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El consumo de forraje: su relación con los cambios en la conducta temporal del pastoreo ante modificaciones en la oferta de forraje y el genotipo vacuno

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Resumen

El objetivo de este trabajo fue evaluar el efecto de incrementar la oferta de forraje de Campos (OF, Alta [AOF, 5 kg MS/kg PV] y Baja [BOF 3 kg MS/kg PV]) sobre la estructura de la pastura (masa y altura del forraje así como sitios con + de 3cm de altura), el consumo de forraje, la calidad de la dieta y la conducta diaria y a escala de estación de pastoreo (FeSt) de vacas de cría multíparas Angus y Hereford [Puras] y las cruzas recíprocas, (F1, Cruzas). Durante gestación (-90±12 días del parto) y lactancia (+40±15 días del parto) se evaluó el consumo de forraje (DMI) con base en marcadores externos e internos de las plantas (n-alcanos) y la conducta diaria de pastoreo y rumia a través de medidos de comportamiento automáticos. Mensualmente se estimó la masa y altura del forraje, los sitios con más de 3 cm de altura (+3cm) y acumulación de forraje, el PV y CC de las vacas y la carga animal. En 6 estaciones del año (1 otoño, 2 inviernos y 3 primavera-verano) se evaluó la digestibilidad de la dieta (DMD), el DMI y el DMI digestible (DDMI), la conducta temporal de pastoreo y rumia y en 2 estaciones (1 invierno y 1 primavera) la conducta de corto plazo en FeSt y bocados/FeSt. La masa, altura, sitios +3cm y acumulación de forraje se incrementaron en AOF, el PV y CC de la vaca, el consumo de energía y forraje y el peso de los terneros al destete también resultaron mayores en AOF. La carga animal no resultó diferente entre AOF y BOF (390 kg PV/ha). El genotipo de la vaca no afectó el DDMI pero las vacas Cruza alcanzaron mayor PV y CC y los terneros mayor peso vivo al destete. El DMI se incrementó con la masa de forraje y resultó en una diferencia anual de 400 kg MS/vaca que se produjeron principalmente en primavera (lactancia). La tasa de consumo de forraje aumentó al incrementarse los sitios +3cm y la masa de forraje, en tanto el tiempo de rumia/kg DMI disminuyó al incrementarse la DMD. Las FeSt no se modificaron con los tratamientos durante gestación a pesar de que las vacas Cruza disminuyeron el DMI/kg PV metabólico, pero se incrementaron en lactancia y bajaron los bocados/FeSt en AOF, lo cual explicaría en parte el incremento del DMI, la DMD y el DDMI a través de la selección de los mejores bocados. Los cambios en la selección de bocados/FeSt así como la diminución de la rumia/kg DMI en AOF se asociaron con mayor DMI y DMD sin disminuir el tiempo diario de pastoreo lo que permitió incrementar el DDMI en AOF. En síntesis, las mejoras en la producción animal individual en AOF se asociaron a mayor DMI y DDMI producto de mayor masa y altura del forraje principalmente en lactancia, mientras que en vacas Cruza la mayor producción animal se debió a mayor eficiencia de uso de la energía, pero sin diferencias en el DMI o DDMI anual.

Palabras clave: consumo de forraje, tiempo de pastoreo, tiempo de rumia, estación de pastoreo, carga animal

Herbage intake: its relationship with temporal grazing and ruminating behavior due to changes in herbage allowance and cow genotype

Summary

With the aim of evaluating the increase in herbage allowance of Campos (HA, high [AOF, 5 kg DM/kg BW] and low [BOF 3 kg DM/kg BW]) and the change of genotype of the cow (Angus and Hereford [Pure] and reciprocal crosses, F1 [Cross]) on animal individual and per ha productivity, dry matter intake (DMI) dry matter digestibility (DMD) and digestible DMI (DDMI) and grazing and ruminating behavior. Using multiparous pregnant-lactating beef cows this work was carried out based on a long-term experiment, the hypothesis that AOF and cows crosses would result in greater production per cow and per hectare due to greater DMI in AOF and greater efficiency use of the herbage in Cross. Based on an experiment of two blocks, multiparous cows were assigned to a factorial arrangement of HA and genotype (AOF-Cross, AOF-Pure, BOF-Cross and BOF-Pure, 4 treatments one for each plot in each block) for 2.5 years. The body weight (BW) and condition score (BCS) of cows, stocking rate, calf BW at weaning, herbage intake (DMI) and digestible DMI (DDMI) and the digestibility of the dry matter (DMD), together with the behavior of grazing and ruminating, as well as the behavior at feeding station (FeSt) and bites per FeSt were evaluated. The herbage mass, height, +3cm sites and herbage growth increased in AOF, the BW and BCS of the cow, DMI and DDMI and the weight of the calves at the weaning were higher in AOF. The stocking rate did not differ between AOF and BOF (390 kg BW/ha). The cow genotype did not affect the DDMI but the Cross cows reached greater BW and BCS and the calves were heavier at weaning compared to Pure. The DMI increased with herbage mass and sites +3cm and resulted in an annual difference of 400 kg DM/cow that occurred mainly in spring (lactation). The intake rate (g/min) increased as sites +3cm and herbage mass increased, while rumination/kg DMI decreased when the DMD increased. The FeSt were not modified with the treatments during gestation but increased during lactation in AOF and bites/FeSt decreased in AOF, which would partly explain the increase in the DMI, the DMD and the DDMI through the selection of the best bites. Changes in grazing and ruminating behavior were related to the results of DMI and DMD in a coordinated way to increase the DDMI in AOF. In summary, the improvements in individual animal production in AOF were associated with greater DMI and DDMI product of greater mass and height of the herbage mainly during lactation, while in Cross cows the greatest animal production was due to greater efficiency of energy use, without differences in the annual DMI or DDMI.

Keywords: herbage intake, grazing time, ruminating time, feeding stations, stocking rate

1. Introducción

Los pastizales del Río de la Plata o *Campos* ocupan unos 700.000 km^2 (Paruelo et al., 2010), lo que incluye el noreste de Argentina, sur de Brasil y toda la superficie de Uruguay, son ecosistemas naturales de alto valor económico, social y ambiental por los beneficios directos (producción de alimentos) y diversos servicios ecosistémicos que brindan (Holechek, 2011). En esta región de Campos, la ganadería es la principal actividad económica y en Uruguay es responsable del principal producto de exportación del país, la carne vacuna y subproductos del sector (cueros) y ganado en pie, que representa, en total, 21 % de las exportaciones de todos los rubros (Uruguay XXI, 2017). Por otra parte, involucra a más de 28.000 productores ganaderos, lo que destaca su importancia socioeconómica en la producción agropecuaria nacional. Dentro de la ganadería de carne, la cría vacuna es la que emplea mayor área y número de cabezas (DIEA, 2011).

La cría vacuna se lleva a cabo principalmente en Campos y su resultado físico-económico define la competitividad de la ganadería de Uruguay. No obstante, la cría vacuna obtiene indicadores productivos muy inferiores (64 % de destete, 120-150 kg de ternero al destete y 70 kg de carne vacuna/ha) al potencial documentado por la investigación nacional y regional (Nabinger et al., 2000; Soca et al., 2007). Dichos niveles se explican mayoritariamente por la elevada intensidad de pastoreo y escasa adopción de prácticas de gestión del rodeo de cría, que determinan un limitado y variable consumo de energía durante el ciclo de la vaca de cría (Soca et al., 2007).

La ganadería también ha sido señalada como causante de la degradación de suelos y contaminación del agua, así como de contribuir al calentamiento global con 18 % de las emisiones de gases de efecto invernadero (GHG) (FAO, 2006). Disminuir las emisiones de GHG requiere incrementar la producción por unidad de área, la productividad por vaca y/o la eficiencia de uso de la energía consumida por kg de ternero destetado, lo que será función del consumo de energía metabólica por vaca (Brosh et al., 2004), la producción individual y la carga animal del sistema para poder reducir el número de animales y mantener o aumentar la producción. Cuando se controla la intensidad de pastoreo (IP) la carga animal de los sistemas pastoriles, depende en gran medida de la tasa de crecimiento de la pastura (Lattanzi et al., 2007). En pasturas de Campos, la tasa de crecimiento depende de la interacción entre masa de forraje, temperatura, y agua disponible en suelo. La masa de forraje es afectada por la intensidad de pastoreo y retroalimenta el nivel de masa de forraje presente, que por su parte afecta los niveles de ingestión de forraje y energía.

A escala de predio, las variaciones en masa de forraje y kilogramos de PV animal definen la oferta de forraje (OF, kilogramos de materia seca (MS) de forraje por kilogramos de peso vivo (PV) animal, kg MS/kg PV, Sollenberger et al., 2005), lo que significa que afectan la intensidad de pastoreo. El nivel de oferta de forraje afecta la productividad (kg/ha) a través de la eficiencia biológica (Do Carmo et al., 2016) lo que impacta directamente en el resultado económico de la ganadería (Paparamborda, 2017). El incremento de OF y/o altura del forraje mejora el consumo de forraje y energía con base en diversos factores (digestibilidad del forraje seleccionado, altura de la pastura, comportamiento animal) que explican el consumo de forraje y afectan la productividad del sistema (Peyraud et al., 1996; Wales et al., 1999; Stakelum y Dillon, 2004; Gibb, 2006, Menegazzi et al., 2021; 2025). Sin embargo, la investigación nacional, regional e internacional sobre las relaciones entre OF y consumo de forraje y energía en Campos o pasturas naturales son escasos y en general emplean vacunos u ovinos en crecimiento (Piaggio, 1994; Rouquette et al., 2012; Carvalho, 2013; Da Trindade et al., 2016; Dickhoefer et al., 2016). Por las razones antes mencionadas, en este trabajo nos proponemos medir y analizar qué factores y en qué momentos se modifica el consumo de forraje de vacas de cría a través del ciclo de producción.

2. Revisión bibliográfica

2.1. **La oferta de forraje y su efecto sobre la estructura del forraje y el consumo de forraje o energía de vacas de cría**

Aumentos en la OF resultan en aumentos en la masa y altura del forraje (Moojen y Maraschin 2002; Wallau et al. 2023), sin embargo cuando se aplica OF variable entre estaciones del año, la masa de forraje ya no cambia de forma lineal al aumento en la OF (Soares et al. 2005). El incremento en la masa de forraje genera diferencias en el "parcheado" del forraje o heterogeneidad y esto se modifica con la intensidad de pastoreo (Cid y Brizuela 1998). La heterogeneidad podría definirse como la variación existente dentro de un grupo, lo que se aplica a cualquier atributo de la población bajo estudio. En nuestro caso, nos interesa describir la heterogeneidad o variación que existe en determinados atributos del forraje, masa, altura, porcentaje de verde, composición de especies. Estos atributos varían en el tiempo y en el espacio y afectan el consumo de forraje directa e indirectamente, directamente a través de la fenología de los tejidos y su asociación con las estaciones del año, pero también a través del efecto que tiene la disposición del forraje sobre la selección del rumiante en el consumo de forraje.

Los atributos de las pastura, altura, masa o composición química del forraje, han sido descritos a través de la media, variable utilizada para el análisis de varianza paramétrico; no obstante, dado que el rumiante se mueve y realiza compensaciones espaciales (Garcia et al., 2003), resulta relevante describir la diversidad de sitios en los que es posible realizar consumo de forraje. Probablemente, en variables como la masa o altura del forraje que resultan asimétricas (Barthram et al., 2005), la moda o la mediana describan mejor la situación más frecuente a la que se enfrentan los rumiantes para cosechar forraje, o medidas de variabilidad o heterogeneidad de varianza también podrían asociarse a la diversidad de situaciones a las que se enfrenta el rumiante.

Es posible que la heterogeneidad espacial no haya sido tenida en cuenta como forma de afectación del consumo de forraje porque el proceso de pastoreo ha priorizado las variables temporales de la conducta (tasa de bocados y tiempo de pastoreo) por sobre las variables espaciales (estaciones de pastoreo). Bailey et al. (1996) definen las escalas espacio-temporales de consumo de forraje de acuerdo al comportamiento animal, y ningún modelo, el temporal (consumo de forraje = tasa de consumo x tiempo de pastoreo) propuesto por Allden y Whitaker (1970) y el espacio-temporal (Bailey et al., 1996) ha sido vinculado o estudiado al mismo tiempo, ni vinculado a medidas de consumo de forraje (Hirata et al., 2015).

Trabajos en los que se aumentó la heterogeneidad del forraje resultaron en mayor productividad animal, comparado con sistemas homogéneos de pastizal, pero resulta necesario conocer si se debió a mejoras del consumo de energía (Allred et al., 2014). Existen varios descriptores de la heterogeneidad del forraje: Barnes et al. (2008) utilizan la desviación absoluta de la media y la homogeneidad de varianza como descriptores de la heterogeneidad del forraje. Tsutsumi et al. (2007) utilizaron el coeficiente p = u^2/o^2 (media al cuadrado/varianza) como descriptor de la variabilidad o heterogeneidad del forraje y su efecto en el tamaño de muestra requerido para estimar la media con una precisión deseada. Shiyomi et al. (1983, 1998) también utilizan el coeficiente p para describir la heterogeneidad y la curva de distribución de la altura del forraje cuando el forraje no difiere en la media, pero sí difiere en la varianza. Shiyomi et al. (1998) reportan que la heterogeneidad (p) y altura o masa de forraje se correlacionan de forma positiva. No obstante, el análisis de la heterogeneidad a través de p en pasturas de Campos se correlacionó significativamente (P < 0,001) de forma negativa (r = -0,25), lo que significa que, al aumentar la altura, la heterogeneidad se incrementa (p disminuye); no obstante, con baja altura o masa de forraje, la heterogeneidad también puede ser alta, pues la correlación es débil y existen puntos de alta heterogeneidad con baja altura (Do Carmo et al., sin publicar).

Al igual que en el proceso de consumo de forraje, detectar cambios en el patrón de distribución y en la heterogeneidad del forraje depende de la escala espacial con la que se mide. En nuestro caso utilizaremos una escala de 0,25 m^2 (50 cm x 50 cm) para describir la heterogeneidad en la masa y altura del forraje en el espacio y podemos utilizar la varianza de la altura (n = 5) dentro del cuadro de 50 cm x 50 cm para describir la varianza dentro del grano. La heterogeneidad en la altura y masa de forraje se ha expresado como la distribución de frecuencias de las alturas (Gibb y Ridout, 1986; Barthram et al., 2005) o a través del área de sitios intensamente pastoreados y poco pastoreados asociados a la altura del forraje (Cid y Brizuela, 1998).

Mayor heterogeneidad del forraje permitiría mayor potencial de selección a las vacas entre sitios de pastoreo, al momento de cada bocado, lo que incrementaría la posibilidad de selección de bocados de mayor masa y calidad de forraje (Cid y Brizuela, 1998).

En el caso de nuestro experimento, el grano fue de 0,25 m^2, mientras que el área de la estación de pastoreo puede medirse como coseno 30° x altura de la vaca a las cruces (Gregorini et al., 2015). Por ejemplo, si la altura de la vaca es de 1,6 m, el área del sitio de pastoreo sería similar a 0,25 m^2, lo que permitiría utilizar las medidas de heterogeneidad del forraje como indicador de la heterogeneidad en las estaciones de pastoreo que la vaca puede encontrar.

