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Sward structure management for a maximum short-term intake rate in annual ryegrass

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Abstract

This study tested the hypothesis that different sward structures, which were constructed by varying the pre- and post-grazing sward heights of annual ryegrass pasture (*Lolium multiflorum* Lam.) in southern Brazil, affect the short-term intake rate (STIR) by dairy cows. Treatments consisted of four sward-management strategies defined by a combination of two pre- (25 and 15 cm) and two post-grazing sward heights (10 and 5 cm): 15-05, 15-10, 25-05 and 25-10. A completely randomized block design with four replicates was used for the experimental design. The STIR was determined by the double-weighing technique. Jaw movements were evaluated using automatic recorders (IGER Behaviour Recorder). The results showed that treatment 25-10 allowed the animals to collect more herbage with a greater bite mass and thus resulted in a greater STIR. Treatments in which sward height was reduced to 10 cm generally favoured the ingestion process than treatments with a post-grazing sward height of 5 cm.

Keywords: bite mass, *Lolium multiflorum*, rotational stocking, dairy cows

Introduction

Herbivores are faced with a series of multifactor decisions during grazing. Many of these decisions are based at the bite level and feeding-station level and are made in the time scale of seconds or minutes, thousands of times per day (Bailey and Provenza, 2008). Therefore, an error in sward management target can become an accumulated error throughout the day, bringing potentially large consequences (Shipley, 2007).

To obtain a better understanding of the foraging process, the sward structure should be approached as a three-dimensional arrangement of aerial biomass of herbage (Laca and Lemaire, 2000). This component of the pastoral environment is assumed to be a determinant for the short-term intake rate (STIR) (Fonseca *et al.*, 2012a) and, consequently, for the performance of grazing animals (Gordon and Benvenutti, 2006; Bailey and Provenza, 2008). Carvalho *et al.* (2009a) argued that the sward structure is a concomitant cause and effect in the grazing process. That is, when an animal grazes, it shapes the spatial structure of vegetation and creates new conditions; these new conditions in turn influence the searching and grazing activities by the animal.

Although animals can modify their ingestive behaviour to minimize the effect of unfavourable feeding conditions (Orr *et al.*, 2004), it is necessary to create sward structures that increase herbage intake per unit time to maximize pasture use in dairy production systems. The relative complexity of grazing management decision-making in most pasture-based livestock farming areas has led to important attempts to develop simple indicators or tools that farmers can apply in their day-to-day management (Chapman *et al.*, 2012). Examples of these management targets include the concept that users define pre- and post-grazing sward heights, as proposed by this study.

The STIR responds directly to the conditions of the sward canopy down its vertical profile and is reported as half of the sward height for all grazers (e.g. Wade, 1991; Carrere *et al.*, 2001; Cangiano *et al.*, 2002; Benvenutti *et al.*, 2008; Goncalves *et al.*, 2009). The bite area is reduced as the sward is grazed down because of access to parts of the plant with a higher proportion

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of stems (Ungar *et al.*, 2001). Therefore, the bite mass decreases as the sward height is grazed down because of the combination of a smaller bite area (Ungar *et al.*, 2001) and reduced absolute bite depth (Laca *et al.*, 1992; Benvenutti *et al.*, 2008).

The objective of this study was to define which combinations of pre- and post-grazing sward heights of annual ryegrass (*Lolium multiflorum* Lam.) are expected to maximize the STIR by dairy cows.

Materials and methods

Site and experimental design

The study was conducted at the Brazilian Agricultural Research Corporation (EMBRAPA) (31°20′S, 54°06′W at an altitude of 216 m). The climate at the experimental site is humid subtropical (Cfa), with an annual average precipitation of 1460 mm. The annual mean temperature is 17·9°C (DNMET, 1992). The soil type at the site is a Ultisol aquult (Soil Survey Staff, 2006) derived from siltic with an initial pH (in water) of 5·1. Grazing tests were performed during an experimental period lasting from 9 to 18 September 2008. The mean temperature during the experimental period was 12·4 ± 3·9°C. The species of herbage used in the experiment was annual ryegrass (*L. multiflorum* Lam cv. Common), which was sown on 14 April 2008 by broadcast seeding of 75 kg seed ha^{-1}. The sward received a fertilizer application of 300 kg ha^{-1} of the formulation 02-20-20 (N-P_2O_5-K_2O) applied at planting plus the application of 100 kg ha^{-1} of nitrogen in the form of ammonium sulphate on 16 June 2008. Approximately 40 d before starting the experiment, the entire area was lightly grazed by cattle to keep the sward in a vegetative stage. Ten days before the beginning of the experiment, the experimental area was subdivided into sixteen plots, which were grazed again by cattle to obtain the pre-grazing sward heights for the experimental period. The different pre-grazing sward heights were achieved through stocking rate adjustment.

