning of the occupation period (pre-grazing leaf mass) on RT treatment. However, according to the theory, the lower post-grazing leaf mass on RT would decrease the time per feeding station at the end of the occupation period. Conversely, time per feeding station remains greater despite the greater herbage depletion on RT treatment. This phenomenon is typical of rotational stocking when post-grazing leaf mass is low. In such a condition, animals just give up from searching for new feeding stations and wait being moved to the new strip.

Also, the lower herbage intake in the RT treatment could be explained by the greater depletion of the top grazing stratum that occurred in this treatment, where only 4% of the area remained non-grazed, while in RN treatment 30% of the area remained non-grazed (Table 1). This indicates that in the RN treatment the sheep had more opportunities to select high-quality forage until the end of the occupation period (Table 2) and over the stocking season (Figure 1). In highly depleted swards such as in RT treatment with only 4% of the pasture left non-grazed, sheep may be more motivated to give up grazing and wait for a new strip, as previously stressed.

Previous studies (Fonseca *et al.*, 2012; Mezzalira *et al.*, 2014) have found that cattle intake rate decreased at greater levels of herbage depletion. Fonseca *et al.* (2013) observed that the bite mass decreased linearly after 40% of the sward height was removed. Carvalho (2013) proposed that the intake rate is constant until the animal's graze two-thirds of the uppermost stratum of the pasture surface layer; afterwards, the intake rate decreases.

Finally, the rule of the 'Rotatinuous' stocking is 'take the best and leave the rest' (Carvalho, 2013), that is, the animal should have the opportunity to eat the top leaves and leave some non-grazed pastures to make sure herbage intake is maximized as found in the present study. Our results indicate that this approach can result in greater animal response than the greater stocking rate strategy as observed in the RT treatment (Table 3) which does not result in greater production. Consequently, it should possible to produce more quality sheep meat with fewer animals. For this reason, the target is to offer sward structures to optimize individual sheep herbage intake and consequently improve daily LW gain, and the stocking rate is just a consequence. This paper addressed the daily pattern of sheep behavioural responses, but more research is needed to understand instantaneously the effect of sward structure on grazing behaviour during sward depletion in rotational stocking and the major consequences on herbage intake and selectivity.

Conclusions

Our findings support the hypothesis that changes in sward structure affect herbage chemical composition, foraging efficiency and daily herbage intake by sheep. This study has shown that grazing time was not affected by grazing management; however, the 'Rotatinuous' stocking strategy, which uses the optimal sward height to maximize herbage intake rate, resulted in greater herbage nutritive value in each grazing period and over the stocking season and greater sheep daily herbage intake. Finally, the results from our study support the idea that when grazing management targets are based on known animal behavioural responses to sward structure such as in 'Rotatinuous' stocking, daily herbage intake is maximized, and the grazing time is optimized. This management strategy in rotational stocking allows the animals to selectively graze the leaves at a greater intake rate by using optimal sward structures and leaving some non-grazed plants at each grazing period.

Acknowledgements

We are grateful to Project Universal-CNPq 481941/2013-4 and CAPES ('Bolsista da CAPES, Programa PVE'). We thank Reuben Mark Sulc, Sila Carneiro da Silva and Jérôme Bindelle for their valuable comments on this manuscript. This work was part of the PhD thesis of the first author.
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Declaration of interest

None.

Ethics statement

This experiment was carried out according to the international ethics committees on animal use.

Software and data repository resources

None.

References

Abrahamse PA, Tamminga S and Dijkstra J 2009. Effect of daily movement of dairy cattle to fresh grass in morning or afternoon on intake, grazing behaviour, rumen fermentation and milk production. Journal of Agricultural Science 147, 721–730.

Amaral MF, Mezzalira JC, Bremm C, Da Trindade JK, Gibb MJ, Suñe RWM and Carvalho PCF 2013. Sward structure management for a maximum short-term intake rate in annual ryegrass. Grass and Forage Science 68, 271–277.