La escala espacial a la cual la vaca explora un potrero por meses o años se le llama *home range* o "área de distribución" y esta escala espacial ha recibido mucha atención en su estudio en pastizales de lugares áridos y semiáridos (Bailey et al., 2004; Russell et al., 2012; Bohnert y Stevenson, 2016) con el objetivo de que las vacas exploren más espacio lejos del agua y en lugares escarpados, pero también como forma de mejorar potencialmente la dieta de esas vacas. Sin embargo, las escalas menores, de "territorio", "campo", "sitio de pastoreo", "parche" y "estación de pastoreo" han recibido muy poca atención (Hirata et al., 2015), aunque probablemente también la forma en que se seleccionan esas escalas menores afecte la selección y el consumo de forraje (García et al., 2003, 2005).

Estudiar el consumo de forraje ante cambios en la altura y heterogeneidad del forraje y vincularlo con el comportamiento temporal del pastoreo a diferentes escalas permitiría comprender mejor el patrón de selectividad y estrategia de conducta en pastoreo que afectan el consumo de forraje en vacas de diferente genotipo en diferente oferta de forraje.

Hasta el momento, la comparación entre OF fija anual o variable entre estaciones del año solamente se ha cambiado durante primavera, con resultados positivos en ganancia diaria y por ha en el tratamiento que utilizó la OF de 8% en primavera y 12% el resto del año (Soares et al. 2005). Sin embargo, incrementar la variación en la OF entre estaciones del año, sumado al cambio en el tamaño animal (Recría vs. Vacas) es esperable que se modifique la respuesta sobre la estructura del forraje y la performance animal (Kramer y Prins 2010) ya que los animales difieren en la selectividad y el consumo de forraje, y por unidad de área difieren en el peso metabólico asignado debido a diferencias de tamaño corporal (Rook et al. 2004).

Mayor oferta de forraje generó mayor productividad y eficiencia de uso de la energía en vacas de cría (Do Carmo et al. 2016) y podría ser debido a: *1*) mayor consumo de energía en alta oferta de forraje, *2*) mayor digestibilidad de la dieta y mejores productos finales de la digestión en alta oferta de forraje (AOF) por mayor selectividad del forraje, *3*) mejor metabolismo energético (más anabólico y con mayor dilución de la energía de mantenimiento) del animal comparando puras y cruzas, donde las vacas cruza resultan más sensibles a la insulina y de esta forma se mejora el metabolismo energético (Galgani et al., 2008). Las diferencias en selectividad del forraje entre OF podría resultar en diferencias de productos finales de la digestión y que eso derive en el desacople insulina-IGF-I en el período -165 a -75 (Laporta et al., 2014); esta resistencia a la insulina podría asociarse a una dieta de menor digestibilidad y menores precursores gluconeogénicos (Waterman et al., 2007) y por último a que el genotipo de la vaca afectó la movilización de tejidos durante la gestación (Casal et al., 2016) y esto estaría relacionado con la resistencia a la insulina, ya que la pérdida de grasa podría generar una sobrecarga de lípidos en los músculos esqueléticos que, si no fuera oxidada apropiadamente, generaría acumulación intracelular de lípidos y posteriormente resistencia a la insulina (Galgani et al., 2008) que en este caso se hizo efectivo en vacas AOF-puras, pero no en AOF-cruzas. A través de la selectividad de la dieta podría modificarse el metabolismo de la energía o bien interaccionar metabolismo y selectividad de la dieta para mejorar el metabolismo energético de la vaca. De aquí se desprende la relevancia del estudio del consumo, conducta y selectividad de vacas en pastoreo y su aporte al metabolismo de la energía.

Construir mejoras en la productividad por vaca y por unidad de superficie requiere conocer si es posible, a través del manejo de la oferta de forraje, incrementar el consumo de energía, ya sea por aumentos del consumo de forraje o en la digestibilidad del forraje consumido, o ambas.

Tampoco sabemos de qué forma se modificó, si es que lo hizo, la conducta espacio-temporal de pastoreo, proceso que estaría muy asociado a los cambios en el consumo de energía. Dado la relevancia de la masa y digestibilidad de la dieta consumida en las estimaciones de consumo de forraje (Keetelars y Tolkamp, 1992;

Piaggio, 1994; Brosh et al., 2004), resulta fundamental comprender y cuantificar la selectividad de vacas de cría en Campos de manera de contribuir a comprender los niveles de consumo de forraje y energía ante cambios en la OF y en la estructura y heterogeneidad de pastura y en el genotipo o el estado fisiológico de las vacas.

Detectar variaciones o cambios en la búsqueda y cosecha de forraje depende de la escala en la que se midan los procesos (Turner, 1989). El consumo de forraje ha sido estudiado a diferentes escalas de tiempo y de espacio; la escala de medida del consumo en pastoreo más extendida ha sido la escala de minutos u horas (Carvalho, 2013; Gibb, 2006; Champion et al., 2004; Rutter 2006; Laca et al., 1992; Black y Kenney, 1984; Allden y Whitaker, 1970) como forma de medir el consumo diario o bien la tasa de consumo en diferentes especies forrajeras o diferentes estructuras del forraje. Las medidas de tasa de consumo de forraje tienen como supuesto que el modelo de consumo de forraje corresponde a tiempo de pastoreo x tasa de consumo; sin embargo, la tasa de consumo cambia con la hora del día en al menos un 28 % (Gibb, 2006) y, por tanto, cuestiona las medidas basadas en la tasa de consumo para estimar el consumo diario o las hace muy engorrosas en la práctica, al medir varias veces (4) y por períodos mayores a 1 hora. Al mismo tiempo, los animales expresan compensaciones comportamentales ante reducciones de la tasa de consumo, que se producen principalmente por reducciones en la altura del forraje que afectan la masa de bocado (Hodgson, 1985). Entre las compensaciones de comportamiento que el modelo de tasa de consumo x tiempo de pastoreo contiene, se encuentran aumentos en la tasa de bocados y del tiempo de pastoreo; sin embargo, también están las compensaciones espaciales (García et al., 2003), cambios en el uso del espacio que permiten compensar el consumo de forraje o energía ante restricciones del ambiente promedio, pues la estructura del forraje resulta heterogénea y la altura promedio no contempla la cantidad de sitios por encima del promedio que el rumiante puede explotar en su beneficio para compensar reducciones de la altura o la digestibilidad promedio (Laca, 2009).

En este trabajo, nos interesa estudiar el consumo de forraje (kg MS/vaca, g MS/kg MBW) y energía (Mcal EM/vaca y EM/kg MBW) a escala diaria, entre otras razones porque cambios que pueden existir en la selectividad y consumo de nutrientes a escala de minutos (Villalba et al., 2015) pueden ser compensados a escala diaria o de período de días (Atwood et al., 2001) y sus efectos sobre el consumo de energía en un ciclo productivo pasan a ser irrelevantes. El consumo de forraje diario en pastoreo ha sido ampliamente estudiado con vacas lecheras en pasturas sembradas (Peyraud et al., 1996; Wales et al., 1999; Stakelum y Dillon, 2004; Gibb, 2006, Menegazzi et al., 2021; 2025), que se caracterizan por tener alta digestibilidad y baja diversidad de especies (Gibb, 2006), donde se documentó que la oferta de forraje y la masa-altura del forraje modifican la respuesta al consumo de forraje diario. El consumo de forraje diario ha sido menos estudiado en vacas de cría y en pasturas sembradas (Baker et al., 1981; Barlow et al., 1988; Sprinkle et al., 2000) y escasamente estudiado en pasturas heterogéneas en especies y en estructura del forraje (Gunter et al., 1993). Para Campos se cuenta con escasos registros del consumo de forraje diario en vacas de cría y fueron medidos puntalmente, no en experimentos que incluyan el ciclo productivo de las vacas y donde la intensidad de pastoreo fuese un tratamiento a largo plazo (Briano et al., 2013; Clariget, 2014). Clariget (2014) utilizó cuatro vacas no gestantes-no lactantes, en un diseño de cuadrado latino, de forma de testar el efecto de suplementos sobre el consumo de forraje. La oferta fue de 10 % del PV y la altura y masa de forraje estuvieron en un rango de 7 a 13 cm y de 1800 a 4100 kg MS/ha, respectivamente, durante otoño-invierno. El consumo de forraje diario resultó entre 8,8 y 11 kg MS/vaca/día, mientras el consumo de energía metabolizable estuvo entre 17 y 19 Mcal EM/vaca/día. Por su parte, Briano et al. (2013) utilizaron vacas primíparas y multíparas en el último mes de gestación sometidas a oferta de forraje de 5 % y 15 % del PV, en las que se estimó el consumo de forraje, que resultó en el rango de 8 a 11 kg MS/vaca o de 1,9 % a 2,5 % del PV, valores superiores a lo reportado por Barlow et al. (1988) en pasturas de digestibilidad media y baja. Clariget (2014) aplicó una única oferta de forraje y Briano et al. (2013, 2024) midieron en un solo momento y sin características del forraje; por tanto, no conocemos la respuesta a la oferta de forraje para un amplio rango de alturas de forraje o ante modificaciones de la fisiología de la vaca (lactante o gestante) y tampoco conocemos si el genotipo de las vacas en pastoreo de Campos afecta el consumo de forraje kg MS/vaca, g MS/kg MBW) y energía (Mcal EM/vaca y EM/kg MBW) todo lo cual hace necesario obtener mejores estimaciones del consumo de forraje y energía de vacas de cría en pastoreo de Campos y, en consecuencia, tomar mejores decisiones de manejo a escala de predio.

En pasturas de Campos, el consumo de forraje diario ha sido cuantificado en vacunos en crecimiento (Piaggio, 1994; Genro et al., 2012; Da Trindade et al., 2016); sin embargo, el modelo animal utilizado no permite realizar inferencias sobre el consumo de forraje diario en animales adultos (Coleman et al., 2014), debido a diferencias anatómicas y de requerimientos de energía y proteína (Kramer y Prins, 2010; Coleman et al., 2014) así como diferencias en la selectividad del forraje consumido entre animales con diferentes requerimientos de energía y proteína (Rutter 2006).

A pesar de la importancia del consumo de forraje y energía en los sistemas de producción sobre Campos, contamos con limitadas estimaciones y por períodos de tiempo muy variables en dos trabajos de muy corto plazo (45 minutos: Gonçalves et al., 2009; Wallau et al., 2023) y cinco trabajos de consumo de forraje diario (tres con animales en crecimiento: Piaggio, 1994; Da Trindade et al., 2016; Cezimbra et al., 2021, y dos con vacas de cría: Orcasberro et al., 2021; Briano et al., 2024). Con excepción de Briano et al. (2024), la estructura del forraje (masa y altura del forraje) fue medida en todos los trabajos. El tiempo durante el que se midió fue de minutos (Gonçalves et al., 2009; Wallau, 2023) a días y de momentos puntuales (Da Trindade et al., 2016) y a todo el ciclo (Orcasberro et al., 2021; Cezimbra et al., 2021). Sin embargo, la desagregación en estructura y el cómo se construye el proceso a través de la conducta y la repetición de medidas en varios años permanece como incógnita.

Conviene analizar la consistencia de los resultados obtenidos en los trabajos con animales en crecimiento. Piaggio (1994) reporta que la relación consumo-oferta de forraje no se puede expresar en una regresión, mientras que Da Trindade et al. (2016) reportan que el consumo de forraje aumenta de forma lineal desde 4 % hasta 16 % de oferta de forraje expresada en porcentaje del PV. Por otro lado, los autores resaltan que, para que el consumo de forraje resulte alto, la masa de forraje debe ser superior a 1680 kg MS/ha. Sin embargo, al analizar el trabajo de Soares et al. (2005, que es del mismo grupo de investigación donde se desarrolló el experimento de Da Trindade et al., 2012, 2016), el tratamiento con la mejor producción animal (230 kg PV/año) resultó ser la oferta de forraje que varió entre 2 y 3 kg de PV/kg MS y la masa de forraje resultó superior a 1680 kg MS/ha solamente durante otoño; incluso durante la primavera la masa de forraje fue de 979 kg MS/ha, casi la mitad del valor recomendado por Da Trindade et al. (2016). El modelo reportado por Da Trindade et al. (2016) no considera la selectividad del forraje y su efecto en el consumo de forraje, ni la digestibilidad de la dieta, ni la digestibilidad de la pastura integran el modelo de consumo de forraje, cuando en todos los modelos de consumo de forraje la digestibilidad de la dieta seleccionada o del forraje ofrecido tienen un rol preponderante en el consumo de forraje alcanzado (Piaggio, 1994; NRC, 2000; Brosh et al., 2004; CSIRO, 2007). Estas carencias en las estimaciones del consumo de forraje en vacunos en pastoreo de Campos marcan la necesidad de mayor cantidad de estimaciones del consumo de forraje vinculado a la selectividad de la dieta en diversas situaciones de pastoreo. Por otra parte, Wallau y Bremm (2017, también del mismo grupo de trabajo), al modelar el consumo de forraje, con base en la masa de bocado y altura del forraje, predicen que el consumo aumenta de forma lineal hasta 2,8 % del PV y que luego se estabiliza y no aumenta debido a baja digestibilidad o llenado ruminal. Sin embargo, no se reportan medidas de llenado ruminal o de digestibilidad del forraje consumido, ni de aspectos digestivos como tasa de pasaje o degradación de la fibra. Al mismo tiempo, la evidencia científica resulta contraria a esta afirmación de estabilización debida a baja digestibilidad o llenado ruminal, pues, a mayor oferta de forraje, la digestibilidad de la dieta aumenta (Piaggio et al., 1995) debido a mayor posibilidad de selección del forraje. García et al. (2003) trabajaron con ovejas pastoreando *Dactylis glomerata* y reportan que en alta carga existe una restricción por cosecha, mientras que en baja carga hay una restricción sobre la tasa de consumo por tiempo de búsqueda de las partes más digestibles de la pastura. Ambos tratamientos alcanzaron similar consumo de MO, pero se explican por razones diferentes y contrapuestas a las propuestas por Wallau y Bremm (2017), ya que el tiempo de pastoreo, aunque alto, no resulta máximo y que a alta masa de forraje hay mucho tiempo de búsqueda, que resulta en alto tiempo de pastoreo para buscar los ítems más digestibles del forraje (García et al., 2003).

Estos resultados indican que la productividad animal no se asocia directamente con la estructura del forraje porque no es el único factor que afecta el consumo de energía o el balance energético (Carvalho et al., 2015). Un factor de importancia es la digestibilidad de la dieta, que no se relaciona directamente con la digestibilidad de la pastura (debido a la selectividad) y que resulta un proceso afectado por la oferta de forraje (Piaggio et al., 1995) que afecta no solo la estructura sino la competencia entre animales. Por tanto, resulta necesario vincular las estimaciones de consumo de forraje a la selectividad de la dieta y la estrategia espacio-temporal del pastoreo, para luego estimar asociaciones con la productividad animal.

Estos resultados marcan la necesidad de continuar midiendo el consumo de forraje en pastoreo, asociado a la digestibilidad de la dieta, y los procesos digestivos y la estrategia de pastoreo de esos rumiantes.