Treatments consisted of sward structures that simulated rotational stocking strategies characterized by the combination of two pre-grazing (25 and 15 cm) and two post-grazing sward heights (10 and 5 cm) resulting in four treatment combinations: 15-05, 15-10, 25-05 and 25-10. A randomized complete block experimental design was used with four replicates: twice in space (two different paddocks) and twice in time (two experimental cycles), totalling sixteen experimental units. Paddock location was randomly assigned, and the block criterion was the grazing period in paddocks (morning or afternoon). The second experimental cycle was started immediately after the first cycle finished, using different paddock locations. The area of the experimental units ranged between 30 and 100 m^2. The areas for the experimental paddocks were reduced proportionately to provide the grazing conditions sufficient for 1 h of grazing per pasture trial. These tests to determine the area occurred during the pre-trial period, which also served to adapt the animals to the experimental conditions. During this period, the animals remained in an adjacent area with an annual ryegrass sward, and they were trained to become familiar with the presence of observers, behavioural equipment and the experimental procedure. The experimental animals were three Holstein cows with an average body weight of 531 ± 12·8 kg; all cows were multiparous, dry and pregnant for approximately 90 d.

Sward measurements

Fifty measurements of the sward-surface height were performed randomly in each experimental unit using a sward stick (Barthram, 1986) in the pre- and post-grazing situations. In addition, samples of the superior stratum of sward, estimated as representative of the herbage grazed by the animals during the grazing tests, were collected by hand plucking – between the pre- and post-sward heights defined for each treatment – to quantify the dry matter (DM) content (g kg^{-1}) of the herbage consumed. Samples were weighed to determine total fresh weight and then oven-dried at 60°C for 48 h to determine DM content.

Using a quadrat measuring 0·127 m^2 (31 cm × 41 cm), two cuts in each of the pre- and post-grazing areas were made to estimate the pre- and post-grazing herbage mass (kg ha^{-1} DM) and to calculate by subtraction the mass of herbage reduced during grazing down. Subsequently, the samples were separated into leaf lamina, stem + sheath and dead material fractions; oven-dried at 60°C for 72 h and weighed on a precision balance. The light interception (LI) of the sward was also determined for the pre- and post-grazing plots by sampling ten sites in each plot using a linear ceptometer (AccuPAR model LP-80 PAR/LAI Ceptometer; Decagon Devices Inc. Pullman, WA, USA).

Animal measurements

During the experimental period, the cows were maintained in an additional paddock, and no concentrate feed was provided before or after the experimental measurement periods. The animals were allowed to graze for periods of approximately 60 min during the first and the last grazing meals (Hodgson, 1990), at 8:00 and 16:00 h respectively. The animals were fasted from solids during the night and for 4 h before the grazing tests in the afternoon.

Herbage intake was estimated by the double-weighing technique (Penning and Hooper, 1985). The animals were weighed on a high-precision balance (±0·01 kg), immediately before (P1) and after grazing (P2) stages and at the beginning (P3) and the end (P4) of the period of insensible weight loss measurement, which had the same duration as the grazing period (Penning and Hooper, 1985). On the basis of this procedure, the STIR was calculated using the following equation:

$$\mathrm{STIR} = \frac{(P2 - P1)}{t2 - t1} + \frac{(P3 - P4)}{t4 - t3} \times \frac{(t2 - t1)}{\mathrm{ET}}$$

where STIR = short-term intake rate (g min^{-1}); $P1$ and $P2$ = weight of the animals before and after grazing respectively; $t1$ and $t2$ = pre- and post-grazing times respectively; $P3$ and $P4$ = weight of the animals before and after insensible weight loss respectively; $t3$ and $t4$ = pre- and post-insensible weight loss times respectively; and ET = eating time.

The weight of herbage DM consumed (kg DM animal^{-1}) was calculated from the fresh weight of herbage and the DM content of the herbage samples collected as representative of that consumed, and from this and the number of bites and eating time (ET), bite mass (mg DM bite^{-1}) and STIR (g DM min^{-1}) were calculated.

During the grazing tests, the animals were fitted with devices for automatic recording of jaw movements (IGER Behaviour Recorder; Rutter, 2000). The data obtained from the IGER devices were subsequently analysed using the GRAZE software (Rutter, 2000). This software distinguishes biting from non-biting grazing jaw movements and discrimination of actual ET within periods of grazing activity. The bite rate (no. min^{-1}) represented the total number of bites divided by the ET (min).

