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# IMPLICATIONS OF MANAGEMENT PRACTICES ON SWARD HEIGHT DISTRIBUTION AND BEHAVIORAL RESPONSES OF SHEEP UNDER CONTINUOUS STOCKING

**Porto Alegre**
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Dissertação apresentada como requisito para obtenção do Grau de Mestre em Zootecnia, na Faculdade de Agronomia, da Universidade Federal do Rio Grande do Sul.
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**Coorientador:** Jean Victor Savian

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**IMPLICAÇÕES DE PRÁTICAS DE MANEJO NA DISTRIBUIÇÃO DA ALTURA DO PASTO E NO COMPORTAMENTO INGESTIVO DE OVINOS SOB MÉTODO DE PASTOREIO CONTÍNUO**

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## RESUMO

A resposta funcional e o comportamento animal desempenham papel importante na definição de metas de manejo do pasto. Recentemente, uma nova abordagem guiada pela resposta de consumo do animal na menor escala do pastejo foi proposta. Essa estratégia, chamada Rotatínuo, recomenda oferecer, aos animais, plantas em uma faixa de alturas que os propiciem maximizar sua taxa de ingestão instantânea de matéria seca. Esta dissertação teve como objetivo aprofundar o entendimento desta nova estratégia aplicada em piquetes sob o método de pastoreio contínuo. Neste contexto, nós delineamos um experimento para testar o efeito de três formas de manipulação da heterogeneidade do pasto sobre o comportamento animal, seguindo as orientações deste conceito. O objetivo foi avaliar se o controle da distribuição da altura do pasto, por meio do ajuste da taxa de lotação, auxiliado por períodos estratégicos de descanso, roçadas e o uso de cercas, modificaria o comportamento ingestivo dos animais. Cordeiros mantidos em pastos de azevém anual manejados com altura média de 15 cm foram avaliados por meio de observações visuais das atividades diárias e do monitoramento contínuo de bocados. As manipulações dos tratamentos serviram para oferecer as estruturas de pasto desejadas sob a ótica do conceito Rotatínuo. Nossas análises não indicaram grandes mudanças nas variáveis de comportamento de curto prazo, no tempo de pastejo, ruminação e ócio, e no padrão de pastejo ao longo do dia. Concluímos que herbívoros se adaptam às mudanças na distribuição espacial do pasto quando pastejando em condições não limitantes. Ressaltamos que a maior heterogeneidade encontrada nos piquetes com menos intervenções não prejudicou o processo de forrageamento e que ajustes no número de animais por área são suficientes para oferecer as estruturas que otimizam o pastejo.

**Palavras-chave:** altura do pasto, herbívoros, heterogeneidade, manejo, produção animal.

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## IMPLICATIONS OF MANAGEMENT PRACTICES ON SWARD HEIGHT DISTRIBUTION AND BEHAVIORAL RESPONSES OF SHEEP UNDER CONTINUOUS STOCKING

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**ABSTRACT**

The functional response and grazing behavior play an important role in setting grazing management goals. A new management approach guided by the intake response was proposed recently. This strategy, named Rotatinuous, recommends offering animals plants in a range of heights that maximizes their dry matter instantaneous intake rate. This dissertation desired to increase the understanding of this novel strategy applied on paddocks under the continuous stocking method. We designed an experiment to test the effect of three forms of manipulate the sward heterogeneity on the animal behavior, following this management guidelines. The objective was to test whether the control of the sward height distribution by adjusting the stocking rate, aided by strategic periods of rest and forage mowing, and the use of fences would modify the ingestive behavior of the animals. Lambs grazing annual ryegrass pastures managed with an average height of 15 cm were evaluated through visual observations of daily activities and the continuous bite monitoring technique. The treatments succeeded in offering the desired sward structures of the Rotatinuous concept. Overall, our results did not indicate major changes in the short-term behavior variables, in the daily activities time and grazing pattern. We concluded that herbivores adapt to changes in the spatial distribution of pasture when grazing in non-limiting conditions. We highlight that the greater sward heterogeneity found in paddocks with less interventions did not jeopardize the foraging process, and that adjustments in the stocking density are enough to offer animals structures that optimize intake.

**Keywords:** sward height, herbivores, heterogeneity, grazing management, animal production.

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# CHAPTER I

# 1. INTRODUCTION

Despite decades of research on the animal-plant interface, the mechanisms of the grazing process, and the benefits of high secondary production in managing grasslands ecosystems, some management tools disregard the animal perspective and focus on biomass production. However, a recent development on grazing management has incorporated the animal approach.

This dissertation aimed to increase the understanding of this approach in continuous stocking. Can we manipulate the heterogeneity of the sward to benefit the foraging process? To address these questions, an experiment at paddock level was carried out with sheep grazing *Lolium multiflorum* pastures. The research question was: How can we create structures that optimize intake in continuous stocking?

So, we created three strategies to manipulate the sward heterogeneity. In the first one we just adjusted the stocking rate (Treatment 1). The second treatment, in addition to adjusting stocking rate, we used fences to alter the paddock`s available area for grazing, either to isolate overgrazed areas or to concentrate the animals to control sward height in previously rejected areas (Treatment 2). The third strategy was composed by all previous interventions, and in addition, it included the mowing of undergrazed areas (Treatment 3).

The key objective was to test whether we could facilitate the grazing process by applying those sward manipulations. The document is divided in three chapters. In the first one, I briefly present a literature review about aspects of ingestive behavior and the new perspective on grazing management that we focus on. In the second chapter, proposed as “Herbivores responses in foraging behavior to manipulations on sward heterogeneity on continuous stocking”, I describe results in a paper format. The third chapter brings the general conclusions and main findings of this dissertation.

# 2. LITERATURE REVIEW

## 2.1. The complexity of the grazing process on pastoral ecosystems

The grazing process in pastoral ecosystems comprehends the act of searching, manipulating, harvesting, chewing, and swallowing of the food, and can be perceived on the lowest scale as a bite removal sequence. Some authors have recorded an enormous number of 30.000 bites per day for grazing animals (Carvalho et al., 2008). Different from livestock on feedlots, they can spend 10-12 hours, investing high amounts of energy (Parker et al., 1996) to meet their nutritional requirements, the time depending on the grazing environment and management. The rest of the day is allocated to rumination, locomotion, watering, resting, reproduction, surveillance, etc.

Herbivores make trade-offs all the time, altering the criteria for selection in a dynamic framework among different patches of vegetation, as to choose between dry matter maximization intake rate, the balance of nutrients, avoiding toxins, and also between foraging and non-foraging decisions, as to hide from predators or look for shelter, water, and mates (Senft et al., 1987, Bhat et al., 2019). On the top of that, their food (primarily grasses) is not uniformly distributed neither in quantity nor quality over the area. Moreover, these variables, along with other ones that describe the condition of pastoral ecosystems, are transitory in space and time, characterizing the pastoral ecosystems as dynamically heterogeneous environments (Li & Reynolds, 1994).

This intrinsic heterogeneity can be considered as one of the factors that influence the functional response of herbivores (Laca & Demment, 1991), as well as plant and soil parameters (Dubeux et al., 2006; Bakker, 1998). At the same time, the spatial heterogeneity interacts with the grazing management imposed and the disturbance it causes (Adler et al., 2001; Bloor et al., 2020; Dumont et al., 2012; Nunes et al., 2018; Oñatibla & Aguiar, 2018; Tonn et al., 2019). Selective grazing (Prache et al., 1998), trampling, and dung and urine deposition (Dubeux et al., 2006) enhance the level of heterogeneity, further influencing patterns and processes related to grazing (Laca & Ortega, 1996; Utsumi et al., 2009).

### 2.2. Grazing scales

Grazing responses can be analyzed under an oriented approach for scale issues (Bailey et al., 1996; Senft et al., 1987). The model of hierarchical levels for the grazing process includes small spatial scales as bites, to larger spatial scales as landscapes, varying the temporal scales of very short time (seconds) to broader ones (years), as seen in Figure 1.

