# PRECISION BITE: MONITORING THE INGESTIVE BEHAVIOR AND DEFINING A MANAGEMENT GOAL UNDER THE CONCEPTS OF ROTATINUOUS STOCKING

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## DISSERTAÇÃO

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*In memory of my mother* ***Sandra Maria Lopes de Lopes****, integrity and simplicity. An example of a warrior against a difficult life, with whom I learned to have persistence, to valorize what is intangible and to see life more clearly. When I was conducting this research in the field she discovered that she was with cancer and forbidden everyone to tell me, because she did not want to disturb my work. Self-denial says a lot about her life. Unfortunately, she cannot see the accomplishment of this step, but her legacy remains.*

*To all those who are unquiet to see a herbivore grazing, perceive with depth the science, art and poetry that exist in grazing process.*

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From a very young age, in the *campos* of *Estância Querência*, my grandfather's *estância*, currently managed by my father, something has always called my attention. Those Pampa Biome *campos* carrying such a complexity and a depth of meanings in their heterogeneous environment with high plant diversity and different grazing herbivores were the scenario I admired and wanted to understand. The relationships between plant and animals in this environment and the grazing process had already aroused my curiosity and admiration, even though I still didn't have the dimension of all this would represent. As I say, the grazing process is science, art and poetry. Through this document, I record another step of my scientific walk where I tried to understand a little more about the plant-animal interface: I'm still connected to the grazing process, questions that intrigued me since I was younger.

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To *mate*, companion of my silences and thoughts.

We keep asking and researching... Because **"the conformity is an attribute of the mediocre"** (Gentil Félix Da Silva Neto).

# Bocados de precisão: monitorando o comportamento ingestivo e definindo uma meta de manejo sob o conceito pastoreio rotatínuo[1]

Autor: Gentil Félix Da Silva Neto
Orientador no Brasil: Paulo César de Faccio Carvalho
Orientador na Bélgica: Jérôme Bindelle

**Resumo:** O manejo do pastejo afeta a dinâmica do comportamento ingestivo e consequentemente o desempenho animal e também consequentemente a dinâmica dos pastos e a produção de forragem. Esse processo pode ser visto sob várias óticas e duas questões permeiam o tema: qual é o objetivo do manejo do pastejo? e qual critério o manejador utilizará para orientar esse processo? Nesse contexto, foi proposto um conceito inovador de manejo do pasto baseado no comportamento ingestivo dos animais, o pastoreio rotatínuo. Baseado na hipótese de que o principal fator limitante da produção animal em pastejo é o tempo necessário para ingerir forragem, o objetivo do pastoreio rotatínuo é permitir que os animais maximizem sua taxa de ingestão instantânea em todo o tempo. A hipótese demonstrada em várias espécies de gramíneas é a de que existe uma estrutura de pasto ideal traduzida em altura do pasto que permite que essa maximização seja utilizada como objetivo de manejo em pastoreio rotatínuo. O objetivo desta tese foi definir a estrutura ideal de pasto para pastos de braquiária cv. Marandu (*Urochloa brizantha*). Portanto, utilizando um curto experimento de pastejo, examinamos a relação entre a altura do pasto (20, 30, 40 e 60 cm) e a taxa de ingestão em curto prazo. Os resultados obtidos mostraram que a massa de forragem correlacionou-se linearmente com a altura do pasto, sem influenciar a densidade volumétrica do pasto. A taxa de ingestão em curto prazo (STIR) apresentou resposta quadrática ($p < 0{,}01$) às alturas do pasto, sendo maximizada em aproximadamente 42 cm (57 g de MS $\text{min}^{-1}$) ($\text{STIR} = 29.0171 + 1.3314(\text{SH}) - 0.015838(\text{SH}^2)$, $R^2 = 0.17$).

**Palavras-chave:** Processo de pastejo, ingestão de forragem, interface planta-animal, manejo do pastejo.

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[1] Dissertação de Mestrado em Zootecnia – Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (64 p.), Março, 2019.

# Bouchée de précision: suivi du comportement d'ingestion et définition d'un objectif de gestion selon les concepts du pâturage rotatinu[1]

Author: Gentil Félix Da Silva Neto
Promoteur au Brésil: Paulo César de Faccio Carvalho
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**Resumé:** La gestion des pâturages affecte la dynamique du comportement d’ingestion et par conséquent les performances des animaux, ainsi que la dynamique des herbages pâturés et de la production fourragères. Ce processus peut être regardé à partir de plusieurs optiques et deux questions majeures sont posées: quel est l'objectif de la gestion des pâturages? et quel critère le fermier utilisera-t-il pour piloter ce processus? Dans ce contexte, un concept innovant de gestion du pâturage a été proposé basé sur le comportement d'ingestion des animaux au pâturage, le pâturage rotatinu (*rotatinuous stocking*). Partant du postulat que le principal facteur limitant la production au pâturage est le temps nécessaire à ingérer le fourrage pâturé, l'objectif du pâturage rotatinu est permettre aux animaux de maximiser en tout temps leur taux d’ingestion instantané. L’hypothèse démontrée dans un certain nombres d’espèces graminéennes est qu’il existe une structure idéale d’herbe traduite en hauteur d’herbe qui permet cette maximisation à utiliser comme objectif de gestion dans le pâturage rotatinu. L’objectif de cette thèse était de définir la structure idéale de pâturages de palisadegrass (*Urochloa brizantha*). Dès lors, au moyen d’une expérience de pâturage de courte durée, nous avons examiné la relation entre la hauteur du couvert herbacé (20, 30, 40 et 60 cm) et le taux d’ingestion à court terme. Les résultats obtenus ont montré que la biomasse disponible était corrélée linéairement avec la hauteur de la végétation sans influence sur la densité volumétrique apparente du couvert. Le taux d'ingestion a présenté une réponse quadratique ($p < 0,01$) à la hauteur du couvert, maximisé à environ 42 cm (57 g de MS $min^{-1}$) ($STIR = 29.0171 + 1.3314 (SH) - 0.015838 (SH^2)$, $R^2 = 0,17$).

**Mots-clés:** pâturage, consommation de fourrage, interface plante-animal, gestion du pâturage.

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[1] Master thèse en Science Animale – Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brésil. (64 p.), Mars, 2019.

# Precision bite: monitoring the ingestive behavior and defining a management goal under the concepts of rotatinuous stocking[1]

Author: Gentil Félix Da Silva Neto
Advisor in Brazil: Paulo César de Faccio Carvalho
Advisor in Belgium: Jérôme Bindelle

**Abstract:** Grazing management affects the dynamics of ingestive behavior and consequently animal performance and also the dynamics of grazed swards and herbage production. This process can be seen from several optics and two questions permeate the theme: what is the goal of grazing management? and what criterion will the manager use to drive this process? In this context, it was proposed an innovative sward management concept based on the ingestive behavior of grazing animals, the rotatinuous stocking. Based on the assumption that the main limiting factor of grazing animal production is the time required to ingest herbage, the goal of rotatinuous stocking is to allow animals to maximize their instant intake rate at all times. The hypothesis demonstrated in several grass species is that there is an ideal sward structure translated to sward height that allows this maximization to be used as a management objective in rotatinuous stocking. The objective of this thesis was to define the ideal sward structure for pastures of palisadegrass (*Urochloa brizantha*). Therefore, using a short grazing experiment, we examined the relationship between the sward height (20, 30, 40 and 60 cm) and the short-term intake rate. The results obtained showed that the available biomass correlated linearly with the sward height, without influencing the sward bulk density. The short-term intake rate presented a quadratic response ($p < 0.01$) to the sward heights, being maximized at approximately 42 cm (57 g DM $min^{-1}$) ($STIR = 29.0171 + 1.3314(SH) - 0.015838(SH^2)$, $R^2 = 0.17$).

**Keywords:** Grazing process, herbage intake, plant-animal interface, grazing management.

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[1] Master thesis in Animal Science – Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (64 p.), Mars, 2019.

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| | |
|---|---|
| BC | Bite category |
| BD | Bulk density |
| CEUA | Animal Use Ethics Committee |
| CONCEA | National Council for the Control of Animal Experimentation |
| DM | Dry matter |
| ET | Eating time |
| EU | Experimental unit |
| G | Grams |
| GJMR | Grazing jaw movement rate |
| GT | Grazing time |
| H | Hour |
| IMU | Inertial measurement unit |
| Kg | Kilogram |
| LI | Light interception |
| LW | Live weight |
| Min | Minutes |
| P | Significance level |
| S | Seconds |
| SE | Standard error |
| SH | Sward height |
| STIR | Short-term intake rate |
| UFRGS | Federal University of Rio Grande do Sul |

# 1. GENERAL INTRODUCTION

## 1.1. Context

Grasslands cover 40% of the ice-free landmass on earth (Blair, Nippert & Briggs, 2014). Such an important extension gives them a key role in many processes at the planet level. Grasslands are also biodiversity reserves of utmost importance and have high cultural and social values (Bengtsson et al., 2019; Boval & Dixon, 2012). Grasslands are indeed known to provide ecosystem services such as water supply and flow regulation, mitigation of greenhouse gas emissions, erosion control, and population-based regulatory services such as pollination and biological control (Stevens, 2018; Bengtsson et al., 2019; Herrero et al., 2016; Boval & Dixon, 2012). In addition to all these aspects, their productions services are crucial since pastures provide the basis of feeding for grazing livestock (Boval & Dixon, 2012).

Boval & Dixon (2012) argue that pastures need to be better managed to fulfill their multiple functions. These authors point out that knowledge is often lacking, particularly for tropical grasslands. Thus, the appropriate management of grasslands is challenging given the diversity of agroecosystems and soil-plant-animal interactions at stake.

The plant-animal interface encompasses topics such as intake, ingestive behavior and diet selection and plays a central role in this context due to their ecological (where the interest is the interaction between the trophic levels), agricultural (for the production of animal products) and natural resource management (by grazing impact on the landscape and vegetation) importance (Ungar, 1996). With a better understanding of these interactions in grazed ecosystems, strategies can be defined that benefit animal production and allow the sustainability of grasslands uses (Gastal & Lemaire, 2015). In pastoral systems, synergies between the animal's and farmer's grazing decisions have the potential to offer greater benefits to the animal, the pasture environment, and the farm than grazing management optimizing one single component of the system (Gregorini et al. al., 2017). The integration of the processes is fundamental to manage the system.

By adequately integrating pastures into agricultural production systems and land use decisions locally and regionally, their potential to contribute to functional landscapes and food security can be greatly enhanced (Bengtsson et al., 2019). Grazing should be managed taking these complex interactions into account and not only focusing on a single component, such as plant growth or the simple application of inputs. Boval & Dixon (2012) argue that evaluation and continuous adjustment of grazing systems requires appropriate and reliable evaluation criteria, which are often non-existent. Thus, management based on the plant-animal interface is a potential tool to manage the system, creating synergies and avoiding trade-offs between production and other ecosystem services.

## 1.2. Spatio-temporal scales of grazing process

The grazing process is defined as the activity that includes short periods of time when the animal is not only actively eating, but is also engaged in activities directly associated with feeding (Gibb, 1996) including searching (scanning, recognition and decision) and handling of the grazed forage (biting, chewings, wallowing) (Ungar & Noy-Meir, 1988). It is the process by which herbivores get feed from the pastoral environment.

This process is organized in ecological hierarchies according to the model proposed by Senft et al., (1987) with different spatio-temporal scales. A complementary approach was proposed where the scales were defined by specific behaviors involving the internal processing of information and resources by the animal (Bailey et al., 1996; Laca & Ortega, 1995). From this conceptual model, six spatio-temporal scales were defined: bite, feeding station, patch, feeding site, camp and home range (Table 1).