Stocking density was expressed as animal units per hectare, based upon one mature, non-lactating bovine weighing 500 kg (Allen *et al.*, 2011).

Statistical analysis

The data were subjected to an analysis of variance at 5% significance using the mixed procedure of the SAS software according to the following statistical model:

$$Y_{ijk} = \mu + \beta_i + T_j + (\beta T)_{ij} + \gamma_k + (T\gamma)_{jk} + \varepsilon_{ijk}.$$

In this model, Y_{ijk} represents the response variables, μ is an average intrinsic to all observations, β_i is the effect of the ith block, T_j is the effect of the jth treatment, $(\beta T)_{ij}$ is the random effect attributed to the interaction of the ith block with the jth treatment (error a), γ_k is the effect of the kth experimental cycle, $(T\gamma)_{jk}$ is the effect of the interaction between the jth treatment and the kth cycle and ε_{ijk} corresponds to the random error, assuming an independent and normal distribution (error b).

When differences between treatment means were detected, the treatments were compared using the Tukey's test at a significance level of 5%. In all of the analyses, the animal test group (plot mean) was considered to be an experimental unit. All analyses were performed with the statistical package SAS (2001).

Results

Sward characteristics

The structural characteristics of the swards in the pre- and post-grazing conditions are presented in Table 1. The sward height, which defines the treatments, was subjected to analysis of variance to observe the actual effect of the combinations of pre- and post-grazing sward heights imposed upon the grazing animals. The fraction of the sward height removed differed between treatments, with greater removal observed in the treatments with the pre-grazing sward height of 25 cm ($P < 0{\cdot}05$).

Differences in the pre- and post-grazing herbage masses were observed between treatments (Table 1). A difference was also observed in the reduced herbage mass, where the highest value was registered for treatments 25-05 and 15-05 ($P < 0{\cdot}05$). Treatments 15-10 and 25-10 showed a relatively small reduction in herbage mass (average of 910 kg ha^{-1} DM). Considering the stocking densities, the greater value was observed in the 25-05 treatment, whereas treatment 15-10 resulted in the smaller number of animals per unit area ($P < 0{\cdot}05$).

The pre-grazing leaf lamina mass (LLM) differed between treatments ($P < 0{\cdot}05$), showing greater values in the 15-10 and 25-10 treatments. Although the 25-05 treatment exhibited the largest quantity of LLM removed, treatment 25-10 had the lowest portion of reduced LLM.

Regarding the leaf/stem ratio prior to grazing, the 15-05 treatment provided the animals with the greatest availability of leaf lamina, whereas treatment 25-05 resulted in the lowest leaf/stem ratio ($P < 0{\cdot}05$). In the post-grazing situation, treatment 15-10 offered a high proportion of leaf lamina, whereas treatment 15-05 supplied the least amount of this part of the plant.

The LI values were similar between treatments for the pre-grazing sward height of 15 cm (91·6%) and

Table 1 Sward height, herbage mass (HM), light interception (LI), leaf lamina mass (LLM), leaf/stem ratio and stocking density in annual ryegrass pasture (*Lolium multiflorum* Lam.) subjected to pre- and post-grazing conditions under rotational stocking.

Variables	Treatments				s.e.m.	P
	15-05	15-10	25-05	25-10		
Pre-grazing sward height (cm)	16·8b	17·3b	26·0a	27·5a	0·87	**
Post-grazing sward height (cm)	7·1c	10·7a	8·2b	11·2a	0·12	**
Grazed-down fraction (cm)	9·7b	6·6b	17·9a	16·1a	0·61	**
Pre-grazing HM (kg ha^{-1} DM)	2617b	2653b	2829a	2800a	97	*
Post-grazing HM (kg ha^{-1} DM)	1517c	1806a	1696b	1827a	101	*
Reduced HM (kg ha^{-1} DM)	1100a	847c	1133a	973b	21·5	**
Pre-grazing LLM (kg ha^{-1} DM)	1025b	1087a	1025b	1064ab	5·3	*
Post-grazing LLM (kg ha^{-1} DM)	210b	466a	175b	512a	14	**
Reduced LLM (kg ha^{-1} DM)	815b	621c	850a	552d	18·7	**
Pre-grazing leaf/stem ratio	1·24a	1·05ab	0·85b	0·96ab	0·05	**
Post-grazing leaf/stem ratio	0·22d	0·69a	0·34c	0·57b	0·01	**
Pre-grazing LI (%)	91·7b	91·5b	94·3a	95·2a	0·98	**
Post-grazing LI (%)	51·5b	68·3a	52·5b	63·5a	1·64	*
Stocking density (animal units ha^{-1})	629b	317c	1060a	652b	9·5	**

DM, dry matter; s.e.m., standard error of the mean; *P*, significance between treatments. Values followed by different letters in each row differ significantly at $P < 0{\cdot}05$ according to the Tukey's test. *, Significant at 5%. **, Significant at 1%.