A pesar de las diferencias en el modelo animal, un aspecto importante que ha estado fuera de la consideración de las características del forraje hasta el momento y que podría estar asociado al consumo de forraje diario es la heterogeneidad de la pastura.

La relevancia del tipo de pastura, heterogénea vs. homogénea, radica en que el patrón de búsqueda y cosecha de forraje podría verse alterado por la interacción selectividad de la dieta-heterogeneidad del forraje, que podría cambiar el consumo de forraje diario (Laca, 2009).

2.2. Estrategias de pastoreo de vacas de cría asociadas a cambios en la oferta y genotipo de la vaca

El uso de diferentes áreas del potrero podría afectar la selección del forraje a través de las decisiones de conducta que toma el rumiante sobre dónde realizar los bocados de consumo de forraje (pastura baja o pastura alta, más digestible, menos digestible, lejos del agua, cerca del dormidero…) una vez que realizó bocados en un lugar previo. La selectividad de la dieta resulta afectada por las especies a pastorear, su nivel de agregación y la cercanía de las plantas menos seleccionadas de las plantas más seleccionadas (Dumont et al., 2002). Durante el día, a escala de parche o estación de pastoreo (FeSt, ver esquema de escalas espacio-temporales de Bailey et al., 1996), la secuencia de pastoreo puede ser afectada por factores como la experiencia previa del rumiante, que afecta el gusto y la necesidad por ciertos alimentos (Ginane et al., 2015; Provenza et al., 2015). De esta forma, la experiencia previa de largo plazo interactúa con el consumo de energía o proteína en la sesión de pastoreo previa, el llenado ruminal, con el ayuno y con la secuencia de pastoreo de diferentes especies (Villalba et al., 2015; Ginane et al., 2015). En condiciones de abundancia y fácil disponibilidad, cuando el consumo de forraje se mide a escala diaria o de período de días, los cambios en la elección de alimento previo o posterior y su desempeño parecen carecer de relevancia, dado que los animales compensan y alcanzan similar productividad (Atwood et al., 2001) No obstante, en pastoreo, la abundancia de alimento no resulta como en corrales de alimentación y la secuencia u orden de pastoreo de los recursos afecta el consumo de forraje (Lyman et al., 2011).

Da Trindade et al. (2012) construyeron un modelo conceptual de la búsqueda de forraje en el cual el desplazamiento diario (metros/día) y la tasa de movimiento (metros/minuto) constituyen los ejes de la búsqueda del forraje durante las sesiones de pastoreo. Sin embargo, aunque la búsqueda de forraje se produce en un espacio donde el recorrido es un componente, en nuestra visión, las escalas que tengan sentido para el animal son las que deben tomarse en cuenta y, en este sentido, las estaciones de pastoreo, que son los lugares que el rumiante elige para detenerse y realizar la cantidad de bocados que considere oportuno, representan una escala espacial capaz de ser medida y que la vaca utiliza para realizar bocados. Así, si dos vacas no se diferencian en la tasa de bocados (número de bocados por minuto) ni el tiempo de pastoreo, pero si una de ellas incrementara las estaciones de pastoreo, podría extender su capacidad potencial de seleccionar forraje y su capacidad espacial de compensar el consumo de forraje ante una disminución en la altura del forraje promedio. Entonces, tan importante como los cambios en el tiempo diario de pastoreo o la tasa de bocados como mecanismos de compensación del consumo de forraje es el número total de estaciones de pastoreo porque describe el área utilizada por la vaca y esto podría indicar mayor o menor selectividad de la dieta. La cantidad de metros recorridos no resulta *per se* un cambio en el uso del espacio, pero, si los animales realizan un recorrido similar en metros (por ejemplo, 3000 metros diarios ambos) y cambian el número de estaciones de pastoreo (por ejemplo, 260 vs. 340 estaciones/hora), esto resulta en diferente exploración de la pastura (uno habrá utilizado ochenta estaciones más por hora, lo que podría resultar en mayor potencial de selección de dieta), distinta selectividad por unidad de forraje y, por tanto, en diferente estrategia de pastoreo o cosecha de energía (Hirata et al., 2015).

La estrategia diaria de pastoreo podría comprenderse mejor si, además de contar con el tiempo de pastoreo y la tasa de bocados, contáramos con las FeSt diarias. De esta forma podemos incorporar una medida del espacio explorado (área de la EP = altura de la vaca a las cruces x coseno de 30°; Gregorini et al., 2013) y de los bocados realizados por estación de pastoreo. Así tendremos el potencial de selección por unidad de área y de forraje. Seguir profundizando en la estrategia utilizada requiere conocer la distancia recorrida en pastoreo y, de esta forma, estimar las estaciones de pastoreo por metro recorrido o por área diaria explorada, lo que permitiría hipotetizar sobre otros aspectos de la exploración espacio-temporal. Contar con este tipo de información permitiría conocer compensaciones espaciales que realizan los rumiantes en pastoreo asociadas a la heterogeneidad de la pastura en estructura del forraje producto de la oferta de forraje. Por ejemplo, para el experimento de oferta de forraje explicado en el punto uno de la revisión, durante invierno en gestación avanzada, las vacas de alta y baja oferta de forraje no difirieron en el tiempo de pastoreo, ni en las estaciones de pastoreo realizadas, pero las vacas cruza utilizaron mayor número de estaciones de pastoreo, lo que se asoció posteriormente con mejor balance de energía de esas vacas (Soca et al., 2016). La estrategia de movimiento de los animales tampoco ha sido descrita junto a la composición de especies de pasturas de Campos, ni a la heterogeneidad del forraje en altura y en espacio. Por estas razones nos interesa describir y cuantificar la estrategia de pastoreo de vacas de cría ante modificaciones de la oferta de forraje o el genotipo de la vaca y su asociación con el consumo de forraje.

2.3 Análisis de los modelos propuestos para predicción del consumo de forraje en pastoreo

Analizar los modelos propuestos para estimar el consumo de forraje o energía en pastoreo resulta útil, entre otras razones, para conocer cuál o cuáles de los factores o mecanismos que afectan el consumo de forraje tendrían superior importancia relativa.

El NRC (2000) reconoce que su modelo de predicción del consumo de forraje se basa en el modelo bifásico de regulación del consumo por factores físicos del forraje y factores fisiológicos de la demanda de energía y los productos finales de la digestión para dietas de alto contenido de energía. Se propone una ecuación para predecir el consumo de forraje (DMI) para vacas de cría $DMI = SBW^{0,75} * (0,0194 + 0,0545 * NE_m)$, donde SBW = peso vivo en ayuno y NE_m = energía neta de mantenimiento del alimento consumido. Esto significa que los factores de mayor relevancia sobre el consumo de forraje lo constituyen el peso metabólico y la digestibilidad de la dieta. Esto indica que los mecanismos representados en el modelo lo constituyen la demanda de energía y la selectividad del forraje. Cambios en la selectividad modificarían la digestibilidad de la dieta y el proceso de digestión. La necesidad de cuantificar e incluir la digestibilidad del forraje seleccionado en la predicción de consumo está presente en todos los estándares de estimación del consumo de forraje diario (CSIRO, 2007; AFRC, 1993; NRC, 2000). Entre los modelos desarrollados por NRC (2000) se le han propuesto enmiendas o factores de corrección tanto para la estimación de requerimentos como para la estimación de consumo de forraje en pastoreo; por ejemplo, en pastoreo, un factor por masa de forraje (la cual, si es inferior a 1150 kgMS/ha, comienza a corregir el valor estimado) corrige el valor de consumo de forraje. Conocer la NE_m de la dieta requiere conocer la digestibilidad del forraje seleccionado, algo extremadamente difícil de hacer en pastoreo. No obstante, es posible que, a través del análisis del mecanismo que emplea la vaca para seleccionar el forraje y los factores que lo afectan, pueda aproximarse a un valor de digestibilidad del forraje seleccionado.

Piaggio (1994), en un diseño completamente al azar donde cada animal se utilizó como unidad experimental (animales de recría Holando *n* = 24) en pastoreo de campo natural mejorado con *Lotus corniculatus*, midió el consumo de forraje a través de marcadores indirectos (óxido de cromo) y la selectividad a través de animales fistulados en esófago con el objetivo de evaluar el efecto de la oferta de forraje sobre el consumo de forraje. La obtención de la extrusa de cada fistulado permitió estimar la MO (materia orgánica), PC (proteína cruda), digestibilidad y EM del forraje seleccionado en las cuatro estaciones del año, en diez momentos, en un amplio rango de oferta de forraje (de 2,5 % a 12,5 % del PV). Piaggio (1994) generó un modelo que permite estimar el consumo de MO a través de un índice (PPEC presión de pastoreo energética corregida), que se construye con tres factores: 1) la oferta de forraje, 2) energía metabolizable del forraje (oferta de energía metabolizable) y 3) 1-MM, donde MM es material muerto. El material muerto, fracción evitada por los vacunos en pastoreo, representa la dificultad de selección del forraje en pasturas con diferente grado de material senescente. Aunque el modelo de Piaggio (1994) alcanza un ajuste muy alto (r2 = 0,82, P < 0,05, *n* = 18) al modelar el consumo de MO de forraje para animales en crecimiento, cuando dicho modelo se aplica a las estimaciones de consumo de forraje para vacas de cría, resulta en valores que parecen (hasta 18 kg en pasturas de 2000 kg MS/ha) demasiado altos en kg de MS forraje/día respecto de las estimaciones realizadas en vacas de cría gestantes (7 a 11 kg MS/vaca Briano et al., 2013) o vacías (9 a 11 kg MS/vaca Clariget, 2014). Este resultado de Piaggio (1994) y los de Coleman et al. (2014) confirmarían que no es posible extrapolar los resultados obtenidos en animales en crecimiento a vacas adultas.

Un modelo similar al empleado por Piaggio (1994) fue construido por Brosh et al. (2004) luego de estimar durante tres años el consumo de energía en vacas de cría lactantes o secas y en diversas condiciones de carga animal y biomasa. El consumo de energía metabolizable (MEI, kJ por kg PV 0,75/día) en vacas de cría resultó afectado mayormente por la biomasa de forraje (B), la energía metabolizable del forraje ofrecido (ME) y el estado fisiológico de la vaca (L, lactante o no lactante) MEI = -1366 + 239,9 (+/-24,9) × ME + 263,1 (71,7)(si Lactante) + 0,0921 (0,0921) × B (R^2 = 0,87). Las aproximaciones de Piaggio (1994) y Brosh et al. (2004) resultan un avance respecto de los modelos de estimación de consumo de forraje realizados por los estándares de NRC, CSIRO o AFRC, puesto que no requieren la digestibilidad de la dieta consumida, sino la energía metabolizable del forraje ofrecido. La digestibilidad de la dieta seleccionada se asocia con la digestibilidad del forraje ofrecido (Piaggio, 1994) y seguramente esto sea la razón por la cual es posible utilizar dicho factor.

CSIRO (2007) propone ecuaciones de estimación del consumo de forraje que se basan en el tamaño animal y en las restricciones de ingestibilidad y digestibilidad en vacunos. El modelo de CSIRO (2007) para estimar el consumo de forraje en pastoreo comienza a activar compensaciones comportamentales para mantener el consumo de forraje si el forraje se encuentra por debajo de tres toneladas, mientras que aumentos de la digestibilidad del forraje de 50 % a 80 % permiten duplicar el consumo de forraje. Sin embargo, las estimaciones realizadas con base en las ecuaciones de CSIRO (2007) parecen muy por debajo de lo esperable comparado con el modelo de NRC y con las estimaciones de Briano et al. (2013) y Clariget (2014), pues una vaca de 500 kg que consume un forraje de 50 % de digestibilidad consumiría 4,5 kg/d, un 0,9 % del PV, y una vaca que consume un forraje de 80 % de digestibilidad consumiría 9,1 kg/día, lo que dista de las estimaciones para vacas primíparas y multíparas que fueron de 8 a 11 Kg/vaca/día o entre 1,9 % y 2,5 % del PV. En el modelo de CSIRO (2007), la digestibilidad del forraje seleccionado resulta el factor de mayor importancia para incrementar el consumo de forraje comparado con otros modelos y estimaciones.

En el presente trabajo, nos planteamos la hipótesis de que es posible construir un modelo conceptual de predicción del consumo de energía de vacas de cría que incluya la energía digestible del forraje (estimada a través de la FDA o la PC a través de fórmulas de CSIRO, 2007), la oferta de forraje o energía (oferta de forraje x concentración de energía del forraje), los requerimientos de la vaca en función del peso vivo y el estado fisiológico y la heterogeneidad de la pastura como principales moduladores del consumo de energía y factores de la conducta en pastoreo como moduladores de la capacidad de selección de forraje en vacas de diferente genotipo.

2.4 Objetivo general

Cuantificar el consumo de forraje de vacas de cría en Campos ante cambios en la oferta de forraje y el genotipo de la vaca y comprender su relación con los procesos de selectividad y conducta espacio-temporal de pastoreo para contribuir a explicar cambios en la eficiencia de uso de la energía en pastoreo de campo natural.

2.5 Objetivos específicos

1. Cuantificar la relación entre oferta de forraje y consumo de forraje de vacas de cría de diferente genotipo que se encuentran en gestación y lactancia e identificar *trade off* entre masa de forraje y concentración energética de la dieta.

2. Describir la heterogeneidad de la estructura, altura y composición química y botánica del forraje ante cambios en la oferta de forraje,

3. Identificar estrategias de pastoreo de vacas de cría de diferente genotipo que se asocian o no con diferencias en consumo, selectividad y conducta espacio-temporal (selección del sitio, parches y estaciones de pastoreo) ante cambios en la oferta de forraje de Campos y que podrían asociarse a cambios en la eficiencia de uso de la energía consumida.

4. Desarrollar un modelo conceptual que integre las relaciones entre el consumo, selectividad de forraje y la conducta espacio-temporal de vacas de cría de diferente genotipo en pastoreo de Campos.

2.6. Hipótesis

1) El incremento en la oferta de forraje resulta en mayor altura y mayor heterogeneidad del forraje, lo cual favorece el incremento en el consumo de forraje y energía (vía superior selectividad del forraje y kilogramos de forraje total) de las vacas de cría pastoreando Campos.

2) A medida que se incrementa la altura del forraje, aumenta la heterogeneidad de la pastura, lo cual genera un patrón espacio-temporal del pastoreo más selectivo, que permite incrementar el consumo de forraje digestible. Dicha modificación varía según la escala e interacciona con el genotipo de la vaca.

3. Estructura de la tesis

El material incluye una revisión bibliográfica, elaboración y publicación de tres artículos y una discusión general.

Artículo 1: «Controlling herbage allowance and selection of cow genotype improve cow-calf productivity in Campos grasslands», *The Professional Animal Scientist*, *34*, 32-41.2018

Artículo 2: «Herbage mass and allowance and animal genotype affect daily herbage intake, productivity and efficiency of beef cows grazing native subtropical grassland», *Journal of Animal Science*, *99*(10), 1-9. 2021

Artículo 3 (en revisión): «Foraging strategy of purebred and crossbred beef cows grazing native subtropical grassland pastures differing in herbage mass and allowance».

