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ESTIMATIVA DA INGESTÃO DE FORRAGEM EM PASTEJO E FORRAGEAMENTO DE EQUINOS E BOVINOS EM SISTEMA DE HERBIVORIA MISTA

Porto Alegre (RS), Brasil
Abril, 2021

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Tese apresentada como requisito para obtenção do Grau de Doutor em Zootecnia, na Faculdade de Agronomia, da Universidade Federal do Rio Grande do Sul.

Orientador: Paulo César de Faccio Carvalho
Coorientador: Olivier Jean François Bonnet

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ESTIMATIVA DO CONSUMO DE FORRAGEM EM PASTEJO E FORRAGEAMENTO DE EQUINOS E BOVINOS EM SISTEMA DE HERBIVORIA MISTA[1]

Autor: Anderson Michel Soares Bolzan
Orientador: Paulo César de Faccio Carvalho

Resumo: O documento de tese está apresentado em três capítulos. No capítulo I, a revisão da literatura sobre métodos de medida do consumo de animais em pastejo e efeitos da herbivoria mista em sistemas pastoris. No capítulo II, apresentamos o estudo que objetivou verificar a concordância do método de monitoramento contínuo dos bocados (CBM) e a técnica de dupla pesagem para estimativa da ingestão de forragem por herbívoros em pastejo, sob a hipótese de que a metodologia CBM permite estimar a quantidade consumida em pastejo, por meio da descrição das ações alimentares realizadas durante o pastejo e a simulação da quantidade consumida das mesmas em diferentes condições de pasto. Os resultados asseguram a capacidade de estimar o consumo de animais em pastejo por meio da observação direta dos bocados. As correlações das estimativas pelos métodos de dupla pesagem e CBM foram na ordem de r = 0,86 mesmo com exposição dos herbívoros a diferentes espécies e estruturas da vegetação, bem como diferente avaliadores. Os limites de precisão entre o CBM e a dupla pesagem são coerentes, e creditamos ao CBM a vantagem de avaliação dos animais com menor intervenção, além de qualificar o processo de ingestão em tempo real. Amparados pela maior clareza dos limites da capacidade de descrever e quantificar a dieta elaborada pelos herbívoros (Cap. II), buscamos compreender a construção bocado a bocado de dois modelos animal (equinos e bovinos) em pastos geridos sobre três sistemas de herbivoria: mista, com equinos e bovinos em coexistência, monoespecífica com equinos e monoespecífica com bovinos. No capítulo 3, o estudo objetivou identificar as ações alimentares (códigos de bocados) de equinos e bovinos e verificar a composição da dieta, fluxos de ingestão e padrões de seleção de ambos os modelos simpátricos em um mesmo sistema pastoril ou em sistemas com herbivoria monoespecífica. Nossos resultados mostram a vantagem do sistema com herbivoria mista em relação ao sistema monoespecifico para ambas as espécies no que tange as oportunidades para forrageamento. O sistema misto permite potencialmente otimizar o forrageamento, pois oferece maior abundância de ações alimentares rentáveis disponíveis no recurso forrageiro (estrutura do pasto), permitindo a seleção potencial de bocados com maior taxa de ingestão instantânea, refletida na composição da dieta selecionada pelos animais. Este efeito é positivamente significativo para bovinos e indiferente para equinos, denotando facilitação proporcionada pelos equinos aos bovinos quando em coexistência.

Palavras-chave: Forrageamento, biodiversidade, ecossistemas pastoris, nicho alimentar, consumo em pastejo.

ESTIMATE OF FORAGE INTAKE AND FORAGING BEHAVIOUR BY GRAZING EQUINE AND CATTLE UNDER MIXED HERBIVORY SYSTEM[1]

Author: Anderson Michel Soares Bolzan
Advisor: Paulo César de Faccio Carvalho

Abstract: This thesis is presented in three chapters. Chapter I brings a literature review on methods for measuring the consumption of grazing animals and the effects of mixed herbivory on pastoral systems. In chapter II, we present the study that aimed to verify the agreement of the continuous bite monitoring method (CBM) and the double weighing technique to estimate the forage intake by grazing herbivores, under the hypothesis that the CBM method allows estimating the amount consumed in grazing, through the description of the feeding actions performed during grazing and the simulation of the amount consumed in different grazing conditions. The results ensure the ability to estimate the consumption of grazing animals through direct observation of the bites. The correlations of the estimates obtained through the double weighing technique and the CBM were given by the coefficients r = 0.87, 0.86, and 0.87, even with exposure of herbivores to different species and vegetation structures, as well as different evaluators. The precision limits between the CBM and the double weighing technique are consistent, and we credit the CBM with the advantage of being less invasive, besides qualifying the ingestion process in real-time. Supported by the greater clarity of the limits of the ability to describe and quantify the diet elaborated by herbivores, we seek to understand the construction bite by bite of two animal models (horses and cattle) in pastures managed under three herbivory systems: mixed, with horses and cattle in coexistence, monospecific with horses and monospecific with cattle. In chapter 3, we aimed to identify the feeding actions (bite codes) of horses and cattle and to verify the composition of the diet, intake flows and selection patterns of both sympatric models in the same pastoral system or systems with monospecific herbivory. Our results show the advantage of the mixed herbivory system compared to both monospecific systems in terms of foraging opportunities. The mixed system potentially allows optimizing foraging, as it offers a greater abundance of profitable feeding actions available in the forage resource (sward structure), allowing for the potential selection of bites with higher instantaneous intake rate, reflected in the composition of the diet selected by the animals. This effect is positively significant for cattle and indifferent for horses, denoting facilitation by horses towards cattle when in coexistence.

Keywords: Foraging, biodiversity, pastoral ecosystems, food niche, grazing consumption

[1] Doctoral thesis in Animal Science, Faculty of Agronomy, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil. (124 p.). April, 2021.

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a.s.l.	above sea level
ANOVA	analysis of variance
cm	centímetros/centimeters
CV	coefficient of variation
DM	dry matter
e.g.	*exempli gratia* (por exemplo; latim)
g	gramas/grams
ha	hectares
i.e.	*id est* (isto é; latim)
LW	live weight
m	metros/meters
mm	milimeters
N	nitrogen
SE	standard error
SEM	standard error of the mean
Mixte	herbivory mixed system
Monoequi	herbivory equine system
Monobov	herbivory bovine system
Mixteequi	equines in herbivore mixed system
Mixtebov	equines in herbivore mixed system

CAPÍTULO I

[1] Doctoral thesis in Animal Science, Faculty of Agronomy, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil. (124 p.). April, 2021.

1.1 INTRODUÇÃO

O desafio em compreender as interações entre o homem e o ecossistema vai além da memória criada pelas sociedades ao longo do tempo. Em uma visão mais apurada, percorremos a reflexão de que além das superfícies exploradas, conhecidas e utilizadas, o que efetivamente nos interessa nas relações ecológicas é a capacidade de interagirmos com o meio em uma visão duradoura (Gordon, 2009, Carvalho et al., 2021), a fim de garantir e/ou prover a repetibilidade dos ciclos biológicos para gerações vindouras (Gordon et al., 2021).

Nos ecossistemas campestres, selvagens ou cultivados, que perfazem 40% da superfície terrestre (Suttie, 2005), as relações de fluxos de ingestão e seleção de componentes morfológicos vegetais em pastos monoespecíficos ou diversificados coordenam a dinâmica populacional dos animais selvagens (Bukombe et al. 2017) e o desempenho animal no caso dos sistemas de produção agrícolas (FAO 2005). A domesticação dos animais pode ser considerada como uma atividade primordial (Mottet et al., 2018) no entendimento da exploração do recurso e sua abundância, e seus efeitos foram (Enri et al., 2017), e ainda são, os pilares do trabalho do homem para desfrute dos diferentes serviços de provisão (Prins & Fritz, 2008; Dumont et al., 2018).

Além disso, a compreensão das relações dos herbívoros com o ecossistema é objeto de interesse também para cientistas e técnicos para a melhor coordenação das ações de gerência nos ambientes pastoris (Sollenberger & Wallau, 2020; Dumont et al., 2020a). Assim, direcionar rebanhos em pastos naturais por trajetos profícuos ao forrageamento (Meuret & Provenza, 2015) ou dimensionar tempo de permanência, carga animal em kg ha^{-1}, e disponibilidade de recurso (i.e., pasto) (Mott & Lucas 1952), intensidade moderada do pastejo (Kunrath et al., 2020; Zubieta et al., 2020), tem sido ao curso da história a base dos pensamentos para provisão de serviços advindos da herbivoria de animais domésticos. Atualmente, a visão intimista da relação planta-animal subsidia conceitos e práticas para gestão dos recursos pastoris no intuito de propiciar condições instantâneas favoráveis à ingestão de forragem (Carvalho et al., 2013; Nunes et al., 2019; Savian et al., 2021), que refletem em desempenho animal, produtividade e rendimento em diversas atividades (e.g. produção de carne, leite, lã e outros) e em sistemas agrícolas sustentáveis (Dumont et al., 2020b; Szymczak et al., 2020a; Jaurena et al., 2021).

Neste sentido, conhecer as relações causa-efeito na interface planta animal e o processo de ingestão (i.e., pastejo) e seus efeitos é o que pode ser entendido como o principal avanço no cenário descrito anteriormente (Carvalho et al., 2013; Savian et al., 2020; Schons et al., 2021). Entretanto, perceber e medir estas relações é uma tarefa desafiadora, uma vez que envolve processos como consumo de forragem e seleção de dietas em pastejo, fluxos de crescimento vegetal, entre outros. A ingestão de forragem pelos animais é um exemplo destes desafios. Métodos diretos [e.g. fistula esofágica (Stobbs, 1973; Geremia et al., 2018)] e indiretos foram propostos para estes fins, alguns relacionados às funções metabólicas [e.g. marcadores particularmente n-alcanos (Dove & Mayes, 2006)], sensores de movimento inercial (Andriamasinoro et al., 2017) e outros de maneira quantitativa [e.g. dupla pesagem (Penning & Hooper, 1985)].

Os métodos acima referidos fornecem um resultado satisfatório para a medida de consumo, entretanto, exigem níveis de intervenção e manipulação animal e/ou estruturas de manejo e suporte próprias, que limitam o emprego das técnicas em muitas situações, seja sobre a medida do animal na espontaneidade do processo de pastejo, ou pela impossibilidade no uso de equipamentos e estruturas de suporte (bretes de contenção ou equipos eletrônicos) no tempo e no espaço. A observação direta das ações alimentares dos animais (Agreil & Meuret et al., 2004; Bonnet et al., 2015), em contrapartida, oportuniza a um indivíduo observador descrever de maneira espontânea os eventos do forrageamento em ambientes pastoris.

A técnica de monitoramento contínuo de bocados, proposta por Agreil & Meuret (2004), qualifica e quantifica o forrageamento dos herbívoros vertebrados e permite verificar o processo de ingestão em diversas condições (e.g. pastos cultivados e nativos, monoespecificos ou diversos). Essa metodologia propõe construir grades de bocados adequadas aos objetivos e do nível das escalas espaço-temporais desejadas nos estudos. Esta observação instantânea da dinâmica de pastejo desnuda a medida até então pouco detalhada e descrita na composição do consumo, e permite construir o processo do forrageamento detalhadamente em tempo real. A partir desse entendimento, melhores manejos podem ser propostos, visando otimizar a interação herbivoros e ambientes pastoris (Schons et al., 2021). Do pondo de vista da gestão dos ambientes pastoris, muitas propostas visam configurar as atividades produtivas, valor paisagístico e funções ecossistêmicas metabólicas (Bonaudo et al., 2014; Ryschawy et al., 2017; Mengyuan Lia et al., 2021).

Com a multifuncionalidade dos ecossistemas pastoris em seus arranjos de biodiversidade (Bengtsson et al., 2019), muitas formas de otimizar o uso dos recursos em uma visão durável têm sido pensadas e exploradas (Dumont, Groot & Tichit 2018). A promoção da herbivoria mista é uma proposição de um saber fazer sustentável (Dumont et al., 2020), para atividades sustentáveis provedoras de serviços e autonomia (Bonaudo et al., 2014). Na configuração desses arranjos, considera-se as particularidades morfofisiológicas dos animais (Janis, 1976; Demment & Van Soest, 1985; Hofmann, 1989) em termos de diferenciação de tamanho (Brown,1988; Fleurance et al., 2009), morfofisiologia e capacidade digestiva dos herbívoros (Duncan et al., 1990), o que reflete na competição ou compartilhamento de nichos alimentares e na seleção de dietas (Menard et al., 2002) e fluxos de ingestão e digestão (Ferreira et al., 2007). São esses fatores que, principalmente em ambientes selvagens, definem os fluxos populacionais na dinâmica entre herbívoros, a disponibilidade de recursos e o tempo de uso/permanência (Bell, 1971; Bukombe et al., 2019). No caso de ecossistemas pastoris para produção animal (i.e., animais domésticos), que visam otimizar o uso dos recursos e potencializar o desempenho animal (Martin et al., 2020), tais fatores são dependentes das limitações antrópicas impostas pela gerência.

A relação dos nichos interespécie afeta a apresentação e a disponibilidade do recurso forrageiro, interferindo nas possibilidades de seleção alimentar e elaboração da dieta destes mesmos herbívoros (Ménard et al., 2002) e evidenciando a razão causa-efeito do processo de pastejo, com efeito no consumo e desempenho animal (Illius & Gordon, 1987). Neste contexto, herbívoros de tamanho semelhante, mas com aparato digestivo com limitações e potencialidades diferentes (Janis, 1976) podem gerar expressões de forrageamento também particulares, como os equinos com aparato intestinal de digestão da fibra (Edouard et al., 2008), portanto, pouco sensíveis à limitação física (tamanho da partícula) para digestão da mesma em comparação aos bovinos, limitados pela taxa de passagem ruminal (Duncan et al., 1990). Além disso, o aparato bucal com diferenças pronunciadas entre os dois modelos animais possibilita ações distintas no forrageamento. Enquanto os bovinos ampliam a capacidade ingestiva em bocados com o auxílio da língua (Illius & Gordon, 1987), os equinos pelos incisivos superiores e inferiores podem otimizar a ingestão em estratos inferiores do pasto (Fleurance et al., 2010).

Embora existam vantagens dos sistemas mistos em relação aos específicos, em funções de provisão (Ormunen-Cristian et al., 2012; Fraser et al., 2014) e imunidade?, como a diluição parasitária interespécie (Forteau et al., 2020), alguns aspectos sobre os fatores que provocam tais vantagens ainda não são claros. Relações ecológicas como competição, complementariedade em que a ação de um não prejudica a ação do outro e beneficia o meio, facilitação em que a ação de um promove a ação do outro e sinergia em que ambas ações são potencializadas por coexistiram (Hooper, 1998; Arsenault & Owen-Smith 2008; McNaughton, 1976; Sinclair & Norton-Griffiths, 1982) estão presentes como argumentos para avalizar estes sistemas. No caso de herbívoros pastejadores, a ingestibilidade é o fator provedor para o êxito do forrageamento, condições para ingestão em menor tempo.

Uma possibilidade para exploração multiespécie, frequente em condições ecológico-sociais (Jouven, Via & Fleurance, 2015), é a coexistência de equinos e bovinos. Considerando estes fatores, centrados nas diferentes potencialidades ingestivas dos modelos equinos e bovinos e com a possibilidade da descrição da seleção alimentar, da dieta e da exploração do recurso pelos animais, buscamos compreender as relações entre os nichos alimentares dos diferentes modelos de herbívoros em coexistência.

1.2 REVISÃO BIBLIOGRÁFICA

1.2.1 Quantificação e qualificação da dieta de herbívoros em pastejo

Conhecer a dieta de herbívoros em ambientes pastoris é uma tarefa desafiadora, em ambos os aspectos, qualitativo e quantitativo. Entretanto, este entendimento permite compreender e interagir com alguns elementos do ecossistema pastoril a fim de favorecer o forrageamento dos animais, visando a eficiência de utilização dos recursos, e a sustentabilidade do ecossistema pastoril. O consumo de forragem pelos animais é o fator determinante para a produção animal, com efeito direto no desempenho individual (Illius & Gordon, 1987). Em herbívoros selvagens, a medida do consumo no forrageamento é importante na verificação dos efeitos presentes na interface planta–animal (e.g. altura do pasto, diversidade florística) que afetam a interação presa-predador (e.g. Belovsky, 1997; Farnsworth & Illius, 1996), o balanço da ingestão de energia, disponibilidade de recurso e deslocamento (Charnov, 1976), as respostas funcionais (e.g. Durant et al., 2003; Smallegange & Brunsting, 2002), o comportamento ingestivo (e.g. Shipley, 2007; Pretorius et al., 2016) e a seleção alimentar (Hodgson, 1979). Assim, como estudos de dinâmica de ocupação e migração (e.g. Briske et al., 2017; Bukombe et al., 2019) em estudos de modelos ecológicos em ambientes naturais, ocupação concomitante ou sucessiva de uma ou mais espécies.

A estimativa do consumo de herbívoros em pastejo continua sendo um dos maiores desafios metodológicos em estudos de ciência animal (May & Dove, 2000; Garnick et al., 2018). Em uma escala diária, o uso de marcadores de plantas, particularmente n-alcanos (Dove & Mayes, 2006) é um método objetivo, embora invasivo, para estimar o consumo individual, digestibilidade aparente e composição da dieta em condições de pastejo (Gordon, 1995; Mayes & Dove, 2000; Barcia et al., 2007). No entanto, requer manipulação intensiva dos animais e mão de obra para dosagem, coleta de amostras fecais, processamento e extração laboratorial (Garcia Gonzalez et al., 2017). Outros fatores, como custo e precisão, dependendo das condições experimentais, tornam sua aplicação menos prática.

Metodologias que fazem uso de sensores, como a medição acústica dos movimentos mandibulares durante a execução dos bocados, foram testadas com ovelhas (Galli et al., 2011) e vacas (Galli et al., 2017). Em uma visão mais refinada sobre o processo de pastejo, para melhor compreender o efeito das diferentes estruturas do pasto no pastejo, dispositivos como "*Walk-over Weighing*" (Gonzalez Garcia et al., 2017) e no "*RumiWatch System*" (Ruuska et al., 2016; Rombach et al., 2018) foram desenvolvidos para estudos do monitoramento sensorial dos movimentos inerciais do processo de pastejo. Este último também possui um acelerômetro triaxial (Rayas-Amor et al., 2017) que pode identificar os movimentos da cabeça e classificar em mordidas de preensão, mastigação e outros. Também, com base no movimento inercial, Andriamasinoro et al. (2017) desenvolveram um algoritmo de código aberto para smartphone que avalia o comportamento de pastejo e ruminação de vacas em pastejo, atualmente em desenvolvimento e calibração em condições de pastejo para qualificação das ações (Rosseto et al., 2021). No entanto, os sensores citados acima fornecem informações gerais sobre o processo de pastejo, o que implica em menos detalhes da dinâmica das ações dos animais frente a estrutura do pasto, altura biomassa, diversidade florística e fenológica.

Como a estrutura e a composição da vegetação afetam a taxa de ingestão de forragem, os processos que regulam a formação de um bocado (Allden & Whitakker, 1970; Laca et al., 1992; Mezzalira et al., 2017; Nadin et al., 2019) e, como resultado, a taxa de ingestão, têm repercussões na ecologia animal e vegetal (Shipley, 2007). A interação planta-animal denota um resultado anabólico com reflexo na performance no caso de animais de produção, e *fitness* no caso de animais selvagens, que é a capacidade de perpetuar o material genético (i.e., reprodução). Além disso, essa dinâmica impacta na produtividade primária do sistema, nível de heterogeneidade e biodiversidade do recurso. Herbívoros tomam decisões sobre onde olhar e que tipo de combinações fazer quando sujeitos à diversidade botânica e estrutural, através de decisões de pastejo por animais em diferentes escalas espaço-temporais (Provenza et al., 2015), o que torna o detalhamento dos componentes da dieta um fator importante para muitos estudos (Azambuja et al., 2020).

Em escalas de curto prazo, a ingestão fornece uma medida direta da interação do animal com as características da vegetação. Esta medição representa uma ferramenta para compreender as restrições de forrageamento e os mecanismos que ligam as propriedades da vegetação às escolhas alimentares e ao uso do habitat (Stephens & Krebs 1986; Spalinger & Hobbs, 1992; Shipley et al., 1994). Para determinar o consumo em curta escala (períodos de cerca de 1 hora, i.e., uma refeição) (Bailey et al., 1996), a técnica de dupla pesagem (Penning e Hooper, 1985) é um dos procedimentos mais tradicionais e utilizados (Giovanett et al., 2017), que estima a quantidade de ingestão através da diferença de peso do animal pré- e pós-pastejo. Essa técnica também requer que os observadores monitorem o tempo efetivo de pastejo e a taxa de bocados (o que permite calcular a massa média de bocados). Embora não seja invasivo em si, os animais treinados precisam ser equipados com aparato de coleta de excretas, o que limita o período experimental a não mais do que algumas horas.

A fistulação esofágica (Stobbs, 1973; Geremia et al., 2018) pode ser usada em diferentes condições de estrutura do pasto para determinar a ingestão e a seleção da dieta. No entanto, esta técnica é extremamente invasiva (requer procedimentos cirúrgicos). Em geral, esses métodos podem capturar apenas a massa média dos bocados, a taxa de bocados e a taxa de ingestão ao longo de sequências inteiras de pastejo ou dias, e não inferem sobre variações dessas respostas em função de diferenças locais na estrutura e composição do pasto (Bonnet et al., 2015).

A simulação de pastejo manual (i.e., *hand plucking*) tem sido usada há muito tempo para simular a ingestão e a seleção de dietas por animais em pastejo (Halls, 1954; Cook, 1964). É simples, causa perturbação mínima ao animal e pode produzir grandes conjuntos de dados a um custo mínimo. É comumente usada para estimar a massa de bocados em estudos de campo com herbívoros selvagens (Collins & Urness, 1983; Renecker & Hudson, 1985; Hudson & Frank, 1987; Okello et al., 2002) e herbívoros domésticos (Hobbs et al., 1983; Agreil & Meuret, 2004; Agreil et al., 2006).

Usando princípios semelhantes, o método de monitoramento contínuo dos bocados (*Continuous Bite Monitoring*, CBM) proposto por Agreil & Meuret (2004) representa uma ferramenta útil para uma descrição completa das atividades de forrageamento e do ambiente pastoril em nível de bocado. Com base em uma pré-avaliação da vegetação disponível e observação do processo de seleção de dieta e pastejo, bocados potenciais são classificados em categorias de códigos para compor uma grade de referência de atividades de forrageamento (ou seja, códigos de bocado, pastejo, ruminação, ócio etc.).