Association of Official Analytical Chemists (AOAC) 1975. Official methods of analysis, 12th edition. AOAC, Washington, DC, USA.

Azevedo EB, Poli CHEC, David DB, Amaral GA, Fonseca L, Carvalho PCF, Fischer V and Morris ST 2014. Use of faecal components as markers to estimate intake and digestibility of grazing sheep. Livestock Science 165, 42–50.

Bailey DW, Gross JE, Laca EA, Rittenhouse LR, Coughenour B, Swift DM and Sims PL 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49, 386–400.

Barthram GT 1985. Experimental techniques: the HFRO sward stick. In Biennial Report of the Hill Farming Research Organization (ed. MM Alcock), pp. 29–30. HFRO Publishing, Midlothian, UK.

Baumont R, Cohen-Salmon D, Prache S and Sauvant D 2004. A mechanistic model of intake and grazing behaviour in sheep integrating sward architecture and animal decisions. Animal Feed Science and Technology 112, 5–28.

Benvenutti MA, Gordon IJ and Poppi DP 2008. The effects of stem density of tropical swards and age of grazing cattle on their foraging behaviour. Grass and Forage Science 63, 1–8.

Benvenutti MA, Pavetti DR, Poppi DP, Gordon IJ and Cangiano CA 2016. Defoliation patterns and their implications for the management of vegetative tropical pastures to control intake and diet quality by cattle. Grass and Forage Science 71, 424–436.

Carvalho PCF 2013. Harry Stobbs Memorial Lecture: can grazing behavior support innovations in grassland management? Tropical Grasslands 1, 137–155.

Champion RA, Orr RJ, Penning PD and Rutter SM 2004. The effect of the spatial scale of heterogeneity of two herbage species on the grazing behaviour of lactating sheep. Applied Animal Behaviour Science 88, 61–76.

Chapman DF, Parsons AJ, Cosgrove GP, Barker DJ, Marotti DM, Venning KJ, Rutter SM, Hill J and Thompson AN 2007. Impacts of spatial patterns in pasture on animal grazing behavior, intake, and performance. Crop Science 47, 399–415.

Charnov EL 1976. Optimal foraging: the marginal value theorem. Theoretical Population Biology 9, 129–136.

Decruyenaere V, Lecomte P, Demarquilly C, Aufrere J, Dardenne P, Stilmant D and Buldgen A 2009. Evaluation of green forage intake and digestibility in ruminants using near infrared reflectance spectroscopy (NIRS): developing a global calibration. Animal Feed Science and Technology 148, 138–156.

Fonseca L, Carvalho PCF, Mezzalira JC, Bremm C, Galli JR and Gregorini P 2013. Effect of sward surface height and level of herbage depletion on bite features of cattle grazing *Sorghum bicolor* swards. Journal of Animal Science 91, 4357–4365.

Fonseca L, Mezzalira JC, Bremm C, Filho RSA, Gonda HL and Carvalho PCF 2012. Management targets for maximising the short-term herbage intake rate of cattle grazing in *Sorghum bicolor*. Livestock Science 145, 205–211.

Forbes JM and Gregorini P 2015. The catastrophe of meal eating. Animal Production Science 55, 350–359.

Gibb MJ, Huckle CA and Nuthall R 1998. Effect of time of day on grazing behaviour by lactating dairy cows. Grass and Forage Science 53, 41–46.

Gonçalves EN, Carvalho PCF, Kunrath TR, Carassai IJ, Bremm C and Fischer V 2009. Relações planta-animal em ambiente pastoril heterogêneo: processo de ingestão de forragem. Revista Brasileira de Zootecnia 38, 1655–1662 (in Portuguese).

Gonçalves RP, Bremm C, Moojen FG, Marchi D, Zubricki G, Caetano LAM, Barth Neto A and Carvalho PCF 2018. Grazing down process: the implications of sheep's ingestive behavior for sward management. Livestock Science 214, 202–208.