**Table 1:** Spatio-temporal scales useful for describing and evaluating foraging behavior of large herbivores (adapted from Bailey et al. 1996; Laca & Ortega, 1995; Owen-Smith 2002; Bailey & Provenza, 2008).

| **Spatial level** | **Spatial resolution of selected unit**[1] | **Temporal level** | **Defining behaviors or characteristics** | **Response variable** | **Motivation to move** | **Some potential selection criteria** | **Potential mechanisms that may affect grazing distribution patterns** | **Vegetation entity** |
|---|---|---|---|---|---|---|---|---|
| Bite | 0.0001 - 0.01 $m^2$ | 1 - 2 s | Jaw, tongue and neck movements | Bite size | Depletion; selection of diet; touch, smell and taste stimuli | Nutrient concentration; toxin concentration; secondary compounds; plant size | Intake rate; diet selection; post-ingestive consequences | Plant part |
| Feeding station | 0.1 - 1 $m^2$ | 5 - 100 s | Front feet placement | Bite rate | Forage depletion; diet selection; forage abundance; mouthful | Forage abundance; forage quality; plant species; social interactions | Transit rate; intake rate; turning frequency | Plant (grass tuft; shrub) |
| Patch | 1 $m^2$ - 1 ha | 1 - 30 min | Animal reorientation to a new location; a break in the foraging sequence | Feeding duration | Forage depletion, intake rate; species composition; olfactory and visual stimulli; social interactions | Forage abundance; forage quality; plant species; social interactions; topography | Transit rate; turning frequency; intake rate; optimal foraging theory and other rules of thumb; frequency of selection (spatial memory) | Clump of plants |
| Feeding site | 1 - 10 ha | 1 - 4 h | Feeding bout | Foraging movements | Forage depletion; intake and digestion rate | Topography; distance to water; forage quality; forage abundance; phenology; predation | Frequency of selection (spatial memory) and rules of thumb | Plant species association |
| Camp | 10 - 100 ha | 1 - 4 weeks | Central areas where animals drink and rest between foraging bouts | Daily time allocation | Phenology; water; cover; forage depletion and regrowth | Water availability; forage abundance; phenology; cover thermoregulation; competition | Transhumance; migration; frequency of selection (spatial memory) | Landscape unit |
| Home range | > 1000 ha | 1 month - 2 years | Dispersal or migration | Life history schedule | Social; reproduction; phenology; competition; thermoregulation; water | Water availability; forage abundance; phenology; cover thermoregulation; competition | Migration; dispersal; transhumance | Geographical region |

[1] The spatial resolution of each level will vary among species of large herbivores. These approximate ranges are given to help the reader visualize differences between levels. The temporal intervals between decisions and animal behaviour are used to define the units of selection.

The bite is the smallest spatio-temporal scale of the grazing process, being considered the atom of the grazing process and the basic unit of intake (Laca & Ortega, 1995; Demment, Peyraud & Laca, 1995). Laca et al. (1994) define a bite as the sequence of herbage prehension, jaw and tongue movements, and severance by head movement (Laca et al., 1994). Stobbs (1973) in a classical study demonstrated the influence of sward structure on the bite mass. The bite dimensions are affected by the sward structure, the bite depth increases with the sward height and decreases with the bulk density (Laca et al., 1992). The bite area is also positively related to sward height, and in tall swards animals can explore the benefits of tongue sweep movements (Gordon & Benvenutti, 2006).

The feeding station is defined as an array of plants available to the herbivore without moving their front feet (Novellie, 1978). At this level, the intake rate is a function of the bite mass (Laca & Ortega, 1995) together with the bite rate (Laca et al., 1994; Ungar, 1996). The depletion of the herbage in the feeding station causes the animal to integrate information and make foraging decisions (Laca & Ortega, 1995).

The patch is an intermediate scale defined as a cluster of feeding stations separated from others by a break in the foraging sequence when animals reorient to a new location (Bailey et al., 1996) and spatial aggregations of resources (Searle et al., 2006 ). On this scale, changes in intake rate lead to decision making. In this context the herbivores are faced with the question: should I stay or should I go, (Searle et al., 2005) evaluating costs and benefits.

A feeding site is a collection of patches in a contiguous spatial area that animals graze during a foraging bout, it may contain one or more plant communities. Foraging bouts are defined by a change in behavior from grazing to resting, ruminating or behaviors other than foraging (Bailey et al., 1996). While camps and home ranges are larger scales that occur within a regional scale. A camp is a set of feeding sites that share a common foci where animals drink, rest, or seek cover. Typically, movements between camps involve the whole social unit and may occur every few weeks. Home ranges are collections of camps and are defined by fences, barriers, extent of migration, or transhumance (Bailey et al., 1996). At this scales, distribution of water and cover take a progressively greater importance in grazing patterns (Laca & Ortega, 1995).

This brief description of the spatio-temporal scales involved in the grazing process is important for the understanding grazing patterns and guiding research in plant-animal interface. Thus, the spatio-temporal scale must be considered in the investigation of the subject, since the central parameters are different at each level (Ungar, 1996; Laca, 2000). Foraging decisions proceed from coarse to fine, and from fine to coarse scales (Laca & Ortega, 1995), where it is evidenced the need to integrate information from the different scales to explain the phenomena that occur during grazing. The impacts on the smaller scales as the bite, alter the intake rate of the animals which reflect at larger scales influencing the nutrient intake and consequently the animal performance.

### 1.3. Rotatinuous Stocking: A sward management concept

The central parameter that determines the herbage intake by grazing animals at the finest scale, namely the bite, is the sward structure. The sward structure is the distribution and arrangement of above-ground plant parts within a community that present themselves to the animal at the time of the bite execution (Laca & Lemaire, 2000). The components of the sward structure are the herbage mass, sward height, bulk density, leaf/stem ratio (Cangiano, 1999). Thus, the sward structure not only provides information about the amount of forage but also how the forage is presented to the animals.

For many years, grazing management has been and is still based on the vegetal component, where management goals have in common the fact of taking into account the herbage accumulation associated with large intervals between grazing. One of the criteria widely used to define the beginning of grazing is the value of 95% light interception (Silva & Nascimento Júnior, 2007; Pedreira et al., 2017; Silva et al., 2017). In addition to this, the ideal time for grazing, interruption is poorly substantiated (Carvalho et al., 2016) and generally based on the concept of higher herbage harvesting efficiency by the animals.

The Grazing Ecology Research Group (GPEP) of the Federal University of Rio Grande do Sul (UFRGS) has been working for more than 15 years in the investigation of relationships between plants and herbivores in different pastoral ecosystems under the scientific leadership of Prof. Paulo César de Faccio Carvalho. Consolidating the results obtained, Carvalho (2013) proposed a grazing management innovation named Rotatinuous Stocking. It is a concept of sward management based on the ingestive behavior of the animals, since the grazing process is the cause and consequence of the sward structure (Carvalho et al., 2016).

In this management concept the ideal sward structure is defined by the sward height that allows the maximization and maintenance of the intake rate. Rotatinuous Stocking can be applied both under rotational and continuous stocking method, once it is fundamentally based on the maximization of intake rate during the period and between the different strips of the paddock (rotational stocking) or along the displacements between the feeding stations (continuous stocking) in a manner analogous to the Marginal Value Theorem (Charnov, 1976). The sward height where the maximum herbage intake rate is defined as pre-grazing height (in the case of rotational stocking). Among the species that have been studied and defined the pre-grazing sward height targets are native grasslands (Gonçalves et al., 2009), *Sorghum bicolor* (Fonseca et al., 2012), *Cynodon sp*., *Avena strigosa* (Mezzalira et al. 2014) and *Lolium multiflorum* (Silva, 2013).

The post-grazing sward height is also based on the ingestive behavior of the animals. It is recommended that depletion should not exceed 40% of the pre-grazing height to keep at high level the intake rate (Fonseca et al., 2012; Mezzalira et al., 2014).

## 2. Objectives of the research:

The main objective of the study was to define the ideal sward structure translated in sward height for maximizing short-term intake rate in palisadegrass (*Urochloa brizantha*) pasture, a widely used forage species for the tropics and subtropics. Once defined, such as ideal sward structure can be used as a management goal in the Rotatinuous Stocking. In order to do so, we hypothesized that there is a sward height between 20 and 60 cm where the animals are able to maximize the short-term intake rate. Hereafter, we present the experiment used to test our hypothesis under the form of an unpublished scientific paper.

# 3. Paper – Monitoring the ingestive behavior and defining a management goal under the concepts of Rotatinuous Stocking

## 3.1. Introduction

The ingestive behavior of herbivores is a process in which a diversity of factors interact, constituting its complexity. A conceptual model organizes this process into ecological hierarchies (Senft et al., 1987) according to the different spatio-temporal scales which have been refined and defined by specific behaviors (Bailey et al., 1996; Laca & Ortega, 1995) ranging from bite, feeding station, patch, feeding site, camp and home range (spatial levels) and from seconds to years (temporal levels) (Laca & Ortega, 1995; Bailey et al., 1996). The spatio-temporal scale should be considered in the investigation of the theme, once the mechanisms and central parameters are different at each level, although the scales are related (Ungar, 1996; Laca, 2000; Bailey & Provenza, 2008; Shipley et al., 1994). In addition, a processes-focused approach should be performed, understanding how they act at the plant-animal interface and integrating mechanisms between the different scales, from reductionism to explanation of high-level phenomena (Demment & Laca, 1994; Owen-Smith, Fryxell & Merril, 2010).

As said before, foraging decisions interact at multiple spatio-temporal scales. They are impacted by factors such as food context (chemical and temporal) seen from the perspective of psychobiology and past food experiences (Burrit & Provenza, 2000; Villalba et al., 2015), post-ingestive feedback

(Provenza, 1995; Villalba & Provenza, 2009), aspects such as satiety and motivation (Newman et al., 1994; Meuret & Provenza, 2015 a, b). In addition, foraging decisions are strongly influenced by the structure of the sward, since in the feeding sequence physical limitations (ingestive) happen prior to chemical limitations (digestive). This makes fundamental the investigation of the link between sward structure and foraging decisions at fine scales such as patch (Griffiths, Hodgson & Arnold, 2003 a; Searle, Hobbs & Shipley, 2005; Searle et al., 2006), feeding station (Gregorini et al., 2009) and bite (Spalinger & Hobbs, 1992; Griffiths, Hodgson & Arnold, 2003 b). Indeed, the latter has its dimensions altered by the sward structure (e.g. mass, depth and volume) (Stobbs, 1973 a, b; Chacon & Stobbs, 1976; Laca et al., 1992; Flores et al., 1993; Griffiths, Hodgson & Arnold, 2003b; Benvenutti, Gordon & Poppi, 2006; Benvenutti et al., 2009). For being the atomic component of the grazing process (Laca & Ortega, 1995) and the basic unit determining intake rate and daily herbage intake (Demment, Peyraud & Laca, 1995), efficiency of the foraging at the short term bite level will reflect in nutrient intake and consequently in animal performance on the long term.