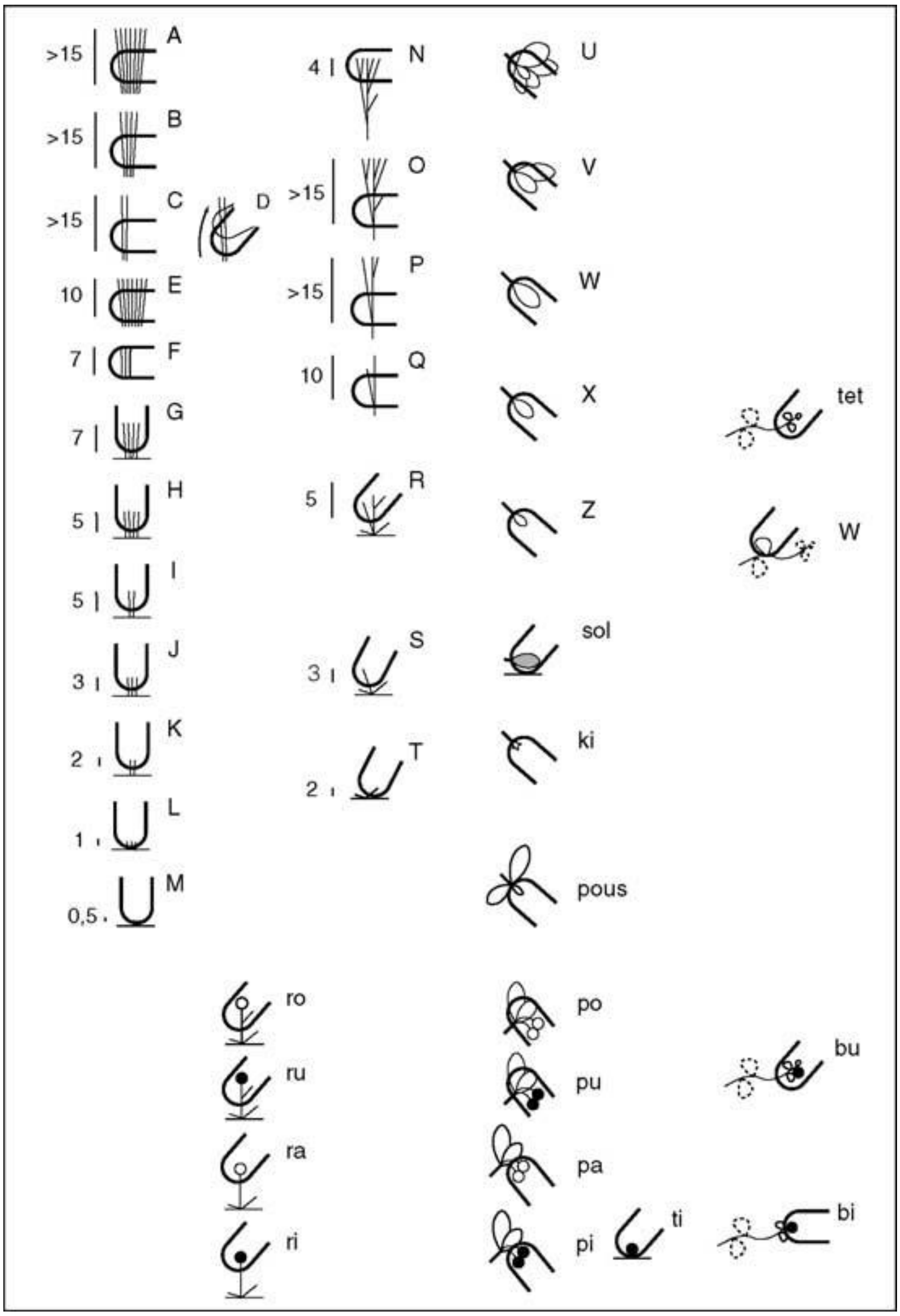

Figura 1. Grade de codificação de categorias de bocados com base na natureza e estrutura das porções da planta cortadas. O ícone em forma de “U” representa as mandíbulas do pequeno ruminante. As porções da planta são indicado por pequenos ícones que simbolizam sua fisionomia: linhas (hastes de arbustos ou lâminas de folhas e hastes de gramíneas), formas ovais (folhas de árvores e arbustos), círculos abertos (flores) e círculos preenchidos (frutas). O comprimento das folhas, dispostas, mas não esticadas, é indicado em centímetros à esquerda dos ícones de dos códigos de bocados (BCs). Os códigos monossilábicos e bissilábicos ditados durante a observação são descritos à direita dos ícones. A coluna à esquerda dá o BCs para os caules dos arbustos e as folhas de gramíneas. A segunda coluna fornece os BCs para arbustos e plantas herbáceas dicotiledôneas ramificadas. Os grupos da terceira coluna BCs na folhagem das árvores. A última coluna é para BCs em plantas trepadeiras. (Adaptado de Agreil & Meuret, 2004)

Com isso em mãos, os observadores monitoram os animais-alvo por um determinado tempo em que todas as atividades são registradas. Os códigos de bocado observados são então simulados pelos observadores para estimar a massa e o valor nutritivo de cada bocado efetuado, para posterior cálculo da ingestão. Este método depende da eficiência do observador na interpretação da grade de codificação durante a observação visual e na capacidade de identificar o tipo de vegetação colhida pelos animais durante o processo de pastejo.

As vantagens do método CBM em relação a outros métodos residem no registro, em tempo real, de uma descrição detalhada de todos os bocados efetuados pelo animal, da estimativa do valor nutricional do tecido vegetal correspondente a cada código de bocado de cada espécie vegetal, e da dinâmica do comportamento por estação alimentar animal (Bonnet et al., 2015, Torres-Fajardo et al., 2019; Bolzan et al., 2020; Azambuja et al., 2020). Assim, este método permite um grande nível de detalhamento na descrição do processo de forrageamento. Por outro lado, sabe-se que o método CBM exige o treinamento progressivo do observador e pode possuir algum grau de viés dependendo da experiência e dedicação.

1.2.2 Ecossistemas pastoris e herbivoria mista

Os ecossistemas pastoris têm grande importância, pela abrangência e pela multifuncionalidade de serviços ecossistêmicos prestados (Suttie, 2005), sendo parte deles os serviços de provisão relacionados com a produção animal. São sistemas que contemplam uma grande amplitude de arranjos de biodiversidade (Bengtsson et al., 2019), organizados em níveis tróficos horizontal (no mesmo nível trófico) e vertical (entre níveis tróficos) (Duffy et al., 2007). Isso implica em complexas relações entre a interface solo-planta-animal-ambiente, no tempo e no espaço, com efeitos na diversidade vegetal (Senft et al., 1987), distribuição espacial dos herbívoros e nichos alimentares (Bell, 1971; Shipley and Spalinger, 1995).

Na multifuncionalidade dos ecossistemas pastoris, o incremento de diversidade dentro do mesmo nível trófico (e.g. sistemas com herbivoria mista) promove em curto prazo a eficiência de utilização dos recursos (Prins and Fritz, 2008; Ormunen-Cristian et al., 2012; Fraser et al., 2014) e, posteriormente, a estabilidade da comunidade vegetal (Henning et al., 2017; Schmitz & Isselstein, 2020), melhoria da resiliência benéfica frente a variações climáticas (Modernel et al., 2019) gerando maior autonomia dos sistemas (Thenard, 2019; Bonaudo et al., 2013) como, por exemplo, as funções imune (Jordan et al., 1998; Eysker and Mirck, 1986; Forteau et al., 2019) e metabólica (Modernel et al., 2019). Elucidar as relações da diversidade de herbivoria que conferem aumento da eficiência de uso dos recursos é um fator chave, pois está intimamente ligado à gerência dos agroecossistemas com base em práticas sustentáveis (Dumont et al., 2020; Martin et al., 2020).

Equinos e bovinos simpátricos potencialmente têm variabilidade de fluxos de ingestão e digestão (Ferreira et al., 2007) decorrentes de diferenças morfofisiológicas (Demment & Van Soest, 1985; Hofmann, 1989) e especificidades de nichos alimentares de cada espécie (Walker, 1994; Menard et al., 2002). Equinos (perissodáctilos) e bovinos (artiodátilos) coevoluíram paralelamente desde o Paleoceno (55 milhões). No processo evolutivo, os ruminantes foram mais eficientes nas adaptações (rumem) para herbívora (Janis, 1976). Um indício desta eficiência é a riqueza e a abundância específica em espécies de herbívoros de tamanho médio com ampla distribuição global. Os equinos contrariamente são um dos poucos representantes dos fermentadores intestinais de tamanho médio potencialmente a compartilhar nichos com ruminantes de mesma escala corporal (Duncan et al., 1990).

Normalmente, os bovinos têm um hábito alimentar generalista, utilizando o movimento da língua para a ampliação da área do bocado, permitindo massas de bocado elevadas (Illius & Gordon, 1987). Os bovinos apresentam o aparato ruminal como vantagem evolutiva e adaptativa para digestão de forragem em nível de fibra moderada, bem como tolerar fatores tóxicos de plantas inertes sob à fermentação (Freeland & Janzen, 1974; Van Soest 1983; Provenza et al., 2003). Os equinos, por sua vez, usam os incisivos superiores e inferiores na apreensão do pasto, viabilizando o pastejo em estratos rasos, onde estes apresentam dossel mais jovem (Fleurance et al., 2010) e conferindo uma vantagem do ponto de vista de acesso aos estratos inferiores, que normalmente apresentam tecidos mais jovens e de maior valor nutricional (Fryxell, 1991) e que os equinos poderiam otimizar a ingestão de nitrogênio (Edouard et al., 2010). Além disso, os equinos são menos afetados por teores elevados de fibra devido à ausência de limite físico sobre a partícula, como acontece no compartimento fermentativo anterior dos bovinos (Edouard et al., 2008), uma vez que a fermentação nos equinos ocorre na porção posterior do intestino (Bell, 1971).

Dessa forma, compensam a baixa taxa de digestão ampliando a ingestão e, consequentemente, aumentando o tempo de pastejo (Janis, 1976; Duncan et al., 1990).

A configuração de nichos alimentares dos animais em pastejo pode ter uma relação de competição pelos mesmos itens alimentares (Murray & Illius, 2000; Lamoot et al., 2005). No entanto, as particularidades morfofisiológicas definem padrões de forrageamento com efeitos sobre o recurso disponível no ecossistema, de modo que é coerente pensar que os efeitos dos herbívoros na estrutura do pasto sejam distintos (Shipley et al., 1994; Shipley, 2007). Através dos mecanismos acima citados, estes dois modelos animais conseguem explorar com particularidades nichos alimentares diferentes em um mesmo recurso disponível (Gwyne & Bell, 1968; Putman et al., 1987; Murray & Illius, 2000; Arsenault & Owen-Smith, 2008), gerando processos de facilitação e complementaridade alimentar (Hooper, 1998; Arsenault & Owen-Smith 2002; McNaughton, 1976; Sinclair & Norton-Griffiths, 1982) devido às diferenças seletivas na exploração das estruturas do dossel do pasto (Grant et al., 1985, 1987; Lamoot et al., 2005, Dumont et al., 2010; Karmiris et al., 2011). Utilizariam, assim, os recursos disponíveis de maneira harmônica (Duffy et al., 2007), um modelo selecionando o preterido pelo outro (Sensenig et al., 2010).

A importância da estrutura do pasto sobre a taxa de ingestão dos herbívoros é bastante conhecida (Ungar & Demment, 1991). De maneira geral, o estádio fenológico (Drescher et al., 2006), densidade volumétrica, arquitetura do dossel (Gordon & Benvenutti, 2006), diversidade florística e heterogeneidade (Bailey et al., 1998; Parsons & Dumont, 2003) interferem no processo ingestivo dos animais (Shipley, 2007), por meio do efeito direto no tamanho e massa do bocado (Shipley et al., 1994). Assim, as decisões dos animais em nível de bocado, determinam a ingestão de forragem de curto e longo prazo (Mezzalira et al., 2017; Bergman et al., 2001).

Bovinos e equinos apresentam biomassa corporal semelhante, estando inseridos em diversos contextos agroecológicos e de composição de paisagem. Tanto em cenários marginais, em caráter de preservação paisagística (Celaya et al., 2011; Osoro et al., 2017), como em sistemas de produção dirigidos para provisões definidas, como leite, carne e outros produtos (Martin-Rosset & Merle 1989). A coexistência de equinos e bovinos fornece a oportunidade para a exploração versátil e durável provedora de manutenção da biodiversidade (Putman et al., 1991; Loucougaray, 2004; Catorci et al., 2012; Nolte et al., 2017).

1.3 HIPÓTESES

As questões abordadas neste documento estão baseadas nas seguintes hipóteses:
- A técnica de monitoramento contínuo dos bocados e simulação manual é uma metodologia confiável para estimar o consumo por herbívoros em pastejo (Capítulo II)
- A coexistência de diferentes herbívoros (i.e., equinos e bovinos), em um mesmo ecossistema pastoril, gera melhores condições para o forrageamento para ambas as espécies pelas relações de facilitação e complementariedade (Capítulo III)

1.4 OBJETIVOS

Dessa maneira, nos capítulos desta tese (objetivos específicos) que visam testar o objetivo geral de verificar as razões de causa e efeito da estrutura do pasto para ingestibilidade de forragem no forrageamento a partir da visão refinada das ações alimentares dos herbívoros, os bocados e a construção da dieta.
- Capítulo II: Comparar o consumo acumulado estimado pelo monitoramento contínuo dos bocados e o consumo medido com a dupla pesagem em diferentes condições de pastejo.
- Capítulo III*:* i) Caracterizar e registrar as ações alimentares (bocados) realizados por diferentes modelos animal (i.e., equinos e bovinos) em pastos permanentes; ii) Estimar o rendimento dos bocados (taxa de ingestão de nutrientes por minuto) para cada modelo animal, em coexistência ou não; e iii) Quantificar o valor potencial de matéria orgânica disponível em cada sistema de herbivoria (misto ou monoespecífico).

CAPÍTULO II

What, how and how much do herbivores eat? The Continuous Bite Monitoring method for assessing forage intake of grazing animals[2]

[2] Manuscrito elaborado conforme as normas do periódico *Ecology and Evolution* (Apêndice 3). Aceito para publicação em Abril,2021 (DOI: 10.1002/ECE3.747).

What, how and how much do herbivores eat? The Continuous Bite Monitoring method for assessing forage intake of grazing animals.

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Running headline: A method for assessing forage intake in grazing

Abstract

Determining herbage intake is pivotal for studies on grazing ecology. Direct observation of animals allows describing the interactions of animals with the pastoral environment along the complex grazing process. The objectives of the study were to evaluate the reliability of the continuous bite monitoring (CBM) method in determining herbage intake in grazing sheep compared to the standard double-weighing technique (DW) method during 45-min feeding bouts; evaluate the degree of agreement between the two techniques; and to test the effect of different potential sources of variation on the reliability of the CBM. The CBM method has been used to describe the intake behaviour of grazing herbivores. In this study, we evaluated a new approach to this method, i.e., whether it is a good proxy for determining the intake of grazing animals. Three experiments with grazing sheep were carried out in which we tested for different sources of variations, such as the number of observers, level of detail of bite coding grid, forage species, forage allowance, sward surface height heterogeneity, experiment site, and animal weight, to determine the short-term intake rate (45 min). Observer (P_{exp1} = 0.018, P_{exp2} = 0.078 and P_{exp3} = 0.006), sward surface height (P_{exp2} < 0.001), total number of bites observed per grazing session (P_{exp2} < 0.001 and P_{exp3} < 0.001) and sward depletion (P_{exp3} < 0.001) were found to affect the absolute error of intake estimation. The results showed a high correlation and agreement between the two methods in the three experiments, although intake was overestimated by CBM on experiment 2 and 3 (181.38 and 214.24 units, respectively). This outcome indicates the potential of CBM to determining forage intake with the benefit of a greater level of detail on foraging patterns and components of the diet. Furthermore, direct observation is not invasive nor disrupts natural animal behavior.

Keywords: Short-term intake rate, grasslands, grazing ecology, herbage intake, Italian ryegrass, foraging, Tall fescue.

1. INTRODUCTION

One of the most important processes influencing the ecology of mammalian herbivores is how vegetation structure and composition affect dry mater and nutrient intake rate. Since herbivores complete thousands of bites per day, processes regulating the formation of a bite and resulting intake rate have tremendous repercussions on animal and plant ecology (Shipley, 2007). In domestic herbivore production, forage intake is well known to be the most important component affecting performance or productivity (Illius & Gordon, 1987). For wild mammalian herbivores, measurement of short-term intake is essential on the study of energy balance between forage intake, exploration and displacement (e.g., Charnov, 1976), functional responses (e.g., Durant, et al., 2003; Smallegange & Brunsting, 2002), habitat selection (Courant & Fortin, 2012), and coexistence between herbivores species (Tilman & Borer, 2015).

Yet, the estimation of Short-Term Intake Rate (STIR) in grazing herbivores remains one of the biggest methodological challenges in animal science studies (Mayes & Dove, 2000; Garnick et al., 2018). At a daily scale, the use of plant markers, particularly n-alkanes (Dove & Mayes, 2006) are an accurate method to estimate individual forage intake, apparent digestibility, and portion of diet composition under grazing conditions (Gordon, 1995; Mayes & Dove 2000; Barcia et al., 2007). However, it requires intensive animal manipulation and labor for dosing, fecal sample collection, processing, and laboratory extraction (González-García et al., 2017). Multiple other methods involving acoustic (e.g. Galli et al., 2011, 2017) or movement/inertia (e.g. Rayas-Amor et al. 2017; Andriamasinoro et al. 2017) sensors have been tested to various levels of success on discriminating jaw movements (i.e., bite, chew, rumination). Walk-over weighing devices (Gonzalez-Garcia et al., 2017) and the "RumiWatch System" (Ruuska et al., 2016; Rombach et al., 2018) were developed for long-term forage intake studies. For determining STIR, the double-weighing technique (Penning & Hooper, 1985) is one of the most used procedures (Giovanett et al., 2017). It estimates the amount of forage intake in grazing sessions by the difference of animal weight pre- and post-grazing. Another previously employed methodology, esophageal fistulation (Stobbs, 1973; Geremia et al., 2018), is extremely invasive and not practical in rangeland situations.

Although those methods provide valuable information, the grazing process is described in terms of number and distribution of jaw movements, total intake, or average bite mass, bite rate, and intake rate over entire grazing sequences or days. They offer little detail of the dynamics of foraging actions and do not infer about variations of these variables as a function of local differences in the vegetation structure and composition (Bonnet et al., 2015). Herbivores respond to the botanical and structural diversity of grasslands, making decisions on choices and combinations of forages harvested at different space-time scales (Provenza et al., 2015). Evaluating in detail the components of a diet is an essential factor for many studies of plant-animal interaction.

Hand plucking (Halls, 1954; Cook, 1964) has been used as a simple and cheap alternative for simulating intake and diet selection by wild (Collins & Urness, 1983; Renecker & Hudson, 1985; Hudson & Frank, 1987; Okello et al. 2002) and domestic herbivores (Hobbs et al., 1983; Agreil & Meuret, 2004; Agreil et al., 2006). By using similar principles, the continuous bite monitoring (CBM) method proposed by Agreil & Meuret (2004) represents a useful tool for a complete description of the foraging activities and grazing environment at the bite level. The advantages of the CBM method over other methods rely on real-time recording of detailed descriptions of all foraging activities performed by the animal, bites taken in each plant species or structure, the estimation of the nutritional value of the plant tissue corresponding to each bite code from each plant species, and the exploration of the dynamics of the animal feeding station behaviour (Bonnet et al., 2015, Torres-Fajardo et al., 2019; Bolzan et al., 2020; Azambuja et al., 2020; Molnár et al. 2020). Thus, it allows for a great level of detail in the description of the foraging process. On the other hand, it is known that the CBM method requires the progressive training of the observer and has a certain level of bias depending on experience and dedication (Bonnet et al., 2011).

Previous studies also questioned the reliability of the method as a function of different variables such as vegetation structure, period and duration of the observation and the level of detail of bite coding grid (Bonnet et al, 2015; Bolzan et al. 2020). Based on a pre-evaluation of available vegetation and observation of diet selection and grazing process, possible “bites” are classified into categories of bite codes (BC) to compose a reference grid of foraging activities (i.e., BC, grazing, ruminating, resting, etc.). Observers then monitor target animals for a determined period to record where all activities are registered. Observed BC taken are then simulated (i.e., hand-plucked) to estimate the mass and nutritive value of each bite for further calculation of intake. Therefore, our objective were: *i*) to evaluate the reliability of the CBM method in determining herbage intake in grazing sheep compared to the standard double-weighing technique (DW) method during 45-min feeding bouts, *ii*) evaluate the degree of agreement between the two techniques, and *iii*) to test the effect of different potential sources of variation (observer and animal identity, vegetation structure and period and duration of the observation) on the reliability of the CBM.

2. MATERIALS AND METHODS

2.1. Site, treatments and experimental design

Three independent studies were conducted in which we tested for different sources of variation: number of observers, level of detail of BC grid (Figure 1), forage species, forage allowance, sward surface height (SSH) heterogeneity, experiment site, and animal breed. Experiment 1 was carried out between 15 September and 15 October 2014, on an area of approximately 0.50 ha of self-seeding Italian ryegrass (*Lolium multiflorum* Lam.) at the experimental farm of the Federal University of Rio Grande do Sul, Brazil (30°05´27” S, 51°40’18” W). The area was divided into two paddocks of 0.25 ha (experimental areas) with salt and water freely available. In this protocol, there were no defined criteria for managing the sward pre-grazing structure. Only average sward surface height measurements were collected at the time of observation.