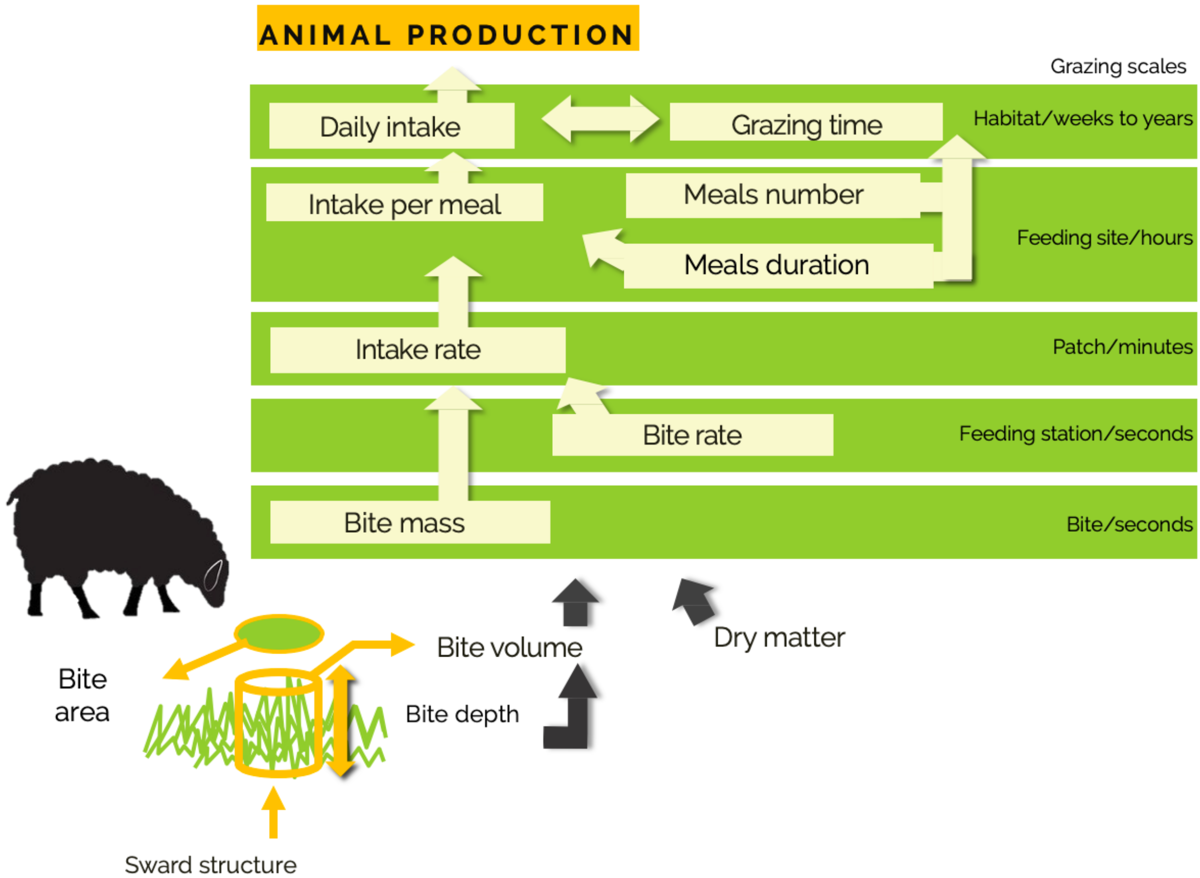


**Figure 1 -** Grazing spatial and temporal scales. Adapted from: Bailey et al., 1996.

The bite (seconds) is the smallest decision scale. It is the first unit of intake and impact on the vegetation (Demment & Laca, 1993). It starts when the animal lowers its head, chooses a plant or parts of plants, and removes a bite with the muzzle, jaw, and sometimes (cattle) with tongue and head movements. After gathering, the herbage is manipulated for chewing and swallowing. The second spatial scale is the feeding station (seconds), a hypothetical semicircle with forage available to the animal without moving its front feet. It is recognized as an arrangement of potential bites an animal can reach just by moving its neck. A new feeding station is considered when the animal performs a step during grazing. It is followed by the patch (minutes), which is related to the measured spatial heterogeneity, as an aggregate of feeding stations, or with the functional response (relationship between forage intake and forage abundance), which is called instantaneous intake rate. A new patch is characterized when the animal modifies its behavior to go to another place or by a break in the grazing session (Jiang & Hudson 1993; Bailey et al., 1996). The feeding site is a continuum space where animals spend a complete meal and the habitat is where they live. Meals in the present study are defined as periods during which the only activity is grazing, being interrupted for calculations (length) every time the animal rests or ruminates, with 5 minutes tolerance. Other animal behavior studies have used more complex time budgets, such as considering intra meal intervals of one, two, or five minutes elapsed without feeding (Bailey et al., 1996; Gillingham et al., 1997; Owen-Smith, 1993).

At each hierarchical level, herbivores face new dilemmas for decision-making, from short-term tactical to longer-term strategic decisions, and so they can alter their foraging approaches (Forbes & Gregorini, 2015; Ward & Saltz, 1994). In this work, we centered the attention on the plant-dependent attributes (e.g., sward height and spatial heterogeneity) that influence animal behavior and their criteria for selection. As the spatial level increases from bite to landscape, animal, and abiotic factors such as memory, gregarious organization, physiological conditions, distance to water, predation, photoperiod and topography rather than plant characteristics play major roles (Bailey et al., 1996).

### 2.3. Ingestive behavior

There exists a very extensive literature on the factors that influence herbivore's large-scale mechanisms (e.g., daily ingestive activities, time and patterns). For example, Larson-Praplan et al. (2015) detected the spatial and temporal pattern of cattle meals in California vary with environmental conditions and season changes. The shortest meals occurred at midday, particularly in summer, and longer meals occurred at sunrise and in the evening. Differences in meal duration were associated with temperatures, quality, and forage abundance. Linnane et al. (2001) reported the same with cows in Ireland. On the contrary, Low et al. (1981) did not find significant changes in the length and number of meals of cows in central Australia along the year, even though forage conditions varied.

The season also influences the time dedicated to the daily activities of deer in Uruguay (Aniano & Ungerfeld, 2020). This result differs from the one Linnane et al. (2001), who reported that despite the adaptation in circadian meals pattern, the total grazing time of cattle did not vary along the year.

On the one hand, Savian et al. (2020) have also recently reported the same daily activities time for lambs under management strategies with entirely different pasture conditions. On the other hand, Freitas-de-Melo & Ungerfeld (2020) found distinct grazing and ruminating time of lambs according to sex; male lambs grazed and ruminate more frequently when submitted to abrupt weaning than female lambs.

The small-scale mechanisms are dependent on the sward structure, as seen in Figure 1. The sward structure is defined as the spatial arrangement of morphological components of a plant, or how the aerial part of the plants is offered to the animals in the plant community (Laca & Lemaire, 2000). It can be described by the sward height, tiller density, pseudostem length, leaf/stem ratio, biomass, density, toughness, tensile strength, species composition, dead material, etc. Early works have investigated plant community attributes (e.g., biomass) affecting grazing patterns and animal performance. Some connections with animal responses and productivity were established (Penning et al., 1994), but the sward surface height was found to be the main factor ruling grazing, through the bite mass (Black and Kenney, 1984; Laca et al., 1994).

The strict relationship between bite mass with sward surface height is proven in many experiments with domestic and wild herbivores (Penning et al., 1991; Laca et al., 1992, Cangiano et al., 2002, Shipley et al., 1994). Bite mass is the product of the volume of the bite (bite depth x area) and the density of the forage. It has been demonstrated that bite depth (cm) has a linear and positive relationship with sward height (Laca et al., 1992, Cangiano et al., 2002). The area ($cm^2$) of the bite depends on the mouth of the animal (Illius & Gordon, 1987) and the density is an intrinsic characteristic of the dry matter content and height of the plant. Too short (lower sward stratum) or too high (top sward stratum) sward high, either decreases or increases time per bite. Consequently, the bite rate increases and decreases, respectively. Simultaneously with the bite mass, the intake rate is affected.

The intake response has been widely reported and extensively explored in the literature. Therefore, it is arguable that managers should try offering plants that boost high rates of intake so the restricted consumption in conditions of time lacking is avoided (de Faccio Carvalho, 2013).

### 2.4. Grazing management oriented by animal ingestive behavior responses – the Rotatinuous concept

A management strategy based on grazing behavior was proposed by de Faccio Carvalho (2013). This management, named "Rotatinuous" Stocking, is designed to maximize dry matter and nutrients intake per unit of grazing time, by prioritizing plant structures (sward surface height) that optimize short-term intake rate, aiding the herbivores time minimization strategy (Bergman et al., 2001; Thornley et al., 1994).

First, it was verified in short-term trials that herbivores exhibit a type II or type IV functional response, increasing dry-matter intake rate until certain sward height, and then stabilizing or decreasing it, respectively (Palhano et al., 2007, Mezzalira et al., 2017). The point of highest intake rate has been established for different forage species, such as native grassland (Gonçalves et al., 2009), *Sorghum bicolor* (Fonseca et al., 2012), *Pennisetum glaucum* (Mezzalira et al., 2013), *Lolium multiflorum* (Silva, 2013), *Cenchrus clandestinus* (Gómez, 2019), *Schedonorus arundinaceus* [Schreb.] (Szymczak et al. (2020), *Cynodon* sp. and *Avena strigosa* (Mezzalira et al., 2014). These are the pre-grazing sward heights when the Rotatinuous concept is managed under rotational stocking method. The post-grazing sward height was determined by the level of depletion. In order to maintain herbage intake rate at its maximum, the defoliation intensity should not exceed 40% of the pre grazing sward height (Fonseca et al., 2013).