The Foraging Theory (Stephens & Krebs, 1986) and its different variants such as the Optimal Foraging Theory (MacArthur & Pianka, 1966) and the Marginal Value Theorem (Charnov, 1976) attempt to model and understand animal decisions. They have in common at their core the fact that they postulate that foraging animals are optimizing, maximizing or minimizing, an objective function (Ydenberg, Brown & Stephens, 2007). Some tactics of the animals are addressed as time-minimizer, other as profit-maximizer (Owen-Smith & Novellie, 1982; Ungar & Noy-Meir, 1988; Owen-Smith, 1994; Bergman et al., 2001; Fortin, Fryxell & Pilote, 2002; Fortin et al., 2015), with profit being the harvest of food or a specific nutrient such as energy. In the case of applying foraging theory to the grazing process, we can assume that the abundance of food is related to the sward structure, since this will determine the intake rate, driving the possibility to either minimize feeding time or maximizing energy harvest per unit of time, or both. Taking energy as driving nutrient, we can describe the foraging sequence as follows: the forager spends energy while it is traveling to the patch, obtaining energy when it starts grazing a patch. This grazing process is characterized by a decelerating intake curve (Figure 1) (Stephens, 2008). This gain function decreases as forage depletion occurs on the patch. Hence, animals optimizing intake will stay on the patch as long as the rate of energy harvest is higher than what they know from the average harvest rate on the paddock they are grazing. When they reach this point of exploitation, patch exploitation cost/gain ratio is greater than what they could have by moving to another patch, characterizing the ideal point of occupation where the animal should move on to the next patch to maintain high intake rates (Charnov, 1976).

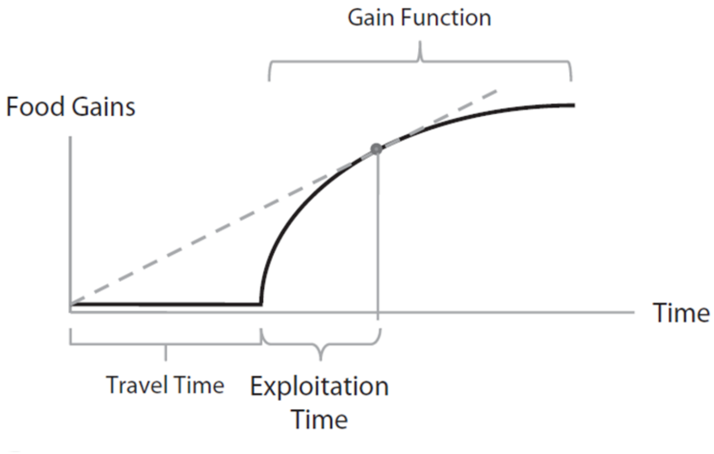

**Figure 1:** Graphical model of patch exploitation (adapted from Stephens, 2008).

In this context, after a series of researches on native grasslands, annual and perennials pastures of temperate and tropical climate, based on the ingestive behavior of animals, Carvalho (2013) proposed an innovation in grazing management. This innovation is not a stocking method, but a sward management concept named Rotatinuous Stocking (Carvalho, 2013), based on the ingestive behavior of the animals. In this management concept the ideal sward structure is defined by the sward height that allows the maximization and maintenance of the intake rate. The sward height where the maximum herbage intake rate occurs is defined as pre-grazing height (in the case of rotational stocking), and post-grazing height is also based on the ingestive behavior of the animals, being recommended the depletion no more than 40% of the pre-grazing height to keep at high level the intake rate. This recommendation derives from studies that have evaluated the proportions of grazing down of ideal height in contrasting pastures (*Avena strigosa*, *Cynodon sp*. and *Sorghum bicolor*) (Fonseca et al., 2012;

Mezzalira et al., 2014). Rotatinuous Stocking can be applied both under rotational and continuous stocking methods, once its fundamental basis is that the maximization of intake rate is allowed continuously during the occupation period and between the different strips of the paddock (rotational stocking) or along the displacements between the feeding stations (continuous stocking), which is defined by a sward structure that allows for the realization of potential bites by the animals.

Since such an ideal sward structure, which is translated in sward height, that allows the animals the maximization of short-term herbage intake rate is different according to the grass species, in this work, we attempted to determine it for palisadegrass (*Urochloa brizantha*) and understand how changes in structural components on the grass with increasing sward height might explain changes in intake rates. Palisadegrass is indeed a widely used forage species in the humid tropics and subtropics (Cook et al., 2005). Hence, the use of Rotatinuous Stocking for the species still lacks such an information.

## 3.2. Material and methods

The scientific protocol involving animals was approved by the Animal Use Ethics Committee of Federal University of Rio Grande do Sul (CEUA - UFRGS), (project 33970) and all animals were handled in accordance with established guidelines by the National Council for the Control of Animal Experimentation (CONCEA).

The experiment consisted of 4 sward heights (20, 30, 40 and 60 cm) with replicates in the evaluation time (morning or afternoon) and the period (two experimental cycles). In each treatment, the sward structure was characterized and the short-term herbage intake rate was measured by the double weighing technique.

### 3.2.1. Site and treatments

The experiment was conducted at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul, in southern Brazil (30° 05’S, 51º 39’W). It consisted of 4 sward heights treatments (20, 30, 40 and 60 cm) in palisadegrass cv. Marandu pasture (*Urochloa brizantha*). The data were collected in May 2018 in sixteen grazing tests. The climate in the region is subtropical humid (Cfa) (Köppen & Geiger, 1928). The soil at the experimental site was classified as a Typic Paleudult (USDA, 1999).

The experimental design was a randomized complete block with four replicates, which consisted of the interaction between the evaluation time (morning or afternoon) and the period (two experimental cycles), totaling sixteen experimental units.

### 3.2.2. Pasture

In the experimental area of 2.0 ha (Figure 2) eight paddocks were delimited (two of 700 $m^2$ for treatment 20 cm and six of 500 $m^2$ for treatments 30, 40 and

60 cm) The 700 and 500 $m^2$ areas was scaled so that the sward height remained relatively constant over grazing test period of 45 min, such that the same sward structure was available throughout the grazing sessions. The cows grazed an area adjacent of the same grass for approximately 30 days prior to the start of the experiment. The pasture consisted of palisadegrass cv. Marandu (*Urochloa brizantha*). This species was sown on 01 December 2017 with conventional tillage and a seeding density of 25 kg $ha^{-1}$. The base fertilization of 13.75 kg N $ha^{-1}$, 82.5 kg $P_2O_5$ $ha^{-1}$ and 41.25 kg $K_2O$ $ha^{-1}$ was performed in 22 December 2017 and the N fertilization as urea 101.25 kg N $ha^{-1}$ was performed on 04 December 2017.

On 24 January 2018, Metsulfuron-methyl was applied on the area (8.0 g a.i. $ha^{-1}$) for weed control. On 26 February 2018, when the average sward height reached 60 cm, an intense crash grazing was carried out for four days with approximately 50 cows and 20 calves to shape the sward structure and favor tillering. Subsequently, on 9 March 2018, the whole area was cut at 5 cm.

On 16 March 2018 other N fertilization as urea was performed 101,25 kg N ha$^{-1}$.

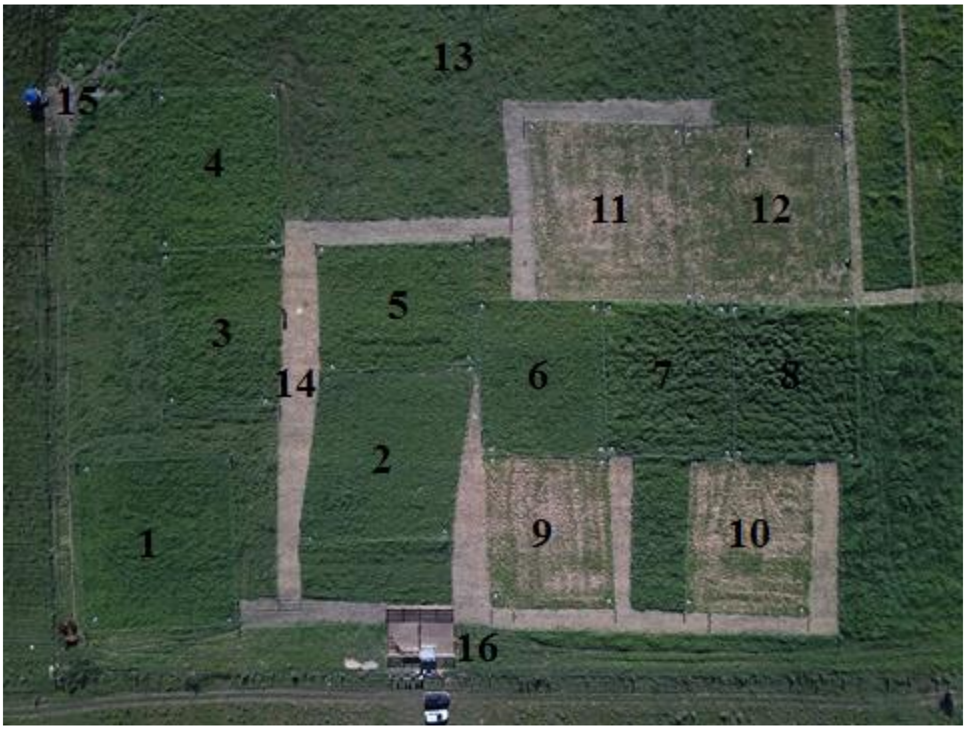

**Figure 2:** Aerial view of the experimental area.

1 and 2 – Paddocks of treatment 20 cm (700 m$^2$). Paddock 1 in the first cycle evaluated in the morning and in the second cycle evaluated in the afternoon. Paddock 2 in the first cycle evaluated in the afternoon and in the second cycle evaluated in the morning;

3 and 4 – Paddocks of treatment 40 cm (500 m$^2$). Paddock 3 in the first cycle evaluated in the afternoon and in the second cycle evaluated in the morning. Paddock 4 in the first cycle evaluated in the morning and in the second cycle evaluated in the afternoon;

5 and 6 – Paddocks of treatment 30 cm (500 $m^2$). Paddock 5 in the first cycle evaluated in the afternoon and in the second cycle evaluated in the morning. Paddock 6 in the first cycle evaluated in the morning and in the second cycle evaluated in the afternoon;

7 and 8 – Paddocks of treatment 60 cm (500 $m^2$). Paddock 7 in the first cycle evaluated in the morning and in the second cycle evaluated in the afternoon. Paddock 8 in the first cycle evaluated in the afternoon and in the second cycle evaluated in the morning;

9, 10, 11 and 12 – Extra paddocks;

13 – Adjacent area of palisadegrass;

14 – Corridor without vegetation;

15 – Water;

16 – Corral and balance.

### 3.2.3. Sward Structure and Sward Measurements

The sward structure was evaluated in each experimental unit (EU) in all treatments 20, 30, 40 and 60 cm of sward height. The sward surface height, an important indicator of sward structure, was measured using a sward stick (Barthram, 1985) coupled to a RTK-GPS (EMLID REACH RS GNSS RTK) (Figure 3) to obtain georeferenced data, were measured 200 points pre- and post-grazing.

**Figure 3:** Sward stick coupled to a RTK-GPS.

The pre-grazing herbage mass was measured by cutting at ground level using a quadrat of 0.25 m² (0.50 x 0.50 m) and replicated on four samples per paddock. Each sample was separated into two strata (top and bottom) that composed the total herbage mass. In each sample 5 sheath heights and 5 sward heights were measured with the sward stick. The average of sward heights in the quadrat was divided in 2 to make the cut of the bottom strata. All herbage samples were oven dried (55°C for 72 h) and subsequently, the components were separated into leaves lamina, stem+sheath, dead material, inflorescence and weeds.

The total sward bulk density was calculated by the ratio between the total herbage mass by the total volume of sample. The sward bulk density of components (leaf and stem+sheath) was calculated by the ratio between the mass of each component by the volume of each strata.

The sample volume was obtained by the multiplication of the quadrat area (0.5 x 0.5 m) by the average sward height or strata height (in the case of the calculation by strata).

The light interception (LI) of the sward was determined in the pre-grazing by sampling ten readings in each paddock using a ceptometer described by Carassai (2010) approximately at 12:00 hours a.m.