Experiments 2 and 3 were carried out at the Canguiri experimental station of the Federal University of Paraná, Brazil (25°26'30''S and 49°7'30''W). The experiments were established in a 0.3 ha experimental area of tall fescue cv. INIA Aurora (*Schedonorus arundinaceus* [Schreb.] Dumort) sown in June 2015 on a prepared seedbed, at 55 kg ha^{-1}. Beginning in September 2015, the experimental area was managed under continuous stocking with sward surface height maintained between 10 and 15 cm, except just prior to and during the grazing events when the different pre-grazing SSH treatments were imposed. Experiment 2 was carried out between 24 June and 12 July 2016 and Experiment 3 was carried out between 15 and 24 November 2016. In Experiment 2, five homogeneous pre-grazing SSH (14, 17, 20, 23, and 26 cm) were evaluated in a randomized complete block design with four replicates. In Experiment 3, five levels of depletion (0, 20, 40, 60, and 70%) of average SSH (20 cm) were evaluated in a randomized complete block design with four replicates, through grazing with non-experimental animals prior to grazing sessions to measure behaviour. A more detailed description management protocol can be found in Szymczak et al. (2020).

2.2. Sward measurements

Five hundred SSH measurements were taken in the two experimental paddocks of Experiment 1 to characterize the vegetation structure. Mean SSH was 38.0 cm (±13.12 cm) and 38.7 cm (±12.98 cm) for paddocks 1 and 2. For Experiments 2 and 3, 150 points pre-grazing SSH within each sampling unit were measured. Pre-grazing SSH were 14.2 (±0.19), 17.3 (±0.20), 19.7 (±0.27), 22.8 (±0.28) and 25.9 (±0.26) cm, for treatment of 14, 17, 20, 23 and 26 cm in experiment 2, respectively. The measured pre-grazing SSH were 20.2 (±0.18), 16.5 (±0.52), 12.2 (±0.52), 8.3 (±0.48) and 5.9 (±0.37) cm, for treatments 0, 20, 40, 60 and 70% of depletion in experiment 3, respectively.

2.3. Intake and grazing behaviour evaluations

2.3.1. Animals and experimental procedures

Procedures involving the experimental animals were conducted under the Guidelines for the Use of Animals (2012) and complied with ethical guidelines published by the International Society for Applied Ethology. All procedures involving animals were approved by the Commission for Ethics in the Use of Animals of the Sector of Agricultural Sciences of the Federal University of Paraná (024/2016).

Two methodologies were used simultaneously during grazing tests to measure short-term intake rate (STIR): the double weighing technique (DW) as the reference practice (Penning & Hooper, 1985) and the continuous bite monitoring (CBM) method (Agreil & Meuret, 2004; Bonnet et al., 2015). In Experiment 1, eight Texel ewes (42.07 ± 3.15 kg LW) were used. Sixty days before the data collection, ewes were allocated on an adjacent Italian ryegrass pasture for acclimation to forage and adaptation to observers and equipment. During the experimental procedure, animals were distributed in two groups of four testers per paddock, where two testers per paddock were used for evaluation of the continuous bite monitoring and double-weighing. After the evaluations, animals were placed back on the adjacent pasture for the remaining of the day. In Experiments 2 and 3, six White Dorper x Suffolk ewes were used with an average weight of 61.9 ± 5.5 kg. Two animals were chosen as testers, all previously adapted to the experimental procedure and maintained in an area similar and adjacent to the experimental paddocks.

2.3.2. Continuous bite monitoring

Experiment 1 involved three observers: one with previous experience on the methodology with wild herbivores and cattle (EO; Bonnet et al., 2015), and two new observers (TO1 and TO2) were trained by EO. Experiments 2 and 3 involved four different observers, all inexperienced. Prior to the beginning of the experiments, a mutual familiarization phase was adopted for three weeks. During this phase, animals were handled daily to acclimate to observers and protocols, and for observers to familiarize with pasture and grazing behavior. Once the tester animals were identified and familiarized with the evaluators, all bites observed were described and classified into categories based on the observation of the animals' intake behavior before the experiments under the following aspects: *i*) structural and nutritional distribution of the components in the sward; *ii*) the nature, size, density, and position of selected plant parts by animals, as a set of leaves, isolated leaves or inflorescences; and *iii*) handling (gathering herbage into the mouth, severing the herbage, ingestive mastication and swallowing, Laca et al., 1994). Simple codes were established for each bite category agreed upon by all observers, composing a grid of codes for the identification of bites in real-time (Fig. 1A and 1B). The level of detail for each BC grid differed based on SSH, phenological stages, plant density heterogeneity, and species diversity. For Experiments 2 and 3 the same grid was used, but the dimensions and masses varied (Annex 1 and 2).

After three weeks of training, both experienced and naïve observers were able to codify with confidence every bite observed (Bonnet et al., 2011). The three observers in Experiment 1 (one observer per tester animal per paddock in each session evaluated) and four observers on Experiments 2 and 3 (two observers per experiment, one observer per tester animal, and one tester per paddock) collected data by standing close to the animals (within 1 m), during 45-min grazing sessions. Thirty-two (Experiment 1) and twenty (Experiments 2 and 3) sessions were conducted. These sessions were blocked into morning and afternoon periods, arranged in a completely randomized design. After each grazing session had finished and while the animals remained in a common pen for determining insensible weight losses, each bite category was simulated (minimum 22 hand-plucks for each type of bite, for bite codes more frequent we replicated the samples). Samples were collected in paper bags and placed in a thermal box and weighed immediately after collection to estimate fresh matter (FM) intake. Intake was calculated as a sum of FM for all recorded bites. Data were registered using a Sony ICD-PX312 (Sony Corp., Japan) digital voice recorder and, subsequently, transcribed using the J Watcher software (www.jwatcher.ucla.edu).

2.3.3. Short-term intake rate

During the experimental period, each day around 5:40 am (Experiment 1) or 6:30 am (Experiments 2 and 3), animals were moved to the handling area, fitted with harnesses for a total collection of urine and feces, and weighed at t_1 (W_1 = initial weight for estimating the rate of insensitive weight losses (H_2O evaporation, CO_2 and CH_4 losses; RIWL pre-grazing). After being weighed, the animals remained in a common pen for 45 min without access to feed or water and then weighed again at t_2 (W_2 = final weight for pre-grazing RIWL and pre-grazing weight). Immediately after, all the animals were conducted and allotted to their paddocks for the 45-min grazing session (*ET*). Once the grazing session was finished, the animals were led to the handling area and the tester animals were weighed at t_3 (W_3 = post-grazing weight and initial weight for the post-grazing RIWL). The tester animals then remained in a common area without access to feed, water or shade for 45 min until being weighed at t_4 (W_4= final weight for post-grazing RIWL). The harnesses were then immediately removed, and the animals returned to the adjacent area. This same procedure was repeated in the afternoon (between 2:15 pm and 6:30 pm for Experiment 1 and between 2:30 and 6:30 pm, for Experiments 2 and 3). The animals were weighed using an electronic scale (MGR-3000 Junior, Toledo, Canoas, Brazil) with a capacity of 200 kg (5-g increments). Short-term intake rate (g FM min^{-1}; Eq. 1) was calculated by measuring the weight change, corrected for insensible weight loss, and the time spent grazing, according to Penning & Hooper (1985).

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

Eq.1

2.4. Statistical Analysis

The data were analyzed using the R software (R Development Core Team, 2016). Animal test group was the experimental unit. We systematically verified normality and homogeneity of the residuals. Pearson correlation was used as mean accuracy between the methods and was considered poor (<0.4), reasonable (0.4 to 0.6), good (0.6 to 0.8), or excellent (0.8 to 1.0). Bland–Altman plots were created to indicate the degree of agreement between the two techniques (Bland and Altman, 1999). The limits of agreement were determined by calculating the bias and standard deviation of the paired differences. The standard deviation was multiplied by the 1.96 quantiles of a normal distribution and then, the amount of the calculated average was added or subtracted to provide the upper or lower limits, respectively. Thus, the agreement limits were calculated as bias ± standard deviation. One Sample T-Test, at a significance level of 95%, was performed to check if there was a significant difference from zero, for the comparison between the methods.

3. RESULTS

The correlation between estimated forage intake (as FM) through the CBM and DW methods for ewes in 45-min grazing sessions is presented in Figure 2. The overall mean correlation over 32 observations was 0.864, in Experiment 1 (Fig. 2A), and over 20 observations was 0.867 and 0.869, in Experiment 2 and 3, respectively (Fig. 2B and C). A significant effect of the observer on the absolute error of intake estimation (Table 1) was found in Experiment 1. In experiments 2 and 3, we found significant effects of sward structure (SSH and sward depletion, respectively), observer and the total number of bites observed per grazing session (Table 1). Day of measurement, individual animals or period of the day had no significant effect on the absolute error in none of the experiments (Table 1).

The Bland-Altman analysis (Fig. 3) showed the bias between methods of 33.90, 181.38, and 214.24 g FM, and the limits of agreement: 259.11 and -191.31, 533.33, and -170.56 and 201.62, and -180.93 g FM, for Experiment 1, 2 and 3, respectively. The bias value obtained in the comparison of the methods means that on average the CBM method measures 33.90, 181.38 and 214.24 more units in relation to the DW method, for Experiments 1, 2 and 3, respectively. There was a significant difference between zero and bias by One Sample T-Test, for Experiments 2 (P = 0.0002) and 3 (P = 0.0001).

4. DISCUSSION

Direct observation has a large capacity for detailed assessment of the grazing processes, considering important factors at the plant-animal interface. Bonnet et al. (2011), using cows (*Bos taurus taurus* L.) and goats (*Capra hircus* L.), showed that the ability of different observers to evaluate short-term intake after training had a correlation greater than 85%. Similarly, our results showed correlation topping 86.4% in comparison to the standard DW technique (Penning & Hooper, 1985). However, we found significant differences in the estimate of intake between the two methodologies in Experiments 2 and 3, with generally overestimation of intake by the CBM regarding to the DW (Fig 2b and 2c). Given the differences in sward pasture conditions and assuming all observers received similar levels of training, this could indicate that a greater detail of bite types in the description of the grazing process could improve the accuracy of the method.

Differences in estimation of intake between the two techniques may be associated with inherent error of both methodologies. Many studies in the literature reported high interindividual variability when using the DW method (Fonseca et al., 2012; Mezzalira et al., 2017; Gusati et al., 2017). Other sources of variation, such as differences between paddocks and shifts (am *vs.* pm) also add to the compound variation for many of the methodologies used for estimating intake (Bailey et al., 1996; Fraser, 2009; Gregorini, 2012). For example, Lukuyu et al. (2014) compared two pasture disappearance-based techniques (rising-plate meter and capacitance meter) and two chemical marker-based techniques (dosed n-alkanes and chromic oxide) techniques of forage intake in steers, showing high internal variation (coefficients of variation of 28% for the capacitance meter and 44% for the plate meter) in estimates and low correlation (r = 0.51) between chromic oxide and the plate meter. They found no correlation between disappearance-based and alkane methods. Greenwood et al. (2014) found correlations between the biomass disappearance and C32/C31 and C32/C33 n-alkane of 0.77 and 0.70, respectively.

The correlation analysis (Fig. 2) shows only of the strength of relationship between the variables but not the agreement between them (Giavarina, 2015). A high correlation between the methods can mostly come from the large range in fresh matter intake observed during the experiment (Giavarina, 2015). The Bland-Altman analysis shows the agreement between the methods and is a parameter of greater consistency to compare techniques (Myles, 2007; Giavarina, 2015), as it is evaluated according to the data dispersion. In cases of good agreement, the scattering of points is diminished and points lie relatively close to the solid, bold line (mean bias; Fig. 3) (Myles, 2007; Giavarina, 2015). Our results had a high dispersion; however, points were mostly within the limits of agreement in all cases. This denotes agreement between methods, but with high variability in measuring intake. In addition, the Bland-Altman analysis demonstrated an intake overestimation measures for CBM compared to DW method, mostly in experiments 2 and 3 (Fig. 3B and 3C). It is important to point out that the observer's interpretation of the animal's action in the execution of the bite, along with the factors that establish the bite category (i.e., the type of tissue, position in the canopy and density), are determinants for the accuracy of the simulation. Therefore, the smaller number of bite codes on experiments 2 and 3 resulted in a greater range of bite mass for each of the BC, increasing the dispersion of the data which resulted in the overestimation of intake with CBM. Alternatively, a more detailed assessment (i.e., experiment 1) dilutes the variations of the effects by the pasture structure (sward surface height and sward depletion), observer and the total number of bites in multiple BC (Bolzan et al., 2020), minimizing the difference between methods (Table 1).

Evaluating foraging behavior at the smallest scale of the grazing process, the bite (Laca & Ortega, 1995), allows us to understand each type of bite during the grazing process (Illius & Gordon, 1987). It elucidates the spatio-temporal distribution and variability of the grazing process in response to the variation in components of the vegetation structure. Our work provides evidence of the potential and limitations of the CBM technique. This tool can be used with great assurance in the estimations of STIR, considering the influence factors such as pasture structure (Allden & Whitakker, 1970; Laca et al., 1992; Mezzalira et al., 2017; Nadin et al., 2019), digestibility (Drescher et al., 2006), and selectivity (Hodgson, 1979). Both the level of observer knowledge of pasture science principles (i.e., understanding of pasture structure and botanical composition in diverse grasslands) and level of training observers receive are limiting factors for the success of this direct observation technique. The posed question to be addressed in the study directly conditions the detailing of the description of the food actions (BCs) to be evaluated, as well as other ethological standards. In addition to the intake rates, we were able to know the fraction of each BC regarding what they eat, how they eat, and how much they eat of each item.

5. IMPLICATIONS

Our results indicate the accuracy of the hand plucking method and CBM as an alternative to quantify forage intake, i.e., there was agreement between the studied methods. We found an overestimated consumption when using CBM in comparison to DW in experiments 2 and 3. However, we hypothesize that the difference between the methods can decrease by increasing the detail of the BC grid. This extends the possibilities of evaluating animals during the foraging process, especially free-ranging, without significant modifications on the environment or animal manipulation. With the knowledge of quantitative reliance, we have the potential to complement other methodologies, sensor calibration and subsequent use in long-term evaluations. This reality would increase the evaluation capacity of several animals at the same time, in comparison with the CBM method, which restricts the evaluation of only one animal per observer over time, which represents a large time cost in training, evaluation, and transcription.

There is a high demand from the scientific community and general society for experimental protocols that promote animal welfare (Driscoll & Bateson, 1988). Non-invasive methodologies are extremely important to preserve natural animal behavioral principles, avoid diseases (e.g., chromium oxide possesses carcinogenic properties; Sedman et al., 2006) or injuries, and not alter the affective states of animal (avoid pain, fear, suffering, frustration, and distress) (Driscoll & Bateson, 1988, Sherwin et al., 2003, Fraser, 2009). We believe in the potential of the CBM methodology as an important alternative because it does not require physical contact, adaptation to unnatural conditions, or the use of equipment coupled to the animal. Thus, it has high potential for reproducing grazing animal intake in different environments and situations while maintaining animal welfare.

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COMPETING INTERESTS

The authors declare they have no competing interests.

AUTHOR CONTRIBUTIONS

Anderson Michel Soares Bolzan: Conceptualization (Equal); Data curation (Equal); Formal analysis (Equal); Methodology (Equal); Writing-original draft (Equal). **Leonardo Silvestri Szymczak**: Data curation (Equal), Formal analysis (Equal), Methodology (Equal), Writing-original draft (Equal). **Laura Nadin**: Data curation (Equal), Formal analysis (Supporting), Investigation (Equal), Methodology (Supporting), Writing-original draft (Equal). **Olivier François Bonnet**: Conceptualization (Equal), Data curation (Equal), Formal analysis (Equal), Investigation (Equal), Methodology (Equal), Writing-original draft (Equal). **Marcelo Osorio Wallau**: Formal analysis (Equal), Writing-original draft (Equal). **Anibal de Moraes**: Investigation (Supporting), Methodology (Supporting), Supervision (Lead), Writing-original draft (Supporting). **Renata Franciéli Moraes**: Data curation (Supporting), Formal analysis (Supporting), Methodology (Supporting), Writing-original draft (Supporting). **Alda Lucia Gomes Monteiro**: Data curation (Supporting), Project administration (Lead), Supervision (Supporting), Writing-original draft-(Supporting). **Paulo César de Faccio Carvalho**: Conceptualization (Equal), Data curation (Supporting), Methodology (Supporting), Project administration (Lead), Supervision (Lead), Writing-original draft (Lead).

DATA AVAILABILITY STATEMENT

These data are available at https://doi.org/10.5061/dryad.573n5tb73

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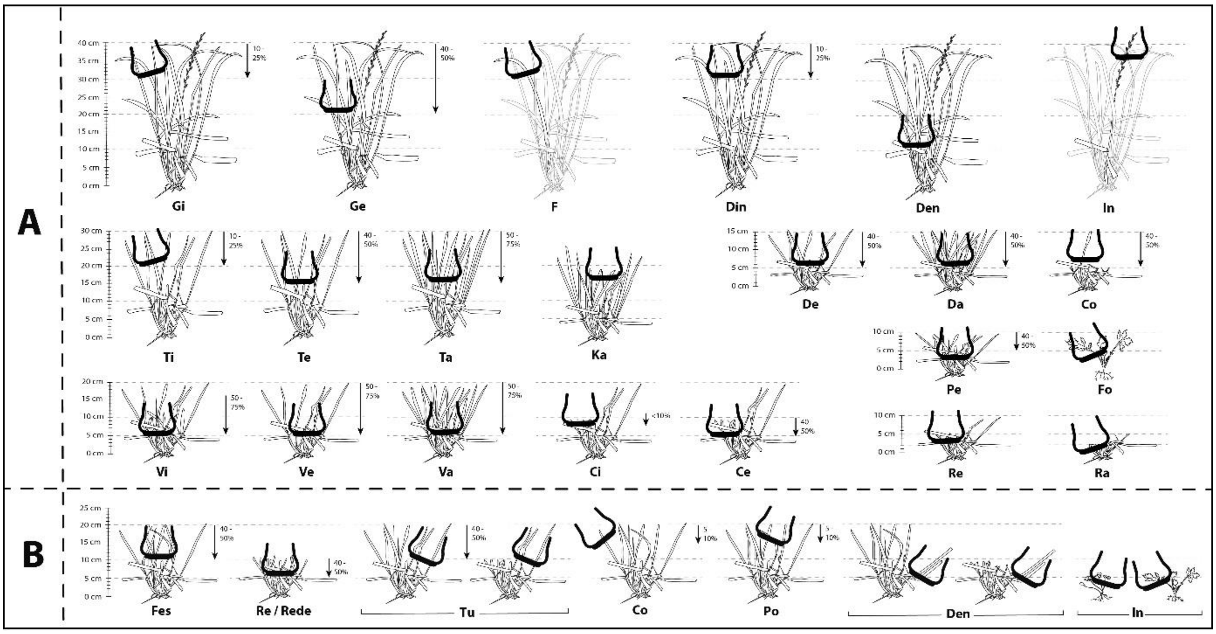

Figure 1. Representation of the types of sheep bites with their respective codes used in the Continuous Bite Monitoring method in Experiment 1 (A) with Italian ryegrass, 2 and 3 (B) with Tall fescue. Drawing, in Experiment 2 and 3 (B), represents the codes used in all tested heights, here demonstrated for the height of 20 cm. Note: The same codes were used for the other treatments. The arrows represent the depth of the bite in bite type. Description of bites is in Table 1 in Supporting Information.

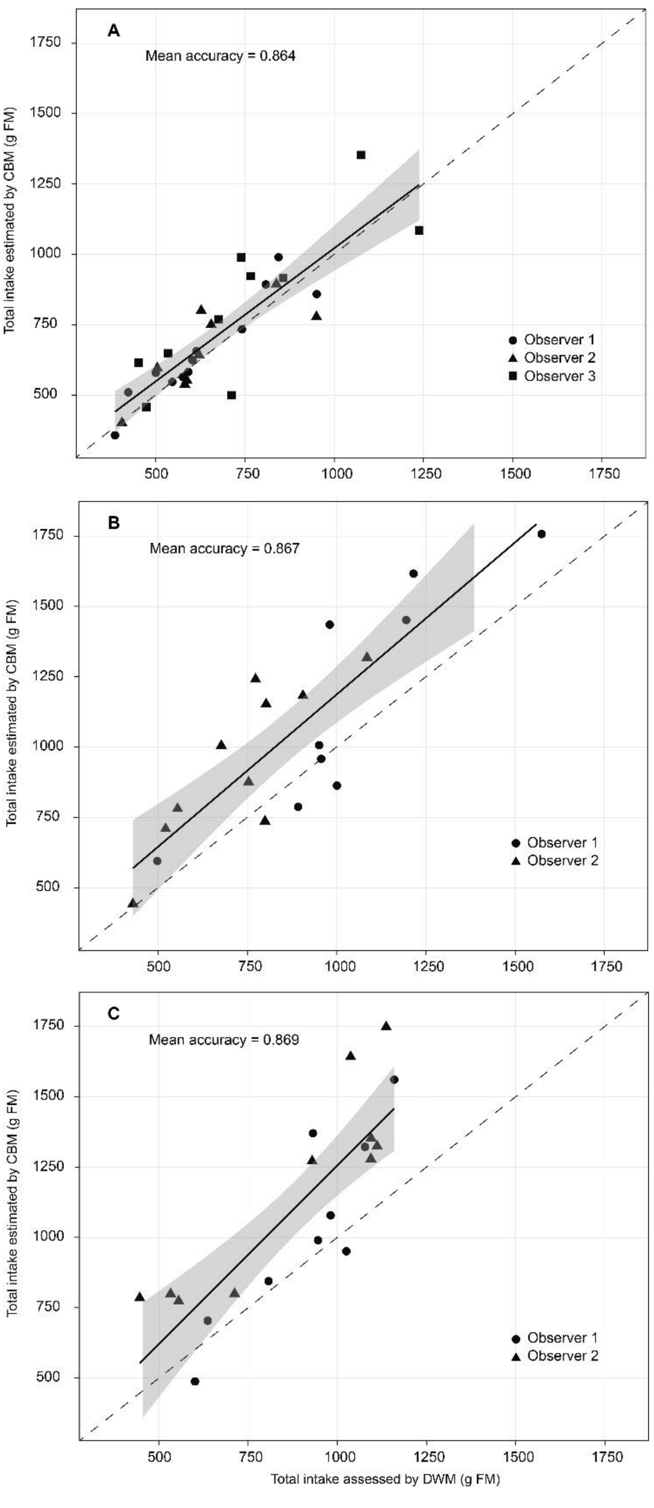

Figure 2. Relationship between the total intake of fresh matter (g FM) of ewes during grazing sessions of 45 min estimated through continuous bite monitoring assessed by the double weight technique, in Experiment 1 (A), 2 (B) and 3 (C). Solid line represents the linear model between the two methods (P < 0.001), dashed lines represent identity (Y = X) and gray area represent the confidence interval of the measurement through double weight with regard to scale precision.