Longer-term grazing trials under rotational stocking have shown "Rotatinuous stocking" achieves great animal productivity as a result of higher daily dry matter intake per animal and area (Savian et al., 2020), high forage production (Schons et al., 2021), and mitigates enteric methane emissions (Savian et al., 2018).

When applied under continuous stocking method, the sward height target is within the range of the target ones for rotational stocking. For instance, in rotational stocking, the pre- and post-grazing Italian ryegrass sward height are 18 and 12 cm, respectively, which means that in continuous stocking the target sward height is 15 cm. However, despite its use in commercial farms (de Faccio Carvalho, 2013; de Faccio Carvalho et al., 2021), scientific evidence on the performance and behavior of animals managed under Rotatinuous in continuous stocking are still lacking. Is the adjustment of the stocking rate enough to keep the target sward height? Would the intake rate maximizer structures be present or are more anthropogenic interventions in the pasture needed? If we indeed can interfere in the frequency and spatial offer of desired structures with manipulations, would these actions facilitate the grazing process? The ingestive behavior of animals grazing paddocks under the Rotatinuous concept and continuous stocking method is the focus of this work.

## 3. HYPOTHESIS

The strategic use of fences and mowing to offer plants that maximize intake rate facilitates the grazing process of sheep in continuous stocking paddocks.

## 4. OBJECTIVES

To test if manipulations to control the spatial heterogeneity affect the foraging process of sheep grazing Italian ryegrass under continuous stocking method oriented by the Rotatinuous concept.

# CHAPTER II

**Herbivores responses in foraging behavior to manipulations on sward heterogeneity on continuous stocking**

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**ABSTRACT**

The functional response and grazing behavior according to sward characteristics play an important role in setting grazing management goals. We tested whether manipulations of the sward heterogeneity of continuously stocking paddocks managed with the same average sward height would affect the foraging process of grazing sheep. We controlled the sward height distribution with three different forms, all including stocking rate adjustments. On Treatment 1, no other manipulation was used; Treatment 2 and treatment 3 had resting periods for overgrazed areas; for undergrazed areas, Treatment 2 had focal grazing on it, and on treatment 3 we mowed the pasture till the target average sward height. We monitored animal behavior through visual observations of daily activities and continuous bite monitoring technique. Our

results did not indicate major changes in the ingestive behavior at the evaluated scales, showing that herbivores adapt to changes in the spatial distribution of pasture when grazing in non-limiting conditions.

**Keywords:** grazing systems, resource heterogeneity, Italian ryegrass, sheep behavior, stocking rate adjust, sward structure

## 1. Introduction

The world grassland area accounts for 40.5% of the total ice-free global land (White et al. 2000). These environments provide natural resources that culturally and economically support numerous people, and deliver key ecosystem services enhanced when dwelled by herbivores (Zhao et al., 2020; Modernel et al., 2016; Bengtsson et al., 2019). However, a large proportion of these ecosystems is threatened, because depending on the management imposed, the effect of grazing can be negative (overgrazing) (Asner et al., 2004; Sanderman et al., 2017).

The design of management practices of the grassland environments should consider animal behavior and proper grazing intensities, so domestic and wild livestock systems would evolve in a climate-smart and profitable manner. Therefore, how herbivores interact with the resources is of particular concern and has been investigated by various studies (e.g., Boval & Sauvant, 2019). Nonetheless, most of the recommendations of grazing management are still plant-production oriented, based on sward growth and utilization. These practices disregard the animal perspective, although several results indicate that grazing management is more environment-friendly and economically viable when animal intake and performance are high (Cezimbra et al., 2021; Sollenberger et al., 2012).

It was verified in some fine-scale studies that herbivores exhibit a type IV functional response over a short-term, increasing intake until a certain sward height, and decreasing after that (Mezzalira et al., 2017; Szymczak et al., 2020). Thereafter, it was ascertained that 40% of depletion maintains the intake rate at its maximum when grazing starts at the point of the highest intake rate (Fonseca et al., 2013). Hence, de Faccio Carvalho (2013) proposed a management strategy, named Rotatinuous, which recommends as pre- and post- grazing sward height target the ones that enable maximum intake rate. Larger spatial-temporal scales studies have confirmed great productive and sustainable results of this concept managed under rotational stocking method (Savian et al., 2018; Savian et al., 2021; Schons et al., 2021).

Despite its use in commercial farms (de Faccio Carvalho, 2013; de Faccio Carvalho et al., 2021), experimental evidence of the Rotatinuous concept under the continuous stocking method are still lacking. When the concept is applied in such conditions, the pasture is managed with sward height between the targets for rotational stocking. However, pastures under continuous stocking are much more heterogeneous than pastures in rotational stocking (Teague & Dowhower, 2003). Sward height frequency distributions can be distinct for the same average height, according to overgrazed and undergrazed areas of the paddock. Moreover, even though the average target height at paddock level is a useful and practical management variable, herbivores respond to sward structure at the plant level (Pontes-Prates et al., 2020).

Thus, the main purpose of our investigation was to test if the animal ingestive behavior is influenced by manipulations of the heterogeneity oriented to offer structures favorable to the maximization of the short-term intake rate. We exposed sheep to continuous grazing with average sward height at paddock level based on the Rotatinuous concept, then we controlled the spatial heterogeneity through grazing, resting, mowing, and fencing, and evaluated the foraging process of sheep through visual assessments of daily activities and continuous bite monitoring.

## 2. Material and methods

Animal procedures performed were approved by the Institutional Animal Care and Use Committee of Federal University of Rio Grande do Sul (number 35741) and were conducted following the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

### 2.1. Study area

The grazing trial was conducted at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul (UFRGS), at the Rio Grande do Sul state in the southern subtropical region of Brazil (30°05' S, 51°39' W).

The experimental period commenced on 23 Jul 2019 and lasted for 95 days, during winter and early springtime in Brazil. Total rainfall in that period was 331 mm, and mean (±standard deviation) minimum and maximum ambient temperature were 11.4°C (±4.3) and 22.5°C (±5.3), respectively.

The total area of the experiment was 2.25 ha, with nine square-shaped paddocks (experimental units) of 0.25 ha each, delimited with wire electro-plastic fencing. Italian ryegrass (*Lolium multiflorum* Lam.) was sown in May 2019 at a density of 35 kg of seed/ha after soil tillage and received an application of urea fertilizer at 75 kg of N per ha when plants reach approximately 5 cm of height and more 75 kg of N per ha at the beginning of the stocking season.

### 2.2. Experimental design and treatments

The experimental design was a randomized complete block with three treatments and three paddock replicates (n = 9), which were blocked based on the slope of the area. The paddocks were virtually divided into eight quadrants of 312 $m^2$ to receive the treatments. Each paddock had three test-sheep (permanent animals over the whole stocking season), plus put-and-take sheep (Mott and Lucas, 1952). The experimental animals were Texel and Corriedale breed growing lambs with an average initial live weight of 29 ± 2 kg and approximately 10 months old at the beginning of the experimental period.

The grazing management practice that oriented the manipulations of the treatments was the "Rotatinuous" stocking strategy, that aims to minimize eating time by offering structures that allow great bite masses, consequently optimizing animal intake per unit of time (de Faccio Carvalho, 2013). In rotational stocking, the concept targets pre-grazing height that maximizes short-term herbage intake rate (Mezzalira et al., 2014) and post-grazing height that allows animals to graze only the top 40% of the sward, which maintains short-term intake rate at its maximum (Fonseca et al., 2013). For Italian ryegrass, it is 18 cm (Silva, 2013) and 40% less of this optimal pre-grazing sward height (~11 cm), respectively. Under continuous stocking method, the Rotatinuous's target for paddock sward height is the average between the optimal ones for pre-and post-grazing. In this way, our goal was to manage the Italian ryegrass swards under continuous stocking targeting 15 cm in all treatments, which is in between the sward height of 18 and 11 cm (pre- and post-grazing, respectively) proposed for rotational stocking.