### 3.2.4. Animals

The experimental animals were three adult Brangus cows (60 ± 2 months old) with an initial live weight (LW) 684.05 ± 88.88 kg. For approximately 30 days prior to the start of the experiment, the cows grazed an adjacent area of palisadegrass to become familiarized with observers, recording and collecting equipment and the experimental procedure. These three cows formed a single group that grazed all experimental paddocks during the experiment.

### 3.2.5. Animal Measurements

#### 3.2.5.1. Ingestive Behavior and Animal Monitoring

In order to understanding the plant-animal interface in different sward structures, the animals were monitored with a fine scale, positioning data and ingestive behavior were obtained from five techniques (four equipment and a visual observation methodology).

#### 3.2.5.2. IGER Behaviour Recorder

The three animals were fitted with IGER Behaviour Recorder (Figure 4) (Rutter, 1997) that registers the number of grazing jaw movements wich comprise biting and non-biting (manipulation + mastication).

In calculating the short-term intake rate (STIR), grazing jaw movement rate (GJMR) including biting and non-biting, the time base employed was eating time (ET), rather than grazing time (GT), since the latter would have led to inclusion of intra-meal intervals (Gibb et al., 1999). Eating time (ET) was calculated as the sum of the periods involving grazing jaw movements, excluding intervals of jaw inactivity > 3 s, whilst grazing time was the sum of the periods involving grazing jaw movements, including any periods of jaw inactivity < 5 min (Gibb et al., 1999).

The data obtained by the recordings of the IGER were analysed using Graze software (Rutter, 2000).

**Figure 4:** Monitoring of ingestive behavior of cows by equipment: (A) IGER Behaviour Recorder; (B) Acoustic monitoring microphone; (C) Halter containing iPhone 5S and Rover EMLID above the box of the iPhone and (D) box containing the pocket recorder connected to the microphone.

### 3.2.5.3. Continuous Bite Monitoring

A direct observation technique, the Continuous Bite Monitoring, was used to monitor the foraging dynamics and the diversity of bites in each treatment (Agreil & Meuret, 2004; Bonnet et al., 2015).

Prior to the start of the experiment, in the period of familiarisation of the animals mentioned above (see item 3.2.4), two observers were trained to allow close cohabitation between the observers and the cows with no influence on the animals behavior and the bite-coding grid was designed and refined. This procedure followed the steps (principles) described by Agreil & Meuret (2004), Agreil, Meuret & Fritz (2006) and Bonnet et al., (2015).

The bite-coding grid was designed on the basis of the following four distinct criteria according to Bonnet et al. (2015): (1) structural attributes of the sward area where carried bites (e.g. sward height, bite mass, three-dimensional architecture, density); (2) nature and position of the selected plant parts (within the plant but also within the plant community e.g. lodging plants, detached leaves and grazed or non-grazed sward); (3) handling and severing behavior of the animal (e.g. tissues being regrouped with the tongue, cleanly cropped with the teeth or broken at their base); and (4) expected nutritional value of the bite (e.g. bite mass combining with plant parts) (Figure 5).

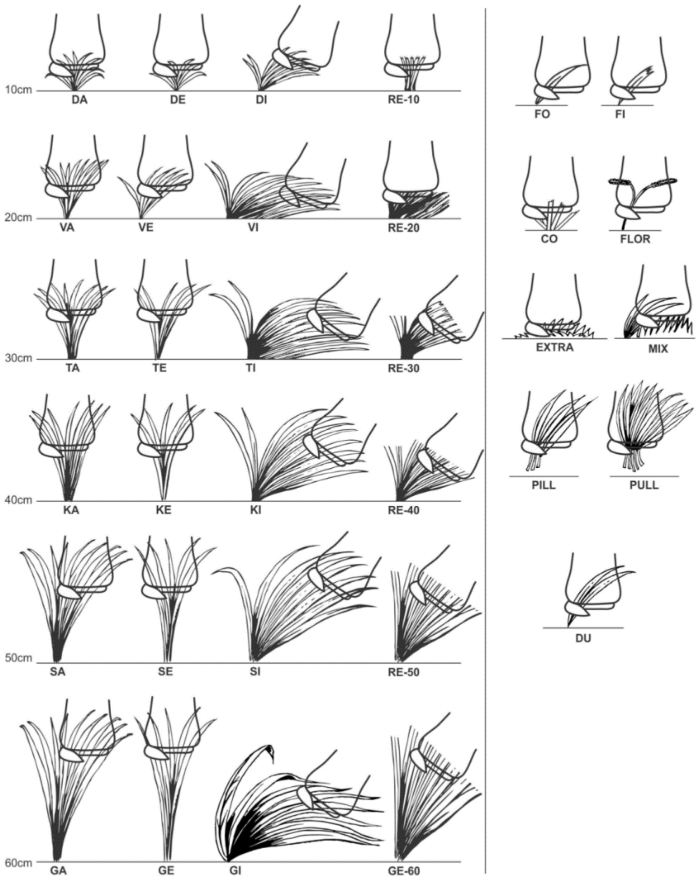

**Figure 5:** Bite-coding grid for cows in palisadegrass pasture. Each pictogram illustrates the 'ideal bite' for each bite category (BC). Numbers on the left side of some pictograms represent plant height (in cm) for the BC. Codes for each BC appear below the pictograms. The letters in parentheses above each BC represent the criteria used in each BC. Criteria were (A) structural attributes of the sward area where carried bites (e.g. sward height, bite mass, three-dimensional architecture, density); (B) nature and position of the selected plant parts (within the plant but also within the plant community e.g. lodging plants, detached leaves and grazed or non-grazed sward); (C) handling and severing behaviour of the animal (e.g. tissues being regrouped with the tongue, cleanly cropped with the teeth or broken at their base); and (D) expected nutritional value of the bite (e.g. bite mass combining with plant parts).

During the grazing tests (45 min), two of the three experimental cows were monitored by the Continuous Bite Monitoring. Each observer evaluated one cow and the same observer evaluated the same cow in all treatments during the first experimental cycle. In the second experimental cycle the observers was alternated (statistical effect retired). Each observer had a digital recorder Sony ICD-PX312 (Sony) for register bites and other observations about the ingestive behavior (Figure 6). After the grazing tests the observers simulated the observed bites by hand plucking on the associated simulation patch (Bonnet et al., 2011). Each BC was simulated 20 times. The audio files of the grazing tests were transcribed using JWatcher® software (Blumstein, Daniel & Evans, 2018).

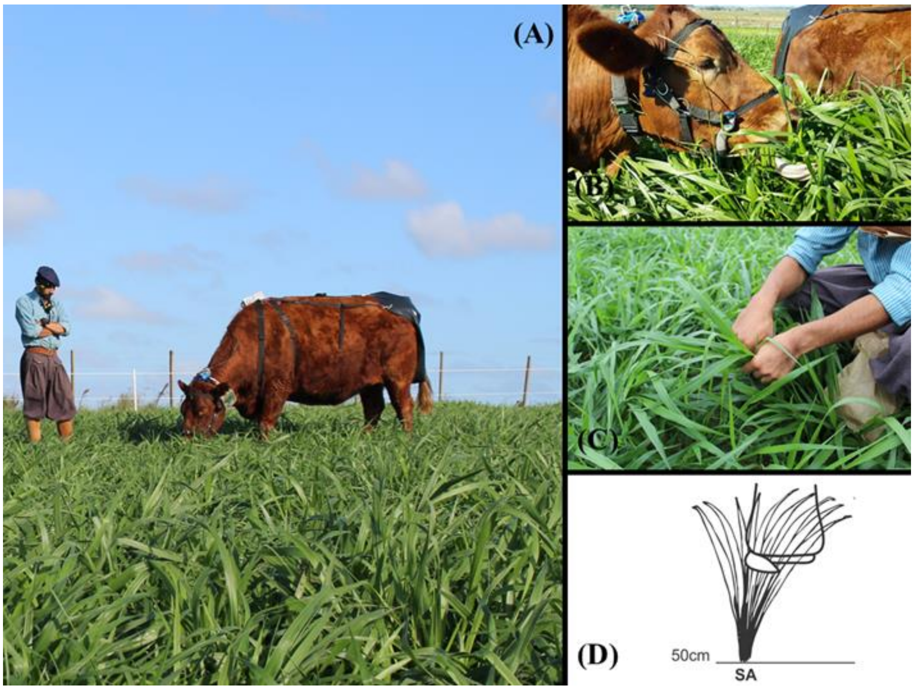

**Figure 6:** Representation of Continuous Bite Monitoring and Hand Plucking. (A) Observer recording bite category (BC) on a voice recorder. (B) Bite occurrence. (C) Simulated the observed bites by hand plucking on the associated simulation patch. (D) Bite category (BC)

The hand-plucking technique (Bonnet et al., 2011) was performed immediately after each grazing test to estimate the bite mass and its nutritional value. Twenty samples of each bite category (BC) were taken manually (see Figures 5 and 6), mimicking the animal's action. After the simulations the samples were immediately weighed on a precision scale (three decimal point) to obtain the green weight, then dried for 72 hours in an oven at 55 °C to obtain the dry weight.

To estimate the percentage of dry matter (DM) ingested by the animals, a range of 3 minutes (1 minute at the beginning of the grazing test, one minute in the middle and one minute near the end of the evaluation) was used of the record the continuous bite monitoring (see item 3.2.5.5.), from which were recorded the number of bite categories that occurred and the frequency of each category that with the dry matter content obtained by drying the hand-plucking samples were used to calculate the weighted average of the percentage of dry matter ingested by animals.

### 3.2.6. Short-term Intake Rate

The short-term intake rate (STIR) was measured using the double-weighing technique (Penning & Hooper, 1985). Before each grazing test, cows were fitted with bags for the collection of faeces and urine and with equipments for monitoring ingestive behavior (Figure 7) (see item 3.2.5.1.). In the calculation of STIR data from IGER Behaviour Recorder (see item 3.2.5.2.) was used. The animals were non-fasted before the grazing tests because this could have changed the ingestive behavior (Greenwood & Demment, 1988), intake rate (Gregorini et al., 2009) and diet selection (Newman et al., 1994). Each cow was weighed before and after the grazing tests. Immediately after the grazing tests, cows were moved to a non-vegetated corral with neither feed, nor water for the same period of time (45 min) to estimate insensible weight losses (evaporation of $H_2O$, loss and production of $CO_2$ and $CH_4$, Gibb, 1999). All weights were taken on a 10 g precision scale. STIR of fresh matter was calculated with the following equation:

$$STIR = \left[\frac{(W2 - W1)}{(t2 - t1)}\right] + \frac{(W3 - W4)}{(t4 - t3)} * \frac{(t2 - t1)}{ET} .$$

Where: *STIR* is short-term herbage intake rate; *W*1 and *W*2 are pre and post-grazing weight; *t*1 and *t*2 pre and post-grazing time; *W*3 and *W*4 animal’s weight pre and post-insensible weight losses; *t*3 and *t*4 pre and post-insensible weight losses time; and *ET* is effective eating time. STIR of DM was calculated as STIR of fresh matter multiplied by forage DM content. We assessed the DM content in forage ingested by the hand-plucking technique using the records of the continuous bite monitoring (see item 3.2.5.5.) to calculate the weighted average of what was ingested.

**Figure 7:** Cow fitted with bags for the collection of faeces and urine and with equipments for monitoring ingestive behavior.

### 3.2.7. Statistical Analysis

Statistical analyses were performed in R (version 3.5.1, R Core Team, 2018). Sward structural characteristics were analyzed using the R lme4 package for mixed linear models (Bates et al., 2015) with treatments as fixed effects and the combination of time of day (morning or afternoon) and period as random effect, according to the model y ~ treatment + (1|time:period). Short-term intake rate was also analyzed as a quadratic function of observed sward heights (SH) as fixed effects with time:period and animals as a random effects, according to the following model: y ~ I (SH - mean (SH)) + I (SH - mean (SH))2 + (1|time:period) + (1|animal).Residuals were visually checked for homogeneity of variance and normality was tested through quantile-quantile plots using the R car package (Fox and Weisberg, 2011). When the residuals were not homogeneous or the distribution was not normal, data were transformed. Differences between treatments were tested with the Tukey HSD test at 95% confidence level ($p = 0.05$) using the R emmeans (Lenth, 2019) and lmerTest (Kuznetsova et al., 2017) packages.