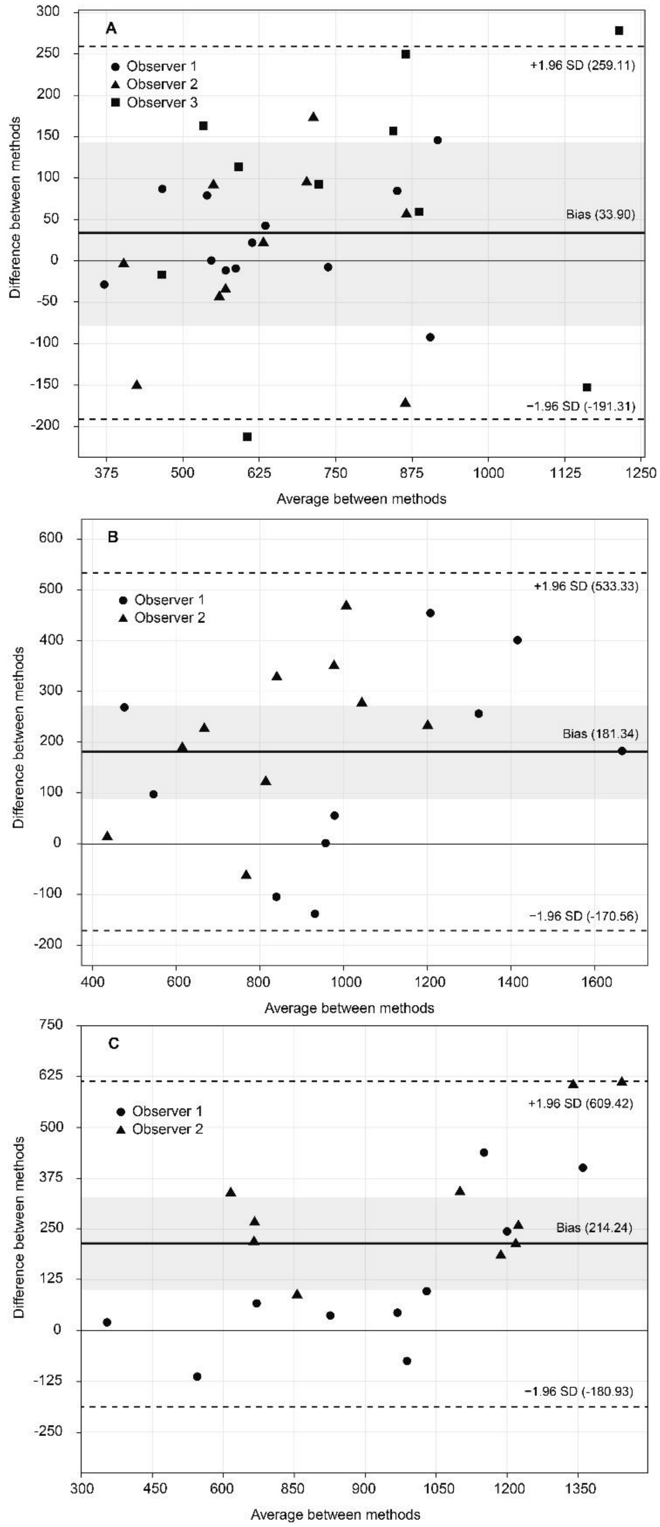

Figure 3. Bland-Altman Plots showing the paired differences against the average between CBM and DWM methods in experiment 1 (Figure A, *P* = 0.1052 in One Sample T-Test), 2 (Figure B, *P* = 0.0002 in One Sample T-Test) and 3 (Figure C, *P* = 0.0001 in One Sample T-Test). Mean bias is represented by black line and limits of agreement are shown by the dashed lines, while confidence intervals are shown by the gray areas.

Table 1. ANOVA table for the potential sources of variation of the error in the estimation of fresh matter intake through CBM. *Day* refers to the number of days with observation since the beginning of the experiment, *Period* to the period of the day evaluated (morning or afternoon) and *Total bites* to the total number of bites observed during one trial. Interactions were not significant and were removed from the final model.

Source of variation	df	*F* value	*P* value
Experiment 1			
Observer	2	4.75	0.018
Animal	3	1.97	0.14
Day	1	0.06	0.81
Total bites	1	0.17	0.68
Experiment 2			
Sward Surface Height	4	12.478	0.0002
Observer	1	3.633	0.078
Day	4	1.091	0.314
Period	1	0.083	0.777
Total bites	1	27.927	0.0000
Experiment 3			
Sward Depletion	4	91.46	0.0000
Observer	1	11.02	0.006
Day	4	7.724	0.101
Period	1	1.640	0.68
Total bites	1	15.392	0.0000

CAPÍTULO III

Foraging behaviour of bovines and equines under mixed herbivory[3]

[3] Manuscrito elaborado conforme as normas do periódico *Oecologia* (Apêndice 4).

Foraging behaviour of bovines and equines under mixed herbivory

Abstract

Sward structure is the cause and consequence of grazing actions, affecting the intake rate of herbivores. We hypothesized that different foraging behaviors of equines and bovines in coexistence and their effects on vegetation structure would enhance the ingestion of both animals due to the inter-niche ecological relationships and the different interactions in the animal-plant interface resulting from morphophysiological differences between species. To test if their coexistence under mixed grazing affects the opportunities for diet selection compared to monospecific grazing, we characterized the feeding actions of equines and bovines in the pastoral environment by continuous bite monitoring during daily foraging behavior. We verified that the mixed herbivory system has a higher availability of bites with a higher intake rate available in the pasture structure compared with the monospecific grazing. This effect is positively evidenced in the food selection and composition of the diet for cattle and neutral for horses, conferring a condition of facilitation of horses towards cattle when in mixed herbivory condition.

Introduction

Pastoral ecosystems have a relevant distribution, ~ 40% of the global surface (Suttie 2005) and in biodiversity disposition (Bengtsson et al. 2019), organized in horizontal (at the same trophic level) and vertical (between trophic levels) trophic levels (Duffy et al. 2007). This implies complex herbivore-resource relationships in time and space, with effects on the plant community (Senft et al. 1987), spatial distribution of herbivores and food niches (Bell 1971; Jarman 1974; Shipley and Spalinger 1995). In the multifunctionality of pastoral ecosystems, increasing diversity (e.g., herbivory mixed system management, Dumont et al. 2020; Martin et al. 2020) promotes resource use efficiency in the short term (e.g., animal performance) (Prins and Fritz 2008; Ormunen-Cristian et al. 2012; Fraser et al. 2014), and subsequently the stability of the plant community (Henning et al. 2017; Schmitz and Isselstein. 2020), greater system autonomy (Thenard 2019; Bonaudo et al. 2013), such as immune (Jordan et al.1998; Eysker and Mirck 1986; Forteau et al. 2019) and metabolic functions (Modernel et al. 2019).

Sympatric equines and bovines potentially have variability in intake and digestion flows (Ferreira et al. 2007) resulting from morphophysiological differences (Demment and Van Soest 1985; Hofmann 1989) and niches specificities (Illius and Gordon 1992; Walker 1994; Menard et al. 2002). The bovines are generalists in foraging behavior, using the movement of the tongue to enlarge the bite area (Illius and Gordon 1987) and having a ruminal apparatus as an evolutionary advantage for digesting forage at a moderate fiber level, as well as tolerating toxic factors of inert plants under fermentation (Freeland and Janzen1974; Van Soest 1983; Provenza et al. 2003).

On the other hand, horses are less affected by high levels of fiber, with no physical constraint on the particle in the fermentative compartment (hindgut), compensating for the low rate of digestion by increasing intake (Edouard et al. 2008), and a consequently increasing in grazing time (Janis 1976; Duncan et al. 1990). In addition, horses can modulate intake in the food niche breadth (Bell 1971; Janis 1988) into distinct structures to balance energy and protein intake (Edouard et al. 2010), and they are more efficient grazing short swards patches (Naujeck et al. 2005), which are likely potentially rejected by cattle (Fleurance et al. 2009).

Accordingly, these two animal models are able to explore different food niches within the same resource (Murray and Illius 2000; Arsenault and Owen-Smith 2008), due to selective differences in the exploitation of canopy structures (Grant et al. 1985, 1987; Lamoot et al. 2005; Dumont et al. 2010; Karmiris et al. 2011) as a consequence of processes of feed facilitation and complementarity (Hooper. 1998; Arsenault and Owen-Smith. 2002; McNaughton 1976; Sinclair and Norton-Griffiths 1982).

Having the bite as the basis of the grazing process (Laca & Ortega.1985; Shipley et al. 1994), and considering the morphophysiological differences of horses and cattle, which affect the form of forage selection and harvest (i.e., diversity of bites) in the sward structure (i.e., sward height and botanical composition) (Flores et al. 1993) we seek to understand the foraging of horses and cattle on this scale, the execution patterns, and the construction of the diet. These animal decisions at the bite level, determine the short and long-term forage intake (Mezzalira et al. 2017; Bergman et al. 2001). The bite diversity in the diet selection of the equine and bovine can confer relations of facilitation and complementarity during the foraging process by the bite diversity (Carvalho 2013).

We intend to approach the grazing process in a fine scale (i.e., bites) and assess the interactions of the pluriespecific coexistence of herbivores on the structure of the vegetation and explore the responses on forage intake comparing monospecific and mixed herbivory systems. In this context, we hypothesize that i) Sympatric equines and bovines promote the availability of more profitable feeding actions (bites), generating a facilitation process; ii) bovines and equines select by profitability and have different diets when in coexistence iii) equines explore a wider range of feeding actions to compose their diet than bovines.

Material and Methods

Study area and experimental design

The protocol was carried out at the INRA experimental station at Le Pin-au-Haras (48°44 N; 0°08 W; 140–248 m a.s.l., Normandy, France). Three different herbivory system managements were assigned to three permanent pasture areas (paddocks) of equivalent dimensions managed under continuous stocking: a mixed-species herbivory system ("Mixte") with two animal models (bovine and equine), consisting of six Charolais heifers (1.0 ± 0.1 years old, 411 kg ± 30 kg body weight (BW)) and three equines (2 ± 0.1 years old, 448 ± 37 kg BW) in a paddock with 5.93 ha^{-1} area; a bovine monospecific herbivory system ("Monobov") with 12 Charolais bovines (1.0 ± 0.1 years old, 408 kg ± 26 kg BW) in a paddock with 6.0 ha^{-1} area; and an Equine monospecific herbivory system ("Monoequi") by six equines Anglo-Arab and French saddle breeds (3.2 ± 0.1 years old, 461 ± 33 kg BW) in a paddock with 5.76 ha^{-1} area. The paddocks had similar history of use (cattle grazing) and floristic composition before the allocation of treatments (see Appendix 2). The grazing season had 177 days, starting at April 25, 2018, and ending on October 18, 2018. The animals had access to half of the total paddock area in the first 68 days (Period 1, spring) whereas the other half of the area was allocated to hay production (i.e., ungrazed). Then the animals had access to the total paddock area (Periods 2 and 3, summer). The stocking density in the spring was two livestock units (LU) ha^{-1} and 1 LU ha^{-1} in the summer. The stocking densities were calculated using the INRA animal unit system for bovines [1.0 ± 0.1 years, 500 kg ± 5.0 kg (BW) 0.6 LU equivalent] (Inosys Réseaux d'élevage, 2018) and for equines [2 ± 0.1 years of age, 500.0 ± 6.5 kg (BW) 0.94 LU equivalent] (Martin-Rosset 2015).

Vegetation resource

Vegetation structure and the availability of bites

To describe the vegetation in each system, 60 quadrats distributed on the surface of the paddocks were characterized before ingestive behavior assessments. At each sampling, a quadrat of 1 m^2 was placed on the ground and forty-five regularly spaced canopy height measurements were taken using a sward stick (Barthram 1985). In each contact point (touch) the sward height was measured, and the type of sward structure was described according to the bite code (BC) determined for the assessment of ingestive behavior. The vegetation structure was previously described in the assessments of ingestive behavior. Then the BCs (Fig. 1) (Appendix 3) were characterized in the spatial distribution of pasture available for animal selection in the different herbivory systems.

Herbage biomass and growth

To determine herbage mass (kg DM ha^{-1}), the forage was cut at ground level in eight quadrats of 0.25 m^2 per paddock, systematically located to represent heterogeneity. Before the cut, five points of height were taken. After cutting, the herbage samples were dried in an oven at 55 °C for 72 hours and weighed (Mannetje 2000). Linear models were generated (Period 1: $y = 115.86x + 0$, $R^2=0.89$, $P<0.001$; Period 2: $y = 121.58x + 0$, $R^2=0.77$, $P<0.001$; Period 3: $y = 236.62x + 0$, $R^2=0.93$, $P<0.001$) between herbage mass and the average sward height to predict herbage mass from sward height assessments (Kunrath et al. 2020). Thereby, the herbage mass was predicted based on approximately 1000 points measured with sward stick on each paddock (i.e., system) performed by systematic sampling in parallel transects (~ 3 m) (Barthram et al. 2005).

The daily rate of herbage accumulation was estimated using four exclusion cages per paddock (Klingman et al. 1943). The initial herbage mass and the herbage accumulated in each subperiods (30 days) were used to calculate the total herbage production (kg DM ha^{-1})

Animal measurements

The evaluations were carried out in three periods: 1) May and June; 2) July and August; and 3) September and October. For the assessment of foraging behavior, three (testers) focal individuals per animal species were evaluated in each herbivory system (n = 12). All animals, including testers, were periodically weighed at 15-day intervals. In addition, body measurements were taken at the beginning of the season and at the end of the equine grazing season.

Continuous bite monitoring

We used the Continuous Bite Monitoring (CBM) method proposed by Agreil & Meuret (2004) and Bonnet et al. (2015) to investigate the grazing process, considering the botanical diversity of swards. We followed the mutual familiarization indicated to ensure the accuracy in the description of food actions (i.e., bite assesment) (Bolzan et al. 2020). The observation time of each individual was defined so that we could obtain a comprehensive description of the daily scale of the foraging. In this sense, we strictly maintained 4 hours of morning observation and 5 hours in the afternoon (7:00 -12: 00 and 14:00 - 19:00). Three animals of each species were observed in each period by a single observer. (3 horses - mixed, 3 mixed cattle, 3 Monoequi and 3 Monobov).

Designing of the bite-coding grid

Based on the plant components in the sward and the foraging characteristics of each animal model, a grid of bite codes (BCs) was elaborated. It is worth noting that the definition of feeding actions in bite codes is an ordered representation of how the animal interprets the resource and performs the feeding action.

Bite codes have been defined that encompass more than one botanical type, as well as codes of isolated botanical types. As a basis for classification, we considered: 1- isolated plants, set of intra and interspecific plants (e.g., grass mixed, or grass mixed plus legume species, or others); 2- nature, size and structural characteristics that affect the bite allocation position (i.e., sward height); 3- handling and cutting behavior of the animal. The bite diversity in this study included 25 types of BCs, combined with nine classes of sward height and 35 types of BCs without height class (Annex 1). Additionally, were characterized other codes to define behavioral expressions such as interaction between individuals, mutual toilet, social grooming, or reactivity towards disturbance by flies, steps, feeding stations, the horizontal distance of feces, their effects on the intake rate. We used a Sony ICD-PX312 portable digital voice recorder to gather BC data. Records were subsequently transcribed using the JWatcher software (www.jwatcher.ucla.edu).

Sampling of feed Items and the evaluation of bite mass

At the end of each grazing event or its intervals (i.e., idleness and rumination), the observer performed a simulation of the BCs in the most reliable way possible to the bites made by the animal. When necessary, the observer used a cutting blade. At the end of the observation day, all BCs performed in the cumulative interval were simulated. Every BC was simulated at least 20 times, and the BCs that occurred with more frequency were simulated two or three times more than the less frequent ones. The mass of each BC was obtained by the total mass of the dry sample after 72 hours at 60 °C divided by the number of BCs in the sample, thus obtaining the value of the average mass of each BC for each animal and day of evaluation. This weighted simulation of the BCs allowed to increase the samples and represent the different moments of accumulated consumption in grazing that make up the diet.

Nutritive value of each bite-code

The nutritive value of each type of BC was obtained by NIRS spectrophotometer analysis according to laboratory protocol and equations INRA - UMRH1213. The calibration equations used for the prediction of the value is based on the following reference methods: ash content per ash at 550 °C for crude protein (CP) content combustion method (Thiex 2009), fiber fractions (neutral detergent fiber [NDF], acid detergent [ADF], acid lignin detergent [ADL]) after Van Soest (1963) and in vitro digestibility of organic matter (OMD, De Boever et al. 1986).

Calculations of variables and statistical analysis

Bite mass and nutritive value

Bite mass (dry matter basis) was modeled and then predicted by using the following linear mixed-effects models through “lmer” function of the *lme4* package (Bates et al. 2015): y ~ bite-code * species + paddock + (1 | period) + (1 | animal). The mass of each nutrient by bite code was calculated as the dry matter multiplied by the concentration of the respective nutrient. The NDF, ADF, nitrogen and mineral matter were predicted by using the following linear model: y ~ bite-code * species * paddock * period. Organic matter was calculated as the difference between total dry matter and the mineral matter, and crude protein CP (nitrogen x 6.25). The total intake observed of dry and organic matter by animal were calculated as a sum of all bite masses.

Bite profitability

The profitability (i.e., the potential gain of intake rate of nutrients) of each bite code (g DM min^{-1}) was calculated by species and herbivory system as the quotient of the bite mass and time per bite. To calculate time per bite, we used “chunks” (i.e. intervals with a sequence of the same bite code and divided the number of bites by the duration of each interval) of rows with sequence of a same bite code and divided the number of bites by the duration of each “chunks”. Chunks with less than 2 bites were discarded. Then, we used the calculated time per bite to parameterize the following linear mixed-effects model: y ~ bite-code + species + paddock + (1 | period) + (1 | animal). We used the "weights" argument in the “lmer” function of the *lme4* package (Bates et al. 2015) to account for the variation in chunk length.

Potential intake available in each herbivory system

In order to test whether herbivores had greater opportunity to select more profitable bites, we calculated the frequency of intake rate available (hereafter called potential intake rate) by multiplying the profitability of each bite code by their respective frequency on the resource (i.e., vegetation structure). The potential intake was analyzed through the linear model formula of the "lm" function of the *lmer* package: y ~ species * system * period. Analysis of variance (ANOVA) was performed and when significant effects were detected, treatment means were compared with Bonferroni test at 95% confidence level using the *emmeans* package.

Intake rate, diet composition and selection

Diet composition (n bites and frequency of observed bites) was verified by the sum of the performed bite, and their relative frequency according to the height classes and botanical types of the universe of bite codes for each animal in each herbivory systems and periods.

The intake rate for each botanical type and height classes of the bite codes were calculated by the accumulated intake of the respective botanical type or height class in each bite code, divided by the number of this bite code and the time of the same bite code. To calculate the time per bite, we used intervals with a sequence of the same bite code and divided the number of bites by the duration of each interval. Diet selection is assumed as the frequency of BCs of each height classes of bites and botanical types of bites present in the diet in relation to the BCs available in the vegetation structure. Selectivity (Si) for each BC was calculated using the Jacob's index (1974) derived from the Ivlev's selectivity index, where:

$$Si = (ci-ai) / (ci + ai-2ciai)$$

being (ci) the ratio between (0 and 1) of the component in the diet, and (ai) the ratio between (0 and 1) of the component (i) in the vegetation matrix.

For each BC (ci), the data of individual animals was aggregated by period, and then related to the relative abundance of this type of bite in the paddock.

Selectivity (Si) varies from -1 (never used) to +1 (used exclusively), with negative and positive values indicating avoidance and preference, respectively, and 0 indicating that a component of the sward is used in proportion to its availability. The Jacobs index was chosen for its low sensitivity to variations in the relative abundance of plant components, making it possible to classify abundant and rare plant components according to their acceptance by animals.

Analysis of variance (ANOVA) was performed using the linear mixed effects model using the "lmer" function of the *lme4* package (Bates et al. 2015). The fixed effect were botanical classes or heights classes, species and herbivorous systems, periods and their interactions, and animals with a random effect. When significant effects were detected, treatment means were compared with Bonferroni test at 95% confidence level using the *emmeans* package.

Results

Forage resource

Sward structure did not show pronounced variations between mixed or monospecific systems for the frequencies and patterns of sward heights (Fig. 2) and botanical distribution in the periods of the grazing season (Fig. 3). We observed equivalence in the herbage mass (kg DM ha^{-1}) predicted from the sward height measurements in each system (i.e., Mixte, Monoequi and Monobov) in each period of the grazing season (Period 1: 2541.8 ± 772.4; 2541.2 ± 828.4; 2700.9 ± 854.6; Period 2: 2673.7 ± 681.6; 2324.9 ± 604.1; 2548.8 ± 689.1; Period 3: 2892.0 ± 529.8; 2553.1 ± 339.2; 2684.0 ± 378.9, for Monoequi, Monobov and Mixte, respectively). The daily herbage accumulation rate was different ($P < 0.05$) only between periods (Period 1: 52.6 ± 8.1; Period 2: 30.0 ± 4.8; Period 3: 23.1 ± 5.8 kg DM ha^{-1} day). The total herbage production (kg DM ha^{-1}) in each herbivory system was 8650 ± 853.3 for Monoequi, 7550 ± 574.4 for Monobov, and 7925 ± 1043.6 for the Mixte system.

Potential intake

The potential intake of organic matter (OM) and crude protein (CP) min^{-1} (Fig. 5a and 5b) depicts the density of feed actions (i.e., bite codes) and their potential intake rate (i.e., profitability) for each currency (OM or CP), for each species, in each herbivory system along the grazing season periods. A higher potential OM intake (Fig. 5a) was observed in Mixte system for bovine species (27.16 ± 0.67) compared to Monobov (19.53 ± 0.49), equines in the Mixte system (18.59 ± 0.42) and Monoequi (17.02 ± 0.42). The potential OM intake min^{-1} did not differ between evaluations periods ($P = 0.5357$). For CP (Fig. 5b), there was no interaction between systems and period. There was a higher potential intake for bovines in Mixte (4.74 ± 0.12) compared to Monobov system (3.8 ± 0.11). For horses, there was no difference between Mixte (3.36 ± 0.08) and Monoequi systems (2.82 ± 0.06). The potential CP intake g min^{-1} was higher in Periods 1 (3.86 ± 0.09) and 2 (3.97 ± 0.09) than in Period 3 (3.18 ± 0.07).