Treatments consisted of three manipulation forms of the heterogeneity of sward surface height under the continuous stocking method. The treatments were: T1) Put-and-take, whereby the target sward height of 15 cm was kept just with weekly stocking rate adjustment with a variable number of sheep, T2) Put-and-take + fence, in which despite the weekly sheep stocking rate adjustment, animals (including test-sheep) were concentrated in the quadrants where the average sward height exceeds 18 cm, and grazing deferment was promoted by isolating quadrants where sward height was below 12 cm; both of them for short periods until pasture reaches 15 cm, and T3) Put-and-take + fence + mowing, in which pasture of quadrants was cut with a mowing machine (cutting height 15 cm) when it exceeds 18 cm and quadrants were also isolated to grazing deferment when sward height was below 12 cm if the sheep stocking rate adjustment did not achieve target sward height. The watering point was placed in the middle of the paddocks. Put-and-take sheep were similar in live weight, breed, and age, and were maintained on adjacent paddocks of Italian ryegrass when not in treatment paddocks.

### 2.3. Sward measurements

The sward height was monitored every week with a sward stick (Barthram, 1985). To apply the treatments, it was necessary to have the spatial distribution, so every 15 days the measurements were georeferenced, using the sward stick coupled to an RTK-GPS (Emlid Reach Rs Gnss Rtk). Records were made in a systematic distribution, equally spaced along the paddock. An example of georeferenced records is in Appendix A.

The latest sward measurements made before animal behavior measurements were not georeferenced. This paper presents the average sward height, the frequency distribution of sward height, made with the *ggplot* function from R, and the coefficient of variation as a proxy of heterogeneity.

### 2.4. Treatments manipulations during animal behavior measurements

Initially, average sward height was maintained between the target ones just with animal number adjustment (until August 6). After that, it was necessary to isolate overgrazed areas (<12 cm of sward height) in both Treatment 2 and Treatment 3 treatments. These manipulations lasted from 4 to 20 days. When the first animal measurements were proceeded, Treatment 2 had two quadrants isolated in one block and Treatment 3 treatment had quadrants isolated in all three blocks (seven in total).

After August 30, manipulations to deplete the sward of undergrazed quadrants were proceeded in paddocks of Treatment 2 and Treatment 3. Ten quadrants of Treatment 3 treatment were cut to 15 cm one week before the second animal assessment. On the same day, the grazing pressure on nine quadrants of Treatment 2 treatment was increased with the addition of put-and-take sheep. Manipulations lasted from 3 to 20 days. When the second animal measurements were made, Treatment 2 had two quadrants isolated in one block, animal concentration in four quadrants of another block, and animal concentration in three quadrants in the paddock of the third block. Treatment 3 had manipulations applied in one block (two quadrants isolated). The treatment manipulations made before the second animal behavior measurements are shown in Figure 1.

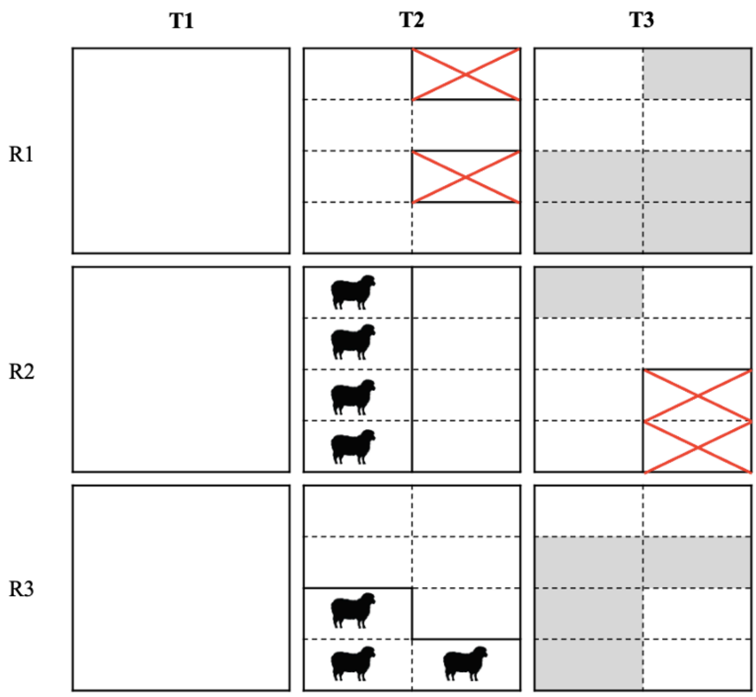


**Figure 1 -** Treatment manipulations made before sheep behavioral assessments. All treatments had stocking rate adjustments. The put-and-take treatment (T1) had no other manipulation for regulating average sward height; the put-and-take + fence treatment (T2) paddocks had deferment of overgrazed areas (<12cm) illustrated by the red X and concentration of animals in areas undergrazed (>18cm) illustrated by the sheep; the put-and-take + fence + mowing treatment (T3) paddocks had areas deferred when overgrazed (<12 cm) illustrated by the red X and undergrazed areas cut with a mowing machine (>18 cm) identified by the grey color.

On the third animal measurements, the test sheep of one paddock of Treatment 2 were concentrated to reduce the sward height in two quadrants, and two quadrants were isolated in another block. Treatment manipulations occurred till the end of the stocking period (Oct 26, 2019); however, they did not impact the measurements described in this paper. The number of quadrants under manipulations (Treatment 2 and Treatment 3) during animal measurements is detailed in Table 1.

**Table 1 -** Manipulations applied in continuously stocking paddocks grazed by sheep during animal behavior assessments. The Put-and-take + fence treatment (T2) paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in Put-and-take + fence + mowing treatment (T3) paddocks, areas were isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm). There were three replicates (R) of each treatment

| Animal measurements | Treatments | Differed quadrants | | | Quadrants with animal concentration | | | Mowed quadrants | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **R1** | **R2** | **R3** | **R1** | **R2** | **R3** | **R1** | **R2** | **R3** |
| 1 | **T2** | 2 | 0 | 0 | 0 | 0 | 0 | - | - | - |
| | **T3** | 4 | 1 | 2 | - | - | - | 0 | 0 | 0 |
| 2 | **T2** | 2 | 0 | 0 | 0 | 4 | 3 | - | - | - |
| | **T3** | 0 | 2 | 0 | - | - | - | 5 | 2 | 3 |
| 3 | **T2** | 2 | 0 | 0 | 0 | 2 | 0 | - | - | - |
| | **T3** | 0 | 0 | 0 | - | - | - | 0 | 0 | 0 |

## 2.5. Sheep ingestive behavior measurements and calculations

The test-sheep of the paddocks were used for behavioral observations. The primary (daily) and secondary (short-term) behaviors were measured three times during the grazing season (Sep 09, Sep 28, and Oct 12, 2019).

### 2.5.1. Primary behaviors

The daily behavior activities (grazing, ruminating, and resting) were assessed visually and recorded every 5 minutes for 24 hours by trained observers (Altmann, 1974). Thus, we calculated grazing, ruminating, and resting time, and estimated the proportion of grazing events per hour and the duration of meals (n = 81; 27 test-sheep × 3 measurements).

Total times of daily activities were calculated by multiplying the number of observations of each activity during the 24 hours by 5 min. The proportion of grazing per hour was calculated as the number of observations marked as grazing per hour divided by the total number of observations per hour. The meal's length was determined by multiplying the number of observations marked as grazing in sequence by 5 minutes initiated at each hour.

### 2.5.2. Secondary behaviors

One day before primary behavior measurements, three trained observers evaluated all test-sheep with the continuous bite monitoring technique (Agreil & Meuret, 2004; Bonnet et al., 2015). The technique permits the recording through direct observation and in real-time all foraging behavior of a focal animal. Before data collection, a period of mutual familiarization occurred between the observers and individuals. Meanwhile, the observers checked the height of the plants commonly defoliated and created a bite code grid.

In the evaluation, bite codes and steps were registered on a digital recorder Sony ICD-PX312. Over 10-min, each observer evaluated a block, during the time of day of more intense grazing activity (i.e., early morning and late afternoon, Orr et al., 1997). Continuous bite monitoring lasted 180 min per treatment. After that, the audio files were transcribed using JWatcher® software.

The hand-plucking method was used to estimate the mass of the observed bite (Bonnet et al., 2011). For each observed bite code and separately for animals, twenty hand-plucked subsamples were taken. Samples were then dried at 55º C for 72 hours and weighed on a precision scale to obtain the estimated dry matter intake per bite code. For the purpose of this paper, bite masses were first predicted by a mixed linear model (lme4 package of R) considering bite code, treatment, period, and shift as fixed effects, and then averaged by observation.