## 3.3. Results

### 3.3.1. Sward characteristics

Sward height (pre-grazing) was very close to the expected values for the treatments and differed accordingly between treatments ($p < 0.001$, Table 2). The average post-grazing sward height did not differ by more than 13% from the pre-grazing sward height, ensuring that a similar sward structure was offered to the animals throughout each 45 min grazing test.

The light interception remained stable, however the 20 cm treatments differed from the others ($p = 0.02243$). The sheath height, herbage mass total and per strata were linearly correlated with the sward height ($P < 0.0001$, Table 2), the leaf/stem ratio decreased with increasing sward height. The sward characteristics, with exception the sward height, remained stable between 30 and 40 cm of sward height (means did not differ by Tukey test).

**Table 2:** Sward characteristics of palisadegrass under different sward height managements (N = 8).

| | Sward height (cm) | | | | SE | *P* value |
|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 60 | | |
| Pre-grazing sward height (cm) | 22.66 d | 32.14 c | 38.10 b | 64.95 a | 8.21 | <0.001 |
| Post-grazing sward height (cm) | 22.34 d | 27.77 c | 33.95 b | 63.30 a | 7.83 | <0.001 |
| Light interception (%) | 85.01 b | 91.10 a | 91.06 a | 91.81 a | 1.41 | 0.02243 |
| Sheath height (cm) | 12.87 c | 19.81 b | 23.63 b | 43.54 a | 1.39 - 2.57* | <0.001 |
| Herbage mass total (kg $ha^{-1}$) | 2148.17 c | 3752.06 b | 3934.10 b | 7479.48 a | 186.81 - 650.42* | <0.001 |
| Herbage mass - top strata (kg $ha^{-1}$) | 832.21 c | 1595.83 b | 1698.34 b | 2859.36 a | 104.22 - 358.08* | <0.001 |
| Herbage mass - bottom (kg $ha^{-1}$) | 1307.38 c | 2172.66 b | 2245.58 b | 4641.48 a | 138.11 - 260.22* | <0.001 |
| Leaf/stem ratio | 1.90 a | 1.25 b | 1.29 b | 0.84 c | 0.09 - 0.12* | <0.001 |

*Different standard errors of the mean were due to missing data.

SE = standard error; P = significance level.

Means followed by the same letter within lines are not statistically different, as determined by Tukey's test ($P < 0.05$).

There were no significant differences in bulk density in top (884 g.DM $m^3$) and bottom strata (1325 g.DM $m^3$), in bulk density of leaf in top strata (800 g.DM $m^3$) and in bulk density in herbage mass (1086 g.DM $m^3$) $p > 0.05$. However, the bulk density of stem+sheath in top strata was greater in 60 cm sward height treatment ($p < 0.001$), although not statistically different from the swards managed at 30 and 40 cm (Table 3).

**Table 3:** Bulk density (BD) 50% in top and in bottom strata, bulk density of leaf and stem+sheath in top strata and bulk density in herbage mass (N = 8).

| | Sward height (cm) | | | | SE | *P* value |
|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 60 | | |
| BD 50% - top strata (g.DM m$^{3}$)[1] | 775 | 1043 | 859 | 858 | 90.10 - 121.26* | 0.1308 |
| BD 50% - bottom strata (g.DM m$^{3}$)[1] | 1260 | 1439 | 1175 | 1426 | 102.75 | 0.1998 |
| BD of leaf in top strata (g.DM m$^{3}$) | 745 | 926 | 791 | 738 | 85.91 - 88.14* | 0.2776 |
| BD of stem+sheath in top strata (g.DM m$^{3}$) | 35 b | 75 ab | 72 ab | 137 a | 35.15 - 136.93* | <0.001 |
| BD in herbage mass (g.DM m3)[1] | 1000 | 1226 | 995 | 1122 | 83.30 - 102.61* | 0.1649 |

[1] For these calculations, it was considered the mass of all the components of the sward (leaf, stem+sheath, inflorescence, dead material and weeds)

*Different standard errors of the mean were due to missing data.

SE = standard error; P = significance level.

Means followed by the same letter within lines are not statistically different, as determined by Tukey's test ($P < 0.05$).

The highest proportion of leaf in the herbage mass was observed in sward heights of 20 cm ($p < 0.05$) and the highest proportion of stem+sheath was observed in the sward height of 60 cm ($p < 0.05$), respectively (Figure 8). In sward heights between 30 and 40 cm, the proportion of leaf and stem+sheath remained stable. The proportion of inflorescence, dead material and weeds was not differ statistically ($p > 0.05$).

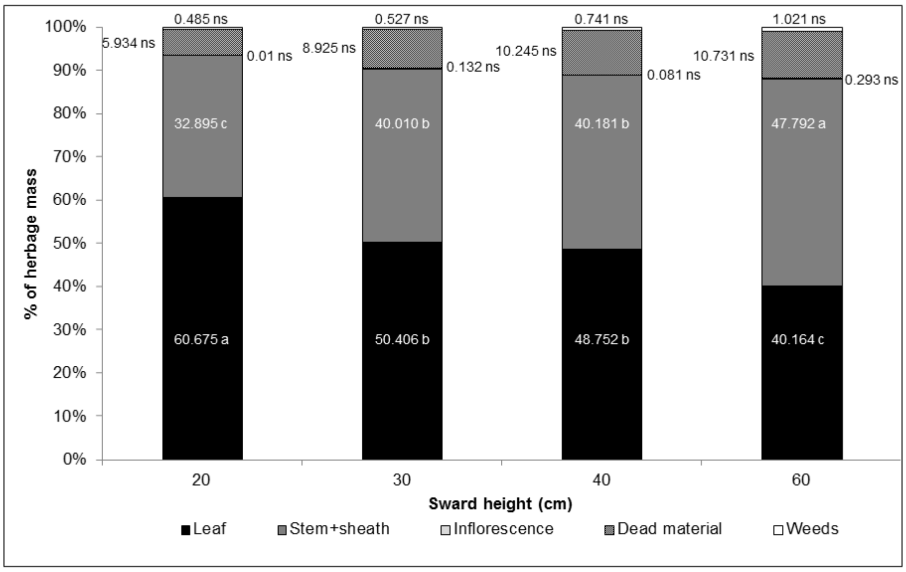

**Figure 8:** Sward components (%) of palisadegrass under different sward height managements. Means followed by the same letter within bars are not statistically different, as determined by Tukey’s test ($P < 0.05$) ($N= 8$).

### 3.3.2. Short-term intake rate (STIR)

The STIR presented a quadratic response ($STIR= 29.0171 +1.3314(SH) - 0.015838(SH^2)$, $R^2= 0.17$, $p < 0.01$) to the sward heights. The maximum response was reached at 42 cm for a value of 57 g DM $min^{-1}$ (Figure 9).

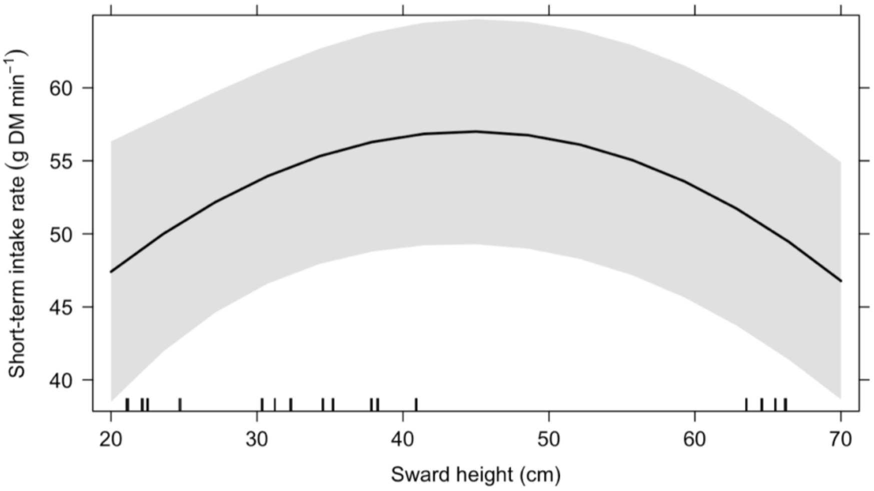

**Figure 9:** Short-term intake rate of cows as function sward height in palisadegrass. STIR= 29.0171 +1.3314(SH) - 0.015838(SH$^2$), $p < 0.01$, $R^2$= 0.17.

## 3.4. Discussion

The main advance of this study is the definition of the sward height where the maximum intake rate occurs to be used as management goal in palisadegrass according to the innovative sward management concept of Rotatinuous Stocking.

The short-term intake rate was maximized at a sward height of approximately 42 cm with the maximum value being about 57 g DM min$^{-1}$ (Figure 9). This value was similar to that found by Fonseca et al., (2012) in swards of *Sorghum* and higher than the values found by Geremia et al., (2018) in palisadegrass pastures using 95% of light interception as the goal of pre-grazing management in crop-livestock-forestry integration area. The average sward height where Geremia et al., (2018) found the highest intake rate was approximately 33.8 cm. However, this difference in sward heights might be explained by a methodological bias in the above cited study where the animals were submitted to a fasting period of 6 hours previous to the evaluation, a procedure which alters ingestive behavior (Greenwood & Demment, 1988; Gregorini et al., 2009) and diet selection (Newman et al., 1994), leading to overestimations of intake rates, especially in sward structures that may be not be ideal.

The light interception remained stable at different sward heights, being only different and lower in swards kept at 20 cm (Table 2). Light interception is widely used as a management goal and although some authors advocate that 95% light interception is the ideal time for grazing to start suggesting convergence between plant and animal responses (Silva & Nascimento Júnior, 2007; Pereira et al., 2018) we did not find such a correlation between the sward structure and the light interception. As the sward structure is the major determinant of the herbage intake, the light interception cannot be used as a management goal when the objective of the management is that the animals can maintain high herbage intake rates. Geremia et al., (2018) in the previously mentioned study did not find differences in the intake rate at the beginning of grazing in one of the evaluation periods, where 95% of light interception occurred at sward heights that ranged from 30.1 to 54.5 cm in pre-grazing, a fact that was attributed to the shading of the trees but that demonstrates the absence of relationship between sward structure and light interception. In this context, Coêlho et al. (2014) evaluated the relationships between sward height, leaf area index and light interception in 10 tropical grasses and concluded that sward height rarely correlated well with light interception and leaf area index.

In our study, the sward structure affected the grazing process in different ways. Short swards as 20 cm, although they have a higher leaf/stem ratio and a higher percentage of leaves, present lower herbage mass (Table 2; Figure 8) and their reduced height may affect mainly the bite depth (Flores et al. al., 1993; Griffiths et al., 2003) limiting the intake. Some authors suggest that the bite depth increases with sward height and decreases with bulk density (Laca et al., 1992; Burlison et al., 1991: Cangiano et al., 2002), whereas in short swards this effect is not present (Ungar et al., 1991; Cangiano et al., 2002). However, Flores et al. (1993) argued that the bite depth seems to be limited by the inherent properties of the stem and not by the greater bulk density of the sward and Benvenutti, Gordon & Poppi (2006) showed for the first time the relationship between stem density, stem tensile resistance and bite dimensions where high tensile-resisting stems worked as both horizontal and vertical barrier to bite mass at low and high stem density, reducing the intake rate (Benvenutti et al., 2009). In our case, since the density did not present any statistical difference between sward heights (Table 3), we can fairly assume that the component of the grazing process that has been affected is the bite depth, mainly due to the sward height.