Intake rate

We ranked the profitability currencies of OM and CP min^{-1} of bites by height classes (Table 1) for each herbivory system, with no interactions with periods. We found higher OM intake rates min^{-1} for bovines in both Monobov and Mixte systems at sward height classes 5-8, 9-13, 14-18 and 19-23 cm ($P<0.05$). In the same height classes, bovines in the Mixte system had a higher OM intake rate compared to Monobov. For equines in the Mixte system, the intake rate was equivalent in all classes for OM currency, except for the 0-2 cm sward heights. Equines in the Monoequi system had higher intake rates at sward height classes 5-8, 9-13, and 14-18 cm. Horses showed similarity in the OM intake rate for all sward height classes between Mixte and Monoequi systems. When grazing together (Mixte), bovines had higher intake rates than horses in equivalent sward heights, except for the class 24-30 cm. When verifying the interaction of height classes between systems for the currency CP, the height classes that promoted the highest OM intake rates were also the classes that most benefited CP intake for Mixte bovines. The CP intake of bovines was lower in Monobov compared to Mixte, considering the sward heights that promoted the highest CP intake rates in both systems (9-13, 14-18 and 19-23 cm). For the classes 3-4, 14-18 and 24-30 cm, the intake rate of bovines was not statistically different between systems. Equines had similar CP intake rates for all sward heights in both systems and lower than bovines.

The intake rate of OM and CP of equines and bovines for different botanical types (Table 2) showed interaction for periods ($P < 0.05$). In Period 1, when observing the classes of botanical types in each system, we found that cattle in Mixte system had a higher rate of ingestion of OM min^{-1} in bites composed by “grass_legu”, “grass_forbs” and “grass_forbs_legu”, the same for Monobov that also had a higher intake of OM from these classes and in the “grass” class. Mixte bovines had a similar or higher intake rate in the most profitable categories compared to Monobov. The rate of OM intake for equines was similar for all botanical types except for “forbs”, with no difference between systems. In Period 2, Mixte bovines had a similar OM intake rate in the botanical types "grass_forbs", "grass_legu" and "grass_forbs_legu". As for the classes “grass_forbs”, “grass_legu” with the addition of the type “grass” are the most profitable for Monobov. Equines had similar intake rates for all types except the “forbs” type with no effect between systems. In the Mixte system, bovines had ingestion rates higher than equines for all items except for the “forbs” type, with an equivalent interspecies ingestion rate. In Period 3, Mixte bovines had similar intake rates for all types except "forbs" and "grass_forbs_legu". For Monobov, the intake rate was equivalent among botanical types. There was no difference in intake rate of bovines for types in the Mixte system. In the Monoequi system, only the “forbs” type had a lower intake.

The CP intake rate of bovines in the Mixte system was higher in bites with legumes in Period 1. For bovines in Monobov, the CP intake was similar for all botanical types except for “forbs”, in which it was lower. The CP intake rate for equines in Monoequi was higher for the types "grass_legu" and "grass_forbs_legu". For equines in the Mixte system, the highest CP intake occurred in the “grass_legu” type. In Period 2, Mixte bovines had a higher rate of ingestion in pieces composed of two or more types. In

Monobov, the rates of ingestion did not differ between types. In the Mixte system, bovines had a higher intake rate than the other systems in the types "grass_legu" and "grass_forbs_legu". In Period 3, bovines had similar ingestion rates between types except for the type "forbs", in which it was lower in the Mixte system, whereas in Monobov the intake rate was equivalent for all types. The CP intake rate of equines was not statistically different between types and systems. In the Mixte system, bovines had a higher intake than in Mixte and Monobov in the “grass” and “grass_legu” types. There was a greater CP intake by Monobov for the type "forbs", with no statistical difference from the Mixte system regardless of the species.

Diet composition

The total number of bites observed during daily observation presented an interaction for herbivory system and period ($P < 0.032$) (Table 3 and 4). In Periods 1 and 2, no differences were detected between the systems, with averages of 11582 and 10290 bites per day respectively. In Period 3, the highest total number of bites was observed in the Monobov system (18407), followed by equines in the Mixte systems (13466), bovines in the Mixte system (13092) and Monoequi (10156). The number of bites observed in each of the sward height classes and botanical types showed a species, system and period interaction ($P < 0.001$). In Period 1, Mixte bovines selected the diet mainly in the classes between 5-8 and 9-13 cm, with the class 5-8 cm being the most selected by Monobov. Mixed equines distributed their diet between 3-4, 5-8, 9-13, 14-18 cm classes. Monoequi had a higher frequency of bites in the 5-8 cm class. In Period 2, Monobov, Monoequi and Mixte equines concentrated their bites in the same height classes (5-8, 9-13 and 14-18 cm). Mixte bovines took more bites in classes similar to other treatments, in addition to class 3-4, 5-8, 9-13 and 14-18 cm. In Period 3, the most frequent height class in the diet of equines and bovines was 5-8 cm. As for botanical types, Mixte bovines pronouncedly selected grasses and legumes "grass_legu" in Period 1, whereas Monobov bovines distributed their diet in all types, except for forbs. Equines preferred types “grass” and “grass_legu” regardless of the herbivory system. In Period 2 Mixte equines took more bites on grasses than Mixte cattle, and like Monobov and Monoequi. Mixte bovines had a greater share of "grass_forbs" in the diet than Monoequi horses, with no statistical differences from Mixte equines and Monobov bovines. In Period 3, Mixte bovines had a higher frequency of "grass", “grass_forbs", and "grass_legu" bites, whereas the Monoequi horses composed their diets with grasses and legumes only (“grass” and “grass_legu” types). Equines Mixte had most bites in grass type grasses. They have more pieces in grasses than Mixte bovines and Monoequi, without differing from Monobov bovines.

Diet selection

For the selection of bites in the height classes (Fig. 6), we observed an interaction between species, system and period (P <0.001). In Period 1, there was a pronounced positive selection by bovines (+1) for the lowest height class (0-2cm) in both herbivory systems. For bovines, there was a difference between monospecific positive (+1) and moderate negative selection for bovines in mixed systems (-0.5). In the 2-4 cm and 5-8 cm height classes, equines and bovines had strong positive selection (+1) regardless of the system. In the 9-13 cm class, the equines had a neutral index (close to 0), regardless of the system. Monobov had moderate negative selection (-0.5) and neutral for Mixte bovines (0). In classes 14-18 and 19-23 cm, horses and cattle had a moderate negative selection (-0.5). For class 24-30 cm, equines and bovines in both systems had a negative selection (-1). The 31-40 cm class showed strong negative selection (-1) for bovines regardless of the herbivory system, moderate negative selection (-0.5) for Mixte equines, and strong negative selection (-1) for Monoequi. Class 41-50 was not consumed by bovines and presented a strong negative selection (-1) for Mixte equines and Monoequi horses. In Period 2 for classes 0-2 and 3-4 cm the selection was moderately negative (0 to -0.5) and did not differ for the same species between systems, nor between species in the mixed system.

The 5-8cm class had moderate positive selection (+0.5), classes (9-13 and 14-18) neutral selection (0) to animals in all systems. The 19-23cm class had moderate negative selection (-0.5) to animals in all systems. The 24-30, 31-40, and 41-50cm class had a negative selection in all systems. In Period 3, the selection was similar to all systems. The 0-2cm class had moderate negative, moderately positive for 3-4 and 5-8 class, moderate negative for 9-13cm class, and negative for other classes (14-18,19-23, 24-30, 31-40, and 41 -50).

The selection of bites relative to the different botanical types did not show interaction for periods. The “forbs” type had a pronounced negative selection (-1) for bovines Intersystem and Mixte equines, and moderate negative for Monoequi (-0.5). The grass type selection was moderate negative for Mixte bovine and neutral for Monobov. For bovines, it was neutral (0) regardless of the herbivory system. The type "grass_forbs" was slightly rejected (-0.25) by bovines in both systems. However, for equines the selection was negative in both systems. For “grass_forbs_legu”, the selection was slightly positive between systems bovines and mild to moderate negative for Intersystem equines (-0.25 to -0.5). The type "grass_legu" did not differ between species between system was moderately positive for all.

Discussion

Vegetation resource

The animals did not experienced forage resource constrains and therefore this condition allows to evaluate the expression of feed selection and the foraging effects of both models on the pastoral ecosystem. As in previous studies (Forteau et al. 2019; Fleurance et al. 2016) the livestock unit (LU) ha^{-1} was used to perform the equivalency among herbivory systems (Inosys Réseaux d'élevage, 2018 – UGB-Bovine; and Martin Rosset, 2015 – UGB-Equine). Thus, we had the equivalent of 2 LU ha^{-1} in Period 1 and 1 LU ha^{-1} in Periods 2 and 3. The difference between periods was adjusted according to the seasonality of the plant growth.

The resource availability in the herbivory systems was isonomic in the canopy height distribution patterns (Fig. 2), on herbage mass (Fig. 4), herbage accumulation rates, and total herbage production showing differences between the periods of the grazing season. Then, we consider the dynamics of occurrence of the potential bites as an effect of the imposed herbivory system itself since the systems were also balanced in floristic terms (Fig. 3).

Potential Intake rate

The characterization of the bites in the vegetation structure (Fig. 1) (see more details in Annex 1), and the simulation of the bites allowed us to calculate both the instantaneous intake rate and to predict the potential intake of nutrients available in each herbivory system. We found that the mixed herbivory system provided a potentially higher nutrient intake (i.e., OM and CP) for bovines than the monospecific herbivory system (Fig. 5). This is because the bites available in the sward would allow bovines to be more profitable in the bite selected, an advantage that we did not see for the equines in the same system. For the same potential bites available in the mixed system, the profitability for equines was not superior to the monospecific system. This point is consistent with our hypothesis that the mixed herbivory system favors foraging for bovines, at least in potential terms, with no disadvantage for equines.

With the profitability calculated for each bite code, we sought to understand how the elements that shaped the feed actions (Fig. 1) (sward height and botanical types) interfered with the intake rate (Table 1 and 2). We examined if the animals select for profitability as inferring foraging models (Stephens and Krebs 1986; Spalinger & Hobbs 1992) in addition, checking if the bovines exploited the potential of the mixed system and if the equines followed the same pattern of foraging of that in monospecific systems to optimize the intake of OM and CP (Bergman et al. 2001; Edouard et al. 2010).

The prediction that the mixed system presents a greater availability of bites with higher potential intake rate in OM and CP (Fig. 5) currencies for bovines and indifferent for equines is a less static way of referring to the forage resource and quantifying the potential ingestive responses resulting from cause-and-effect relationship in grazing systems (Parsons & Penning 1988). Our prediction considered the different peculiarities of foraging in sympatric equines and bovines or in a monospecific system as suggested by Lamoot et al. (2005) and Karmiris et al. (2011).

We attributed a facilitation interaction (McNaughton 1976; Sinclair and Norton-Griffiths 1982; Arsenault and Owen-Smith. 2008) from equines to bovines by predicting the highest potential intake rate for bovines in the mixed system, with no negative effect for equines. The potential CP (Fig. 5b) intake rate was also higher for bovines, despite the reduction in the potential CP intake rate observed in Period 3 (Fig. 5b). This difference might be related to forage resource maturation (Drescher et al. 2006). No matter how much the animals have the ability to select higher than available nutritional value (Prache et al.1998), the structural limits for ingestion (Ungar and Demment. 1991) reflected in the lower levels of nutrient intake at the end of the grazing season (Fryxell 1991), which was verified in the content of the observed bites that supported this prediction.

Intake rate

The higher intake rates observed for bovines and equines (Table 1 and 2) in intermediate heights are consistent with other studies that considered this factor and conceived the highest intake rate within these limits, as the forage maturation theory (Drescher et al. 2006). The constrain imposed by digestibility does not seem to be the strongest in our case, but the benefits of for ingestibility do (Fryxell 1991), for this considering the morphophysiology of the bovine oral apparatus, which can expand the bite size by using the tongue (Illius and Gordon 1987) making cattle able to take bites with greater density (Shipley 2007) and therefore suffering less with the effects of the canopy dispersion at taller heights (Gordon and Benvenutti 2006).

The same classes that optimized the OM intake rate also optimized the CP intake for bovines in the mixed herbivory system (Table 1). Cattle in the monospecific system had a lower number of profitable classes for CP available than mixed bovines. In the lower classes (0-2 and 3-4 cm) and classes above 24-30 cm, the intake rate was equivalent for bovines in both systems. It is likely that below the lower limit the intake rate was compromised by the limited harvesting capacity of bites at excessively short swards (Allden and Whitakker 1970; Laca et al. 1992; Mezzalira et al. 2017; Nadin et al. 2019), while beyond the upper limit it was compromised by the searching time and manipulation of taller, sparse plants, which ended compromising bite formation as well (Wallis de Vries, Laca and Demment 1998; Gordon and Benvenutti, 2006).

In comparative terms, equine have an equal or lower intake rate of OM and CP than Monobov, and lower than Mixte bovines. This difference was already presented by previous authors (Bell 1971; Janis 1976; Duncan et al. 1990), as there were no major differences in the concentration of nutrients in the yield of feeding actions (to be noticed in the OM and CP contents of intake rates, Table 1 and 2). The ingestive response is more dependent on the factors previously mentioned that interfere in instantaneous intake.

Based on our intake rate results, the coexistence of equines and bovines shows an advantage in the intake rate of bovines, consistent in part with our hypothesis. On the other hand, the intake rate of OM and CP was similar for equines, regardless of the system. As we found a greater similarity in the interclass intake rates for Mixte bovines compared to Monoequi, we suggest that this higher intake rate in the diversity of height classes could provide a strategy for optimizing nutrient intake. However, it is not clear whether horses would have a preference for optimizing CP intake (Edouard et al. 2010; Fleurance et al. 2005), but we can infer that this optimization would not be limited by competition with bovines in the case of the Mixte system, as predicted and reflected in the composition of the diet.

The differentiated oral morphology of equines (lip mobility and upper incisors) gives them the capacity for greater elasticity in feeding actions by manipulating vegetation structures and allowing them to more easily adapt to the structural challenges of swards (Shipley, 2007). This characteristic could explain why equines achieve rates of ingestion in some conditions similar to bovines (e.g., classes 3-4 cm). This would be a useful strategy for coexistence when competing with another herbivore (Duncan 1990). In our case, bovines that are skilled at higher ingestion rates in the most profitable structural strata (Table 1).

Although the Mixte equines were exposed to the effects of competition with the bovines, they were able to explore the sward height gradient in equal or superior profitability that the Monoequi equines through their foraging elasticity, which does not denote a disadvantage of the mixed herbivory system. At this point, it would be consistent with our hypothesis that the mixed system provides an ingestion rate for both species, and that equines explore the greatest range of feeding actions for ingestion as an adaptive effect to competition (Janis and Ehrhardt 1988).

Diet Composition and Selection

We assume that the non-harmful conditions for equines and advantageous for bovines in the mixed system predicted by the potential intake reflected in the composition of the diet. At the time of greatest stocking density, we credit the elasticity of foraging by equines on exploring the sward structure to optimize intake, which is consistent with our hypotheses (Janis and Ehrhardt 1988; Duncan 1990; Bukombe et al. 2019). At the beginning of the season, the bovine diet does not differ in botanical types of bites (Table 4). More than half of the bites of Mixte bovines are in the “grass_legu” type, which optimizes the intake rate of OM and CP and with positive selectivity for all animals. For Monobov, the diet partition is balanced between types "grass", "grass_forbs and "grass_legu”

However, although the hierarchy of types in the diet is different for bovines, the proportions are equivalent between systems. Equine diets do not differ in types. The interspecies botanical types in the Mixte system do not differ, showing a niche overlap for this period. Equines and bovines compete for the same types for the elaboration of the diet but explore different compartments in the canopy structure. We attribute this to a complementarity effect (Sinclair and Norton-Griffiths. 1982) at this moment in the mixed system, which guarantees the equivalent intake between equines between systems, and the facilitation that allows bovines to exercise preference for the profitability in bites (Arsenault and Owen-Smith 2002; McNaughton 1976).

For equines, the diet composition was similar between the hierarchy of botanical types, with the most participatory being "grass" (neutral selectivity) and "grass_legu" (positive selectivity). Mixte equines took more bites of "grass" type than Monoequi. This would be a disadvantage of the system to bovines for the intake rate, but it is consistent with other studies that show preference of horses for grasses (Fleurance et al. 2016). In the Mixte system, bovines had more "grass_forbs" than equines, the latter rejecting this type whereas it presented null selectivity by bovines. The equines have more “grass” bites (null selectivity) in the diet than bovines (rejected), supporting the complementarity of niches, because in the same gradient of height strata, they explore different components (Gwyne and Bell 1968; Putman et al 1987; Murray and Illius 2000; Arsenault and Owen-Smith 2008).

Period 3 was under the effect of canopy structure depletion (Fig. 2 and 3) and presenting the memory of the effects of grazing on the herbivory systems (Monoequi, Monobov, and Mixte). The bovines exercised their preference and composed their diet by optimizing the intake rate (5-8), however, the bovines Monobov have ~ 30% of the diet in the preferred class (3-4cm) but outside the maximum intake rate, therefore penalizing the foraging. We can understand the consumption of the types 'grass' and mainly 'grass_legu' as a compensatory selection for Monobovs since these types make up most of the diet in this period and have a null and positive selection, respectively.

In conditions where the pastoral ecosystem imposed constrains due to the higher stock density or resource depletion, sympatric animals explore the complementarity and facilitation of niches to optimize intake rates. We noticed that equines were able to compensate for the competition for forage resources with bovines by modulating the selection of the diet in classes of the height of the canopy and in botanical such as grass for horses and grass legu for cattle, exploring the gradient of heights (Table 3 and 4). This factor has already been mentioned in studies with equines and bovines in which the diversification of the diet allows success in equines foraging (Bell 1971) compared to cattle that potentially have higher ingestion rates. We verified this phenomenon where similar accumulated daily consumption was observed between species and systems (Table 5). Because of foraging elasticity (Belovsky 1997; Laca et al. 2010), equines had similar ingestion rates for many height classes and in different botanical types in the universe of potential bites.

We credit oral and lip mobility, which denotes an important tool for the challenge of the animal-plant interface in foraging (Flores et al. 1993; Naujeck, Hill and Gibb 2005), for preparation of bites (apprehension and cutting), such as exploring parts of plants in the selection (e.g., claw bites on leaf tips), or shallow bites in structural components of legumes (e.g., "grass_legu" in which equines press the canopy against the ground). Therefore, equines, even when sharing patches (Bailey 1996), have greater possibilities to explore the diversity of feeding actions (bites), even though in the universe of equine and bovine bites they explored a similar number of bite codes.

Conclusion

Our results support the positive property of mixed herbivory systems for bovines and without prejudice for equines when compared to monospecific herbivory systems. The scale of observation of the study, the bites, allowed checking the animals' ability to modulate their diet selection to optimize intake rate. During the grazing season, with the effects of the variation in stock density and depletion of the advantage resource for the intake rate of bovines and horses in the mixed herbivory systems.

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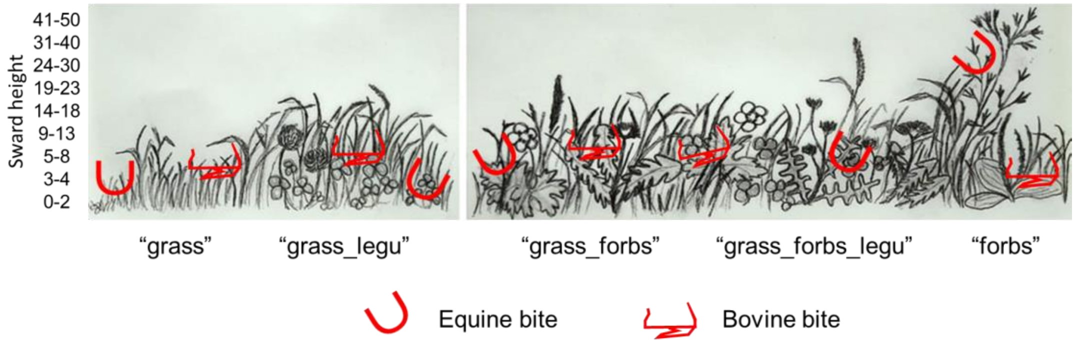

Fig.1 Characterization of bite codes according to botanical types

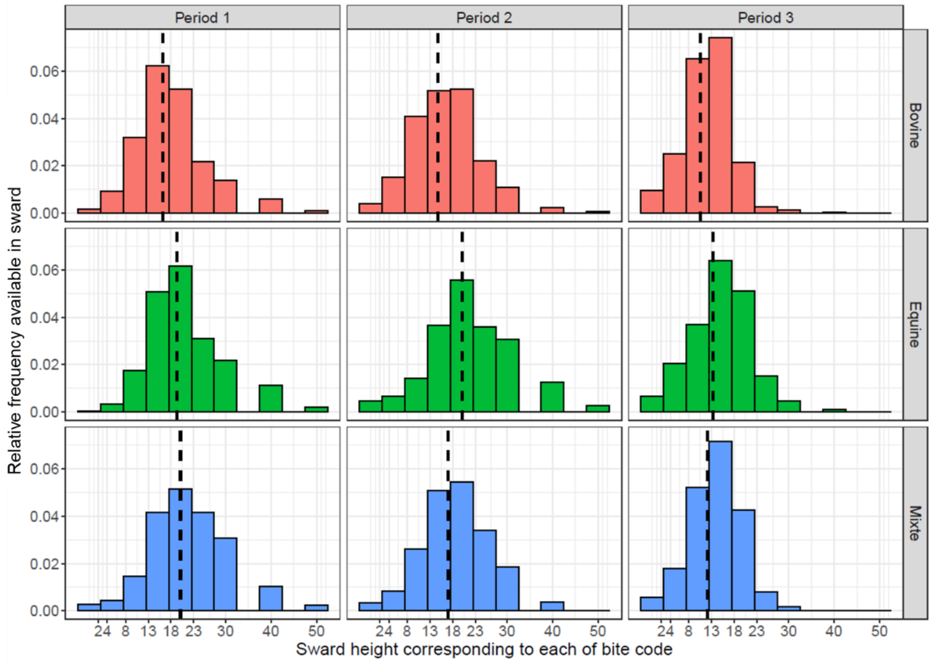

Fig.2 Relative frequency the sward height classes of bites available accounted in sward structure. Section lines represent of the average of the height classes. Periods: 1) May and June; 2) July and August; and 3) September and October.