In total, 143 valid animal transcriptions were obtained. For each one, we calculated the variables as follows: bite mass (g DM/bite) as the sum of bite masses divided by the number of bites from each recording; bite rate (bites/min) as the number of bites from each recording divided by the total recording time; intake rate (g DM/min) as the product of the number of bites and mean bite mass divided by the total recording time; step rate (steps/min) as the number of steps from each record divided by the total recording time; feeding station rate (per min) as the sum of feeding stations divided by the total time of recording; number of bites per feeding station as the sum of bites of each feeding station; intake per feeding station (g DM/feeding station) as the sum of bite masses of each feeding station; steps per feeding station as the number of steps taken between feeding stations; time per feeding station as the total time of recording divided by the number of feeding stations in that record. All variables are summarized as the average throughout the recording.

### 2.6. Statistical Analysis

All calculations and statistical analyses were carried out in RStudio version 1.2.1335 (Venables & Smith, 2003).

Average sward height, daily activities time, and secondary behaviors (short-term response) variables were submitted to analysis of variance using linear mixed-effects models (*lmer* function from the lme4 R library) with the treatment as the unique fixed effect. The meal's length was analyzed using a linear mixed-effects model with treatment and hour as fixed effects. We included paddocks nested each period as random effects to account for a potential lack of independence among repeated observations on the same paddocks over the periods. The means were compared based on Tukey's test for significant difference ($P < 0.05$), using the *multicompview* and *emmeans* package from R. Before ANOVA, residuals plots of the analyses were used to check normality, homogeneity of variance, and residual independence using the *gplot* function. When necessary, data were $\log_{10}$ transformed.

We used a generalized additive model with the gam function from the *mgcv* package to analyze the proportion of grazing in each hour. Treatment was considered as a fixed parametric effect and hour as a smoothing fixed effect.

## 3. Results

### 3.1. Sward characteristics

There was no statistical difference ($P = 0.80$) in Italian ryegrass average sward height (with standard deviation within parenthesis) between Treatment 1 (14.5 ± 3.06 cm), Treatment 2 (14.9 ± 2.64 cm), and Treatment 3 (14.6 ± 2.67 cm) over the entire grazing season. The coefficients of variation were 51.4, 43.1, and 45.3 for Treatment 1, Treatment 2, and Treatment 3, respectively. As expected, the Treatment 1 had the highest heterogeneity likely due to the absence of fencing and mowing practices. The frequency distributions of sward height before sheep behavior measurements are presented in Figure 2, with the mean values and coefficient of variation of each treatment.

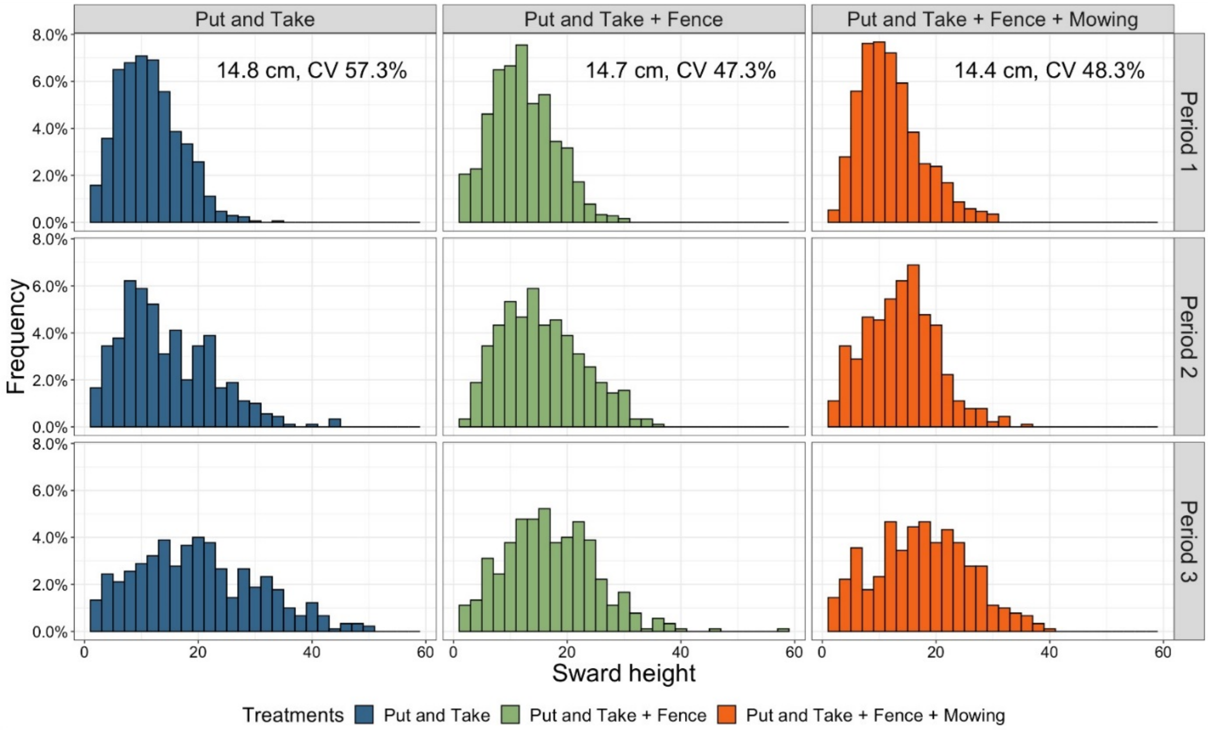


**Figure 2 -** Sward height frequency distribution of continuous stocking paddocks grazed by sheep under different manipulations of heterogeneity in periods 1, 2, and 3 of the experiment, right before animal measurements. The put-and-take treatment (blue) uses just animals for regulating average sward height; the put-and-take + fence treatment (green) paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in the put-and-take + fence + mowing treatment (orange) paddocks, areas were also isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm). Means sward height and coefficient of variation in each treatment are plotted

### 3.2. Animal behavior

Figure 3 compares the daily behavioral activity times of sheep in each treatment. No difference between treatments was observed for total time spent grazing, ruminating, and resting, with an average of 526 min ($P = 0.801$), 341 min ($P = 0.083$), and 577 min ($P = 0.378$) per day, respectively.

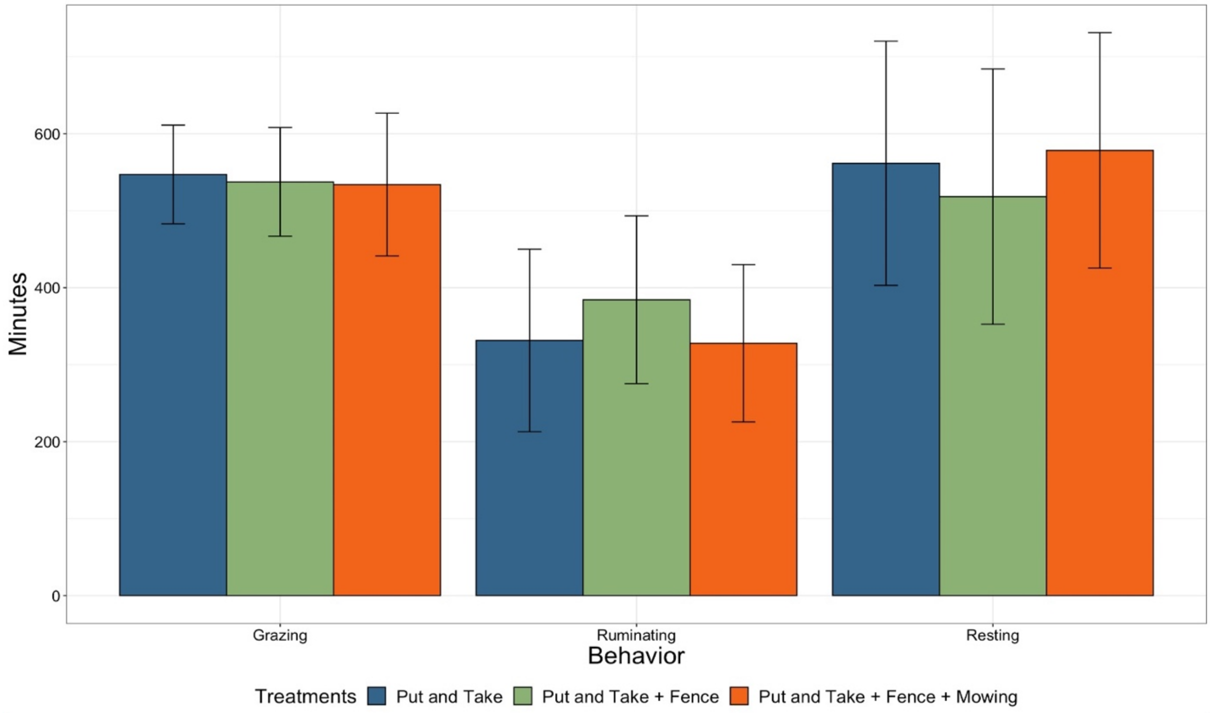


**Figure 3 -** Average daily grazing, ruminating, and resting time of sheep in continuous stocking paddocks under different manipulations of heterogeneity. The put-and-take treatment (blue) uses just animals for regulating average sward height; the put-and-take + fence (green) treatment (green) paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in put-and-take + fence + mowing treatment (orange) paddocks, areas were also isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm). The black bars represent the means standard deviation.