4. Control de la oferta de forraje y selección del genotipo de la vaca mejoran la productividad de la cría vacuna sobre Campos

4.1. Resumen

Este trabajo tuvo como objetivo cuantificar el efecto de la oferta de forraje y el genotipo de la vaca sobre la masa y altura del forraje, la acumulación de forraje, el peso vivo (PV) y condición corporal (CC) de las vacas, la carga animal, el peso de los terneros al destete y el consumo de energía promedio. Para esto se utilizaron 95 ha de Campos en dos bloques con cuatro parcelas cada uno y 54 vacas fijas puras y cruzas distribuidas en las ocho parcelas en un arreglo factorial 2 x 2 de oferta de forraje alta (AOF) y baja (BOF) y vacas cruzas y puras. Los resultados muestran que en AOF aumentó la masa y altura del forraje, la acumulación de forraje, la CC y PV de las vacas, el consumo de energía y el peso de los terneros al destete, pero la carga animal no cambió entre tratamientos. Esto significa que AOF permitió incrementar la productividad individual de las vacas a través de un mayor consumo de energía, que resultó mayor en AOF en primavera-verano, pero similar en otoño-invierno. La carga animal no se vio modificada a escala anual, pero sí entre estaciones del año, donde en primavera-verano resultó menor en AOF, pero en otoño-invierno fue mayor en AOF.

Palabras clave: oferta de forraje, vacas de cría, Campos, carga animal, peso al destete

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Controlling herbage allowance and selection of cow genotype improve cow-calf productivity in Campos grasslands

Martín Do Carmo,*[1] Lynn E. Sollenberger,† Mariana Carriquiry,* and Pablo Soca‡
*Animal Production and Pastures Department, School of Agronomy, Universidad de la República, Garzón 780, CP 12900, Montevideo, Uruguay; †Agronomy Department, University of Florida, Gainesville 32611; and ‡Animal Production and Pastures Department, School of Agronomy, Universidad de la República, Ruta 3 km 363, CP 60000, Paysandú, Uruguay

ABSTRACT

An experiment was conducted to determine the effect of herbage allowance and cow genotype on herbage and animal responses. High (Hi) and Low (Lo) herbage allowance (4.9 and 2.9 ± 0.14 kg of DM/kg of cattle BW, respectively) and pure (Pu, Hereford and Angus) and crossbred (Cr, F1 crosses) cow genotypes were compared in terms of herbage traits, stocking rate, cow BCS, energy intake, and calf BW at weaning during 2 cow-calf cycles (−240 to +120 d postpartum). Herbage height (5.5 vs. 3.5 ± 0.18 cm, mean ± SE) and herbage accumulation (15.0 vs. 12.5 ± 1.1 kg of DM/ha per d) were greater ($P > 0.01$) for Hi than Lo, whereas stocking rate did not differ ($P > 0.2$) between Hi and Lo (382 vs. 398 ± 7 kg of BW/ha, respectively). Cow BCS was greater ($P > 0.05$) in Hi than Lo (4.3 vs. 3.9 ± 0.02) and in Cr than Pu cows (4.2 vs. 4.0 ± 0.04). Calf BW at weaning was greater (20 and 10 kg) for Hi than Lo and for Cr than Pu cows, but energy intake (473 vs. 455 ± 4.6 kJ/kg of $BW^{0.75}$ per d) was greater ($P > 0.05$), only in Hi compared with Lo cows. Modeling BCS evolution during the cow-calf cycle confirmed that Hi herbage allowance and Cr cows improved energy balance and cow-calf biological efficiency. This information can be used to improve profitability and mitigate weather variability effects on Campos grassland livestock systems.

Key words: beef cow, body condition, herbage mass, biological efficiency

INTRODUCTION

The control of grazing intensity through the management of stocking rate is an important tool for regulating the amount of solar energy captured and converted into beef production (Briske and Heitschmidt, 1991). In environments with large variation in herbage production due to seasonal differences in rainfall or temperature, the optimal stocking rate to reach a specific performance target varies widely among seasons and years (Mott, 1960; Wheeler et al., 1973; Aiken, 2016). Within this context, herbage allowance (**HA**), defined as kilograms of herbage DM per kilogram of animal BW (Sollenberger et al., 2005; Allen et al., 2011), may be more useful than stocking rate alone for managing the grazing process. For Campos grassland, manipulation of HA with growing steers from 4 to 12% of the animal BW increased beef production from 80 to 145 kg of BW/ha and herbage production from 10 to 13 kg/ha per d (Maraschin et al., 1997).

Cow-calf production is a long-term and energetically inefficient process within the context of the Campos's livestock systems (Do Carmo et al., 2016). Matching cow requirements and energy intake in grazed ecosystems with seasonal variability in herbage production and nutritive value is one of the main challenges to intensification of Campos's livestock (Tittonell et al., 2016). Grazing management based on HA could improve the economic and environmental response of beef cow-calf systems (Do Carmo et al., 2016). However, knowledge is limited of the HA–BCS relationship and the nature of interactions among herbage growth, stocking rate, and productivity per animal or hectare for cow-calf responses (Claramunt et al., 2017).

Previous reports have shown that reciprocal crossbreeding between Angus and Hereford (F1), the most common breeds in Campos, increased kilograms of calf weaned per cow exposed and biological efficiency over purebreds (Morris et al., 1987; Cundiff, 2004). However, we do not have grazing experiments evaluating the effect of HA and cow genotype in interaction with year (different climate conditions) on productivity or efficiency of energy use. Grazing experiments that evaluated the interaction of HA and cow genotype and year are of primary importance to assess the effect of HA and cow genotype on stocking rate, herbage growth, cow adaptability, and productivity in a variable climate. This information emphasizes the role of grazing experiments as a basis for ecological intensification in beef cow-calf systems on Campos grassland or other

The authors declare no conflict of interest.
[1] Corresponding author: martindocarmocorujo@gmail.com

subtropical-subhumid grassland (Gunter and Cole, 2016). The objective was to study the effect of HA and cow genotype on herbage mass and accumulation, stocking rate, cow BCS and BW, calf BW at weaning, and biological efficiency during 2 cow-calf cycles.

MATERIALS AND METHODS

Experimental Site, Design, and Treatments

The experiment was conducted on 95 ha of Campos grassland located at the Prof. Bernardo Rosengurtt Experimental Station, School of Agronomy, Uruguay (32°35′S, 54°15′W), between August 2007 and March 2010. Average annual rainfall is almost 1,200 mm, and the climate type is classified as Cfa (subtropical, humid, without dry season, where mean temperature in the coldest month is between −3 and 18°C and the warmest is above 22°C) according to Köppen (Panario and Bidegain, 1997). During the first spring-summer (2007–2008, HA establishment and early gestation in cycle 1), rainfall was similar to the long-term average (1961–1990), but a drought occurred during spring-summer 2008 to 2009 (lactation of cycle 1) when rainfall was 55% below the long-term average. In contrast, during the last spring-summer period (2009–2010, lactation of cycle 2), rainfall was 88% above the long-term average (Figure 1A).

The experimental design was a randomized complete block, with 2 blocks that were based on differences in soil characteristics. Block 1 consisted of Hapludalfs and Argiudolls soils and block 2 of Hapluderts and Argiudolls soils. Campos grassland was dominated by "pasto chato" *Axonopus affinis* Chase, *Oxalis* sp., "pasto bolita" *Cyperus* sp., "gramilla" *Cynodon dactylon* (L.) Pers., *Eryngium nudicaule* Lam., *Gaudinia fragilis* (L.) P. Beauv., *Chevreulia sarmentosa* (Pers.) S. F. Blake, *Stipa setigera* (Trin. & Rupr.) Backworth, "pasto horqueta" *Paspalum notatum* Fluegge, and "cola de lagarto" *Coelorhachis selloana* (Hack.) A. Camus [F. Olmos, 2011, formerly with Instituto Nacional de Investigacion Agropecuaria (INIA), Tacuarembo, Uruguay, personal communication], similar to a Campos grassland botanical composition previously reported (Altesor et al., 1998).

Block 1 was 60 ha and block 2 was 35 ha in area. Each block consisted of 4 experimental units (pastures) to which the 2 × 2 factorial combinations of HA [high (**Hi**) and low (**Lo**)] and cow genotype [pure (**Pu**) and crossbred (**Cr**)] treatments were allocated. Herbage allowance, the ratio between herbage mass and stocking rate (kilograms of herbage DM/kilograms of BW; Sollenberger et al., 2005; Allen et al., 2011) was varied with season of the year. Target levels of Hi and Lo HA were 5 and 3 kg of DM/kg of BW during autumn; 3 and 3 kg of DM/kg of BW during winter; and 4 and 2 kg of DM/kg of BW during spring and summer, respectively. Average HA achieved across years was somewhat greater than target levels for both treatments. Herbage allowances were 4.7, 6, 5.6, and 3.3 kg of DM/kg of BW (annual average of 4.9) for Hi and 2.3, 2.8, 3.6, and 2.9 kg of DM/kg of BW (annual average of 2.9) for Lo during spring, summer, autumn, and winter, respectively.

Target levels of HA were based on a previous experiment where maximum per animal and per hectare beef cattle production was achieved at HA of 4 and 2.5 kg of DM/kg of BW, respectively (Piaggio, 1994). Continuous stocking was applied throughout the year (Allen et al., 2011), with stocking rate adjusted monthly starting in August 2007. Adjustments occurred after monthly measurement of herbage mass, which together with animal BW per hectare, was used to calculate HA.

Pasture Measurements

Herbage mass (kg of DM/ha) and height (cm) were quantified monthly using the comparative yield method (Haydock and Shaw, 1975). Approximately 10 reference quadrats were used for calibration, and 100 randomly selected quadrats were rated at each sampling event on each experimental unit. Reference quadrats were 0.25 m^2, and after being assigned a ranking, herbage heights were measured and cut to ground level to quantify herbage mass. The ranking and actual herbage mass data from the reference quadrats were used to develop the equation for predicting herbage mass and height from the average of the ranking of the 100 randomly selected quadrats. Herbage accumulation (kg of DM/ha per d) was quantified from winter 2007 to summer 2010 using portable cages to protect quadrats (0.5 × 0.5 m) from grazing. Herbage accumulation was calculated as dry weight change in kilograms per hectare daily between consecutive sampling dates. Paired quadrats were chosen based on similarity of herbage mass. For one of each pair of quadrats, herbage mass was determined to soil level, and for the other area, a cage was placed to preclude grazing until subsequent harvest at the next sampling date (Mannetje `t, 1978). The difference was considered to be herbage accumulation.

Herbage for laboratory analyses was composited across reference quadrats within an experimental unit and was weighted to represent herbage mass of each reference quadrat sample included. Herbage samples were dried to constant weight at 60°C, weighed, and then double ground using a Wiley mill (Model 4 Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen for chemical composition analyses. Analyses of herbage CP (Kjeldahl N percentage × 6.25, AOAC International, 2005) and ADF (Fiber Analyzer 200, Ankom Technology Corporation, Fairport, NY; Van Soest et al., 1991) were performed.

Animals

Animal procedures used in this research were approved by the Animal Experimentation Committee of the Universidad de la República. Experimental animals belonged

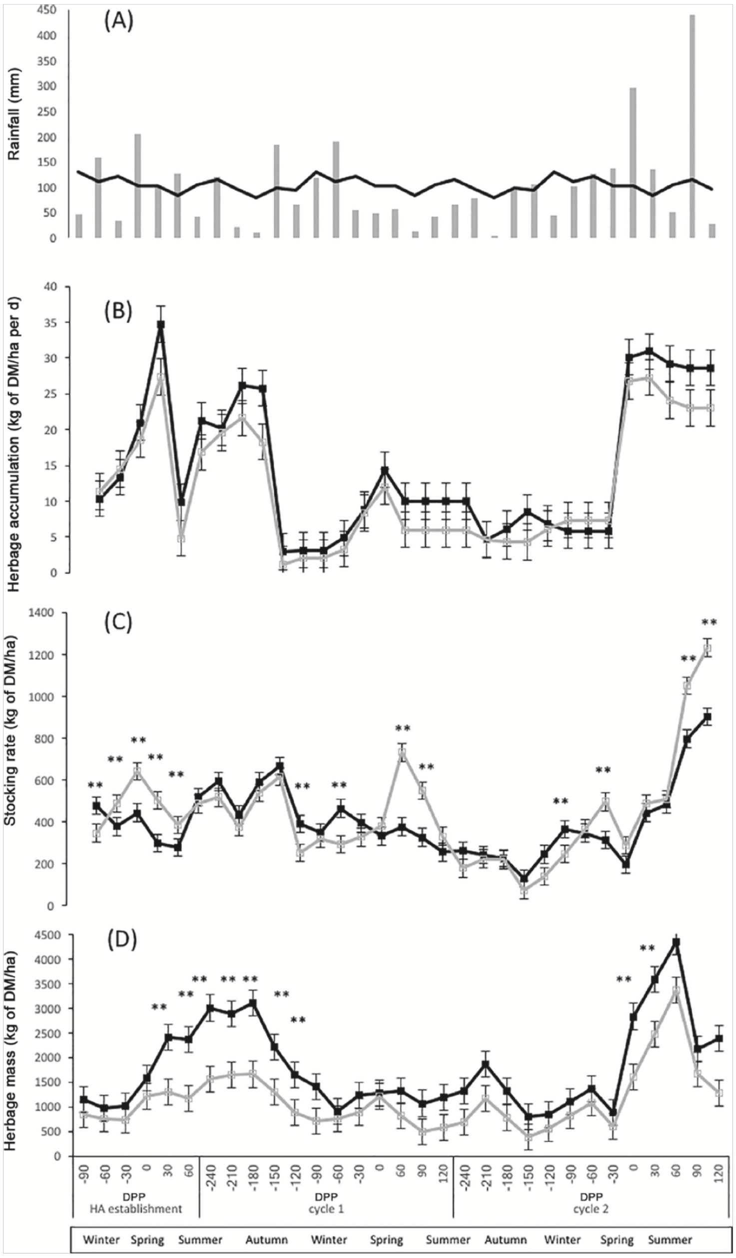

Figure 1. (A) Seasonal rainfall (gray bars) quantified at experiment site, and long-term (black line) seasonal average (1961 to 1990, Dirección Nacional de Meteorología, 2011). Effect of high (black line) and low (gray line) herbage allowance (least squares means ± SE) and days relative to calving (DPP) within cycle upon herbage accumulation (B), stocking rate (C), and herbage mass (D). HA = herbage allowance. Asterisks indicate statistical significance at $P < 0.05$.

to a group described by Gutierrez et al. (2013). Thirty Pu [Hereford (n = 17) and Angus (n = 13)] and 24 Cr (F1 reciprocal Hereford and Angus crosses) multiparous cows, aged 4 to 8 yr, with normal calving and pregnancy confirmed by ultrasound, were randomly assigned as core animals to the experimental units. Extra cows with similar physiological stage and genotype were added or removed based on measurement of herbage mass and the HA targets. Core cows (n = 54) were maintained on the same treatment throughout the experiment if they calved annually (the range in core animals was from 38 to 60 cows). Calf sires were Hereford or Angus, determining that calves from Pu dams were half pure and half crossbred (AA and HH, and F1: H × A and A × H), whereas calves from CR dams were backcross progeny (H-H × A, H-A × H, A-H × A, and A-A × H). Because of the limited cow replacement and the importance of keeping the cows in the experiment to test the effects of year and treatments on the same animals, treatments to increase the pregnancy probability were applied at mating (see below). Cow BW (kilograms) and BCS were assessed monthly. Cow BW was measured without fasting during the morning and within 1 h of when animals were removed from experimental units. Cow BCS was visually assigned on a scale from 1 = very thin to 8 = very fat (Vizcarra et al., 1986).