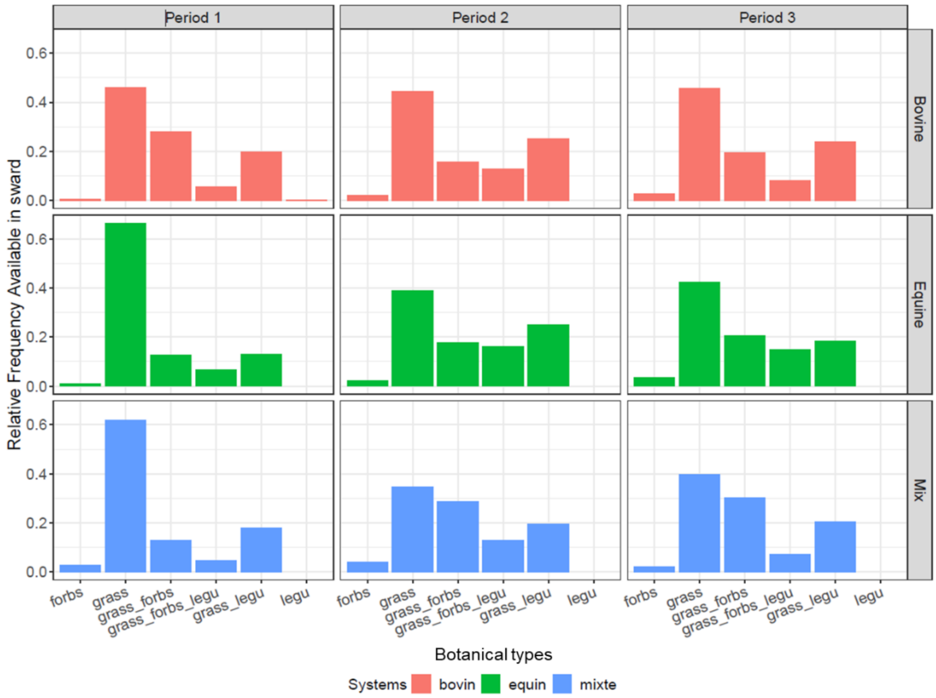

Fig.3 Botanical composition corresponding of bites available accounted in sward structure. Periods: 1) May and June; 2) July and August; and 3) September and October.

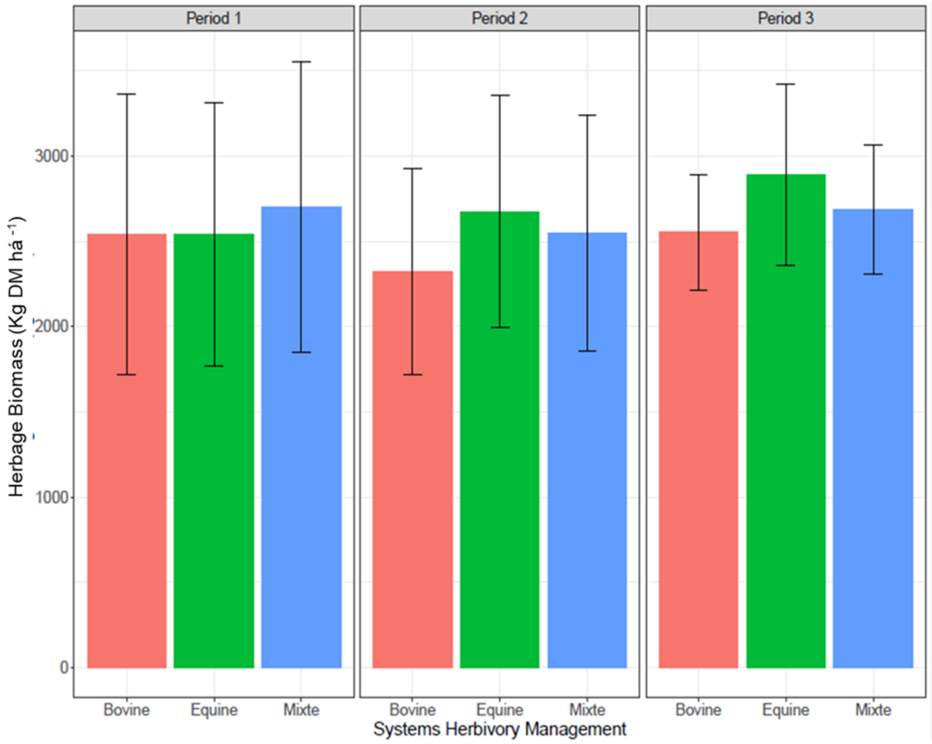

Fig.4 Herbage biomass kg DM ha^{-1} of the resource available was calculated with base by the linear models were generated between herbage biomass and the average sward height observed in the quadrat with the intercept adjusted to zero to each availed period [Period 1: $y = 115.86x + 0$, $R^2 = 0.89$ $P < 0.001$; Period 2: $y = 121.58x + 0$, $R^2 = 0.77$, $P < 0.001$; Period 3: $y = 236.62x + 0$, $R^2 = 0.93$, $P < 0.001$]. Subsequently, the equations and

height measurements in each system were predicted the herbage biomass available. Periods: 1) May and June; 2) July and August; and 3) September and October.

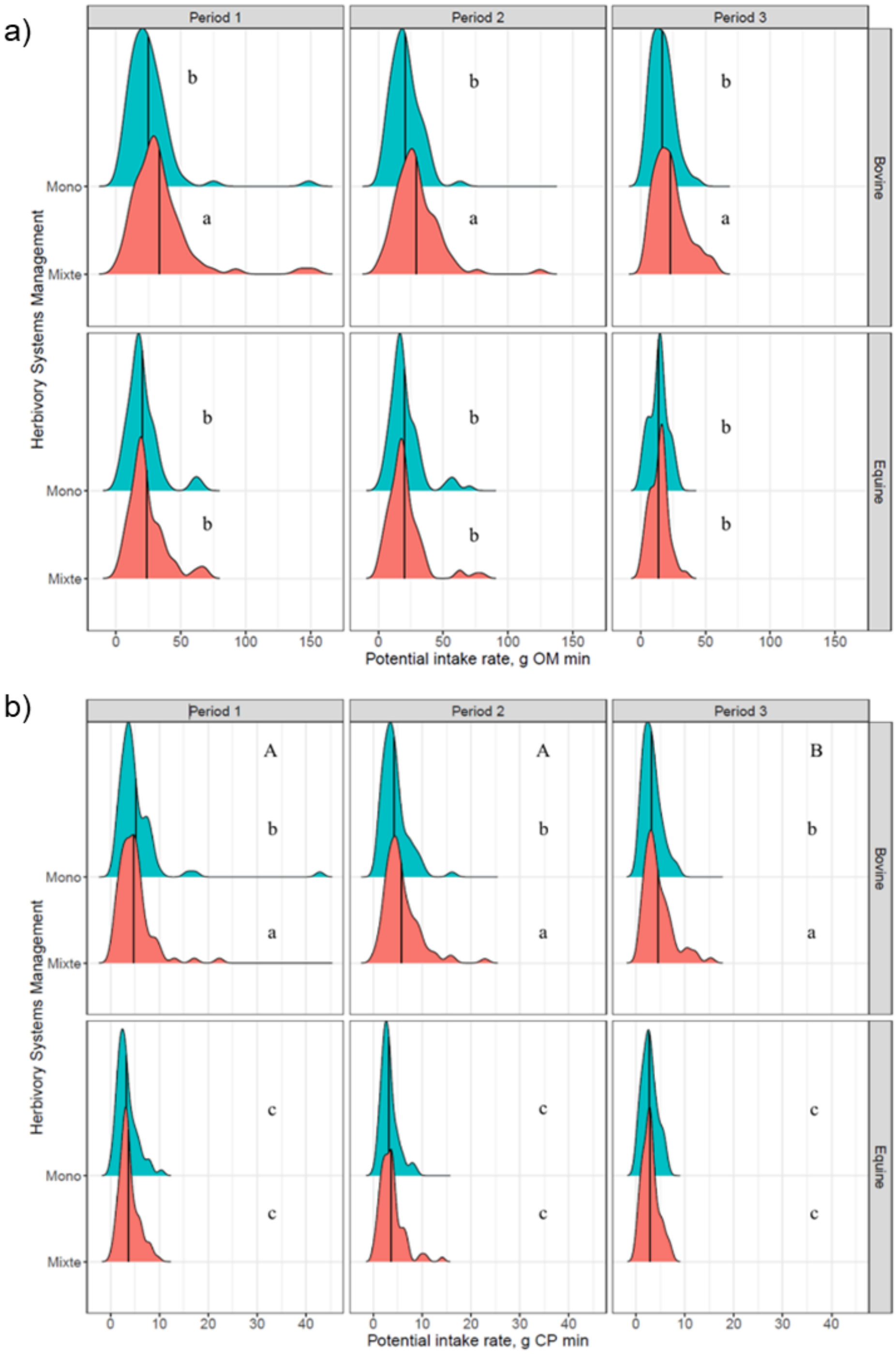

Fig.5 Potential intake rate of (a) organic matter (OM) and (b) crude protein (CP) predicted by the profitability of the bite-codes available in the canopy (x axis) for each herbivory system and animal model (y axis) over the stocking season. The potential OM and CP intake rates (g min^{-1}) were calculated considering the profitability of each bite type predicted based on the nutritional value obtained by hand plucking sampling for each bite-code recorded during the Continuous Bite Monitoring evaluation. Periods: 1) May and June; 2) July and August; and 3) September and October.

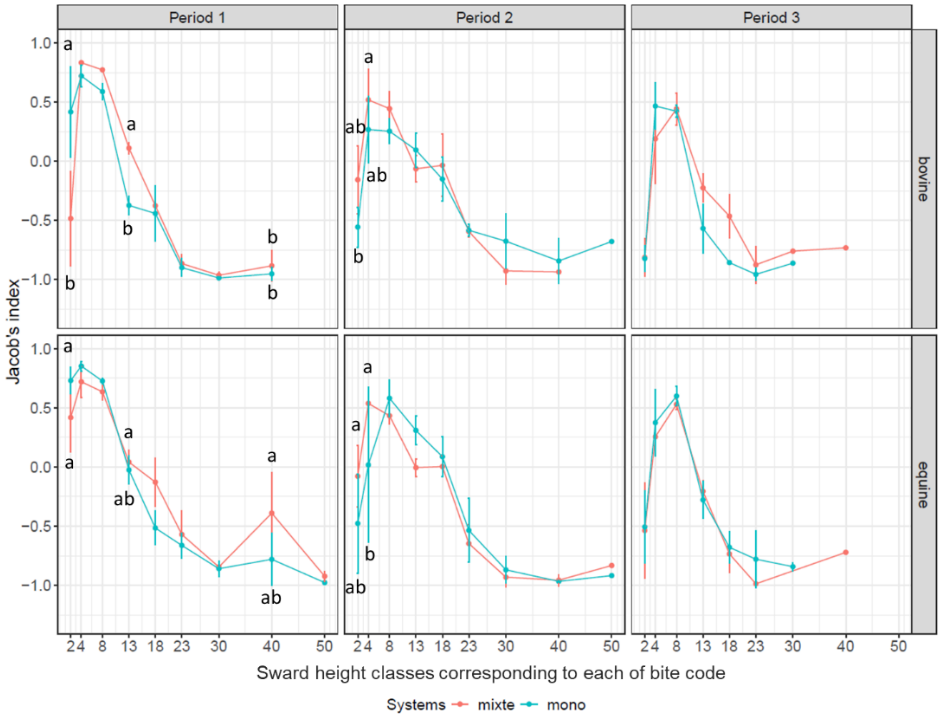

Fig.6 Diet selection of the sward height classes by Jacob's index; Varies from -1 (never used) to +1 (used exclusively), with negative and positive values indicating evasion and preference, respectively, and 0 indicating that a component of the sward is used in proportion to its availability. The different letters refer to statistical difference (P <0.05) by the Bonferroni multiple comparison test.

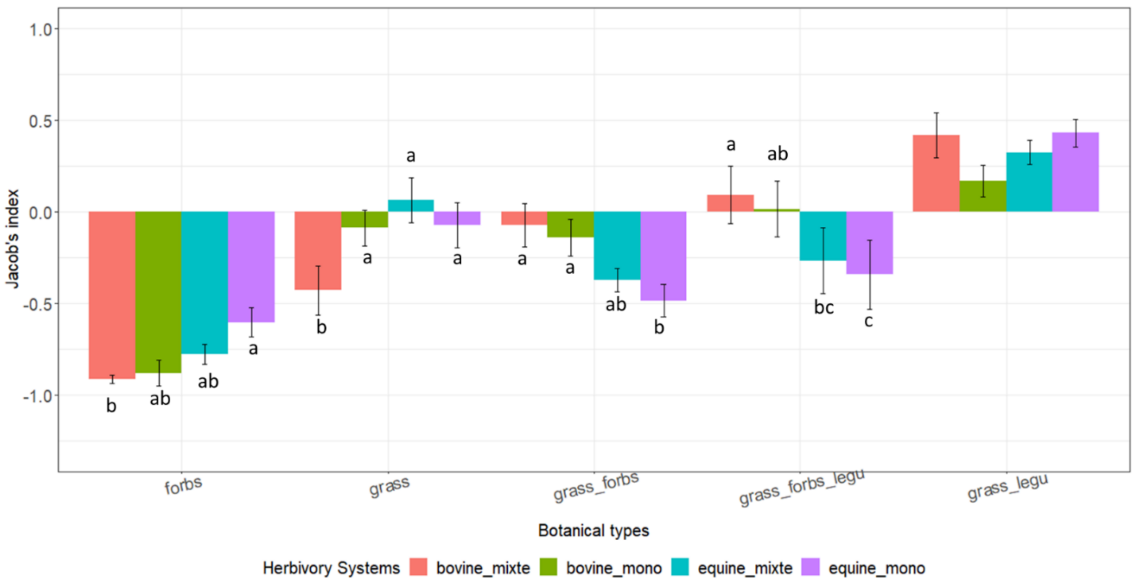

Fig.7 Diet selection of the botanical types by Jacob's index; Varies from -1 (never used) to +1 (used exclusively), with negative and positive values indicating evasion and preference, respectively, and 0 indicating that a component of the sward is used in proportion to its availability. The different letters refer to statistical difference (P <0.05) by the Bonferroni multiple comparison test.

Table 1. Intake rate by sward height classes of bites

Species		Equine		Bovine	
System		**Mono**	**Mixte**	**Mono**	**Mixte**
Currency		Organic matter (g min^{-1})			
Height (cm)	0-2	6.31 (1.085) d	6.21 (0.982) b	7.55 (0.997) c	7.00 (1.165) c
	3-4	7.70 (0.773) bc	7.32 (0.707) a	8.14 (0.710) bc	9.94 (0.689) b
	5-8	10.00 (0.683) a B	9.06 (0.675) a B	10.47 (0.683) a B	13.25 (0.653) a A
	9-13	9.29 (0.651) ab B	8.75 (0.660) a B	11.50 (0.672) a B	14.21 (0.637) a A
	14-18	9.64 (0.683) ab C	9.37 (0.676) a C	12.30 (0.702) a B	15.48 (0.646) a A
	19-23	8.68 (0.813) bc B	10.25 (1.062) a B	9.80 (1.249) ab B	16.20 (0.804) a A
	24-30	6.88 (0.995) cd B	---------	9.50 (1.689) bc AB	10.42 (1.668) b A
	31-40	---------	7.54 (1.845) ab	---------	11.87 (1.816) bc
	41-50	---------	---------	---------	---------
Currency		Crude protein (g min^{-1})			
Height (cm)	0-2	1.27 (0.209) bc	1.29 (0.187) b	1.65 (0.190) d	1.43 (0.226) d
	3-4	1.38 (0.141) abc B	1.49 (0.125) a AB	1.68 (0.126) cd AB	1.93 (0.121) bc A
	5-8	1.71 (0.120) a B	1.70 (0.118) a B	2.01 (0.120) bc B	2.38(0.113) ab A
	9-13	1.56 (0.112) ab B	1.65 (0.114) a B	2.29 (0.117) ab B	2.55 (0.109) a A
	14-18	1.61 (0.120) ab C	1.65 (0.118) a BC	2.28 (0.124) a AB	2.63 (0.111) a A
	19-23	1.55 (0.150) abc C	2.27 (0.204) a BC	2.25 (0.244) ab B	2.99 (0.148) a A
	24-30	1.25 (0.190) c B	---------	2.02 (0.336) bcd AB	2.06 (0.332) cd A
	31-40	---------	0.811 (0.369) c	---------	1.49 (0.363) d
	41-50	---------	---------	---------	---------

Letters lowercase in column refer to the statistical difference between height classes to specie. Uppercase letters in on lines refer statistical difference between species in treatments ($P < 0.05$) by the Bonferroni multiple comparison test, (*) mean standard error. The intake rate for each height class was calculated whit time per bite code, we used intervals with a sequence of the same bite code and divided the number of bites by the duration of each interval. After we checked the intake rate of each bite code in each height class in the sward.

Table 2. Intake rate by botanical types by species in each herbivory system

	Species	Equine		Bovine		Equine		Bovine	
	System	Mono	Mixte	Mono	Mixte	Mono	Mixte	Mono	Mixte
		Currency OM g min^{-1}				Currency CP g min^{-1}			
Period 1	forbs	7.46 (1.220) b A	5.26 (1.332) b AB	3.30 (1.584) b B	6.99 (1.187) c A	1.220 (0.232) b A	0.928 (0.255) c A	0.757 (0.306) b B	1.681 (0.225) c A
	grass	7.55 (0.848) ab B	6.15 (0.805) a B	8.22 (0.798) a AB	10.66 (0.802) b A	1.458 (0.154) b	1.543 (0.145) b	2.040 (0.143) a	1.954 (0.144) bc
	grass_forbs	10.80 (0.835) a B	9.35 (0.721) a B	11.52 (0.753) a B	17.00 (0.697) ab A	1.410 (0.151) b B	1.395 (0.126) b B	2.405 (0.134) a A	2.148 (0.121) b AB
	grass_legu	11.33 (0.909) a B	10.92 (0.947) a B	13.08 (0.927) a B	20.76 (0.968) a A	2.452 (0.167) a	2.383 (0.175) a	2.235 (0.171) a	3.067 (0.180) a
	grass_forbs_legu	11.71 (0.850) a A B	9.24 (0.946) a B	11.45 (0.749) a AB	16.31 (0.779) ab A	1.989 (0.154) a AB	1.740 (0.175) b B	2.113 (0.133) a AB	2.443 (0.139) ab A
Period 2	forbs	4.75 (1.187) b B	5.21 (1.134) b AB	5.82 (1.965) c B	10.07 (1.584) c A	0.696 (0.225) b C	1.243 (0.214) b BC	1.630 (0.383) AB	1.861 (0.306) c A
	grass	6.26 (0.893) ab B	6.57 (0.888) ab B	8.57 (0.905) ab AB	10.30 (0.859) b A	1.213 (0.164) ab B	1.410 (0.163) ab AB	1.649 (0.166) AB	2.327 (0.157) bc A
	grass_forbs	8.66 (0.731) ab B	9.21 (0.728) a B	11.07 (0.822) ab AB	15.46 (0.714) ab A	1.601 (0.129) a B	1.557 (0.128) b B	1.751 (0.148) AB	2.612 (0.125) ab A
	grass_legu	9.17 (0.947) a B	10.83 (0.918) a B	12.69 (1.122) a B	17.00 (0.917) a A	1.511 (0.175) a B	2.063(0.169) a B	2.081 (0.169) B	3.707 (0.212) a A
	grass_forbs_legu	10.12 (0.895) a B	10.48 (0.936) a B	10.42 (0.979) bc B	15.92 (0.831) ab A	1.655 (0.164) a B	2.110 (0.173) a B	1.884 (0.182) B	3.226 (0.151) ab A
Period 3	forbs	4.53 (1.135) b AB	4.95 (1.439) AB	8.03 (1.957) A	6.35 (1.958) c AB	0.868 (0.215) b B	1.062 (0.277) b AB	2.359 (0.382) A	1.402 (0.382) b AB
	grass	6.97 (0.901) ab	7.75 (0.980)	8.58 (0.946)	9.72 (0.872) ab	1.425 (0.165) ab B	1.928 (0.182) a AB	1.405(0.175) B	2.056 (0.159) a A
	grass_forbs	9.15 (0.805) ab	9.18 (0.809)	10.30 (0.843)	10.61 (0.789) ab	1.509 (0.145) ab	1.754 (0.146) a	1.951 (0.153)	1.894 (0.141) ab
	grass_legu	9.28 (1.006) a B	9.07 (1.053) AB	11.22 (1.020) AB	13.01 (1.020) a A	1.565 (0.188) a B	1.797 (0.198) a AB	1.624 (0.191) B	2.238 (0.191) a A
	grass_forbs_legu	8.78 (1.008) ab	8.27 (0.981)	9.76 (0.919)	9.0 (0.865) bc	1.705 (0.188) a	1.631 (0.182) a	1.593 (0.169)	1.791 (0.158) ab

Letters lowercase in column refer to the statistical difference between botanical types to specie. Uppercase letters in on lines refer statistical difference between species in treatments ($P < 0.05$) by the Bonferroni multiple comparison test, (*) mean standard error.