The pattern of grazing distribution over time is shown in Figure 4 (P = 0.846). Sheep had a similar grazing pattern between treatments, with three main grazing events over the day. One punctuated and rapidly initiated grazing peak occurred around sunrise. This event was slightly different between treatments. Treatment 3 had a little decline in the proportion of grazing at 09:00 h. One grazing event markedly peaked before sunset (17:00 h) in all treatments (around 60% of observations as grazing over 3 hours). This dusk grazing event abruptly terminated at 20:00 h, after which grazing probability lowered to 40%. Another peak period occurred at night, between 23:00 h and 2:00 h in all treatments. The period with less probability of grazing occurs just before the first grazing event of the day (less than 30% of grazing observations at 03:00 h).

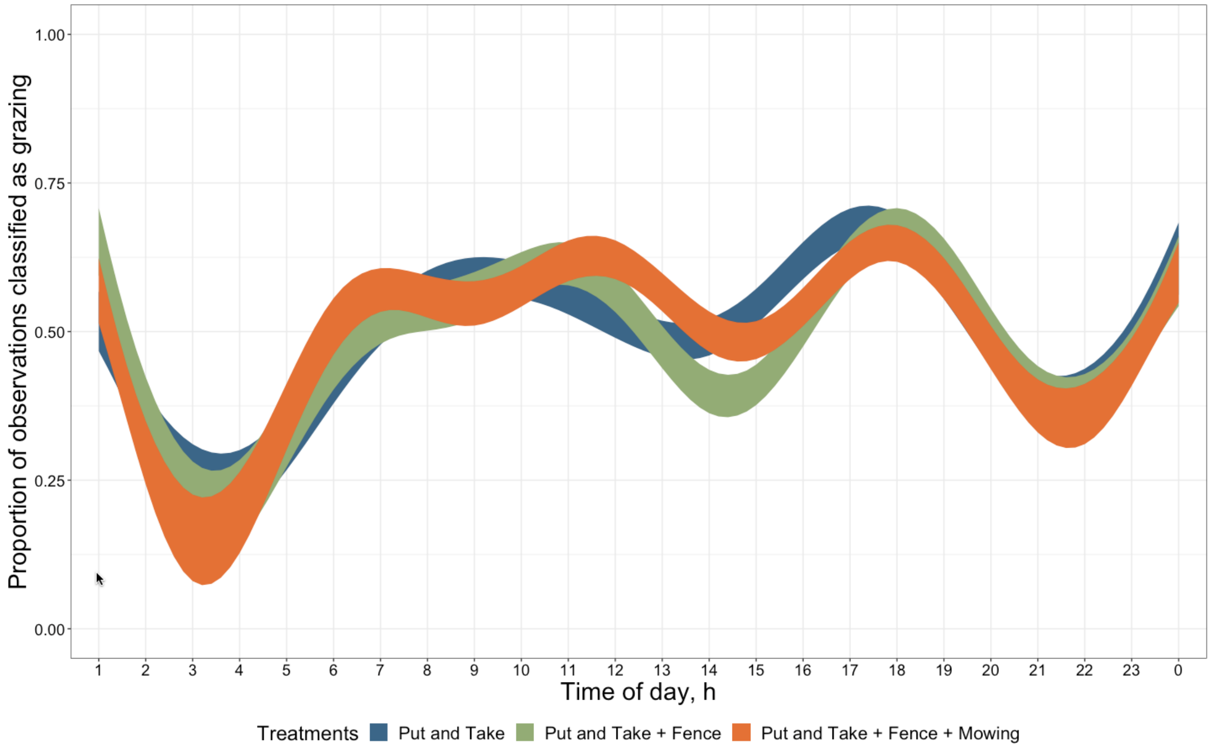


**Figure 4 -** Circadian grazing pattern (average grazing proportion +- standard error) of 27 animals by types of manipulation of continuous stocking methods (treatments). The put-and-take treatment (blue) uses just animals for regulating average sward height; the Put-and-take + fence treatment (green) paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in Put-and-take + fence + mowing treatment (orange) paddocks, areas were also isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm).

The duration of meals started in each hour of the day is presented in Figure 5 (P = 0.8106). Overall, during daylight, the pattern of meal length goes along with the probability of grazing (Figure 3). The grazing events with the highest probability of occurrence happened at the same time of day of the longest meals (sunset and sunrise). On Treatment 3, meal durations tended to be more constant from 05:00 h to 18:00 h than the other treatments, with an average of 60 minutes per hour. Sheep had the shortest meals per hour between 01:00 h and 04:00 h, the same time as the lower probability of grazing.

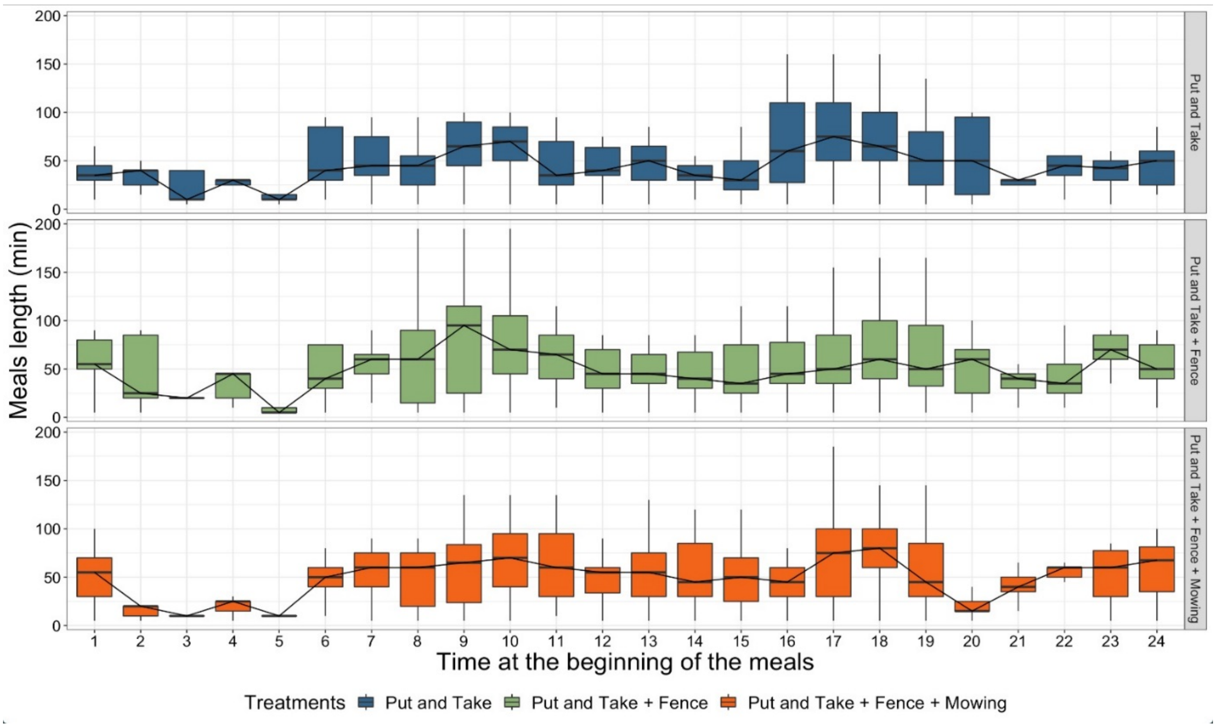


**Figure 5 -** Meal length of sheep grazing continuous stocking paddocks under different manipulations of heterogeneity. The line represents the median meal length grouped by replicated animals, blocks, and periods. The put-and-take treatment (blue) uses just animals for regulating average sward height; the put-and-take + fence treatment (green) paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in put-and-take + fence + mowing treatment (orange) paddocks, areas were also isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm).

Secondary behavioral variables showed a similar pattern between treatments, as shown in Table 2. Bite mass averaged 0.1 g DM. Bite rate, intake rate, step rate, and feeding station rate averaged 33.13 bites/min, 2.22 g DM/min, 11.7 steps/min, and 4.16 feeding stations/min. Bites per feeding station, intake per feeding station, number of steps between feeding stations, and time per feeding station values averaged 11.7 bites, 1.17 g DM, 6.55 steps, and 20.7 s, respectively.