Gregorini P 2012. Diurnal grazing pattern: its physiological basis and strategic management. Animal Production Science 52, 416–430.

Gregorini P, Eirin M, Wade MH, Refi R, Ursino M, Ansin O, Masino C, Agnelli L, Wakita K and Gunter SA 2007. The effects of a morning fasting on the evening grazing behavior and performance of strip-grazed beef heifers. The Professional Animal Scientist 23, 642–648.

Hirata M, Iwamoto T, Otozu W and Kiyota D 2002. The effects of recording interval on the estimation of grazing behavior of cattle in a daytime grazing system. Asian-Australasian Journal of Animal Sciences 15, 745–750.

Johnson AD 1978. Sample preparation and chemical analysis of vegetation. In Measurement of grassland vegetation and animal production (ed. L. T. Manejte), pp. 96–102. Commonwealth Agricultural Bureaux, Aberystwyth, UK.

Laca EA, Ungar ED and Demment MW 1994. Mechanisms of handling time and intake rate of a large mammalian grazer. Applied Animal Behaviour Science 39, 3–19.

Laca EA, Ungar ED, Seligman NG, Ramey MR and Demment MW 1992. An integrated methodology for studying short-term grazing behavior of cattle. Grass and Forage Science 47, 81–90.

Meuret M and Provenza FD 2015. When art and science meet: integrating knowledge of French herders with science of foraging behavior. Rangeland Ecology & Management 68, 1–17.

Mezzalira JC, Carvalho PCF, Fonseca L, Bremm C, Cangiano C, Gonda HL and Laca EA 2014. Behavioural mechanisms of intake rate by heifers grazing swards of contrasting structures. Applied Animal Behaviour Science 153, 1–9.

Mittelmann A 2017. Azevém BRS Integração. In Boas práticas agropecuárias na produção de leite: da pesquisa para o produtor (ed. MB Zanela and RM Dereti), pp. 39–41. Embrapa Clima Temperado, Pelotas, Brazil (in Portuguese).

Mott GO and Lucas HL 1952. The design, conduct, and interpretation of grazing trials on cultivated and improved pastures. In Proceedings of the 6th International Grassland Congress, 17–23 August 1952, PA, USA, pp. 1380–1385.

Nadin LB, Sánchez Chopa F, Gibb MJ, Trindade JK, Amaral GA, Carvalho PCF and Gonda HL 2012. Comparison of methods to quantify the number of bites in calves grazing winter oats with different sward heights. Applied Animal Behaviour Science 139, 50–57.

Orr RJ, Penning PD, Harvey A and Champion RA 1997. Diurnal patterns of intake rate by sheep grazing monocultures of ryegrass or white clover. Applied Animal Behaviour Science 52, 65–77.

Penning PD 2004. Animal-based techniques for estimating herbage intake. In Herbage Intake Handbook (ed. PD Penning), pp. 53–93. British Grassland Society, Reading, UK.

Pérez-Prieto LA, Peyraud JL and Delagarde R 2011. Pasture intake, milk production and grazing behaviour of dairy cows grazing low-mass pastures at three daily allowances in winter. Livestock Science 137, 151–160.

R Development Core Team 2010. R: A Language and Environment for Statistical Computing. ISBN 3-900051-07-0. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Romera AJ and Doole GJ 2015. Optimising the interrelationship between intake per cow and intake per hectare. Animal Production Science 55, 384–396.

Tharmaraj J, Wales WJ, Chapman DF and Egan AR 2003. Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture. Grass and Forage Science 58, 225–238.

Ungar ED and Noy-Meir I 1988. Herbage intake in relation to availability and sward structure: grazing processes and optimal foraging. Journal of Applied Ecology 25, 1045–1062.

Wright W and Illius AW 1995. A comparative study of the fracture properties of five grasses. Functional Ecology 9, 269–278.