Table 3. Diet composition by Sward height classes of bites

Species			Equine				Bovine			
System			mono		mixte		mono		mixte	
Diet			bites %	bites n	bites %	bites n	bites %	bites n	bites %	bites n
total bites observed				11864.0		9810.7		13132.7		11266.7
Period 1	height (cm)	0-2	0.016	192.2 de	0.040	396.4 bc	0.029	379.5 de	0.006	64.2 c
		3-4	0.177	2102.3 b AB	0.144	1413.7abc B	0.241	3165.0 b A	0.201	2266.9 b AB
		5-8	0.380	4509.5 a A	0.265	2603.8 a B	0.425	5581.4 a A	0.382	4303.9 a AB
		9-13	0.247	2929.2 bc	0.224	2193.7 ab	0.171	2249.6 bc	0.248	2793.0 ab
		14-18	0.126	1494.9 cd	0.216	2120.1 ab	0.125	1637.6 cd	0.138	1555.9 bc
		19-23	0.036	429.5 e	0.069	677.9 bc	0.007	85.4 e	0.060	676.0 c
		24-30	0.009	109.1 e	0.015	147.2 c	0.001	6.6 e	0.003	37.2 c
		31-40	0.008	92.5 e	0.026	250.2 bc	0.001	9.2 e	0.003	38.3 c
		41-50	0.000	1.2 e	0.004	3.9 c	0.000	0.0	0.000	0.0
total bites observed				8303.7		11643.7		8253.5		11252.3
Period 2	height (cm)	0-2	0.001	7.9 c	0.015	178.1 bc	0.006	48.7 c	0.013	150.8 b
		3-4	0.050	416.0 bc	0.131	1521.8 b	0.136	1121.7 bc	0.142	1596.7 ab
		5-8	0.242	2012.0 a	0.278	3235.8 a	0.304	2510.7 a	0.190	2135.7 a
		9-13	0.302	2506.0 a	0.254	2954.0 a	0.299	2470.3 a	0.233	2622.9 a
		14-18	0.319	2650.5 ab	0.275	3204.3 a	0.210	1732.4 ab	0.268	3011.1 a
		19-23	0.066	548.0 bc	0.043	499.5 bc	0.032	261.6 c	0.050	557.0 b
		24-30	0.013	107.1 c	0.004	43.1 c	0.012	94.9 c	0.040	45.0 b
		31-40	0.001	9.1 c	0.000	4.7 c	0.001	7.4 c	0.060	68.0 b
		41-50	0.001	4.2 c	0.001	9.3 c	0.001	4.1 c	0.000	0.0
total bites observed				10203.3		13481		18397.7		13077.3
Period 3	height (cm)	0-2	0.012	123.5 d	0.011	141.6 de	0.005	90.1 d	0.003	41.8 d
		3-4	0.222	2269.2 b B	0.144	1944.0 b B	0.298	5478.8 b A	0.156	2044.0 bcB
		5-8	0.478	4880.3 aC	0.534	7202.9 a B	0.546	10041.4 a A	0.482	6303.3 aBC
		9-13	0.211	2157.0 c	0.270	3633.1 b	0.142	2606.9 c	0.262	3427.6 b
		14-18	0.062	636.7 d	0.041	552.7 cd	0.009	167.4 d	0.093	1212.3 cd
		19-23	0.011	112.2 d	0.002	2.7 e	0.000	5.5 d	0.000	3.9 d
		24-30	0.001	20.4 d	0.000	0.0 e	0.001	9.2 d	0.001	15.7 d
		31-40	0.000	0.0	0.000	0.0 e	0.000	0.0	0.001	7.8 d
		41-50	0.000	0.0	0.000	0.0 e	0.000	0.0	0.000	0.0

Letters lowercase in column refer to the statistical difference between height classes to specie. Uppercase letters in on lines refer statistical difference between species in treatments ($P < 0.05$) by the Bonferroni multiple comparison test.

Table 4. Diet composition by Botanical types of bites

Species		Equine				Bovine			
System		Mono		Mixte		Mono		Mixte	
Diet		bites %	n bites	bites %	n bites	bites %	n bites	bites %	n bites
total bites obseved		11864		9810.7		13132.7		11266.7	
Period 1	forbs	0.006	68.8 c	0.002	18.6 c	0.001	7.9 b	0.002	21.4 b
	grass	0.413	4899.8 a A	0.412	4040.0 a AB	0.309	4055.4 a AB	0.138	1550.3 b B
	grass_forbs	0.074	882.7 bc	0.084	824.1 c	0.245	3210.9 a	0.11	1239.3 b
	grass_legu	0.326	3872.4 ab B	0.392	3843.8 ab AB	0.301	3955.6 a AB	0.562	6331.9 a A
	grass_forbs_legu	0.18	2137.9 abc	0.110b	1082.1 bc	0.145	1899.0 ab	0.188	2121.5 b
total bites obseved		8303.7		11643.7		8253.5		11252.3	
Period 2	forbs	0.007	55.6 b	0.009	107.1c	0.005	42.1b	0.002	27.0 b
	grass	0.445	3691.8 a AB	0.439	5110.4 a A	0.476	3932.0 a AB	0.161	1813.9 ab B
	grass_forbs	0.075	622.8 b B	0.135	1566.1 bc AB	0.17	1403.1 ab AB	0.374	4203.9 a A
	grass_legu	0.423	3513.3 a	0.373	4346.6 ab	0.211	1743.1ab	0.372	4183.6 a
	grass_forbs_legu	0.05	417.7b	0.044	508.8 c	0.136	1124.1ab	0.091	1024.0 b
total bites obseved		10203.3		13481		18397.7		13077.3	
Period 3	forbs	0.59	60.2b	0.003	36.4 c	0	3.7 b	0.001	7.8b
	grass	50.43	5145.5 a B	0.605	8152.0 a A	0.483	8884.2 a A	0.41	5363.0 a B
	grass_forbs	4.92	502.0 b	0.139	1871.2 bc	0.114	2091.8 b	0.205	2676.9 ab
	grass_legu	41.53	4237.4 a AB	0.228	3075.0 b B	0.363	6676.5 a A	0.324	4239.7a AB
	grass_forbs_legu	2.5	255.1 b	0.026	343.8 bc	0.04	737.7 b	0.06	130.8 b

Letters lowercase in column refer to the statistical difference between height classes to specie. Uppercase letters in on lines refer statistical difference between species in treatments ($P < 0.05$) by the Bonferroni multiple comparison test.

Table 5. General variables of the intake process

Variables	Bovine Mono	Bovine Mixte	Equine Mono	Equine Mixte	Period 1	Period 2	Period 3	*P* system	*P* Period	Interaction
Cumulative intake observed of the OM (g)	1469.5 (121)	1656.7 (112)	1521.9 (112)	1490.9 (112)	1180.9 (90)	1467.3 (96)	1596.0 (90)	0.7414	0.7584	0.1744
Intake rate DM (g min^{-1})	5.51ab (0.50)	8.04a (0.48)	5.42b (0.46)	5.03ab (0.48)	6.73a (0.29)	5.64ab (0.36)	5.64b (0.32)	0.0185	0.0235	0.1538
Intake rate currency. OM (g min^{-1})	20.72b (1.00)	28.44a (0.95)	18.09b (1.01)	19.11b (0.99)	25.55a (0.84)	22.54b (0.80)	16.69c (0.92)	<0.001	<0.001	0.5357
Bite mass (g)	0.27a (0.02)	0.33b (0.02)	0.34a (0.02)	0.30ab (0.01)	0.30b (0.01)	0.34a (0.01)	0.28c (0.01)	<0.001	<0.001	0.1501
Bite rate (bites min-1)	29.55ab (2.49)	32.40a (2.40)	21.95b (2.39)	23.87b (2.34)	29.6a (1.39)	23.33b (1.65)	27.38ab (1.51)	0.0088	<0.001	0.1501
Number of bite-code observed in grazing saeson (n)	67.6 (3.88)	74.6 (3.56)	65.3 (3.56)	66.0 (3.56)	78.0a (3.04)	72.9a (3.20)	54.1b (3.04)	0.2453	<0.001	0.6284

Different letters in the column indicate statistical difference between sward height classes for each animal species in each system ($P < 0.05$). (*) mean standard error.

CAPÍTULO IV

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[1] Doctoral thesis in Animal Science, Faculty of Agronomy, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil. (124 p.). April, 2021.

4.1 CONSIDERAÇÕES FINAIS

No capítulo II, foi apresentado os limites de precisão para quantificar o consumo de herbívoros em pastejo. A metodologia CBM apresenta um detalhamento refinado para caracterização instantânea da seleção de dietas, e o respaldo com o resultado deste estudo confere uma potencialidade para a utilização desta, no estudo de fluxos de ingestão em pastos de natureza diversa. Visto que a capacitação para a metodologia é capaz de preparar avaliadores para o conhecimento do recurso forrageiro, caracterização do mesmo e capacidade de mimetizar em termos seguros ~ 0,86 a quantidade ingerida pelos herbívoros.

No capítulo III, foi apresentada a vantagem do sistema de herbivoria mista por equinos e bovinos simpátricos para oportunidades potenciais de taxas de ingestão. Esta potencialidade proveniente da rentabilidade de cada bocado para cada espécie, considerando as particularidades da interface planta – animal interespecífica.

O sistema misto apresentou maior taxa de ingestão potencial aos bovinos durante todo o período da estação de pastejo (primavera-outono), e não apresentou desvantagem para os equinos em sistema misto ao sistema monoespecifico. O sistema misto oportunizou aos bovinos a seleção de bocados de maior taxa de ingestão, refletidos na composição da dieta. E os equinos modularam a ingestão, explorando maior diversidade estrutural da estrutura do pasto (por rendimentos semelhantes em bocados em estruturas distintas) para otimizar a ingestão. Atribuímos à complementaridade interespecífica de nichos, e a facilitação dos equinos para com bovinos as melhores condições para ingestibilidade no sistema misto.

Estas respostas auxiliam no entendimento dos mecanismos pelos quais a coexistência pode prover uma interação positiva para otimizar a ingestão que é o fator determinante para performance animal. Além disso, subsidia o incremento de diversidade para a exploração de ambientes pastoris, com as valências que o incremento de diversidade pode conferir, como melhor utilização dos recursos e potencialização das funções ecológicas destes ambientes.

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APÊNDICES

Apêndice 1 – Material suplementar do manuscrito "*What, how and how much do herbivores eat? The Continuous Bite Monitoring method for assessing forage intake of grazing animals.*" (Capítulo II).

Supporting Information

Annex1. Description of the types of sheep bites with their respective codes used in the continuous monitoring of bite method in Experiment 1, 2 and 3, represented in the Figure 1.

Bite Code	Bite Category Description
	Experiment 1
Gi	Superficial bite 10 - 25 % in sward 40 cm
Ge	Bite with depth 40 - 50 % in sward 40 cm
Din	Superficial bite 10 - 25 % of sparse leaves in sward 40 cm
Den	Bite of exploration in sward 40 cm
Ti	Superficial bite 10 - 25 % of sparse leaves in sward 30 cm
Te	Bite with depth 40 - 50 % in sward 30 cm
Ta	Dense bite of leaves with depth 50 - 75 % in sward 30 cm
Vi	Bite with depth 50 - 75% in sward 15 cm
Ve	Bite of sparse leaves with depth 50 - 75 % in sward 20 cm
Va	Dense bite of leaves with depth 50 - 75 % in sward 20 cm
De	Bite with depth 40 - 50% in sward 15 cm
Da	Dense bite of leaves with depth 40 - 50% in sward 15 cm
Ci	Superficial bite < 10 % in sward 10 cm
Ce	Bite with depth 40 - 50% in sward 10 cm
Co	Bite of plant stalks
Ra	Bite in sward grazed < 8 cm

Re	Bite in sward < 8cm
Fo	Bite in other plants or plants parts (i. e., *Sida rhombifoli*a L.)
In	Bite in inflorescences of Italian ryegrass
Ka	Bite superficial in leaves grazed and ungrazed in sward 20 cm
F	Single leaf Italian ryegrass
	Experiment 2
Fes[1]*	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 14 cm.
Fes[2]	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 17 cm.
Fes[3]	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 20 cm.
Fes[4]	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 23 cm.
Fes[5]	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 26 cm.
Tu[1]	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 14 cm.
Tu[2]	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 17 cm.
Tu[3]	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 20 cm.
Tu[4]	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 23 cm.
Tu[5]	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at the sward surface height of 26 cm.
Den[1]	Bite of exploration of tall fescue leaves from lower strata or close to the ground at the sward surface height of 14 cm.

Den^{2} Bite of exploration of tall fescue leaves from lower strata or close to the ground at the sward surface height of 17 cm.

Den^{3} Bite of exploration of tall fescue leaves from lower strata or close to the ground at the sward surface height of 20 cm.

Den^{4} Bite of exploration of tall fescue leaves from lower strata or close to the ground at the sward surface height of 23 cm.

Den^{5} Bite of exploration of tall fescue leaves from lower strata or close to the ground at the sward surface height of 26 cm.

Po^{1} Exploration bite of 4 to 2 leaf tips at the sward surface height of 14 cm. Bite with low mass.

Po^{2} Exploration bite of 4 to 2 leaf tips at the sward surface height of 17 cm. Bite with low mass.

Po^{3} Exploration bite of 4 to 2 leaf tips at the sward surface height of 20 cm. Bite with low mass.

Po^{4} Exploration bite of 4 to 2 leaf tips at the sward surface height of 23 cm. Bite with low mass.

Po^{5} Exploration bite of 4 to 2 leaf tips at the sward surface height of 26 cm. Bite with low mass.

Co^{1} Exploration bite of 1 leaf tip at the sward surface height of 14 cm. Bites with less mass compared to the others.

Co^{2} Exploration bite of 1 leaf tip at the sward surface height of 17 cm. Bites with less mass compared to the others.

Co^{3} Exploration bite of 1 leaf tip at the sward surface height of 20 cm. Bites with less mass compared to the others.

Co^{4} Exploration bite of 1 leaf tip at the sward surface height of 23 cm. Bites with less mass compared to the others.

Co^{5} Exploration bite of 1 leaf tip at the sward surface height of 26 cm. Bites with less mass compared to the others.

Re^{1} Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at the sward surface height of 14 cm. Bite made by the animal itself after intake the first grazing horizon.

Re^{2} Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at the sward surface height of 17 cm. Bite made by the animal itself after intake the first grazing horizon.

Re^{3}	Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at the sward surface height of 20 cm. Bite made by the animal itself after intake the first grazing horizon.
Re^{4}	Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at the sward surface height of 23 cm. Bite made by the animal itself after intake the first grazing horizon.
Re^{5}	Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at the sward surface height of 26 cm. Bite made by the animal itself after intake the first grazing horizon.
$Rede^{1}$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at the sward surface height of 14 cm. Bite performed in places grazed by another animal.
$Rede^{2}$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at the sward surface height of 17 cm. Bite performed in places grazed by another animal.
$Rede^{3}$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at the sward surface height of 20 cm. Bite performed in places grazed by another animal.
$Rede^{4}$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at the sward surface height of 23 cm. Bite performed in places grazed by another animal.
$Rede^{5}$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at the sward surface height of 26 cm. Bite performed in places grazed by another animal.
In^{1}	Bite in other species at the sward surface height of 14 cm.
In^{2}	Bite in other species at the sward surface height of 17 cm.
In^{3}	Bite in other species at the sward surface height of 20 cm.
In^{4}	Bite in other species at the sward surface height of 23 cm.
In^{5}	Bite in other species at the sward surface height of 26 cm.
Experiment 3	
Fes^{A}	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 0% depletion of pasture sward.

Fes^B	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 20% depletion of pasture sward.
Fes^C	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 40% depletion of pasture sward.
Fes^D	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 60% depletion of pasture sward.
Fes^E	Bite with greater mass compared to the others. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 70% depletion of pasture sward.
Tu^A	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 0% depletion of pasture sward.
Tu^B	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 20% depletion of pasture sward.
Tu^C	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 40% depletion of pasture sward.
Tu^D	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 60% depletion of pasture sward.
Tu^E	Bite similar to FES but with less mass. Bites depth corresponding to 40 to 50% of the sward surface height of the tall fescue (first grazing horizon) at 70% depletion of pasture sward.
Den^A	Bite of exploration of tall fescue leaves from lower strata or close to the ground at 0% depletion of pasture sward.
Den^B	Bite of exploration of tall fescue leaves from lower strata or close to the ground at 20% depletion of pasture sward.
Den^C	Bite of exploration of tall fescue leaves from lower strata or close to the at 40% depletion of pasture sward.
Den^D	Bite of exploration of tall fescue leaves from lower strata or close to the ground at 60% depletion of pasture sward.
Den^E	Bite of exploration of tall fescue leaves from lower strata or close to the ground at 70% depletion of pasture sward.
Po^A	Exploration bite of 4 to 2 leaf tips at 0% depletion of pasture sward. Bite with low mass.

Po^B Exploration bite of 4 to 2 leaf tips at 20% depletion of pasture sward. Bite with low mass.

Po^C Exploration bite of 4 to 2 leaf tips at 40% depletion of pasture sward. Bite with low mass.

Po^D Exploration bite of 4 to 2 leaf tips at 60% depletion of pasture sward. Bite with low mass.

Po^E Exploration bite of 4 to 2 leaf tips at 70% depletion of pasture. Bite with low mass sward.

Co^A Exploration bite of 1 leaf tip at 0% depletion of pasture sward. Bites with less mass compared to the others.

Co^B Exploration bite of 1 leaf tip at 20% depletion of pasture sward. Bites with less mass compared to the others.

Co^C Exploration bite of 1 leaf tip at 40% depletion of pasture sward. Bites with less mass compared to the others.

Co^D Exploration bite of 1 leaf tip at 60% depletion of pasture sward. Bites with less mass compared to the others.

Co^E Exploration bite of 1 leaf tip at 70% depletion of pasture sward. Bites with less mass compared to the others.

Re^A Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at 0% depletion of pasture sward. Bite made by the animal itself after intake the first grazing horizon.

Re^B Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at 20% depletion of pasture sward. Bite made by the animal itself after intake the first grazing horizon.

Re^C Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at 40% depletion of pasture sward. Bite made by the animal itself after intake the first grazing horizon.

Re^D Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at 60% depletion of pasture sward. Bite made by the animal itself after intake the first grazing horizon.

Re^E Bite in places where they have already been grazed (second grazing horizon) within the same feeding station at 70% depletion of pasture sward. Bite made by the animal itself after intake the first grazing horizon.

$Rede^A$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at 0% depletion of pasture sward. Bite performed in places grazed by another animal.
$Rede^B$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at 20% depletion of pasture sward. Bite performed in places grazed by another animal.
$Rede^C$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at 40% depletion of pasture sward. Bite performed in places grazed by another animal.
$Rede^D$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at 60% depletion of pasture sward. Bite performed in places grazed by another animal.
$Rede^E$	Bite in places where they have already been grazed (second grazing horizon) outside of feeding station at 70% depletion of pasture sward. Bite performed in places grazed by another animal.
In^A	Bite in other species at 0% depletion of sward surface height of the fescue.
In^B	Bite in other species at 20% depletion of sward surface height of the fescue.
In^C	Bite in other species at 40% depletion of sward surface height of the fescue.
In^D	Bite in other species at 60% depletion of sward surface height of the fescue.
In^E	Bite in other species at 70% depletion of sward surface height of the fescue.

* **X^Y model: X** represent the bite code category and ^{Y} represent the bite class, i.e., treatment within of experiment 2 and 3, different sward surface heights and sward depletion, respectively.

Apêndice 2 – Foraging behaviour of bovines and equines under mixed herbivory.” (Capítulo III).

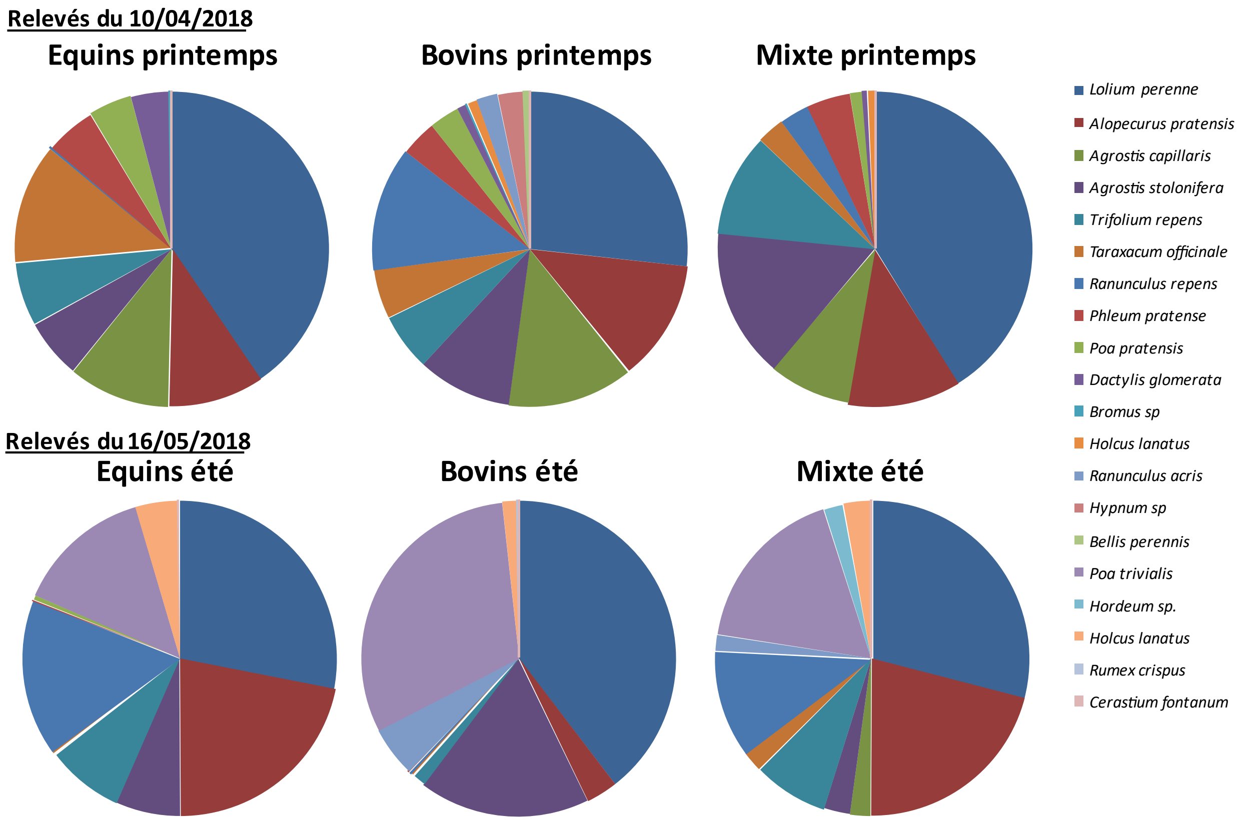
Supporting Information

Annex 1. Botanical composition on different herbivory systems: mixed equine and bovine, specific equine and specific bovine. in Prairies – Normandie -France

PAMIEBO

4 lignes par traitement
Points contacts (lignes de 10m, tous les 20cm : 50 points)
% de présence

2018



2018	Equins printemps		Bovins printemps		Mixte printemps		Equins été		Bovins été		Mixte été	
	moyenne %	**se**	**moyenne %**	**se**	**Moyenne %**	**se**	**moyenne %**	**se**	**Moyenne %**	**se**	**moyenne %**	**se**
Lolium perenne	**86,5**	2,6	**68,5**	2,9	**88,0**	2,5	**96**	1,6	**91,5**	3,4	**96**	2,5
Alopecurus pratensis	**21,0**	3,6	**32,0**	11,1	**24,5**	5,3	**74,5**	6,4	**7,5**	2,0	**69,5**	4,5
Agrostis capillaris	**22,5**	2,9	**33,0**	3,5	**18,0**	3,4	**0**	0,0	**0**	0,0	**7**	1,5
Agrostis stolonifera	**13,0**	3,5	**25,0**	9,7	**33,0**	5,7	**23**	3,3	**40,5**	11,0	**9**	4,3
Trifolium repens	**14,0**	6,5	**15,0**	5,4	**22,5**	13,7	**27**	5,5	**3**	2,0	**25,5**	5,8
Taraxacum officinale	**26,5**	4,4	**13,0**	5,2	**6,0**	2,5	**1,5**	1,7	**0,5**	0,6	**7**	4,1
Ranunculus repens	**0,5**	0,6	**32,5**	8,6	**6,5**	2,0	**54,5**	9,9	**0,5**	0,6	**36,5**	8,2
Phleum pratense	**11,0**	2,7	**9,5**	3,9	**9,5**	1,7	**0,5**	0,6	**0,5**	0,6	**0**	0,0
Poa pratensis	**9,5**	3,8	**8,0**	4,1	**3,0**	0,7	**1,5**	1,7	**0**	0,0	**0**	0,0
Dactylis glomerata	**8,5**	2,7	**2,5**	1,7	**1,0**	0,7	**0**	0,0	**0**	0,0	**0**	0,0
Bromus sp	**0,5**	0,6	**0,5**	0,6	**0,0**	0,0	**0**	0,0	**0**	0,0	**0**	0,0
Holcus lanatus	**0,0**	0,0	**2,5**	1,1	**1,5**	0,6	**0**	0,0	**0**	0,0	**0**	0,0
Ranunculus acris	**0,0**	0,0	**5,5**	1,5	**0,0**	0,0	**0**	0,0	**12**	5,0	**5,5**	4,1
Hypnum sp	**0,0**	0,0	**7,0**	6,6	**0,0**	0,0	**0**	0,0	**0**	0,0	**0**	0,0
Bellis perennis	**0,0**	0,0	**1,5**	1,1	**0,0**	0,0	**0**	0,0	**0**	0,0	**0**	0,0
Poa trivialis	**0,0**	0,0	**0,0**	0,0	**0,0**	0,0	**47,5**	8,4	**71,5**	7,4	**58**	11,7
Hordeum sp.	**0,0**	0,0	**0,0**	0,0	**0,0**	0,0	**0**	0,0	**0**	0,0	**6,5**	2,9
Holcus lanatus	**0,0**	0,0	**0,0**	0,0	**0,0**	0,0	**15**	9,2	**3,5**	4,0	**10**	3,9
Rumex crispus	**0,0**	0,0	**0,0**	0,0	**0,0**	0,0	**0**	0,0	**0,5**	0,6	**0**	0,0
Cerastium fontanum	**0,0**	0,0	**0,0**	0,0	**0,0**	0,0	**0,5**	0,6	**0**	0,0	**0**	0,0

Apêndice 3 – Foraging behaviour of bovines and equines under mixed herbivory." (Capítulo III).