As the sward parameters were similar in swards managed between 30 and 40 cm, the following question arises, why was the intake rate higher in swards managed at 40 cm? On the one hand, although not statistically different, swards managed at 40 cm of height had a higher herbage mass, leaf/stem ratio (Table 2) and lower bulk density than swards managed at 30 cm (Table 3). These factors may explain the superiority of the intake rate in swards managed at 40 cm, in addition to the higher sward height (Table 2), which has a positive correlation with the bite depth, making it possible to obtain larger bites and consequently higher intakes. On the other hand, swards as tall as 60 cm, although they have a higher herbage mass, have a lower leaf/stem ratio (Table 2), a lower percentage of leaves and a higher percentage of stems (Figure 8). In addition, the height of the sheath was greater than half the sward height (Table 2) and the density of stems in the top strata was higher (Table 3). Thus, ingestion may be limited by the high sheath height, corresponding to 67% of sward height and the highest proportion of stems in the top strata of the sward representing barriers to the bite. Stems limit the prehension (Gordon & Benvenutti, 2006; Benvenutti, Gordon & Poppi, 2006), require more tensile strength for the animals to shear the plant tissue and more chewing than leaves (McLeod, 1990), may affect the bite effort although these mechanisms are not well explained (Griffiths & Gordon, 2003; Benvenutti, Gordon & Poppi, 2006). Flores et al., 1993 reported that the presence of stems reduced bite mass however, pseudostem seems to little affect bite depth (Griffiths, Hodgson & Arnold, 2003 b; Cangiano et al., 2002). In this case the height where the sheath is positioned in relation to ground level can be an indication of the presence of stems and can show better relations with the bite dimensions, which needs further investigation.

Fonseca et al., (2012) and Mezzalira et al., (2014) investigating the relationship between the short-term intake rate and the sward structure, defined pre- and post-grazing targets to maintain high intake rates according to the sward management concept Rotatinuous Stocking. In these studies, the authors found in contrasting species (*Avena strigosa*, *Cynodon* sp. and *Sorghum bicolor*) a similar ideal grazing down level for all three species (40% of the sward height).

In our study, the ideal sward height was 42 cm and the 40% of grazing down of this sward height would correspond to 25 cm of post-grazing sward height. We can infer, from a plant-based ecophysiological perspective, that this post-grazing sward height would correspond to a moderate grazing, impacting little on the leaf area index of the canopy and also benefiting the vegetal component. Such assumptions need to be tested over a longer period of time, especially in perennial species. However, the impact of vertical and horizontal sward structure on grazing process, species dynamics and herbage growth is clear (Laca & Lemaire, 2000; Gastal & Lemaire, 2015).

Many studies deal with grazing management with different approaches and targets. The question we ask is: what should be the guideline of grazing management? Our approach focuses on plant-animal relationships, where the concept Rotatinuous Stocking in addition to optimizing the grazing process can benefit plants. In this context, this management goal should provide a high intake rate continuously during de occupation period and between the different strips in rotational stocking or along the displacements between the feeding stations in continuous stocking, in a situation analogous to the marginal value theorem (Charnov, 1976), with profit greater than costs and precisely because it provides high intake rates, is not related to a high grazing intensity and may benefit the vegetal component, should be in the future perspectives of study of this concept.

### 3.5. Conclusion

We conclude that palisadegrass pastures must be managed at 42 cm of sward height in pre-grazing according to the Rotatinuous Stocking concept to maximize intake rate. Light interception, despite being widely used is not a good criterion for grazing management, because it has no relation to the sward structure. Instead, sward height should be the key criterion for grazing management.

## 4. Final considerations and future steps

This thesis was an effort to monitor both the vegetation and the animals with high precision. We believe that only with the fine-scale monitoring of vegetation and animals can we advance the understanding of short-term foraging decisions, understanding the dynamics of the grazing process and its construction day after day, bite by bite to integrate knowledge and to rebuild the process along larger spatio-temporal scales, advancing toward the frontier of knowledge of the plant-animal interface, always with a research focused on the processes and not on methodologies, which would be a misconception.

Working both in the literature review and in the experimental protocol we thought of new questions that can should studied about the management concept of sward Rotatinuous Stocking, listed below.

From the ecophysiological perspective:

- we need to understand the flow of tissues (growth and senescence) in swards managed under the Rotatinuous Stocking concept from the plant scale. Also monitor the phenology of the plants, the evolution of the leaf area index and the dynamics of tillering to understand the impact on the vegetal component of a management based on the ingestive behavior of the animals;
- regarding the heterogeneity of the sward, to understand the dynamics of this process being able to apply the concept Rotatinuous Stocking in continuous stocking method where there is less control over the sward structure. From this understanding we can better manage the pastures to maintain sward structures suitable for the grazing process, without eliminating the heterogeneity that is an important factor. This point needs to be studied mainly for perennial swards.

From the animal perspective:

- in addition to the animal-plant interface issues that interest me the most, questions arise about post-ingestive feedbacks. In this sense, it should be investigated whether a high intake rate will significantly affect chewing and consequently the particle size of the ingesta. If this phenomenon occurs, we should investigate whether it affects the fermentation patterns of the rumen and the excretions, to verify if there is some kind of ingestive-digestive trade-off.

An example of a plant-animal interface question about what was mentioned in the previous items is that, in previous experiments in rotational stocking using the concept Rotatinuous Stocking, the results showed that 30% of the area of each strip grazing area remains un-grazed before moving the animals to the next strip. The results also showed that stocking cycles were faster compared with the traditional rotational stocking method, which, in general, may explain the non-occurrence of problems in this area as evolution of phenology. In this context, we still have to better understand at the plant level the sward dynamics under this management. We should characterize the vegetation structure during stocking cycles, monitoring plant phenology, mapping non-grazed areas and monitoring the condition of these points in the next stocking cycle, verifying whether structural changes occur (such as changes in height, tillering and senescence) and phenology. Also, from the perspective of the animal, we have to understand how the dynamics of the ingestive process occurs through the monitoring of the animals in fine scale throughout the stocking cycles. Thus, in these areas that were previously non-grazed, we can verify if these areas will be the first ones to be grazed because they are detached or not, understanding the relationships involved and the impact on the vegetal component.

The questions move science therefore these issues emerge. Some authors argue that is questionable to enable the animals achieve high intake rates and the extrapolation of short-term results, mentioning that the management should avoid non-grazed areas, which would be of low quality and senescent. They also mention that a balance must be struck between what is produced and what is consumed. We disagree with this view, for thus we would go against the natural behavior of herbivores which are always trying to optimize their intake, so we should not try to eliminate heterogeneity and we propose these questions. In addition, we particularly think that many visions overestimate the digestive issues leaving in the background the ingestive issues that are the main determinants of grazing animal intake.

We also observed that many authors mention that the sward structure affects the grazing process but they do not take it into account, since in their studies the sward structure is not characterized and often describe their treatments based on forage allowance, which says little about the sward structure. Therefore the understanding of the processes is fundamental and not the concentration in small factors that do not alter the process but its magnitude.

Searching for studies over the last years for the state of the art we made a statement that we want to highlight. Among the terms we have looked for are "grazing management", "plant-animal interface", "intake rate" and we found many scientific papers. Reading those papers, we must unfortunately affirm that the errors mentioned by Demment & Laca (1994) are still made. In many papers the emphasis is on the phenomenological rather than the mechanistic. Measures are taken in response to treatments such as stocking rates and forage allowance, without an understanding and a conceptual model that links the processes at play. As Demment & Laca (1994) mentioned, in order to advance in grazing science, it is necessary to understand the processes that operate at the different scales (from the lowest, as bite scale well as at the high hierarchical levels, understanding their impacts in the system) and the integration of these processes to understand these complex systems. After more than 20 years if we search for terms related to grazing science we will still face this serious situation of repetition of philosophical misconceptions in the research, which unfortunately are predominant.

Finally, we believe that in order to advance knowledge in plant-animal interface, we must improve the structural description of the vegetation, accurately georeferencing the vegetal component and also monitoring the animals at a fine scale, in order to superimpose information and have a better dimension of foraging decisions and interactions that will help us to advance scientifically. These will be the next steps of the work that was done in this experimental protocol.

## 5. REFERENCES

AGREIL, C.; MEURET, M. An improved method for quantifying intake rate and ingestive behaviour of ruminants in diverse and variable habitats using direct observation. **Small Ruminant Research**, Amsterdam, v. 54, n. 1/2, p. 99–113, 2004.

AGREIL, C.; MEURET, M.; FRITZ, H. Adjustment of feeding choices and intake by a ruminant foraging in varied and variable environments: new insights from continuous bite monitoring. *In*: BELS, V. (ed.) **Feeding in domestic vertebrates:** from structure to behaviour. Wallingford: CABI, 2006. p. 302–325.

ANDRIAMANDROSO, A. L. H. *et al.* Development of an open-source algorithm based on inertial measurement units (IMU) of a smartphone to detect cattle grass intake and ruminating behaviors. **Computers and Electronics in Agriculture**, Amsterdam, v. 139, p. 126-137, 2017.

BAILEY, D. W.; PROVENZA, F. D. Mechanisms determining large-herbivore distribution. *In*: PRINS, H.H.T.; VAN LANGEVELD, F. (ed.). **Resource ecology**: spatial and temporal dynamics of foraging. Wageningen: UR Frontis Series, 2008. cap. 2A, p. 7-29.

BAILEY, D. W. *et al.* Mechanisms that result in large herbivore grazing distribution patterns. **Journal of Range Management**, Denver, v. 49, p. 386-400, 1996.

BARTHRAM, G. T. Experimental techniques: the HFRO sward stick. *In*: THE HILL Farming Research Organization Biennial Report 1984/1985. Penicuik: HFRO, 1985. p. 29–30.

BATES, D. *et al*. Fitting linear mixed-effects models using lme4. **Journal of Statistical Software**, Los Angeles, v. 67, n. 1, p. 1-48, 2005. DOI:10.18637/JSS.V067.I01.

BENGTSSON, J. *et al*. Grasslands - more important for ecosystem services than youmight think. **Ecosphere**, Washington, D.C, v. 10, n. 2, [art.] e02582, 2019. DOI: 10.1002/ecs2.2582.

BENVENUTTI, M. A.; GORDON I. J.; POPPI, D. P. The effect of the density and physical properties of grass stems on the foraging behavior and instantaneous intake rate by cattle grazing an artificial reproductive tropical sward. **Grass and Forage Science**, Oxford, v. 61, n. 3, p. 272-281, 2006.

BENVENUTTI, M. A. *et al*. The horizontal barrier effect of stems on the foraging behavior of cattle grazing five tropical grasses. **Livestock Science**, Amsterdam, v. 126, n. 1/3, p. 229-238, 2009.

BERGMAN, C. M. *et al*. Ungulate foraging strategies: energy maximizing or time minimizing? **Journal of Animal Ecology**, London, v. 70, n. 2, p. 289–300, 2001.

BLAIR, J.; NIPPERT, J.; BRIGGS, J. Grassland ecology. *In*: MONSON, R. K. (ed.). **Ecology and the Environment**. New York: Springer, 2014. p. 389-423.

BLUMSTEIN, D. T.; DANIEL, J. C.; EVANS, C. S. **J Watcher**. Los Angeles: University of California; Sydney: Macquarie University, 2012. Disponível em: http://www.jwatcher.ucla.edu/. Acesso em: 23 jan. 2019.