25 cm (94·7%). Treatments with a post-grazing sward height of 5 cm had an LI of 52%, compared with an LI of 66% observed for the post-grazing sward heights of 10 cm ($P < 0{\cdot}05$).

Behavioural responses

With regard to the ingestive behaviour by the animals, the largest bite mass was recorded for the 25-10 treatment ($P < 0{\cdot}05$), as well as the short-term intake (Table 2). Both the cumulative herbage intake and the ET were higher in treatments 15-10 and 25-10 ($P < 0{\cdot}05$). Treatments 25-10 and 15-10 were also associated with a higher bite rate than treatment 25-05 ($P < 0{\cdot}05$). Thus, treatments 25-10 and 15-10 exhibited the highest total jaw movement rate, whereas treatment 25-05 had the lowest value.

Discussion

Results for herbage removal in each of the evaluated management strategies reveal that, in some situations, the proportion of the pre-grazing sward height that was grazed down was too high. Treatment 25-05 removed 18 cm (69%) of the pre-grazing sward height. The animals may have consumed a larger portion of the stems and sheaths in this treatment than in the treatments with the higher post-grazing sward height. This fact is confirmed by the post-grazing LLM (Table 1), which indicates two fundamental problems:

Table 2 Bite mass (BM), short-term intake rate (STIR), bite rate (BR), herbage intake, total jaw movements rate (TJMRs) and eating time (ET) for dairy cows when grazing down annual ryegrass sward (*Lolium multiflorum* Lam.) submitted to combinations of pre- and post-grazing sward heights under rotational stocking.

Variables	Treatments				s.e.m.	P
	15-05	15-10	25-05	25-10		
BM (mg DM kg LW^{-1})	2·06b	2·10ab	2·03b	2·30a	0·08	*
STIR (g DM min^{-1} kg LW^{-1})	0·11b	0·10b	0·09b	0·13a	0·005	**
BR (no. min^{-1})	49·0ab	51·9a	45·3b	52·1a	0·75	*
TJMR (no. min^{-1})	67·6b	70·1a	65·5c	69·1a	0·2	**
Herbage intake (kg $animal^{-1}$ DM)	2·8b	3·7a	2·5c	3·9a	0·1	*
ET (min)	52·3b	59·0a	44·2c	56·1a	2·68	*

DM, dry matter; s.e.m., standard error of the mean; *P*, significance between treatments. Means followed by different letters in each row differ significantly at $P < 0{\cdot}05$ according to the Tukey's test. *, Significant at 5%. **, Significant at 1%.

(i) the reduction in the LLM throughout the grazing-down period can complicate the process of herbage selection for the animal, and (ii) for the sward, the reduced LLM may cause damage to the process of LI and subsequent growth. After the grazing period, the treatments in which sward height was reduced to 10 cm intercepted more light than the treatments that were grazed down to 5 cm (Table 1), which results in a greater post-grazing growth potential, as previously observed in tall fescue and perennial ryegrass by Groff *et al.* (2002). According to these authors, the regrowth should be higher in smaller defoliation intensities (e.g. 15-10), because higher leaf-area index will provide higher LI and regrowth after each grazing event and, consequently, enable greater stocking rates. In this management strategy, the rest period should be around 13 d, totalling ten grazing events throughout the stocking period (Carvalho *et al.*, 2009b), with smaller stocking density per grazing event (Table 1). On the other hand, more frequent and intense defoliations (e.g. 15-05) would provide smaller regrowth after grazing, because of a reduction in the LI caused by the higher removal of the photosynthetic tissue (leaf laminas, Table 1). This management strategy would promote grazing intervals of 28 d, totalling six grazing events throughout the stocking period (Carvalho *et al.*, 2009b) with intermediate stocking density per grazing event (Table 1). According to these authors, the management strategies 25-05 and 25-10 would imply higher periods of rest (approximately of 30 d) and only four grazing events during the utilization period of pasture. However, the management strategy 25-05 would promote higher stocking density than 25-10 (Table 1). Considering both number of grazing events and periods of rest, the 15-10 management strategy becomes more predictable, because shorter rest periods are needed to achieve the pre-grazing sward height.