Annex 2. Description of the bite codes to Equines and Bovines in Prairies – Normandie -France

.Code_bc	Classes	Sward_stade	Type	Description	Nom commun
mix	height	ungrazed	grass	*Mixed Poacea (Agrostis stolonifera, Agrostis tenuis, Alopecurus pratensis, Bromus sterilis, Cynosurus cristatus, Dactylis glomerata, Festuca pratensis, Glyceria fluitans, Holcus lanatus, Lolium perenne, Phleum pratense, Poa pratensis, Poa trivialis)*	Mix graminées (Agrostis stolonifère, Agrostis fin,Vulpin des prés,Flouve odorante, Brome stérile, Crételle, Dactyle aggloméré, Fétuque des prés, Fétuque rouge, Glycérie flottante, Holque laineuse, Orge faux-seigle, Ray-grass anglais, Fléole des prés, Pâturin annuel, Pâturin des prés, Pâturin commun)
mix_blanc	height	ungrazed	grass_legu	*Mixed Poacea + Trifolium repens*	mix graminées + Trèfle blanc
mix_tarax	height	ungrazed	grass_forbs	*Mixed Poacea + Taraxacum officinalis*	mix graminées + Pissenlit
mix_repens	height	ungrazed	grass_forbs	*Mixed Poacea + Ranunculus repens*	mix graminées + Ranoncule rampante
mix_acris	height	ungrazed	grass_forbs	*Mixed Poacea + Ranunculus acris*	mix graminées + Ranoncule acre
mix_corriola	height	ungrazed	grass_forbs	*Mixed Poacea + Convolvulus arvensis*	mix graminées + Liseron commun
mix_potentilla	height	ungrazed	grass_forbs	*Mixed Poacea + Potentilla reptans*	mix graminées + Potentille rampante
mix_tarax_blanc	height	ungrazed	grass_forbs_legu	*Mixed Poacea + Taraxacum officinalis + Trifolium repens*	mix graminées + Pissenlit + Trèfle blanc
mix_repens_blanc	height	ungrazed	grass_forbs_legu	*Mixed Poacea + Ranunculus repens + Trifolium repens*	mix graminées + Ranoncule rampante + Trèfle blanc
mix_acris_blanc	height	ungrazed	grass_forbs_legu	*Mixed Poacea + Ranunculus acris + Trifolium repens*	mix graminées + Ranoncule acre + Trèfle blanc
lanus	height	ungrazed	grass	*Holcus_lanatus*	Holque laineuse
remix	height	grazed	grass	*Mixed Poacea*	mix graminées re-pâturage, paître sur des feuilles déjà coupées
remix_blanc	height	grazed	grass_legu	*Mixed Poacea + Trifolium repens*	mix graminées + Trèfle blanc - re-pâturage
remix_tarax	height	grazed	grass_forbs	*Mixed Poacea + Taraxacum officinalis*	mix graminées + Pissenlit - re-pâturage
remix_repens	height	grazed	grass_forbs	*Mixed Poacea + Ranunculus repens*	mix graminées + Ranoncule rampante -re-pâturage
remix_acris	height	grazed	grass_forbs	*Mixed Poacea + Ranunculus acris*	mix graminées + Ranoncule acre - re-pâturage
remix_corriola	height	grazed	grass_forbs	*Mixed Poacea + Convolvulus arvensis*	mix graminées + Liseron commun - re-pâturage
remix_potentilla	height	grazed	grass_forbs	*Mixed Poacea + Potentilla reptans*	mix graminées + Potentille rampante - re-pâturage
remix_tarax_blanc	height	grazed	grass_forbs_legu	*Mixed Poacea + Taraxacum officinalis + Trifolium repens*	mix graminées + Pissenlit + Trèfle blanc - re-pâturage
remix_repens_blanc	height	grazed	grass_forbs_legu	*Mixed Poacea + Ranunculus repens + Trifolium repens*	mix graminées + Ranoncule rampante + Trèfle blanc - re-pâturage,
remix_acris_blanc	height	grazed	grass_forbs_legu	*Mixed Poacea + Ranunculus acris + Trifolium repens*	mix graminées + Ranoncule acre + Trèfle blanc - re-pâturage
relanus	height	grazed	grass	*Holcus_lanatus*	Holque laineuse - re-pâturage
dacty	height	ungrazed	grass	*Dactylis glomerata*	Dactyle aggloméré
glyceria	height	ungrazed	grass	*Glyceria fluitans*	Fétuque rouge
rubra	height	ungrazed	grass	*Festuca rubra Glyceria fluitans*	Glycérie flottante
inflorescence	without height	ungrazed	grass	*inflorescence of poaceae*	Inflorescence graminées

fleur	without height	ungrazed	forbs	*Flowers*	Fleurs
achillea	without height	ungrazed	forbs	*Achillea millefolium*	Achillée millefeuille
acris	without height	ungrazed	forbs	*Ranunculus acris*	Ranoncule acre
ajuga	without height	ungrazed	forbs	*Ajuga reptans*	Ajuga
aparine	without height	ungrazed	forbs	*Galium aparine*	Gaillet apariné
argentine	without height	ungrazed	forbs	*Potentilla anserina*	Argentine
aubepine	without height	ungrazed	shrubs	*Crataegus monogyna*	Aubepine
bellis	without height	ungrazed	forbs	*Bellis perennis*	Pâquerette
blanc	without height	ungrazed	legu	*Trifolium repens*	Trèfle blanc
cabaret	without height	ungrazed	forbs	*Dipsacus fullonum*	Cabaret aux oiseaux
cardus	without height	ungrazed	forbs	*Cardus nutans*	Chardon penché
chene	without height	ungrazed	tree	*Quercus sp*	Le Chêne
cirsium	without height	ungrazed	forbs	*Cirsium vulgare*	Chardon commun
copro	without height	ungrazed	feces	*Coprophagy*	Coprophagie - Crotin
corriola	without height	ungrazed	forbs	*Convolvulus arvensis*	Liseron commun
érable	without height	ungrazed	tree	*Acer campestre*	Érable
ficaria	without height	ungrazed	forbs	*Ranunculus ficaria*	Ranoncule ficaria
fresne	without height	ungrazed	tree	*Fraxinus excelsior*	Fresne
hypochaeris	without height	ungrazed	forbs	*Hyopochaeris radicata*	Porcelle enracinée
juncus	without height	ungrazed	forbs	*Juncus effusus*	Jonc épars
lance	without height	ungrazed	forbs	*Plantago lanceolata*	Plantain lancéolé
lion	without height	ungrazed	forbs	*Leontodon autumnalis*	Liondent d'automne
major	without height	ungrazed	forbs	*Plantago major*	Plantain major
mollugo	without height	ungrazed	forbs	*Galium mollugo*	Gaillet commun
mousse	without height	ungrazed	forbs	*Hypnum sp*	Mousse
polygo	without height	ungrazed	forbs	*Polygonum persicaria*	Persicaria
potentilla	without height	ungrazed	forbs	*Potentilla reptans*	Potentille rampante
repens	without height	ungrazed	forbs	*Ranunculus repens*	Ranoncule rampante
robus	without height	ungrazed	shrubs	*Robus fructicosus*	Ronce
ronçe	without height	ungrazed	shrubs	*Robus sp.*	Ronce
rumex	without height	ungrazed	forbs	*Rumex crispus; Rumex obtusifolius*	Rumex
silaum	without height	ungrazed	forbs	*Silaum silaus*	Fenouil des chevaux

symphitum	without height	ungrazed	forbs	*Symphytum officinale*	Grande consoude
tarax	without height	ungrazed	forbs	*Taraxacum officinalis*	Pissenlit
Urtica	without height	ungrazed	forbs	*Urtica dioica*	Ortie dioïque

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Last updated 15 January 2021

Apêndice 5 – Normas para elaboração e submissão de trabalhos científicos ao periódico *Oecologia.*

***Oecologia* Author Instructions – Manuscript Guidelines**

Instructions for authors at Springer.com do not include all formatting expectations for *Oecologia* submissions. *Oecologia*'s Editors-in-Chief have combined all of Springer's instructions along with their additional detailed expectations into two user-friendly files; "*Manuscript Guidelines*" and "*Artwork Instructions*". Please prepare submissions to *Oecologia* according to the instructions in these two files. Submissions that do not follow these guidelines may be returned to authors or their review may be delayed.

Aims and scope
Legal and ethical requirements
Manuscript submission and preparation
Manuscript contents
After acceptance

Aims and scope

Oecologia publishes innovative ecological research of general interest to a broad international audience. We publish several types of manuscripts in many areas of ecology:

Categories:
Concepts, Reviews and Synthesis Views and Comments
Methods
Physiological ecology – Original research
Behavioral ecology – Original research
Population ecology – Original research
Plant-animal interactions – Original research
Community ecology – Original research
Ecosystem ecology – Original research
Global change ecology – Original research
Conservation ecology – Original research
Special Topic

In general, studies that are purely descriptive, mathematical, documentary, and/or natural history will not be considered.

In the *Concepts, Reviews and Syntheses* section, we seek papers on emerging issues in ecology, especially those that cross multiple boundaries in ecology, provide synthesis of important bodies of work or delve into new combinations of theory and observations with the potential to create new paradigms or challenge existing paradigms. These papers are usually invited, but we welcome unsolicited contributions. In the *Views and Comments* section we seek short papers with the intent to provide contrary and/or broader perspectives on papers recently published in Oecologia. Alternatively, pairs of short papers which present opposing views on a topic of high interest in the ecological research community will be published in this section, with the intent to stimulate open debate. In both cases, the papers must be relatively short (up to 5 printed pages in the case of opposing view pairs of papers, or up 2

to 3 printed pages in the case of comments on previously-published work), and to contain not only an opinion or criticism on methods or statistics, but also relevant data or original analyses that support the opposing view or comment. Manuscripts or letters intended for the Views and Comments section will be reviewed by one of the Editors-in-Chief and a Handling Editor in the field appropriate to the submission. *Special Topics* are a collection of integrated papers on a critical topic of broad interest. Proposals for Special Topics should be submitted to one of the Editors- in-Chief. *Methods* are papers that outline new approaches that address standing questions in the discipline. *Original Research* papers are published by subject; they provide the core of our journal and represent original investigations that offer new insights into ecological systems.

Legal and ethical requirements

Ethical responsibilities of authors

This journal is committed to upholding the integrity of the scientific record. As a member of the Committee on Publication Ethics (COPE) the journal will follow the COPE guidelines on how to deal with potential acts of misconduct.

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 A single study is not split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time (e.g. “salami-publishing”).

 No data have been fabricated or manipulated (including images) to support your conclusions

 No data, text, or theories by others are presented as if they were the authors own (“plagiarism”). Proper acknowledgements to other works must be given (this includes material that is closely copied (near verbatim), summarized and/or paraphrased), quotation marks are used for verbatim copying of material, and permissions are secured for material that is copyrighted.

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 Consent to submit has been received from all co-authors and responsible authorities at the institute/organization where the work has been carried out *before* the work is submitted.

 Authors whose names appear on the submission have contributed sufficiently to the scientific work and therefore share collective responsibility and accountability for the results.

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In addition:

 Changes of authorship or in the order of authors are not accepted *after* acceptance of a manuscript.

 Requests to add or delete authors at revision stage or after publication is a serious matter, and may be considered only after receipt of written approval from all authors and detailed explanation about the role/deletion of the new/deleted author. The decision on accepting the change rests with

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When reporting studies that involve human participants, authors should include a statement that the studies have been approved by the appropriate institutional and/or national research ethics committee and have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

If doubt exists whether the research was conducted in accordance with the 1964 Helsinki Declaration or comparable standards, the authors must explain the reasons for their approach, and demonstrate that the independent ethics committee or institutional review board explicitly approved the doubtful aspects of the study.

The following statements should be included in the text before the References section:

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For studies with animals, the following statement should be included:

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“This article does not contain any studies with human participants or animals performed by any of the authors.”

For retrospective studies, please add the following sentence: “For this type of study formal consent is not required.”

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Providing funds, supervising or hosting researchers, belonging to a research consortium, attending a meeting or a workshop, offering access to samples,

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Please follow the format of the following examples:
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- Format dates as day-month-year with months abbreviated: e.g., 01-Jan-2008

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- Use the equation editor of a word processing program or MathType for equations. (Note: If you use Word 2007, do not create equations with the default equation editor but use the Microsoft equation editor or MathType instead.) Symbols for parameters should be *italicized*.
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□ Introduction
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□ **Results** Avoid “Results are shown in Figure 3”. Instead, say for example, “Biodiversity declined with the addition of nitrogen (Fig. 3).” Be specific: e.g., “positively correlated” instead of “correlated”. Refer to magnitudes of effects (e.g. give effect sizes and confidence intervals) rather than just *P*-values.

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□ **Acknowledgements** Please keep this section as short as possible. Acknowledgements of people, grants, funds, etc. should be placed in a separate section before the reference list. The names of funding organizations should be written in full. Compliance with ethical standards may be stated in the cover letter rather than the acknowledgements section.
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Funding (information that explains whether and by whom the research was supported)
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Ethics approval (include appropriate approvals or waivers)
Consent to participate (include appropriate statements)
Consent for publication (include appropriate statements)
Availability of data and material (data transparency)
Code availability (software application or custom code)
Authors' contributions
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Here are some examples of statements to be included in the manuscript:
Ethics Approval:
□ This study follows the guidelines declared in the Declaration of Helsinki, and was approved by [ethics committee name]; Reference number XXXX.
□ All animal experiments were approved by [ethics committee name], reference number XXXX
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 Ethics approval was not required for this study according to local legislation [name of legislation]
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Consent to Participate:
 All patients included in this study gave written informed consent to participate in this research. If the patient was less than XXXX years old at the time of the study, written informed consent for their participation was given by their parent or legal guardian.

Consent for publication:
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 All data produced from this study are provided in this manuscript.
 The data was deposited in [repository name] under the reference number [identifier number].
 The single-cell RNA sequencing clean data reported in this paper have been deposited in the [repository name] under accession number XXXX, which can be publicly accessed at [link].

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Reference examples:
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Savidge WB, Blair NE (2004) Patterns of intramolecular carbon isotopic heterogeneity within amino acids of autotrophs and heterotrophs. Oecologia 139:178-189 doi: 10.1007/s00442-004-1500-z
Chapter in a book: name(s) and initial(s) of all authors; year; title of article; editor(s); title of book; edition; volume number; publisher; place of publication; page numbers
Hobson KA (2003) Making migratory connections with stable isotopes. In: Berthold P, Gwinner E, Sonnenschein E (eds) Avian migration. Springer, Berlin, pp 379-391
Book: name and initial(s) of all authors; year; title; edition; publisher; place of publication Körner C (2003) Alpine plant life, 2nd edn. Springer, Berlin
Theses: name and initial(s) of author; year; type (e.g., “Master thesis” or “PhD dissertation”); department; institution; place of publication.
Wilson JA (2004) Habitat quality, competition and recruitment processes in two marine gobies. PhD dissertation, Department of Zoology, University of Florida, Gainesville, Florida, USA.
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VITA

Anderson Michel Soares Bolzan, filho de Iva Maria Soares Bolzan e Erli Bolzan, nasceu no dia 26 de setembro de 1985, em Santa Maria, Rio Grande do Sul, Brasil. Na cidade natal cursou ensino fundamental nos colégios Lourenço Dalla-Corte e colégio Santa Helena. O ensino médio na Escola Edna Mey Cardoso e Colégio Agrícola de Santa Maria – Universidade Federal de Santa Maria (UFSM) onde concluiu seus estudos no ano de 2003. Cumpriu serviço militar obrigatório 2004-2005 na Cia. Cmdo. da 6ª Brigada de Infantaria Blindada e no 29º Batalhão de Infantaria Blindado, com diploma de mérito, formação de Cabo de Infantaria QM 0701, Infante combatente Blindado, posição de curso 1/79 nota 9,79. Condecorado com diploma de melhor aptidão física, diploma e medalha de Praça mais distinta. Ingressou na formação acadêmica no curso bacharelado em Zootecnia UFSM (2005 – 2010) e direcionou esforços para um objeto caro do ponto de vista pessoal, os ovinos em especial os lanares que já tinha envolvimento de trabalho como esquilador. Assim durante o período de graduação participou de iniciativas de iniciação cientifica no setor de ovinocultura sob orientação do professor Cléber Cassol Pires, sendo monitor na mesma disciplina, e bolsista de iniciação científica CNPQ. Estas experiencias subsidiaram manipular conceitos da investigação durante estágio curricular no Haras Santa Maria de Araras (2010), em Bagé RS - Brasil marcando a inserção nos estudos sobre o modelo animal equino e o processo de pastejo, o qual dedicaria atenção até hoje. Durante um período curto de atividade laboral (2012) como zootecnista, em uma empresa de nutrição animal desempenhando função de formulador e consultor. Mantive conexão com os sistemas de criação de equinos e com o cenário acadêmico na área da ciência educação, onde concluiu graduação em formação pedagógica no Centro de Ciência e Educação UFSM (2012 -2013). Com insistente dedicação e a oportunidade de ingressou domínio da pesquisa, tendo início na pós-graduação (2013) (especialização) e estudos com equinos nos campos com tutoria da Professora Adriana Pires Neves na Universidade Federal do Pampa, que posteriormente direcionou à Universidade Federal do Rio Grande do Sul para o ingresso no Grupo de Pesquisa em Ecologia do Pastejo - GPEP, coordenado pelo Professor Paulo César de Faccio Carvalho. No mestrado (2014 – 2016) sob orientação do professor Paulo César de Faccio Carvalho, evolui na visão do universalismo científico e conceitualmente nos domínios da interface solo -planta-animal. Neste período foi influenciado pelo ecólogo Olivier Bonnet, a quem refere a inquietação cientifica, além da apresentação e treinamento na metodologia de observação direta “Continuous bite monitoring” na qual dispenderia muitas horas de observação e descrição de ações alimentares “os bocados”, de animais em pastejo em diversos ambientes pastoris sob o propósito de variadas hipóteses totalizando mais de 894 horas de observação experienciadas. Desenvolveu com esta ferramenta o protocolo de mestrado no entendimento do processo de forrageamento de potros nos Campos da Pampa, na sequência auxiliou colegas em protocolos sobre o estudo do processo de pastejo em pastos cultivados. Na busca da compreensão das funções do forrageamento equino em coexistência com bovinos desenvolveu parte da tese (2017 -2021) no protocolo PaturEquiBov - Pâturage Mixte Equin – Bovin, nos domínios do Haras National du Pin - Normandie – France (2018-2019), em programa de cooperação Brasil – França CAPES-COFECUB.   Foi orientado pelo professor Paulo Carvalho GPEP – UFRGS, Bertrand Dumont INRAE - Unité Mixte de Recherche sur les Herbivores, e Géraldine Fleurance IFCE - Institut français du cheval et de l’équitation. Atualmente além do desenvolvimento da tese, colabora em protocolos na interface solo - planta- animal no grupo de pesquisa e outras instituições. Mantem atenção ao estudo do forrageamento, estimativas de fluxo ingestivo, composição de dieta e arranjo espaço temporal dos pastos, especialmente ecossistemas naturais. Até o momento da publicação deste documento, tem em seu currículo 5 artigos científicos e 2 capítulos de livros publicados, 2 artigos científicos em tramitação. Foi submetido à banca de defesa da Tese de Doutorado no dia 28 de Abril de 2021.