BONNET, O. J. F. *et al*. Continuous bite monitoring: a method to assess the foraging dynamics of herbivores in natural grazing conditions. **Animal Production Science**, Collingwood, v. 55, n. 3, p. 339, 2015.

BONNET, O. *et al*. Is hand-plucking an accurate method of estimating bite mass and instantaneous intake rate of grazing herbivores? **Rangeland Ecology & Management**, Lakewood, v. 64, n. 4, p. 366–374, 2011. DOI:10.2111/REM-D-10-00186.1.

BOVAL, M.; DIXON, R. M. The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. **Animal**, Cambridge, v. 6, n. 5, p. 748–762, 2012.

BURLISON, A. J.; HODGSON, J.; ILLIUS, A. W. Sward canopy structure and the bite dimensions and bite weight of grazing sheep. **Grass and Forage Science**, Oxford, v. 46, p. 29-38, 1991.

BURRITT, E. A.; PROVENZA, F. D. Role of toxins in intake of varied diets by sheep. **Journal of Chemical Ecology**, New York, v. 26, n. 8, p. 1991–2005, 2000.

CANGIANO, C. A. **Conpast 3.0**: programa de computación para la estimación del consumo de bovinos en pastoreo. Buenos Aires: INTA, 1999. 228 p.

CANGIANO, C. A. *et al*. Effect of liveweight and pasture height on cattle bite dimensions during progressive defoliation. **Australian Journal of Agricultural Research**, East Melbourne, v. 53, n. 5, p. 541–549, 2002.

CARASSAI, I. J. **Modelagem do crescimento de azevém anual (*Lolium multiflorum* Lam.) submetido a diferentes níveis de nitrogênio, em função da radiação solar absorvida**. 2010. 241 f. Tese (Doutorado em Zootecnia) - Programa de Pós-Graduação em Zootecnia, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2010.

CARVALHO, P. C. F. *et al*. Como a estrutura do pasto influencia o animal em pastejo? Exemplificando as interações planta-animal sob as bases e fundamentos do pastoreio 'rotatínuo'. *In*: SIMPÓSIO SOBRE MANEJO ESTRATÉGICO DA PASTAGEM, 8., 2016, Viçosa, MG. **Anais** [...]. Viçosa: UFV, 2016. v. 1, p. 303-333.

CARVALHO, P. C. F. Harry stobbs memorial lecture: can grazing behavior support innovations in grassland management? **Tropical Grasslands – Forrajes Tropicales**, Cali, v. 1, p. 137–155, 2013.

CHACON, E.; STOBBS, T. Influence of progressive defoliation of a grass sward on eating behaviour of cattle. **Australian Journal of Agricultural Research**, East Melbourne, v. 27, n. 5, p. 709–727, 1976.

CHARNOV, E. L. Optimal foraging, the marginal value theorem. **Theoretical Population Biology**, New York, v. 9, n. 2, p. 129–136, 1976.

CÔELHO, J. J. *et al*. Canopy height and its relationship with leaf area index and light interception in tropical grasses. **Tropical Grasslands**, Cali, v. 2, n. 1, p. 31-32, 2014.

COOK, B. G. *et al*. **Tropical Forages:** an interactive selection tool. Bisbane: CSIRO, DPI&F(Qld), CIAT, ILRI 2005. Disponível em: http://www.tropicalforages.info/key/forages/Media/Html/entities/brachiaria_brizantha.htm. Acesso em: 18 fev. 2019.

DEMMENT, M. W.; LACA, E. A. Reductionism and synthesis in the grazing sciences: models and experiments. **Proceedings of the Australian Society of Animal Production**, [Australian], v. 20, p. 6-16, 1994.

DEMMENT, M. W.; PEYRAUD, J. L.; LACA, E. A. (1995) Herbage intake at grazing: a modelling approach. *In*: JOURNET, M. *et al*. (ed.) **Recent Developments in the Nutrition of Herbivores**. Paris: INRA Editions, 1995. p. 121-141.Trabalho apresentado no IV International Symposium on the Nutrition of Herbivores, realizado em Clermont-Ferrand (France),1995.

FONSECA, L. *et al*. Management targets for maximising the short-term herbage intake rate of cattle grazing in *Sorghum bicolor*. **Livestock Science**, Amsterdam, v. 145, p. 205–211, 2012.

FORTIN, D.; FRYXELL, J. M.; PILOTE, R. The temporal scale of foraging decisions in bison. **Ecology**, Washington, D.C., v. 83, n. 4, p. 970–982, 2002. DOI: 10.1890/0012-9658(2002)083[0970:TTSOFD]2.0.CO;2.

FORTIN, D. *et al*. Temporal dynamics in the foraging decisions of large herbivores. **Animal Production Science**, Collingwood, v. 55, n. 3, p. 376–383, 2015. DOI: 10.1071/AN14428.

FLORES, E. R. *et al*. Sward height and vertical morphological differentiation determine cattle bite dimensions. **Agronomy Journal**, Madison, v. 85, n. 3, p. 527–532, 1993.

FOX, J.; WEISBERG, S. **An {R} companion to applied regression**. 2nd ed. Thousand Oaks CA: Sage, 2011.

GASTAL, F.; LEMAIRE, G. Defoliation, shoot plasticity, sward structure and herbage utilization in pasture: review of the underlying ecophysiological processes. **Agriculture**, Basel, v. 5, p. 1146–1171, 2015.

GEREMIA, E. V. *et al*. Sward structure and herbage intake of Brachiaria brizantha cv. Piatã in a crop-livestock-forestry integration area. **Livestock Science**, Amsterdam, v. 212, p. 83-92, 2018.

GIBB M. J. Animal grazing/intake terminology and definitions. *In*: PASTURE ECOLOGY AND ANIMAL INTAKE, 3., 1996, Dublin. **Proceedings** […]. Dublin: [*s.n.*], 1996. p. 20-35.

GIBB, M. J. *et al*. The effect of physiological state (lactating or dry) and sward surface height on grazing behaviour and intake by dairy cows. **Applied Animal Behaviour Science**, Amsterdam, v.63, p. 269–287, 1999.

GONÇALVES, E. N. *et al*. Relações planta-animal em ambiente pastoril heterogêneo: processo de ingestão de forragem. **Revista Brasileira de Zootecnia**, Viçosa, v. 38, n. 9, p. 1655–1662, 2009.

GORDON, I. J.; BENVENUTTI, M. Food in 3D: how ruminant livestock interact with sown sward architecture at the bite scale. *In*: BELS, V. (ed.). **Feeding in domestic vertebrates**. Wallingford: CAB International, 2006. p. 273-287.

GREGORINI, P. *et al*. Short-term foraging dynamics of cattle grazing swards with different canopy structure. **Journal of Animal Science**, Champaign, v. 87, n. 11, p. 3817–3824, 2009.

GREGORINI, P.; SODER, K. J.; KENSINGER, R. S. Effect of rumen fill on foraging behavior, intake rate, and plasma ghrelin, serum insulin and glucose levels of cattle grazing a vegetative micro-sward. **Journal of Dairy Science**, Champaign, v. 92, n. 5, p. 2095–2105, 2009.

GREGORINI, P. *et al*. Grazing management: setting the table, designing the menu and influencing the diner… **Animal Production Science**, Collingwood, v. 57, n. 7, p. 1248-1268, 2017. DOI: 10.1071/AN16637.

GREENWOOD, G.; DEMMENT, M. The effect of fasting on short-term cattle grazing behaviour. **Grass and Forage Science**, Oxford, v. 43, n. 4, p. 377–386, 1988. DOI: 10.1111/ j.1365-2494.1988.tb01893.x.

GRIFFITHS, W. M.; GORDON, I. J. Sward structural resistance and biting effort in grazing ruminants. **Animal Research**, Cambridge, v. 52, n. 2, p. 145–160, 2003.

GRIFFITHS, W. M.; HODGSON, J.; ARNOLD, G. C. The influence of sward canopy structure on foraging decisions by grazing cattle. I. Patch selection. **Grass and Forage Science**, Oxford, v. 58, n. 2, p. 112–124, 2003a.

GRIFFITHS, W. M.; HODGSON, J.; ARNOLD, G. C. The influence of sward canopy structure on foraging decisions by grazing cattle. II. Regulation of bite depth. **Grass and Forage Science**, Oxford, v. 58, n. 2, p. 125–137, 2003b.

HERRERO, M. *et al*. Greenhouse gas mitigation potentials in the livestock sector. **Nature Climate Change**, London, v.6, p. 452–461, May 2016.

KÖPPEN, W.; GEIGER, R. **Klimate der erde**. Gotha: Verlag Justus Perthes, 1928. 1 mapa de parede, 150 x 200 cm.

KUZNETSOVA, A.; BROCKHOFF, P. B.; CHRISTENSEN, R. H. B. lmerTest package: tests in linear mixed effects models. **Journal of Statistical Software**, Los Angeles, v. 82, n. 13, p. 1-26, 2017.

LACA, E. A.; LEMAIRE, G. Measuring sward structure. *In*: T´MANNETJE, L.; JONES, R.M. (ed.). **Field and laboratory methods for grassland and animal production research**. New York: CABI, 2000. p. 103-122.

LACA, E. A. Modelling spatial aspects of plant-animal interactions. *In*: LEMAIRE, G. *et al*. (ed.). **Grassland ecophysiology and grazing ecology**. Wallingford: CABI Publishing, 2000. p. 209-231.

LACA, E. A. *et al*. Effects of sward height and bulk density on bite dimensions of cattle grazing homogeneous swards. **Grass and Forage Science**, Oxford, v. 47, p. 91–102, 1992.

LACA, E. A.; ORTEGA, I. M. Integrating foraging mechanisms across spatial and temporal scales. *In*: WEST, N.E. (ed.). **Rangelands in a sustainable biosphere**. Denver: Society for Range Management, 1995. p. 129-132.

LACA, E. A.; UNGAR, E. D.; DEMMENT, M. W. Mechanisms of handling time and intake rate of a large mammalian grazer. **Applied Animal Behaviour Science**, Amsterdam, v. 39, n. 1, p. 3–19, 1994.

LENTH, R *et al*. **Package Emmeans:** estimated marginal means, aka least-squares means. R package version 1.3.1. [S.l.]: CRAN, 2019. Disponível em: https://cran.r-project.org/web/packages/emmeans/emmeans.pdf. Acesso em: 28 jan. 2019.

MACARTHUR, R. H.; PIANKA, E. R. On optimal use of a patchy environment. **The American Naturalist**, Chicago, v. 100, n. 9, p. 603–609, 1966. DOI: 10.1086/282454.

MCLEOD M. N.; KENNEDY, P. M.; MINSON, D. J. Resistance of leaf and stem fractions of tropical forage to chewing and passage in cattle. **British Journal of Nutrition***,* Wallingford, v. 63, n. 1, p. 105-119, 1990.

MEURET, M.; PROVENZA, F. How french shepherds create meal sequences to stimulate intake and optimise use of forage diversity on rangeland. **Animal Production Science**, Collingwood, v. 55, n. 3, p. 309–318, 2015b. DOI: 10.1071/AN14415.

MEURET, M.; PROVENZA, F. When art and science meet: integrating knowledge of french herders with science of foraging behavior. **Rangeland Ecology & Management**, Lakewood, v. 68, n. 1, p. 1-17, 2015b.

MEZZALIRA, J. C. *et al*. Behavioural mechanisms of intake rate by heifers grazing swards of contrasting structures. **Applied Animal Behaviour Science**, Amsterdam, v. 153, p. 1–9, 2014.

NEWMAN, J. A. *et al*. Fasting affects intake behavior and diet preference of grazing sheep. **Animal Behaviour**, London, v. 47, n. 1, p. 185–193, 1994. DOI: 10.1006/anbe.1994.1021.