Calf BW without fasting was assessed at birth and at the beginning of the breeding season when they were separated from the cows (early weaning at 66 ± 20 d, mean ± SD) during HA establishment or when suckling was restricted (cycle 1, calves fitted with nose plates for 11 d, at 76 ± 11 d postpartum during summer 2009) at 102 ± 11 d and 123 ± 15 d postpartum (permanent weaning in cycle 1 and 2, respectively). During the first and second (summer 2008 and 2009) breeding seasons, a 20-d supplement period with 2 kg/cow on a fresh basis of rice (*Oryza sativa*; 86.5% DM, 13.5% CP, 44% NDF, and 13.5% ether extract) middling began with early weaning or suckling restriction (nose plates applied to calves at the beginning of breeding season, see Soca et al., 2013). In summer 2010 cows were not mated and not supplemented and definitive weaning was performed at 123 ± 15 d. Lactation period was calculated as the period from calving to weaning. Male calves were castrated at birth.

Cow NE Requirements and Calf BW at Weaning

Net energy requirements were estimates in megajoules per cow and in megajoules per kilogram of metabolic BW ($BW^{0.75}$) using energy requirements (NRC, 2000, 2001) of the cow (Smit et al., 2005). Calculations were based on cow BW and BCS, days of gestation, calf BW at birth, and energy in milk of our cows [milk production and composition based on Gutierrez et al. (2013)]. Lactation periods in cycle 1 were from parturition to 77 ± 11 d, and after 11 d of suckling restriction, lactation continued until 102 ± 11 d postpartum (February 2, 2009). In cycle 2, lactation extended to 123 ± 15 d (March 23, 2010).

Herbage traits, BW, BCS, and calf BW and energy intake were summarized in 3 periods: (a) herbage allowance establishment that corresponds to the first 140 d of the experiment [from −77 to +66 d postpartum (**DPP**)] and (b) cow-calf cycles 1 and 2, which cover all of the cow physiological states from −240 to +120 DPP of 2 successive years. We also presented the correspondence between the DPP and seasons of the year.

Statistical Analysis

Data were analyzed using the SAS Systems program (SAS 9.0V, SAS Institute Inc., Cary, NC). Herbage responses (mass, accumulation, and chemical composition) and stocking rate were analyzed with days (relative to calving date) as a repeated measure and pasture as the experimental unit. The model included HA (Hi or Lo), DPP (relative days to parturition within each cow cycle), and their interaction as fixed effects and block and pasture as random effects. Herbage accumulation, mass, height, and chemical composition were analyzed using the MIXED procedure, with CS (compound symmetry) or AR (1) (first-order autoregressive) as the covariance structure and Kenward-Rogers procedure to adjust degrees of freedom. The effect of cow genotype was removed from the model for analyses of herbage responses and stocking rate because it was not significant ($P > 0.20$).

For cow BW and BCS, calf BW at weaning and ADG and NE requirement (MJ/d or MJ/kg of $BW^{0.75}$), the experimental unit was the cow or calf, and data were analyzed as repeated measures using the MIXED procedure. Data were analyzed by cow cycle and the model included HA, cow genotype, DPP within cow cycle (repeated measure), and their interactions as fixed effects and block and plot as random effects. For calf ADG and BW at weaning, the model also included calf sex as a fixed effect and days to weaning as a covariate. Calf BW at weaning was separated by cycle as was the case for cows, and we focused on cycles 1 and 2 for cows and calves because of the partial application of HA treatments for cow during herbage allowance establishment. The covariance structure used for all animal variables was AR(1) (first-order autoregressive), and the Kenward-Rogers procedure was used to adjust the denominator degrees of freedom. The initial values (August 2007) of herbage mass and accumulation and cow BW and BCS were used as covariates in their respective analyses. The Tukey-Kramer procedure was used for mean separation ($\alpha = 0.05$).

Correlation between variables was determined by the CORR procedure. Analysis of covariance between seasonal rainfall and herbage accumulation (excluded data from winters) was performed by the MIXED procedure to test whether slopes were different from zero, and one or more models were needed. Slopes were different from zero, but slopes for the 2 levels of HA were not different ($P > 0.05$); thus, one model, performed using the REG procedure, was adequate to describe the data.

RESULTS AND DISCUSSION

Herbage allowance and cow genotype did not interact ($P > 0.05$) for any herbage or animal response. The Hi allowance resulted in greater herbage mass and height, cow BCS, and calf BW at weaning. The use of Cr cows in comparison with Pu cows increased cow BCS and calf BW at weaning. Importantly, the improved individual animal performance observed for Hi versus Lo occurred with no difference in stocking rate. Despite the overriding influence of rainfall on herbage accumulation (Fynn and O'Connor, 2000; Gillen and Sims, 2004; Lattanzi et al., 2007), there was a significant effect of HA on herbage accumulation, with Hi resulting in greater herbage accumulation than Lo. These novel results highlight the effect of HA and cow genotype on simultaneously improving herbage mass and height, energy intake, and biological efficiency to convert herbage in calf BW, and emphasize the role of HA grazing experiments as the basis for studying the ecological intensification in beef cow-calf systems on Campos grassland (Aiken, 2016; Do Carmo et al., 2016; Gunter and Cole, 2016; Rouquette, 2016).

Effect of HA, on Herbage Traits and Stocking Rate

Herbage allowance affected all response variables ($P < 0.05$) except for herbage ADF and CP concentrations and stocking rate ($P > 0.10$). Average herbage mass, height, and accumulation were 82%, 57%, and 21% (1,650 vs. 910 ± 68 kg/ha; 3.5 vs. 5.5 ± 0.18 cm; 15 vs. 12.5 ± 1.1 kg of DM/ha per d, respectively) greater in Hi than Lo.

Herbage allowance did not affect herbage chemical composition, as reported previously by Sollenberger and Vanzant (2011). Herbage ADF and CP concentrations differed ($P < 0.05$) among seasons; CP was greater and ADF was lower in spring than in the other seasons (% CP = 10.5 ± 0.2, 8.4 ± 0.25, 7.2 ± 0.37, and 8.6 ± 0.37 and % ADF = 36 ± 0.8, 39.5 ± 0.9, 41.4 ± 0.4, and 40.6 ± 1.2 for spring, summer, autumn, and winter, respectively). However, herbage samples were clipped at the soil level and may not reflect the nutritive value of diet consumed (Piaggio et al., 1995).

Herbage mass, height, and stocking rate were affected ($P < 0.05$) by the interaction of HA × DPP within cow-calf cycle. Differences in herbage height between HA were significant from −240 to −60 DPP and 90 to 120 DPP of cycles 1 and 2, respectively (Figure 2A and 2D). Herbage accumulation was numerically greater at 30 and 60 DPP and at −210 and −180 DPP of HA establishment and cycle 1, respectively (Figure 1B), and it was also related to seasonal rainfall [$y = -6.09 + 0.1169x$; $R^2 = 0.5$, $P < 0.0001$; where y = herbage accumulation (kg of DM/ha per d) and x = rainfall for spring, summer, or autumn].

Differences in herbage height and mass that occurred between Hi and Lo could be explained by a previous reduction in stocking rate and greater herbage accumulation rate for Hi than Lo (average difference of 4.5 kg of DM/ha per d between 0 DPP of HA establishment and −180 DPP of cycle 1). Average values of herbage accumulation were similar to a previous Campos experiment where herbage mass varied from 1,000 to 1,800 kg of DM/ha (Moojen and Maraschin, 2002). This likely occurred because herbage mass is positively correlated with leaf area index, and greater leaf area index results in greater herbage accumulation rate (Parsons et al., 1983; Sollenberger et al., 2012). The differences in herbage mass between HA were coupled to herbage growth, because they were greater during seasons with average or above-average rainfall and were minimal during drought (spring-summer 2008, Figure 1B, and 1D).

Average stocking rate was not affected by HA (382 vs. 398 ± 7 kg of BW/ha, Hi and Lo, respectively). Stocking rate was greater ($P < 0.05$) in Lo than Hi at the beginning of the experiment (HA establishment, Figure 1C), and at +60 and +90 DPP of cycle 1 and +90 and +120 DPP of cycle 2 (Figure 1C). Stocking rate was greater ($P < 0.05$) in Hi than Lo at −120 and −60 DPP of cycle 1 and at −90 DPP of cycle 2 (Figure 1C). The lack of significant differences in stocking rate at other times may at first seem counterintuitive, but it can be explained within the context of a multiyear experiment and the structure of the HA treatments. Starting the experiment with all pastures at approximately the same herbage mass, by definition greater stocking rate will be required to establish the Lo HA treatment. Indeed, the Lo treatment had greater stocking rate than Hi at the beginning of the experiment during HA establishment from −30 to +60 DPP (Figure 1C). Thereafter, the primary driver of stocking rate was herbage accumulation rate. Thus, because there was greater herbage accumulation rate for Hi than for Lo, as a direct response to greater herbage mass for Hi than Lo (Parsons et al., 1983; Kim et al., 2001; Moojen and Maraschin, 2002), subsequent upward adjustments of stocking rate on Hi reduced the magnitude of the difference between treatments. A second feature of the experiment that minimized differences in average stocking rate between HA treatments was the stipulation that HA was the same for Hi and Lo during winter. Because herbage accumulation rate was greater during the growing season for Hi, and HA was required to be the same for Hi and Lo during winter, stocking rate had to be increased for Hi during winter (−120 and −60 DPP of cycle 1 and −90 DPP of cycle 2) to reach equal HA (Figure 1C). This further mitigated any stocking rate advantage of Lo versus Hi and led to the finding that stocking rate was not different on an annual basis for the different HA treatments.

Stocking rate was positively correlated with herbage mass ($r = 0.65$, $P < 0.01$) and herbage accumulation during spring, summer, and autumn ($r = 0.58$, $P < 0.01$) as previously reported by Hill et al. (1993) and Lattanzi et al. (2007) when grazing intensity was controlled. Thus, changes in stocking rate were also related to rainfall as mediated through herbage growth. Positive correlation between herbage mass and stocking rate contrasted with

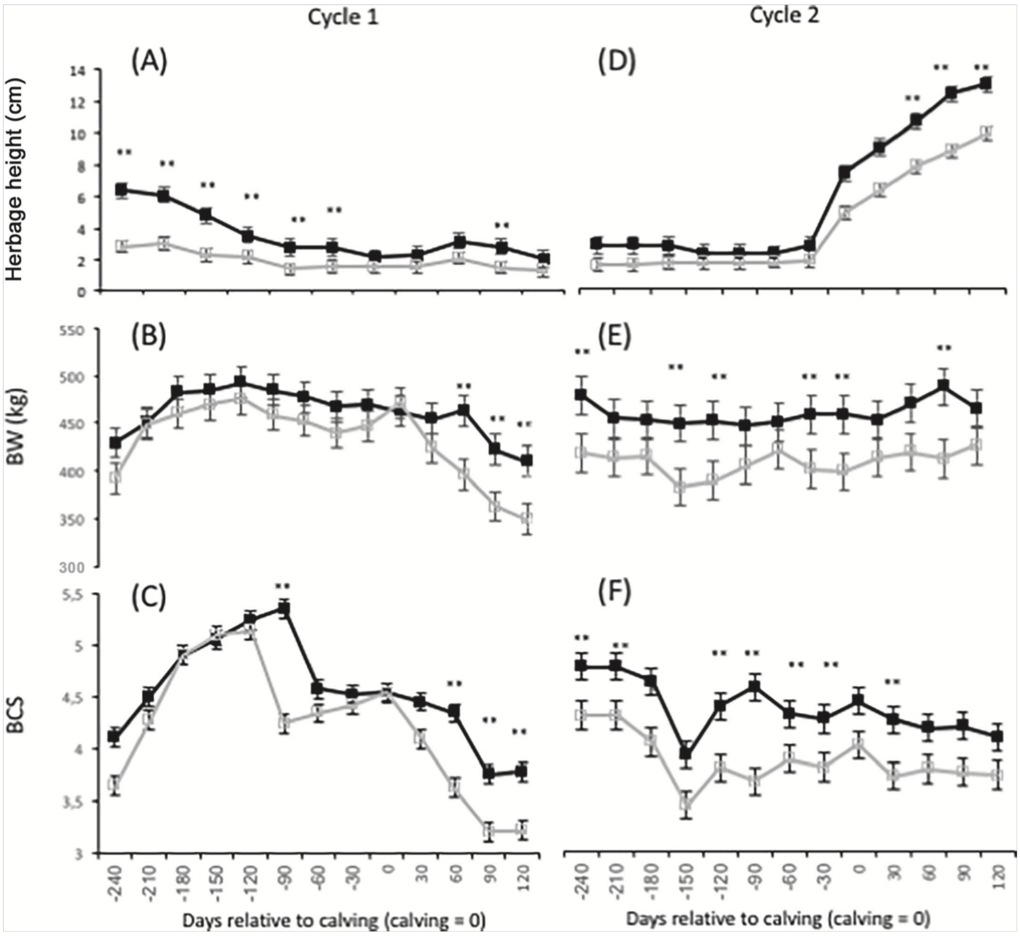

Figure 2. Effect of herbage allowance (least squares means ± SE) and days relative to calving on herbage height (A, D), cow BW (B, E), and BCS (C, F). **Differences exist between high (black line) and low (gray line) herbage allowance at $P < 0.05$. Calving day (0) was October 21, 2008, in cycle 1 and November 12, 2009, in cycle 2.

previous results (Bransby et al., 1988; Hernandez-Garay et al., 2004; Stuedemann and Franzluebbers, 2007) because our experimental control variable was HA, not stocking rate or herbage mass as was the case in those studies.

Effect of HA and Genetic Group on Cow BCS and BW Change

During cycle 1, between −120 and +120 DPP, BCS decreased for cows in both HA treatments; however, Lo cow BCS decreased earlier (−120 vs. −90 DPP for Lo and Hi, respectively) and also experienced greater BCS decline (Figure 2C). During cycle 2, cow BCS difference between Hi and Lo was evident from −210 to +30 DPP and numerically greater until +120 DPP (Figure 2F).

Greater BW and BCS for Hi than Lo cows could be explained by greater (4%, 0.473 vs. 0.455 MJ/BW$^{0.75}$ per d) estimated energy intake, which could be attributed to an increase of 40 min/d in rumination time and a reduction of 32 min/d in daily grazing time for Hi compared with Lo, respectively (Scarlato et al., 2012). These changes in grazing behavior also could be associated with increases in intake rate (Da Trindade et al., 2016) and selectivity (Piaggio et al., 1995). In addition, retained energy (milk, BW, BCS) in Hi cows under grazing represented an increasing proportion of total energy intake; thus, as intake in megajoules per $BW^{0.75}$ per d increased, dilution of energy cost of maintenance would be expected on this improvement (Brosh et al., 2004).