**Table 2 -** Grazing behavior variables of sheep grazing on continuously stocking paddocks with different manipulations in sward heterogeneity. The Put-and-take treatment uses just animals

for regulating average sward height; the Put-and-take + fence treatment paddocks had deferment of overgrazed areas (<12cm) and concentration of animals in areas undergrazed (>18cm); in Put-and-take + fence + mowing treatment paddocks, areas were also isolated when overgrazed (<12 cm) and were cut with a mowing machine when undergrazed (>18 cm). FS = feeding station; sd = standard deviation.

| Behavioral responses | T1 | T2 | T3 | sd | P |
|---|---|---|---|---|---|
| Bite mass (g DM) | 0.0940 | 0.0997 | 0.0975 | 0.02 | 0.249 |
| Bite rate (bites/min) | 33.6 | 31.9 | 33.9 | 8.36 | 0.656 |
| Intake rate (g DM/min) | 2.23 | 2.28 | 2.16 | 0.81 | 0.822 |
| Step rate (steps/min) | 11.6 | 11.1 | 12.5 | 6.02 | 0.850 |
| Feeding station rate (FS/min) | 4.16 | 3.90 | 4.42 | 1.46 | 0.702 |
| Bites per feeding station (bites) | 11.7 | 12.9 | 10.5 | 4.64 | 0.440 |
| Intake per feeding station (g DM) | 1.15 | 1.29 | 1.06 | 0.52 | 0.428 |
| Steps per feeding station (steps) | 5.74 | 6.82 | 7.10 | 6.34 | 0.608 |
| Time per feeding station (s) | 21.4 | 21.0 | 19.7 | 12.58 | 0.844 |

## 4. Discussion

We proposed controlling the spatial heterogeneity of the sward height through manipulating the sward structure by changing the animal density, deferring overgrazed areas, and mowing or applying targeted grazing on undergrazed areas. Overall, our results pointed that the manipulations with fences and mowing did not alter the animals' behavior in the observed spatial-temporal scales (bite, feeding station, and daily levels), showing that herbivores adapt themselves to the spatial distribution of pasture when grazing in non-limiting conditions (the targeted sward height is considered optimal to grazing). The greater offer of structures favorable to high ingestion rates created by anthropic actions along with the stocking rate adjustment did not seem to be a more efficient management than the animals' adaptative mechanisms.

### 4.1. Effect of sward manipulations on animal behavior

Grazing is the main creator of resource heterogeneity, especially in continuous stocking paddocks (Adler et al., 2001). Animals benefit from heterogeneity (Laca, 1993) since the selected diet is of better quality than the average offered. In Treatment 1, for example, which had the highest sward coefficient of variation, heterogeneity itself may have helped in the short-term, allowing animals to adapt their behavior at the feeding station level and achieving the same rates. This compensation margin was aided by the effects of the treatment, as the animals may not have spent time looking for the maximizing stations because they had vast sub-optimal options to modulate intake, since they had free access to low and high sward heights. Depending on the supply and the spatial distribution of resources, the time of apprehension may overlap the time of chewing; or the time to chew the previous bite overlaps the time for searching for the next bite (Laca et al., 1994). It could be argued that the intake response through a sequence of light bites may have been the same as that achieved by the ingestion of heavy bite masses and the search time until the next bite, as the time allocated for chewing reduces the ingestion rate. This result is in agreement with Wallis De Vries et al. (1998) who found no difference in the intake rate between patches of different heights. As we presented the average bite mass, we did not capture the difference or similarity of the height range and consequent bite masses in the diet.

Some studies state that selection is facilitated when heterogeneity is on a large scale (aggregated) over a fine-scale (Dumont et al., 2002; Wallis De Vries et al., 1999; Edwards et al., 1994). We expected the animals' cost in the dynamics of meeting the desired (maximizer) structures to decrease with the implication of Treatment 2 and Treatment 3. On the contrary, we observed a slightly lower number of steps per feeding station of animals in Treatment 1. Does it mean they found the preferred structures more easily? Also, the time per feeding station of animals in this treatment was a little longer. Three potential explanations are: offering the favorable plants dispersed in the paddock facilitates the encounter; or it supports the hypothesis that they appreciated the heterogeneity of this treatment that allowed them to modulate the intake in the feeding station; or because of the trade-off between shifting energy to find “better” patches and staying at the same ones. Furthermore, Parsons et al. (1994) reported that selectivity is only constrained when preferred plant species have an abundance of less than 20%. Even in Treatment 1 that had higher spatial heterogeneity of sward heights, the optimal range of height (12 to 18 cm) was very frequent (about 35%, Figure 2). Thus, it is unlikely that animals have been jeopardized by the lack of further manipulations in this treatment.

Treatments could modify the mechanisms and patterns on larger scales if they had made difference at the bite level. We expected the grazing time to decrease due to the higher selection of dry matter maximizer structures when they were more abundant and aggregated. The grazing time of animals in Treatment 2 could also be affected by competition because test-sheep of some paddocks were in a smaller area in the second and third behavior measurements. However, a recent spatial model has found the effects of heterogeneity to be compensated on large temporal scales (Pontes-Prates et al., 2020).

We can verify the three principal grazing events of ruminants in our experiment by the peaks of the proportion of grazing, as has been shown in the literature (Gregorini et al. 2008). However, the grazing events merged during the day. These findings are in agreement with the results previously reported by Larson-Praplan et al. (2015), which found a similar pattern between meal length and proportion of grazing per hour. Also, there was a large proportion of night grazing in all treatments. Our results corroborate with Linnane et al. (2001) and Somparn et al. (2005) who found 18 to 50% of grazing time occurring at night.

The results can give rise to the assumption that in continuous stocking sheep did not act as time minimizers and did not prioritize structures favorable to the highest dry matter intake rate all the time, having enough time to maximize other functions as neither time nor pasture was limiting. Whereas we expected to observe lambs grazing plants within the range of optimal heights (12-18), they exhibited a more diverse pattern of bites. Naujeck et al. (2005) also observed this with horses. Animals in their experiment stayed longer in areas of higher sward heights, but also visited and grazed from other patches. They concluded that in addition to the height of the pasture, the quality of the youngest plants influenced the selection of the horses' diet. What could have happened if conditions were limiting? If the experiment was extended to more demanding categories, such as time-restricted lactating dairy cows, perhaps the foraging pattern would differ more abruptly between treatments and the animals under interventions would have the foraging assisted by the great offer of maximizer structures.

Another point is that the heterogeneity perceived by the manager is different from the animal's perception. Although we perceive the spatial differences created by the treatment's manipulations (Appendix A), animals have a different matter of the scale of detection, so we cannot assume they saw the aggregated structures. Thus, the animals could not walk directly to the areas where the structures that reduce the grazing time were closer.

The plasticity and adaptation to the imposed management, causing the animals to reach the same levels of diet quality and performance have already been registered in horses (Fleurance et al., 2016) and sheep (Iason et al., 1999; Garcia et al., 2013).

### 4.2. Performance of Rotatinuous under continuous stocking

First, we entrust animals the sward maintenance in a continuous stocking paddock, just adjusting the stocking rate when necessary. Then, we restricted their total displacement, by fencing overgrazed areas. In previously neglected areas, we either cut the pasture or forced animals to lower sward height themselves. From the viewpoint of offering plants with similar heights that optimize grazing when harvested, paddocks with manipulations with fences and mowing were structurally benefitted. This is supported by the lower coefficient of variation of sward height and greater proximity to the desired range of Treatment 2 and Treatment 3, in addition to the controlled access to areas with average sward height in the first extremity of the distributions.

Although we recognize the multiple positive effects of resource heterogeneity such as on herbage production and stability (Duchini et al., 2018), and consequently livestock production stability (Allred et al., 2014), most grazing managers have been disregarded these benefits. Yet, one of the explanations for managers to use rotational stocking is the reduction of the spatial heterogeneity within-paddock, aiming to avoid animal selectivity. It should be noted that our interventions were not to impose constraints on the natural eating process. On the contrary, the spontaneous decisions and the implication of their choices in terms of short-term intake rate over different height options were first observed (Amaral et al., 2012; Mezzalira et al., 2014). Manipulations were also not intended to penalize selection. The maintenance of the sward height between 12 and 18 cm already provides a functional range for the animal and pasture perspective (Planisich et al., 2020). Thus, the sward manipulations used in our study respected the structural guidelines of the Rotatinuous concept and tried to offer more plants in the structural range that maximize intake rate and so could be desired by the animal.