NOVELLIE, P. A. Comparison of the foraging strategies of blesbok and springbok on the Transvalal highveld. **African Journal of Wildlife Research**, Bloubergstrand, v. 8, p. 137–144, 1978.

OWEN-SMITH, N. **Adaptive herbivore ecology:** from resources to populations in variable environments. Cambridge: Cambridge University Press, 2002.

OWEN-SMITH, N. Foraging responses of kudus to seasonal changes in food resources: elasticity in constraints. **Ecology**, Washington, D.C., v. 75, n. 4, p. 1050-1062, 1994. DOI: 10.2307/1939429.

OWEN-SMITH, N.; FRYXELL, J. M.; MERRILL, E. H. Foraging theory upscaled: the behavioural ecology of herbivore movement. **Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences**, London, v. 365, n. 1550, p. 2267-78, 2010.

OWEN-SMITH, N.; NOVELLIE, P. What should a clever ungulate eat? **The American Naturalist**, Chicaco, v. 119, n. 2, p. 151-178, 1982. Disponível em: http://www.jstor.org/stable/2461108. Acesso em: 29 jan. 2019.

PEDREIRA, C. G. S.; BRAGA, G. J.; PORTELA, J. N.; Herbage accumulation, plant-part composition and nutritive value on grazed signal grass (*Brachiaria decumbens*) pastures in response to stubble height and rest period based on canopy light interception. **Crop & Pasture Science**, Collingwood, v. 68, n. 1, p. 62-73, 2017.

PENNING, P. D.; HOOPER, G. E. An evaluation of the use of short-term weight changes in grazing sheep for estimating herbage intake. **Grass and Forage Science**, Oxford, v. 40, n. 1, p. 79–84, 1985.

PEREIRA, L. E. T. *et al*. Grazing management for sustainable grazing systems. *In*: MARSHALL, A.; COLLINS, R. (ed.). **Improving grassland and pasture management in temperate agriculture**. Cambridge: Burleigh Dodds Science, 2018. p. 1-44. Disponível em: https://www.researchgate.net/publication/326686735_Grazing_management_for_sustainable_grazing_systems. Acesso em: 25 jan. 2019.

PROVENZA, F. D. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. **Journal of Range Management**, Denver, v. 48, n. 1, p. 2–17, 1995. DOI: 10.2307/4002498.

R CORE TEAM. **R:** a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, 2018. Disponível em: https://www.R-project.org/. Acesso em: 28 jan. 2019.

RUTTER, S. M.; CHAMPION, R. A.; PENNING, P. D. An automatic system to record foraging behaviour in free-ranging ruminants. **Applied Animal Behaviour Science**, Amsterdam, v. 54, n. 2/3, p. 185–195, 1997.

RUTTER, S. M. Graze: a program to analyze recordings of the jaw movements of ruminants. **Behavior Research Methods, Instruments & Computers**, Austin, v. 32, n. 1, p.86–92, 2000.

SEARLE, K. R.; HOBBS, N. T.; SHIPLEY, L. A. Should i stay or should i go? Patch departure decisions by herbivores at multiple scales. **Oikos**, Copenhagen, v. 111, n. 3, p. 417-424, 2005.

SEARLE, K. R. *et al*. Spatial context influences patch residence time in foraging hierarchies. **Oecologia**, Berlin, v. 148, n. 4, p. 710, 2006.

SENFT, R. L. *et al*. Large herbivore foraging and ecological hierarchies. **BioScience**, Washington, D.C., v. 37, n. 11, p. 789-799, 1987.

SHIPLEY, L. A. *et al*. The scaling of intake rate in mammalian herbivores. **The American Naturalist**, Chicago, v. 143, n. 6, p. 1055-1082, 1994.

SILVA, D. F. F. **A altura que maximiza a taxa de ingestão em pastos de azevém anual (*Lolium multiflorum* Lam.) é afetada pela existência de palhada quando o método de estabelecimento é em semeadura direta?** 2013. 88 f. Dissertação (Mestrado) - Curso de Pós-Graduação em Agronomia, Universidade Federal do Paraná, Curitiba, 2013.

SILVA, S. C.; NASCIMENTO JUNIOR, D. Avanços na pesquisa com plantas forrageiras tropicais em pastagens: características morfofisiológicas e manejo do pastejo. **Revista Brasileira de Zootecnia**, Viçosa, v. 36, p. 122-138, July 2007. Suplemento. Disponível em: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982007001000014&lng=en&nrm=iso. Acesso em: 10 mar. 2019.

SILVA, S. C. *et al*. Tillering dynamics of Mulato grass subjected to strategies of rotational grazing management. **The Journal of Agricultural Science***,* London, v. 155, n. 7, p. 1082-1092, 2017. DOI: 10.1017/S0021859617000223.

SPALINGER, D. E.; HOBBS, N. Mechanisms of foraging in mammalian herbivores: new models of functional response. **The American Naturalist**, Chicago, v. 140, n. 2, p. 325–348, 1992.

STEPHENS, D. W. Decision ecology: foraging and the ecology of animal decision making. **Cognitive, Affective, & Behavioral Neuroscience**, Austin, v. 8, n. 4, p. 475–484, 2008.

STEPHENS, D. W.; KREBS, J. R. **Foraging theory**. Princeton: Princeton University Press, 1986.

STEVENS, C. J. Recent advances in understanding grasslands [version 1; referees: 2 approved]. **F1000 Research**, London, v. 30, n. 7, pii: F1000 Faculty Rev-1363, 2018. DOI: 10.12688/f1000research.15050.1.

STOBBS, T. H. The effect of plant structure on the intake of tropical pastures I. Variation in bite size of grazing cattle. **Australian Journal of Agricultural Research**, East Melbourne, v. 24, n. 6, p. 809–819, 1973a.

STOBBS, T. H. The effect of plant structure on the intake of tropical pastures. II. Differences in sward structure, nutritive value and bite size of animals grazing *Setaria anceps* and *Chloris gayana* at various stages of growth. **Australian Journal of Agricultural Research**, East Melbourne, v. 24, n. 6, p. 821–829, 1973b.

UNGAR, E. D. Ingestive behavior. *In*: HODGSON, J.; ILLIUS, A.W. (ed.). **The ecology and management of grazing systems**. Wallingford: CAB International, 1996. p. 185-218.

UNGAR, E. D.; NOY-MEIR, I. Herbage intake in relation to availability and sward structure: grazing processes and optimal foraging. **Journal of Applied Ecology**, Oxford, v. 25, n. 3, p. 1045-1062, 1988.

USDA. Natural Resources Conservation Service. **Soil taxonomy**: a basic system of soil classification for making and interpreting soil surveys. 2nd ed. Washington, D.C.: USDA, 1999. (Agriculture Handbook, 436).

VILLALBA, J. J.; PROVENZA, F. D. Learning and dietary choice in herbivores. **Rangeland Ecology & Management**, Lakewood, v. 62, n. 5, p. 399–406, 2009.

VILLALBA, J. J. *et al*. Understanding and manipulating diet choice in grazing animals. **Animal Production Science**, Collingwood, v. 55, n. 3, 261–271, 2015. DOI: 10.1071/AN14449.

YDENBERG, R. C.; BROWN, J. R.; STEPHENS, D. W. Foraging: an overview. *In*: STEPHENS, D. W.; BROWN, J. R.; YDENBERG, R. C. (ed.). **Foraging:** behavior and ecology. Chicago: The University of Chicago Press, 2007. p. 1–30.

## AUTHOR BIOGRAPHY

Gentil Félix Da Silva Neto was born on July 30, 1991 in Itaqui, West Border of Rio Grande do Sul, Brazil. Son of José João Sampaio da Silva and Sandra Maria Lopes de Lopes, e grew up between the city of Itaqui and *Estância Querência*, his grandfather's *estância* located in *Três Bocas* - Third District of Itaqui, currently managed by his father and where they breed horses, sheep, cattle and buffaloes. Since he was a child, he’s been passionate for this environment, and it was precisely in those *campos* of the Pampa Biome, between whinnies of horses and mooing of cattle, that he learned from the *campeiros* about the management of the *campos* and the culture of the *gaúcho* people, which carries a rich country wisdom and values such as respect for nature and manliness. During the daily activities at *Estância Querência*, besides admiring the campos of the Pampa, he always remained curious and sought to understand what was happening between plants and animals in that heterogeneous environment. Even though he still didn’t have the dimension of this, plant-animal relationships had already aroused his curiosity and admiration. Still during his childhood he had contact with the different kinds of literature from his grandfather's library, which has been maintained and enlarged by his father.

He finished high school in 2008. In 2010, he was approved to study Agronomy at the Federal University of Pampa (UNIPAMPA) - Campus Itaqui but due to compulsory military service he could not start the course that year. In 2011 he co-authored the book *Querência: porque meu canto apampou-se* authored by his father, the poet João Sampaio, where he recorded some poems related to the *gaúcho*’s way of living and culture. That same year he began his degree in Agronomy after the end of compulsory military service.

In the second semester of the course he began working as a volunteer in research projects of the Group of Studies in Water and Soil (GEAS) under the guidance of Dr. Cleber Maus Alberto where later he became a fellow of the Academic Development Scholarship Program (PBDA) working with research related to agrometeorology, ecophysiology of crops and forage plants, and soil and water management.

In 2013, he started working as a fellow of the Tutorial Education Program (PET Agronomy of UNIPAMPA) in the areas of teaching, research and extension. In that same year, besides acting in GEAS and PET, he began to volunteer in research projects of the Group of Studies in Production and Nutrition of Ruminants (GENUR) under the guidance of Dr. Eduardo Bohrer de Azevedo.

In 2014, he obtained the 1st place in the area of Agrarian Sciences, oral modality, research category in VI SIEPE - International Salon of Teaching, Research and Extension, Federal University of Pampa - UNIPAMPA. In that year, he performed an extracurricular internship at the Grazing Ecology Research Group (GPEP) and was instigated by the research topics developed by this group, with which he shared the same philosophy. Through the internship, he was able to see with more clarity the dimension of the issues related to the grazing process that had been present in his life since his childhood and decided that this was the line of research he wanted to follow.

In 2015, he completed his degree in Agronomy. At the end of that year, he was approved in the selection to the Master's degree in Agronomy at the Federal University of Santa Maria (UFSM) but decided not to attend because it wasn’t related to his study interests - the interactions between plants and herbivores. At the end of 2016, he was approved in the selection process of three institutions for the Master’s degree in Animal Science: Federal University of Rio Grande do Sul (UFRGS), Federal University of Pampa (UNIPAMPA) and Federal University of Santa Maria (UFSM). He chose to study at the Federal University of Rio Grande do Sul (UFRGS) under the mentorship of Dr. Paulo César de Faccio Carvalho due to his interest in the scientific questions explored by the Grazing Ecology Research Group (GPEP).

In GPEP, he works on the plant-animal interface research line and developed his Master's dissertation studying the relationships between sward structure and the ingestive behavior of cattle, generating management goals based on the ingestive behavior of the animals and seeking to understand the dynamics of the grazing process by monitoring both vegetation and animals with a high degree of detailing using precision livestock tools. During this period, he was co-advised by Dr. Jérôme Bindelle from the Université de Liège, Belgium.

In 2018 he obtained an Erasmus + scholarship and spent the last five months of the Master's degree at the Université de Liège - Gembloux Agro-Bio Tech. From an agreement between UFRGS and ULiège he defended his Master's dissertation in Belgium at the University of Liège - Gembloux Agro-Bio Tech. He was recently approved for the PhD in Animal Science at UFRGS under the mentorship of Dr. Paulo César de Faccio Carvalho, interested in further researching questions of plant-animal interface and understanding the dynamics of the grazing process.