Cow genotype affected ($P < 0.05$) all animal response variables except NE requirements in kilojoules per kilogram of $BW^{0.75}$ per d or BW × DPP interaction ($P = 0.10$). Averaged across seasons and years, similar to previous reports, cow BCS and BW were greater in Cr than Pu cows (4.2 vs. 4 ± 0.05 and 458 vs. 427 ± 13 for BCS and BW for Cr and Pu cows, respectively; Morris et al., 1987; Cundiff, 2004). In cycle 1, BCS was affected ($P < 0.05$) by the interaction of cow genotype × DPP (Figure 3B). Although all cows lost BCS during cycle 1 (from −120 to +120 DPP), Cr cows maintained greater BCS from −60 to +30 DPP (Figure 3B). In cycle 2, BCS change did not differ between genotypes, but it was numerically greater in Cr than Pu cows, mainly from −240 to −180 DPP (Figure 3D).

Greater cow BCS in Cr than Pu cows could be explained through reduction in maintenance energy requirements, because they lost more muscle than lipid tissue (Casal et al., 2016). However, during cycle 2, probably due to the limiting herbage mass and height, Cr cows could not improve BCS statistically and cow genotypes did not differ. Nevertheless, Cr cows maintained greater BW and BCS and produced more milk (Gutierrez et al., 2013) than Pu cows with the same HA and without differences in stocking rate, indicating a greater biological efficiency for Cr cows (Do Carmo et al., 2016).

Effect of HA and Cow Genotype on Calf BW at Weaning and Energy Intake

The Hi HA increased calf BW at weaning by 18 and 10 kg and ADG by 0.2 kg/d in cycle 1 and 0.1 kg/d in cycle 2 (Table 1). Greater calf BW in Hi than in Lo can be explained by greater cow milk production (20%, Gutierrez et al., 2013) as a result of greater energy intake in Hi than Lo cows and probably in calves (Baker et al., 1981; Wright and Russel, 1987). Difference in calf BW at weaning between Hi and Lo was greater during the drought period (cycle 1), probably because during the rainy season (lactation of cycle 2, Figure 1A), calves would have been able to compensate partially for lower milk production by increasing herbage intake (Wright and Russel, 1987). The increment in energy intake (4% in kJ/$BW^{0.75}$ per d or 10% in MJ/cow) was lower than the increment in calf BW (17

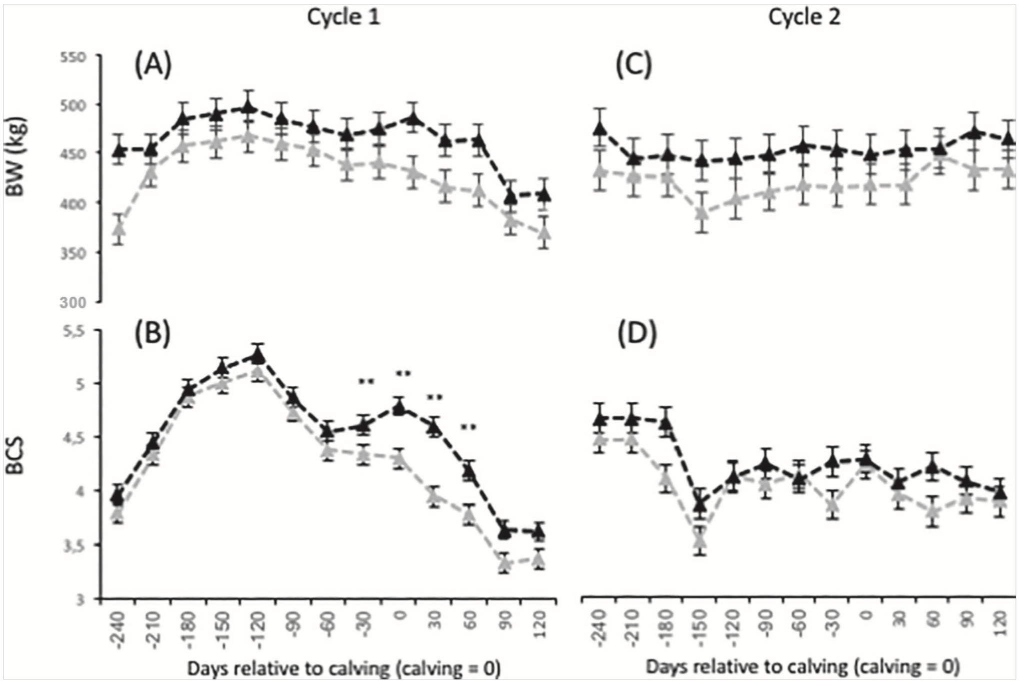

Figure 3. Effect of cow genotype (least squares means ± SE) and days relative to calving on cow BW (A, C) and BCS (B, D). The dashed black line represents cross cows, and the dashed gray line represents pure cows. **Differences exist between genotypes. Calving day (0) was October 21, 2008, in cycle 1 and November 12, 2009, in cycle 2.

Table 1. Effect of herbage allowance and cow genotype on calf BW by cow cycle

	Herbage allowance				Cow genotype[1]			
Item	High	Low	SE	*P*-value	Cr	Pu	SE	*P*-value
Cycle 1								
Calf BW at birth (kg)	35.9	35.7	1.4	NS	36.6	35.1	1.4	NS
Calf BW at weaning[2] (kg)	119.5	101.8	4.3	<0.01	119.8	101.5	4.2	<0.01
Calf ADG (kg/d)	0.82	0.62	0.04	<0.05	0.81	0.63	0.04	<0.05
NE (kJ/metabolic BW per d)	0.487	0.480	0.004	NS	0.478	0.489	0.006	NS
Cycle 2								
Calf BW at birth (kg)	34.5	36.5	1.4	NS	36.1	34.8	1.6	NS
Calf BW at weaning[2] (kg)	133.7	123.7	3.5	<0.05	134	123	3.4	<0.05
Calf ADG (kg/d)	0.80	0.69	0.03	<0.01	0.77	0.72	0.03	NS
NE (kJ/metabolic BW per d)	0.492	0.472	0.004	NS	0.474	0.490	0.006	NS

[1]Cr = crossbred (F1 crosses); Pu = pure (Hereford and Angus).

[2]Weaning days for cycle 1 (2008) averaged 102 d and for cycle 2 (2009) averaged 125 d.

to 8%), which would indicate greater biological efficiency in Hi than Lo cows. These findings agreed with Baker et al. (1981), who reported that greater HA resulted in greater herbage mass, intake, milk production, and calf and cow BW. Calf ADG during cycle 1 (0.82 vs. 0.62 kg/d for Cr vs. Pu) was similar to that reported for Pu and Cr cows grazing in medium-quality pastures in the subtropics of Australia (Barlow et al., 1994), although nutritive value of our pastures was lower.

The Cr genotype increased calf BW at weaning by 18 and 10 kg in cycles 1 and 2, respectively, but ADG was affected only for cycle 1 (Table 1). The Cr cows produced more milk than Pu cows (Gutierrez et al., 2013), and this explains greater calf BW at weaning, because calf BW at birth did not differ between genotypes (Table 1).

Energy intake in kilograms per unit of metabolic BW was greater on average (0.473 vs. 0.455 ± 0.0046 MJ/$BW^{0.75}$ per d) for Hi than Lo cows, estimated through NRC (2000) models; however, the interaction of HA × cycle was not significant.

We found that in Campos grazing systems, a change in cow genotype (cross) modifies animal production a similar amount to that obtained by modifying the plant–animal relationship (HA). An increase in kilograms of meat without major changes in forage intake associated with Hi HA and Cr cows, represents an important improvement in biological efficiency of grazing animals.

In summary, greater HA increased herbage mass, height, and growth, allowing maintenance of a similar stocking rate on an annual scale, and Hi HA also increased cow energy intake, BW, BCS, and kilograms of calf weaned. Improvement in individual performance did not require a decrease in stocking rate because the greater HA treatment had greater herbage accumulation. Additionally, our data showed that the use of Cr cows resulted in greater cow BCS and calf BW at weaning than Pu cows.

Herbage allowance has been employed as a grazing management tool to improve profitability and sustainability of similar beef cow-calf systems in the Campos (Ruggia et al., 2015) and other grasslands. This grazing management approach involved varying the HA seasonally to match herbage growth and nutritive value with cow energy intake requirements. To apply this adaptive grazing management for other animal categories and herbage conditions, options for supplementation and timing of sale of cattle must be taken into account (Ruggia et al., 2015; Do Carmo et al., 2016).

IMPLICATIONS

Simultaneous control of grazing intensity by manipulating HA and use of Cr cows increased (by addition) herbage production, utilization (intake per cow), and conversion (kilograms of calf BW at weaning), improving biological efficiency of beef cow-calf systems and contributing to resilience of Campos grasslands. Controlling HA represents an adaptive grazing management that can be applied worldwide to any grassland, and its relevance lies in the possibility of improving herbage production during the growing season, improving herbage intake through the management of HA for the entire cow-calf cycle, or both. Increments in HA can be attained by supplementation or adjusting stocking rate as shown in the current paper. Managing grazing livestock based on efficiency of energy use may provide an important starting point for the conversation about how to produce the same quantity of animal product while reducing greenhouse gas emissions.

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5. Masa y oferta de forraje y genotipo animal afectan el consumo de forraje diario, la productividad y la eficiencia de uso del forraje de vacas de cría sobre pasturas nativas subtropicales

5.1. Resumen

Este trabajo tuvo como objetivo cuantificar el efecto de la oferta y masa de forraje, así como el genotipo de la vaca sobre el consumo de forraje (DMI) en gestación y lactancia, su relación con la productividad y la eficiencia biológica de uso del forraje. Se utilizó el mismo dispositivo experimental descrito en el artículo anterior, en el cual en seis estaciones del año (tres primaveras, dos inviernos y un otoño) se estimó a través de n-alcanos el DMI de vacas puras y cruzas en alta y baja (AOF y BOF) oferta de forraje. El DMI se utilizó como variable regresora para estimar la productividad animal y como denominador para estimar la eficiencia (gramos de ternero/kg de DMI). La oferta de forraje no cambió el DMI en gestación temprana (otoño) y resultó sin diferencia estadística durante gestación media-tardía (invierno), pero fue superior en AOF (115 vs. 94 g/MBW/d) durante la lactancia (primavera-verano). Al buscar relaciones generales, la oferta no tuvo ningún efecto sobre el DMI, pero la masa de forraje resultó el factor más importante y presentó una relación lineal positiva con el DMI, mientras el estado fisiológico lactante también incrementó el DMI. La mejora en la masa de forraje permitió aumentar el DMI, la productividad individual y la eficiencia biológica del forraje consumido.

Palabras clave: oferta de forraje, vacas de cría, Campos, masa de forraje, eficiencia de uso del forraje

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Forage Based Livestock Systems

FORAGE BASED LIVESTOCK SYSTEMS

Herbage mass and allowance and animal genotype affect daily herbage intake, productivity, and efficiency of beef cows grazing native subtropical grassland

Martin Do Carmo,[†,‡,1] Teresa C. M. Genro,[ǀ] Andrés F. Cibils,[$] and Pablo M. Soca[¶]

[†]Centro Universitario de la Región Este, Universidad de la República, Rocha, Rocha, Uruguay, [‡]Department of Pastures and Animal Production, Facultad de Agronomía, Universidad de la República, Bañado de Medina, Cerro Largo, Uruguay, [ǀ]Embrapa Southern Livestock, Bagé, RS Brazil, [$]Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM 88003, USA, [¶]Department of Pastures and Animal Production, Facultad de Agronomía, Universidad de la República, Paysandú, Paysandú, Uruguay

[1]Corresponding author: martindocarmocorujo@gmail.com

ORCiD number: 0000-0001-7632-8449 (M. Do Carmo).

Abstract

The beef sector in Campos grasslands must increase animal productivity without external inputs, while reducing environmental impact. The objective of this study was to estimate herbage intake (g/metabolic body weight [**MBW**]/d) of straightbred (Hereford/Angus) and crossbred (F1 of Hereford × Angus) beef cows grazing subtropical native grassland with High and Low herbage allowance (**HA**, 5 vs. 3 kg DM/kg bodyweight [**BW**]) during gestation and lactation and its relationship with biological efficiency of cow-calf productivity. Herbage intake (estimated via *n*-alkanes C_{32}:C_{33} ratio) was measured during early (Ge1, −163 d prior calving) and mid to late [Gm1 (−83) and Gm2 (−90 d prior calving)] gestation and lactation (L0, L1, and L2, 60, 47, and 31d following calving) periods in 24 to 36 cows, selected to create 8 groups (4 per block) of HA × cow genotype treatment. Cows grazed native grassland year-round, under High and Low HA (except in winter). We analyzed the effect of cow genotype (straightbred vs. crossbred cows) and HA (High vs. Low) on herbage mass and height, daily herbage intake rate (**DMI**), cow body condition score (**BCS**), calf average daily gain (**ADG**) and BW at weaning (**BWW**) and g of calf weaned/kg DMI. High allowance improved DMI during lactation periods (High 115.6 vs. Low 94.1 ± 5.3; $P < 0.05$ g/MBW/d). Crossbred cows decreased DMI during gestation (Crossbred 81 vs. Straightbred 94 ± 4.3; $P = 0.05$ g/MBW/d) compared with straightbred cows. Crossbred and High HA improved biological efficiency, 40.0 vs. 26.2 and 36.0 vs. 29.7 g of calf/kg DMI, respectively. High allowance increased herbage mass and sites with greater canopy height that allow greater DMI, positively associated with cow BCS at weaning, calf ADG, BWW, and g of calf/kg DMI. Crossbred cows reduced DMI during gestation showing no greater annual DMI. Animal productivity and biological efficiency can be improved using High HA and crossbred cows, which should decrease the environmental impact of cow-calf systems.

Key words: beef cattle, feed efficiency, *n*-alkanes, herbage heterogeneity, crossbred cows

Abbreviations

ADF	acid detergent fiber
ADG	average daily gain
BCS	body condition score
BCS-P	cow BCS at calving
BCS-W	cow BCS at weaning
BW	body weight
BWW	calf BW at weaning
CG	cow genotype
CP	crude protein
DM	dry matter
DMI	dry matter intake
HA	herbage allowance
ME	metabolizable energy
MEI	metabolizable energy intake
RE	retained energy

Introduction

Beef cow-calf systems in subtropical native grasslands must improve their cow-calf and economic productivity that could be done through the control of herbage allowance (**HA**), improving herbage production, cow herbage intake (**DMI**), and biological efficiency, while maintaining or improving ecosystem services (Do Carmo et al., 2016; Ruggia et al., 2021). In Campos grasslands, an increase of annual HA from 3 (Low) to 5 (High) kg of DM/kg body weight (**BW**) improved 10 to 20 kg and 7% to 30% the calf BW at weaning (**BWW**) and pregnancy rate, respectively (Do Carmo et al., 2016, 2018; Claramunt et al., 2018, 2020). Using NRC (2000) models, we estimated a higher net energy requirement (**NEreq**) in High compared with Low HA, which can be explained by greater cow BW (+29 kg), body condition score (**BCS**; +0.4 units), and milk production (+1 kg/d/cow, Do Carmo et al., 2018) in High. However, in grazed systems, when changes in BW and BCS are detected, DMI changes likely precede such changes by several weeks, due to changes in herbage mass, canopy height, HA, and interactions with physiological stage and season. Therefore, measurement of DMI through external markers during gestation and lactation when cows graze under different herbage mass and allowance is of critical importance.