The herbage intake results (Table 2) are consistent with the data from the structural characteristics of the sward. According to Carvalho (2005), on a scale from minutes to an hour of grazing, herbage intake is the result of the structure and accessibility of the pasture as well as its abundance and quality. The combination of pre- and post-grazing sward heights in treatment 25-05 resulted in a low herbage intake by the animals throughout the grazing-down period because of a decrease in bite rate and bite mass (Table 2). The combination of the decrease in the bite mass with the decrease in the bite rate at higher levels of herbage depletion was related to an increase in the number of jaw movements that were expended while selecting leaves and avoiding stems (Prache, 1997; Searle *et al.*, 2005; Gregorini *et al.*, 2009). In addition to these, there was a decrease in the ET (Table 2), because those animals stopped grazing when the sward structure became a limiting factor (e.g. proportion of leaves at the end of the grazing period; Table 1). This effect has been described by Ribeiro Filho *et al.* (2003) as a change in the disposition of the animal waiting to enter a new plot, which leads to reduced total herbage intake.

The smaller values of bite rate and bite mass were also observed in the treatment 15-05 (Table 2), which suggests that by grazing down swards to 5 cm, the animals grazed on more than one grazing horizon, when considering the assumptions that animals graze by horizons (Baumont *et al.*, 2004). By grazing down swards up to 10 cm, the animals did not graze the lower horizons of the sward, which resulted in a higher bite mass and bite rate, considering that the sward structure in lower horizons presents smaller proportions of intact leaf laminas and higher proportions of stems + sheaths, which constrain the bite mass (Fonseca *et al.*, 2012b). The 25-05 and 15-05 treatments showed a lower LLM and leaf/stem ratio in the post-grazing period, indicating that these variables had a strong influence on the bite mass and bite rate (also observed by Stakelum and Dillon, 2007) and, consequently, on the STIR. Searle *et al.* (2005) confirmed that animals initially remove larger bite masses and progressively reduce STIR as the sward height declines. Animals graze preferentially on the leaf lamina portion, because the severance of pseudostems requires a greater expenditure of energy than leaf laminas (Griffiths *et al.*, 2003). Therefore, it is important that animals maintain a high leaf-lamina intake rate as a proportion of the total STIR. The 25-10 and 15-10 treatments showed a higher LLM and leaf/stem ratio after grazing (Table 1), implying larger bites throughout the grazing period by animals (Table 2). The larger bite masses observed in the treatments with higher post-grazing sward height are consistent with the work of Demment and Laca (1993), who found that in taller swards with lower bulk density, tongue movements by cattle effectively increase the bite area they can achieve. In such conditions, the tillers are sufficiently long to be brought within reach of the incisors and dental pad.

Treatment 25-05, which possibly provided a high STIR at the beginning of the sward grazing down, does not guarantee the same STIR in the lower layers of the sward. The low post-grazing sward height may have reduced the bite mass by reducing the bite depth (Carrere *et al.*, 2001; Cangiano *et al.*, 2002; Benvenutti *et al.*, 2008; Goncalves *et al.*, 2009) because an equal bite depth was maintained at half the sward height, and this sward suffered a significant reduction in height (Table 1). These observations indicate that the STIR likely decreased at the end of the grazing period, which led to a reduced average STIR for this treatment.

Finally, Da Silva and Carvalho (2005) warned of the necessity of constructing sward structures that optimize the STIR of the animal. The results presented here indicate that under rotational stocking, the management strategy of increasing both the pre- and post-grazing sward heights (25-10) resulted in a higher STIR. However, considering that efficient management of pasture in dairy systems using rotational stocking requires removal of sufficient leaf mass at each grazing event to feed animals with adequate high-quality herbage, while leaving sufficient leaf mass after grazing is completed to maximize sward regrowth rates (Parsons and Chapman, 2000), the 15-10 management strategy should be chosen.

Conclusion

The strategy of rotational stocking of annual ryegrass characterized by pre- and post-grazing sward heights of 15 and 10 cm, respectively, results in a better combination between sward and animal production. Considering only the parameters of herbage intake, the sward management strategy 25-10 is the most indicated, because it provides a sward structure that allows greater bite mass and, therefore, a higher STIR. This management strategy agrees with the assumption that the animal will eat the diet in smaller grazing time. However, considering also the sward structure, in addition to providing high STIR the management strategy 15-10 provides a structure with a predominance of leaves in the post-grazing situation. This management strategy promotes shorter intervals between grazing (more frequent with low grazing intensity), with maintenance of leaf area and higher regrowth after grazing.

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