Treatments' animals had different availability of resources in space and time, but never limited, and so, they managed to express their natural behavior. The same behavior, intake, and productive responses (Freitas et al., unpublished result.) between animals managed in continuous or rotational stocking method (Savian et al., 2020) guided by the Rotatinuous concept support the idea that when pastures are maintained under proper management, discussions on manipulations or stocking method are pointless (Briske et al., 2008, Sollenberger et al., 2012). Moreover, Farias et al. (2020) have evaluated an integrated crop-livestock system and conclude that the impact of the grazing pressure stipulated by the Rotatinuous concept on the pasture phase enhances energy and system productivity.

In limited resource conditions, such as beef cattle managed under a higher stocking density, the manipulations can be an interesting alternative to better control livestock distribution. Likewise, with the interventions support, should be easier to control the sward structure at larger paddocks, considering their respond differently according to the size and level of heterogeneity (Barnes et al., 2008; Dumont et al., 2020).

Our results can be used to generate new hypothesis about the animal and sward heterogeneity interface, and to assist in the design of livestock systems, since the management concept that guided the treatments is effective in animal and pasture production, (Savian et al., 2018, Savian et al., 2019, Schons et al., 2021), in the reduction of environmental impacts (Savian et al, 2021) and it is already applied beyond experimentation (de Faccio Carvalho, 2013; de Faccio Carvalho et al., 2021).

## Declaration of interest

The authors declare no conflict of interest.

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# CHAPTER III

## FINAL CONSIDERATIONS

A manutenção de sistemas pastoris orientados sob o conceito de manejo Rotatínuo se mostrou mais uma vez como alternativa de intensificação sustentável na produção de alimentos. Este novo conceito de manejo preconiza intensidades de pastejo moderadas, para que “sobre” pasto e o animal seja capaz de expressar sua seletividade natural, atingindo elevado consumo de matéria seca e consequentemente altos níveis de produção.

As intervenções no pasto feitas no protocolo experimental são comumente realizadas por produtores por esperarem um rebrote de maior qualidade, e também com o objetivo de homogeneização da estrutura do dossel, dando a impressão que os animais comeram “tudo”. Quando acompanhadas da manutenção do pasto em alturas muito baixas, essas ações limitam as oportunidades de seleção do animal diminuindo o potencial produtivo da área. Contudo, quando aplicadas de forma estratégica, auxiliam no aproveitamento espacial e no processo de ingestão dos animais. As manipulações dos tratamentos contribuíram para uma menor distribuição de alturas, mas eram impostas de forma a manter uma faixa de altura ótima, controlando abaixo e acima disto. Além do uso de cercas para direcionar o pastejo, pode-se fazer o uso de atrativos como cochos de suplementação e água.

Sobre o tema de estudo desta dissertação, comportamento ingestivo, esperávamos encontrar sinais diferentes referentes à qualidade dos ambientes que, embora manejados sob uma mesma altura média, foram criados de formas distintas. Sabemos que os herbívoros reagem ao manejo imposto e que as metodologias utilizadas são eficientes para mensuração dos parâmetros avaliados. Porém, as condições ambientais criadas pelos tratamentos não foram suficientemente contrastantes para que encontrássemos grandes diferenças nos parâmetros comportamentais dos animais em cada condição.

Apesar disso, evidenciamos que o emprego da meta de manejo para altura média de pastagem de azevém em 15 cm apenas com ajuste na taxa de lotação resulta em alta oferta de plantas com alturas que maximizam a taxa de ingestão. A menor heterogeneidade espacial criada com as intervenções não beneficiou o processo de forrageamento dos animais.

Pode-se concluir que os animais modularam e transitaram sobre a heterogeneidade que pastos sob método de pastoreio contínuo manejados em condições não limitantes oferecem, alcançando as mesmas taxas de ingestão, padrões de consumo e alto desempenho, independente das intervenções antrópicas realizadas nos potreiros.

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# APPENDICES

## Appendix A.

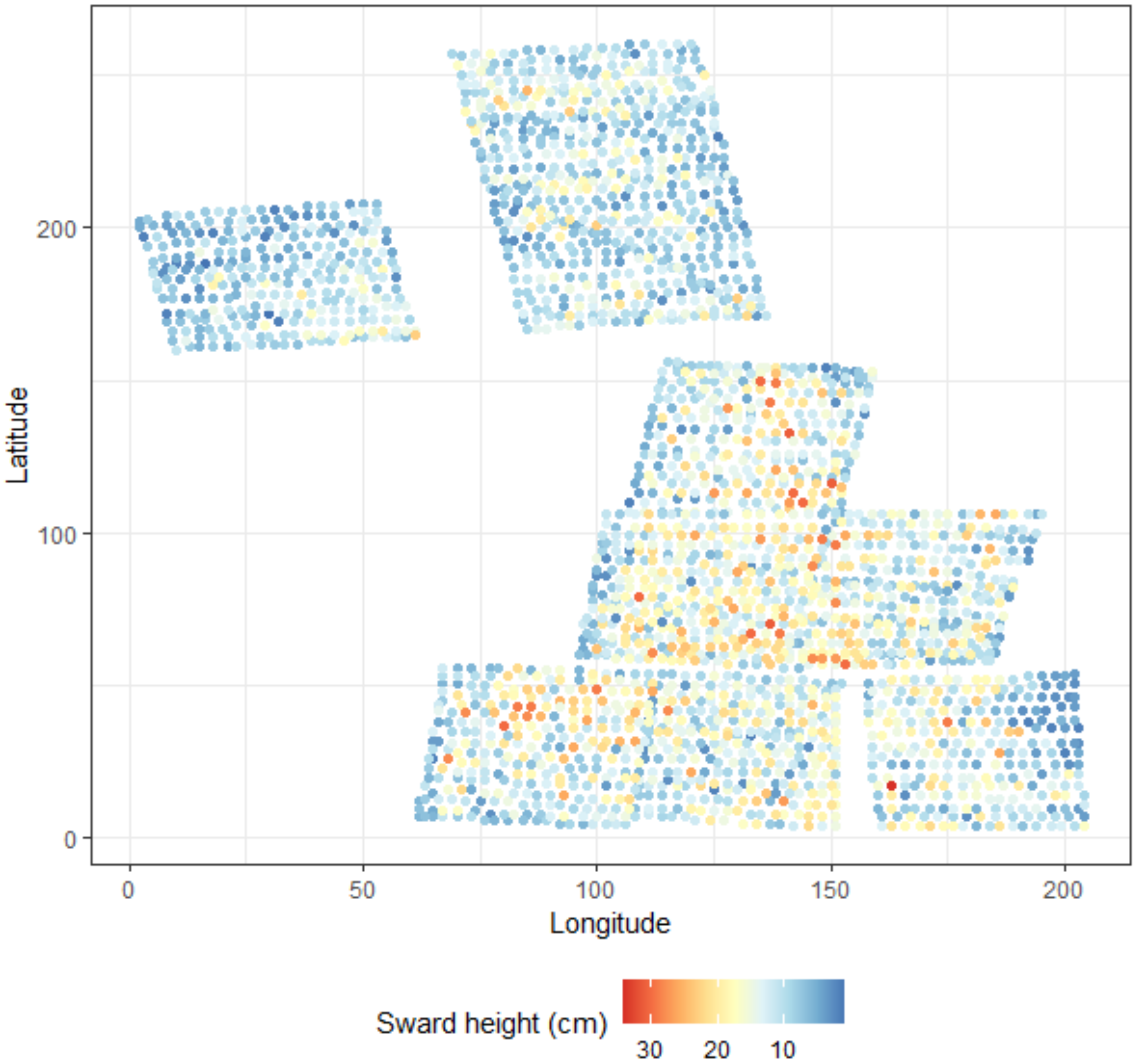


**Figure 6 -** An example of a georeferenced sward height measurement in all 9 padocks

**Appendix B.** Rules to elaborate and submit a manuscript for Applied Animal Behaviour Science

# APPLIED ANIMAL BEHAVIOUR SCIENCE

An international journal reporting on the application of ethology to animals managed by humans.

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http://grants.nih.gov/grants/olaw/Guiding_Principles_2012.pdf

Authors may also wish to refer to the ethical guidelines published on the website of the International Society for Applied Ethology http://www.applied-ethology.org/ethicalguidelines.htm, or read the following article: Sherwin, C.M., Christiansen, S.B., Duncan, I.J., Erhard, H., Lay, D., Mench, J., O'Connor, C., and Petherick, C. (2003), 'Guidelines for the ethical use of animals in applied animal behaviour research', Applied Animal Behaviour Science, 81: 291-305.
Unnecessary cruelty in animal experimentation is not acceptable.

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**VITA**

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