Earlier studies showed that crossbred cows weaned calves that were 10 to 20 kg heavier, cows had greater BCS (0.20 units) and BW (31 kg heavier), and 17% greater probability of pregnancy (Do Carmo et al., 2016, 2018) and greater milk production (+ 1.1 kg/d/cow, Gutiérrez et al., 2013). However, using NEreq models (NRC, 2000), they did not differ from straightbred cows (Do Carmo et al., 2018). Previous work reported lower (15%) energy requirements for maintenance in F1 cows compared with Angus and Hereford (Ferrell and Jenkins, 1987; Solis et al., 1988), however NEreq models do not differentiate energy requirements for maintenance between Hereford, Angus, and the reciprocal crosses. Therefore, estimating DMI using external markers in different seasons associated with the interaction of cow genotype and HA is needed.

Experiments and models that quantify DMI or MEI of grazing beef cows confirm the multifactorial nature of control of DMI. Herbage mass, digestibility, and cow physiological stage were the most important factors explaining the DMI and MEI of beef cows (NRC, 2000; Brosh et al., 2004; CSIRO, 2007). However, this kind of empirical model may need local adjustment due to changes in herbage structure, herbage kg/cm, and possible interaction with cow physiological stage and grazing behavior that justify the DMI measurement with different genotypes in the context of native subtropical grasslands differing in HA and mass.

It is well known that higher DMI can increase cow-calf productivity, however the biological efficiency, that is, the ratio of input (DMI) and output (calf kg/cow exposed), depends on the cow genotype and its physiological stage × amount of DMI (Freetly et al., 2000, 2005). This interaction justifies the study of DMI of beef cows grazing during different physiological stages with different herbage mass and allowance.

The objectives of this experiment were to determine the effect of cow genotype and its interaction with HA on DMI during gestation and lactation, as well as to explore associations between DMI, vegetation attributes, cow-calf performance, and biological efficiency.

Materials and Methods

Experimental site, design, and treatments

The experiment was conducted on 95 ha of *Campos* grassland located at the Prof. Bernardo Rosengurtt Experimental Station, School of Agronomy, Uruguay (32°35′S, 54°15′W) between August 2007 and March 2010 (Figure 1). Campos grassland was dominated by *Axonopus affinis* Chase, *Oxalis* sp., *Cyperus* sp., *Cynodon dactylon* (L.) Pers., *Eryngium nudicaule* Lam, *Gaudinia fragilis* (L.) P. Beauv, *Chevreulia sarmentosa* (Pers.) S. F. Blake, *Stipa setigera* (Trin & Rupr.) Backworth, *Paspalum notatum* Flügge, and *Coelorhachis selloana* (Hack.) A. Camus (Do Carmo et al., 2018). The general results of herbage mass, canopy height, herbage

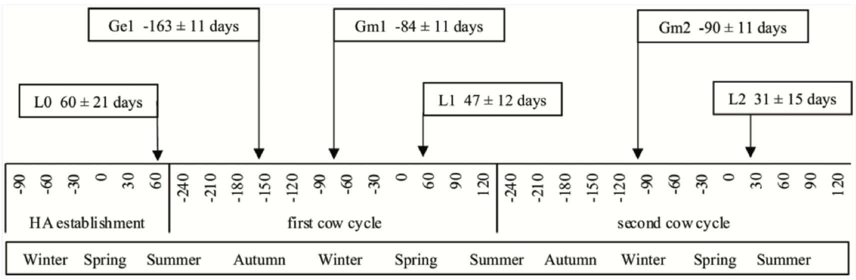

Figure 1. Calendar of DMI measurement during pre and post-partum day of the beef cows in different CCs. HA, herbage allowance; Ge1, early gestation of first CC; Gm1, mid-gestation of first CC; Gm2, mid-gestation of second CC; L0, measurement of DMI at the beginning of the experimental period; L1 and L2, measurement of DMI during lactation of first CC and second CC; DMI, dry matter intake.

accumulation as well as stocking rate, cow BCS and BW, and calf BW at weaning have been previously reported by Do Carmo et al. (2018). Average annual rainfall is approximately 1,200 mm and the climate type is classified as Cfa (subtropical, humid, without dry season, where mean temperature in the coldest month is between −3 °C and 18 °C and the warmest is above 22 °C) according to Köppen (Panario and Bidegain, 1997). During the first spring-summer (Lactation zero [L0]), rainfall was similar to the long-term average (629 mm, 1961 to 1990; 633 mm the actual rainfall), but a drought occurred during the second spring-summer (Lactation one [L1]) when rainfall was 55% below the long-term average (281 mm). In contrast, during the last spring-summer period (Lactation two [L2]), rainfall was (1,187 mm), 88% above the long-term average.

The experimental design was a randomized complete block with two blocks with different soil characteristics (soil fertility data [mean ± SD] block one, pH = 5.1 ± 0.1, % organic matter [OM] = 2.8 ± 0.23, cation exchange capacity [CEC] = 6.3 ± 2 and soil apparent density [AD] = 1.2 ± 0.12, while block two, pH = 5.3 ± 0.5, % OM = 4.6 ± 0.25, CEC = 23.8 ± 2.4 and AD = 0.98 ± 0.1). Block one covered 60 ha (20 ha for High and 10 ha for Low HA treatments) and its soils were classified as Hapludalfs and Argiudolls, whereas block two covered 35 ha (12.5 ha for each High and 5 ha for each Low HA treatments) and consisted of Hapluderts and Argiudolls. Each block consisted of 4 experimental units (plots) to which the 2 × 2 factorial combinations of HA (High and Low, 5 and 3 kg DM/kg BW on average) and cow genotype (CG = straightbred and crossbred) treatments were allocated. HA, the ratio between herbage mass and livestock weight (kg of herbage DM/kg of BW; Sollenberger et al., 2005) varied with season according to previous research (Do Carmo et al., 2016), target levels of High and Low HA were 4 and 2.5 kg DM/kg of BW during autumn; 3 and 3 kg DM/kg of BW during winter; and 4 and 2 kg DM/kg of BW during spring and summer, respectively. Average HA achieved across years was somewhat greater than target levels (5 and 3 kg DM/kg of BW for High and Low) for both treatments and were 4.7, 6, 5.6, and 3.3 kg DM/kg BW for High, and 2.3, 2.8, 3.6 and 2.9 kg DM/kg BW for Low HA, during spring, summer, autumn, and winter, respectively (Do Carmo et al., 2018). Continuous stocking was applied throughout the year (Allen et al., 2011), with stocking rate adjusted monthly starting in August 2007. Adjustments occurred after monthly measurement of herbage mass, which together with animal BW/ha was used to calculate HA. Actual HA during the period of daily herbage intake measurement was calculated based on herbage mass and stocking rate (kg BW/ha). We performed six DMI measurements, five of which were performed when treatments were applied through the entire cow cycle (**CC**; from early gestation to weaning during two CCs) and first measurement of DMI was done after 4 mo of control of HA, we call it Lactation zero (L0).

Vegetation attributes

Monthly herbage mass (kg DM/ha, at ground level) and canopy height (cm, when herbage becomes dense ignoring tall stalks, Stewart et al., 2001) were determined using the comparative yield method (Haydock and Shaw, 1975). Approximately 10 reference (from 1 [the lowest] to 5 [the greatest] and 1 replication) quadrats per plot were selected to represent the range and used for calibration. Reference quadrats were 0.25 m^2 (50 × 50 cm) and after being assigned a ranking (1, 1.5, 2, 3, and 5), canopy heights were measured and quadrats were harvested to ground level and dried to constant weight at 60 °C, to determine herbage mass (Do Carmo et al., 2018, 2020). At each sampling event, 51 to 297 systematically selected (in a straight line and quadrats placed each 10 to 30 steps) quadrats were rated on each plot depending on the size of the plot (5 to 20 ha). The ranking and actual herbage mass data from the reference quadrats were used to develop the equation for predicting herbage mass (generally showing a coefficient of determination [r^2] greater than 0.90) and canopy height from the average of the ranking of the systematically selected quadrats (Do Carmo et al., 2020). Frequency distribution of canopy height was divided into two ranges (0 to 3 cm or >3 cm that represent a level of herbage mass near the threshold value when it limits DMI) that were constructed for each plot.

Animals and experimental period

Animal procedures used in this research were approved by the Animal Experimentation Committee of Universidad de la República No 021130-006374-12. Experimental dams were selected from a herd described by Gutiérrez et al. (2013) and Do Carmo et al. (2018). Multiparous cows 4 to 8 yr old, Straightbred (Angus and Hereford) and Crossbred (F1 reciprocal Hereford and Angus crosses) were allocated to one of the two treatments of HA, High and Low (5 and 3 kg DM/kg BW on average). Cows were maintained in the same treatments if they calved and became pregnant annually. Body weight (**BW**, kg) and BCS (scale from 1 to 8, Vizcarra et al., 1986) of straightbred and crossbred cows were recorded monthly (14 to 48 d interval) during the morning without fasting period, the initial BW of cows was 455 vs. 430 ± 13 for High and Low and 456 vs. 431 for ±13 Crossbred and Straightbred cows.

Calf BW without fasting was assessed at birth and at the beginning of the breeding season when calves were early weaned (L0) or when suckling was restricted (calves fitted with nose plates for 11 d, at 76 ± 11 d postpartum) during L1 and weaning was performed at 102 ± 15 d postpartum. During the breeding seasons of L1, a 20-d supplement period with 2 kg/cow on a fresh basis of rice middling (*Oryza sativa*; 86.5% DM, 13.5% CP, 44% NDF, and 13.5% ether extract) began with suckling restriction (for details see Do Carmo et al., 2018). In L2, cows were not bred, and not supplemented and calves were weaned at 123 ± 15 d. Measurements of cow DMI during lactation periods were done before the suckling restriction or supplementation application, for this reason, the mentioned treatment could alter the pregnancy rate but not the DMI measurements performed before.

DMI estimation using *n*-alkanes technique

C_{32} dosage and feces and forage collection

Herbage intake (DMI) was measured in six periods, three lactation periods (L0, L1, and L2 that correspond to spring-summer period), and three gestation periods during autumn (Ge1) and winter (Gm1 during CC 1 and Gm2 during CC 2); Figure 1 and Table 1.

Three to six beef cows were selected from the tester group of cows in each plot (total *n* = 24 to 36 in the 8 paddocks; Table 1) and were dosed once a day (at 0700 hours) with a cellulose capsule containing 400 mg ± 1.82 of C_{32}-alkane (dotriacontane, 97%, Sigma-Aldrich Corp., St. Louis, MO) for 12 uninterrupted d in each evaluation. From days 7 to 12, fecal samples were collected once daily at morning, per rectum, before the dotriacontane dosage as reported by Genro et al. (2013). The samples were identified individually, packed in plastic bags, and frozen at −20 °C. At the end of the collection period, the samples from each animal were dried (i.e., 60 °C until constant weight), milled

Table 1. Number of cows and cow genotype employed per treatment to quantify herbage intake in the different periods and least square means of MBW (kg ± SE) between parentheses[1]

Period	High HA		Low HA		dpp ± SD
	Crossbred	Purebred	Crossbred	Purebred	
Ge1	6 (102 ± 3)	12 H + A (98 ± 3)	6 (97 ± 3)	12 H + A (105 ± 3)	−163 ± 11
Gm1	6 (98 ± 4)	12 H + A (98 ± 4)	6 (96 ± 4)	12 H + A (91 ± 4)	−84 ± 11
Gm2	5 (97 ± 3)	11 H + A (94 ± 2.5)	5 (94 ± 3)	10 H + A (86 ± 2)	−90 ± 11
L0	8 (99 ± 3)	8 H (93 ± 3)	8 (94 ± 3)	8 H (90 ± 3)	60 ± 21
L1	6 (98 ± 3)	12 H + A (95 ± 3)	6 (102 ± 3)	12H + A (98 ± 3)	47 ± 12
L2	6 (100 ± 5)	6 H (99 ± 5)	6 (91 ± 5)	6 H (90 ± 5)	31 ± 15

[1]Ge1 and Gm1, early and mid-late gestation of CC 1; Gm2, mid-late gestation of CC 2; L0, first measurement during lactation; L1, lactation of CC 1; L2, lactation of CC 2; H, Hereford; A, Aberdeen Angus; Crossbred, F1 reciprocal crosses of A and H; HA, herbage allowance; High and Low, dpp, days pre or post parturition. The cows were distributed within the eight plots, four per block.

to pass through a 1-mm mesh, identified, and stored in plastic bags for subsequent analysis of *n*-alkanes profile.

Forage samples were collected to quantify the *n*-alkanes profile and nutritive value. In order to obtain a sample of forage similar to the forage consumed by the animals, we used the hand-plucking technique (t'Mannetje and Jones, 2000) during the dosage and collection period. To perform hand plucking, we followed 2 to 3 cows per paddock during 2 to 3 d in the morning and in the evening to see the areas grazed for collecting samples by hand plucking to simulate grazing. The forage samples were dried (i.e., 60 °C for 72 h), milled using a 1-mm mesh, identified, and stored in plastic bags for subsequent analysis of *n*-alkanes and chemical composition. Herbage from hand-plucked samples were mixed between cows of the same plot. Analyses of herbage CP (Kjeldahl N percentage × 6.25, AOAC International, 2005) and ADF (Fiber Analyzer 200, Ankom Technology Corporation, Fairport, NY; Van Soest et al., 1991) were performed.

n-alkane analysis

The *n*-alkane profiles of individual samples of forage and feces were analyzed in duplicate according to the method of Dove and Mayes (2006). Identification and quantification of the *n*-alkanes were carried out by gas chromatography, using a SHIMADZU GC-2010 (Shimadzu, Tokyo, Japan), equipped with flame ionization detector, an AOC-20S autosampler, and temperature-programmable AOC-20i autoinjector. The *n*-alkane extracts were injected (1 μL) by on-column Rtx-5 RESTEK (30 m × 0.25 mm × 0.25 μL, absorbent composed of 5% diphenyl and 95% dimethylpolysiloxane). Nitrogen was used as the carrier gas at a constant flow of 30 mL/min. Gradients of temperature were used for the injector (270 °C) and the column (170 °C for 1 min; from 30 °C/min to 215 °C/min and 6 °C/min at 300 °C; for a 21 min period). The flame ionization detector was maintained at 340 °C.

Gas chromatographic procedures were calibrated with a standard solution containing a mixture of synthetic *n*-alkanes (from C7 to C40; N99% pure, Sigma-Aldrich Corp.) with similar concentrations to those found in the extracts.

The response factors for individual *n*-alkanes were calculated from peak areas and the known concentrations. Within the peak areas, *n*-alkane concentrations were determined using the Shimadzu GC Solution software, in which the identification of *n*-alkanes is based on comparison with an external standard (alkane C_{34}) for the average retention time in each column *n*-alkane. The peaks identified were converted into quantities of *n*-alkanes with reference to the internal standard C_{34} and expressed in mg/kg DM. Herbage intake was estimated following the formula number four proposed by Aguiar et al. (2013) using the relationship of C_{32} and C_{33} in feces and C_{33} in herbage.

Cow-calf performance and efficiency of DMI

Cow BCS was measured monthly, at calving (BCS-P) and at weaning (BCS-W). Calf average daily gain (**ADG**), BWW, and BCS of cows employed to estimate daily herbage intake (DMI) was used (n = 24 to 36) to construct multiple regressions involving cow or calf performance, and the independent variables used were: DMI, postpartum d (dpp), calf sex, and cow BCS-P to explain the calf ADG, calf BWW, and cow BCS-W.

The g of calf/kg DMI was assessed for the CC 1 (Figure 1) using the DMI of the cow divided in 3 periods as did by Brosh et al. (2004) from 0 to 180 d of gestation using DMI data from Ge1, from 181 to parturition (102 d) using DMI data from Gm1, and the lactation period using data from L1 (83 d to complete 1 yr). The numerator was the calf BWW simulated to 200 d (to facilitate the comparison with Jenkins and Ferrell, 1994) multiplied by the weaning rate of each treatment (Do Carmo et al., 2016) which were 0.76, 0.70, 0.81, and 0.65 for High, Low, Crossbred, and Straightbred, respectively. We also estimated the amount of DMI/cow/y.

Data and statistical analysis

Data were analyzed using SAS University Edition 3.8 (SAS University Edition, 2018, SAS Institute Inc., Cary, NC). Vegetation attributes (herbage mass, canopy height, herbage ranges from 0 to 3 cm or >3 cm) stocking rate and actual HA, chemical composition of hand-plucked herbage, as well as DMI for comparison of two mid-late gestation and two lactation periods, were analyzed using the MIXED procedure with the plot as the experimental unit. The model included HA, CG (for animal variables only), and CC and their interaction as fixed effects and block as random effect, with Kenward–Rogers procedure to adjust degree of freedom and Tukey procedure was used for mean separation.

The herbage mass and DMI relationship was determined with all DMI evaluations through the MIXED procedure using the SOLUTION and OUTPRED statement to determine the coefficients, to estimate the variation explained by the model, we used the relationship (Proc CORR) of the DMI and the predicted. Coefficient of determination (r^2) was estimated as the square of r from the Proc CORR. We tested linear and quadratic response to herbage mass, canopy height, canopy range >3 cm, and the combination, only the linear response to herbage mass was significant and, we present this relationship.

To explore the relationships between DMI and cow BCS at weaning (BCS-W), calf BW at weaning (BWW), and calf ADG (from birth to weaning), we used two lactation periods when cows stayed the entire cycle in the treatments (L1 and L2), the experimental unit used was the cow or calf. The independent variables used to explain the BCS-W, calf ADG, and BWW were: DMI, postpartum d (dpp), cow BCS at calving (BCS-P), and calf sex, using the MIXED procedure (SAS University Edition, 2018; SAS Institute Inc.).

Estimation of DMI during the cycle one was analyzed as a repeated measures, using the plot as the experimental unit (n = 8). The DMI during first CC differed (P < 0.05) between HA (110 vs. 102.7 ± 2.3 g/metabolic body weight [**MBW**]/d High and Low, respectively), and tended to differ (P = 0.06) by CG (109.7 vs. 103±2.3 g/MBW/d Straightbred and Crossbred, respectively), the interaction of HA × CG was not significant, and the interaction of HA or CG with period was not significant either. Nonetheless, we used the least square means of DMI for each period (Ge1, Gm1, and L1) by HA or by CG to estimate the g of calf weaned/kg DMI and total DMI in the CC, because accumulated differences could impact evaluation of efficiency and because periods differ in number of days. For the comparison of calf weaned/kg of DMI, we used the mean of HA or CG within each block (n = 4, df = 1), using the cow BW of each treatment to estimate the amount of DMI during the cycle and the result of kg of calf weaned per cow.

Results

Effect of HA on vegetation attributes

Greater HA improved herbage mass and canopy height (P < 0.01) during gestation and lactation (Table 2) that was associated with greater frequency of sites with >3 cm in High than Low (Figure 2). Herbage CP was greater in Low than High in all periods and ADF was lower in Low than High during lactation (Table 2). Stocking rate was greater in High than Low during mid-late gestation, while was lower during lactation (Table 2). Stocking rate was a result of herbage mass values that reflected experimental design of HA.

Effect of HA, mass, and cow genotype on DMI

During gestation, DMI was not affected by HA and was 16% lower in Crossbred (P < 0.05) than Straightbred cows during both CCs (Table 3). During lactation DMI was 23% greater in High than Low (Table 3). Interaction between treatments or treatments with CC were not detected neither during gestation nor during lactation (Table 3).

Cow genotype did not affect the DMI during lactation (Table 3); however, during the second CC, Crossbred cows had 59% greater DMI than Straightbred counterparts in Low (P = 0.10, Crossbred 112.9 vs. Straightbred 71.0 g/MBW/d).

An increment of 1,000 kg/ha in herbage mass was associated to an increase of 15 g/MBW/d in DMI (Figure 3). Lactation tended (P = 0.08) to increase DMI by a fixed value of 10.13 g/MBW/d compared with gestation period.

Effect of DMI on cow-calf performance and biological efficiency

Cow DMI and BCS-P contributed to explain the 41%, 74%, and 60% of the variation on calf ADG, calf BWW, and cow BCS-W, respectively (Table 4). For each increment in 20 g/MBW/d of DMI, calf BWW and cow BCS-W increased 5 kg and 0.24 unit, respectively.

DMI during first CC (Ge, Gm, and L) tended to differ between HA (P = 0.07; Table 5) and did not differ (P > 0.1) between CG (Table 5). Biological efficiency increased 23% and 56% when using High HA and Crossbred cows, respectively (Table 5).

Discussion

To our knowledge, this is the first study reporting the effects of HA and cow genotype grazing native subtropical grassland on cow DMI during gestation and lactation. Furthermore, this is one of few reports linking herbage DMI with cow-calf performance and biological efficiency in g of calf/kg DMI in grazing cow-calf systems.

Effect of HA and mass on cow DMI

Greater DMI with High HA could be explained by greater intake rate, which is a consequence of the greater canopy height and sites of canopy height >3 cm probably increasing bite mass. This coincides with a previous report for growing cattle (160 kg

Table 2. Effect of HA on herbage mass, canopy height, actual HA, chemical composition (ADF and CP), and stocking rate during mid-late gestation and lactation periods of DMI[1] measurements in two CC

	HA		CC			P-value		
	High	Low	First	Second	SEM	HA	CC	HA × CC
Mid-late gestation								
Herbage mass, kg DM[1]/ha	1,254^{a}	770^{b}	1,060	964	113	<0.01	0.30	0.03
Canopy height, cm	2.5^{a}	1.6^{b}	2.2^{a}	1.9^{b}	0.4	<0.01	<0.05	<0.05
Actual HA, kg DM/kg BM	3.0	2.9	2.7	3.1	0.3	0.75	0.17	0.34
CP[1], g/kg	119^{a}	136^{b}	118^{a}	138^{b}	5	<0.05	<0.05	0.66
ADF[1], g/kg	368	356	378	346	10	0.39	<0.05	0.77
Stocking rate, kg BW/ha	425^{a}	272^{b}	388^{a}	309^{b}	12	<0.01	<0.01	<0.05
Lactation								
Herbage mass, kg DM/ha	2,080^{a}	1,216^{b}	1,078^{a}	2,219^{b}	86	<0.01	<0.01	<0.05
Canopy height, cm	5.0^{a}	3.0^{b}	2.2^{a}	5.9^{b}	0.4	<0.01	<0.01	0.12
Actual HA, kg DM/kg BM	4.7^{a}	2.2^{b}	2.4^{a}	4.4^{b}	0.4	<0.01	<0.01	0.34
CP, g/kg	109^{a}	118^{b}	105^{a}	121^{b}	2.8	<0.05	<0.01	0.81
ADF, g/kg	360^{a}	340^{b}	362^{a}	338^{b}	5	<0.05	<0.01	0.99
Stocking rate, kg BW/ha	439^{a}	564^{b}	492	511	21	<0.01	0.54	<0.05

[1]CP, crude protein; ADF, acid detergent fiber; DM, dry matter; DMI, dry matter intake; CC, cow cycle.
[a,b]Different letters indicate differences within moments and treatments P < 0.05. The number of experimental units was eight, four for High and four for Low HA in two blocks.

BW) grazing Campos, where short-term intake rate (45 min) was doubled when canopy height increased from 3 to 5 cm (Gonçalves et al., 2009). We also postulated that greater sward heterogeneity, through increased sites of canopy height >3 cm in High, could modify cow spatial grazing behavior at the feeding station scale to improve the probability of finding those sites to improve bite mass and quality of each bite (Hirata et al., 2015). Those changes could be obtained if cows change the velocity (m/s) or area covered (feeding station/min) during foraging (Spallinger and Hobbs, 1992) as confirmed by the increased number of feeding stations/h (High 366 vs. Low 272 ± 25, $P < 0.05$) with equal bite rate (bites/min) of cows in High during lactation. Less bites/feeding station but greater area of bite selection through greater number of feeding stations is a mechanism similar to what Spallinger and Hobbs (1992) proposed.

The relationship of herbage mass and DMI was consistent with results from a stocking rate experiment using beef cows grazing Mediterranean rangeland (Brosh et al., 2004), where

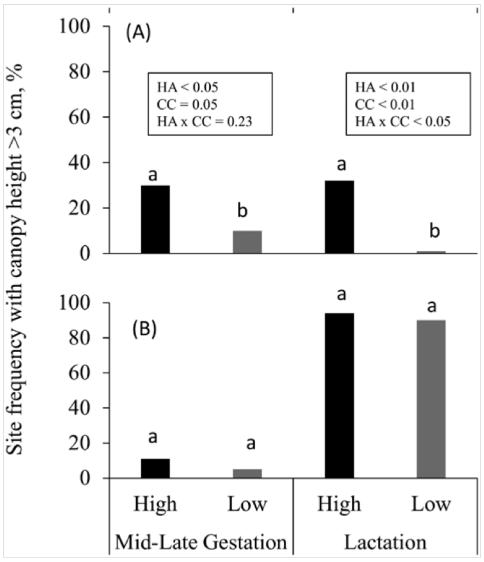

Figure 2. Least square means for frequency of sites with canopy height >3 cm during DMI measurement in gestation and lactation. Black columns represent High HA, and gray columns represents low, HA. First (A) and second (B) CCs. HA, herbage allowance; CC, cow cycle. We used eight experimental units, four per block.

increments of 1,000 kg DM/ha of herbage mass increased the DMI by 9 to 12 g/MBW/d. Brosh et al. (2004) also found a significant positive effect of lactation on cow MEI, while our relationship tended ($P = 0.08$) to be affected by lactation.

Herbage mass and DMI increased linearly from 500 to 2,500 kg DM/ha (Figure 3) in contrast with NRC (2000) and NASEM (2016) models that predict maximum DMI at grazing above 1,150 kg DM/ha of herbage mass. More research is needed to improve DMI modeling for grazing animals but consideration of canopy height distribution should improve predictions of DMI of grazing cattle. A more detailed comparison between the NASEM (2016) DMI model and our results is beyond the scope of this article and should be addressed separately. On the other hand, we recognize that DMI is highly variable among days (Forbes, 2003) and measurement through markers could contain errors which make comparisons between methods and animal categories difficult (Galyean and Gunter, 2016).

Influence of cow genotype on cow DMI

A 16% DMI reduction in Crossbred cows during mid-late gestation coincides with recent reports of 7% lower DMI during gestation in feedlot F1 Angus–Hereford cattle (Andresen et al., 2020). However, we did not find a reduction in BCS or BW of Crossbred cows (Do Carmo et al., 2018) that suggests at least three possibilities: 1) crossbred cows improved diet digestibility and energy intake through selectivity; 2) they were more efficient to extract energy by digestive changes such as increased digestibility through greater mastication and retention time of digesta (Prendiville et al., 2010); or 3) metabolically, using the energy intake more efficiently. Crossbred cows showed more selective grazing patterns as indicated by the greater number of feeding stations ($P = 0.09$, 320 vs. 263 ± 26 feeding stations/h) without changes in bite rate (55 vs. 57 ± 2 bites/min) during gestation (Soca et al., 2016). The lower number of bites/feeding station allow to increase the bite selection per area, but during winter when greater herbage mass could be associated to lower digestibility (Table 2) and greater digestibility with lower bite mass, in these conditions, an increment of selectivity could reduce the intake rate (Demment and Laca, 1994) which contribute to explain the fall in daily DMI.

Previous reports showed a reduction (15% to 17%) of energy requirements for maintenance in F1 compared with Angus and Hereford cows (Ferrell and Jenkins, 1987; Solis et al., 1988). During gestation, all cows lost weight and BCS; however, Straightbred cows mobilized greater amount of fat tissue and lesser amount of protein tissue than Crossbred cows (Casal et al., 2016) that could explain the lower energy requirements for maintenance in Crossbred (Solis et al., 1988). Moreover, greater amount of protein mobilized could improve the gluconeogenic precursors improving the efficiency to transform dam tissue into calf tissue or energy for maintenance of crossbred cows (Casal et al.,

Table 3. DMI (g/kg MBW/d) for each HA (High, H and Low, L) CG (Crossbred, C and Straightbred, S) and CC

	HA		CG		CC			P-value[1]			
DMI	H	L	C	S	First	Second	SEM	HA	CG	CC	HA × CG × CC
Mid-late gestation	91	83	81[b]	94[a]	100[a]	74[b]	4.3	0.22	0.05	<0.01	0.67
Lactation	115.6[a]	94.1[b]	109.2	100.5	102	107	5.3	<0.05	0.28	0.54	0.10

[1]The interactions HA CG, HA CC, and CG CC showed not statistical significancy or tendency to ($P > 0.1$).
[a,b]Differences in letters means statistical differences within file ($P < 0.05$). Eight experimental units, four per HA and four per CG, in two blocks.
DMI, daily herbage intake; HA, herbage allowance; CG, cow genotype; CC, cow cycles.

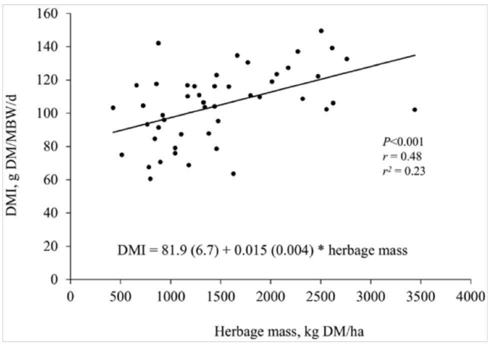

Figure 3. DMI of beef cows expressed in g/MBW/d, as a function of herbage mass (kg DM/ha). The graph represents 48 values (6 periods × 8 experimental units [plots] per period).

2016). Energy demand is a powerful driver of DMI and the lower requirement of energy for maintenance could be related to the more selective ingestive behavior that could partially explain the lower DMI observed in crossbred cows.

Effect of DMI on cow-calf performance and cow genotype and HA on biological efficiency

As postulated, increase (23%) in DMI could explain the greater calf ADG and BWW, which can be explained by greater ($P < 0.05$) cow milk production (20% greater) in High vs. Low (Gutiérrez et al., 2013). As DMI increases, energy partitioning to productive functions increase, signaled by greater levels of insulin, IGF-I, and expression of genes related to gluconeogenesis as reported for High (Laporta et al., 2014). This agrees with previous reports for lactating or gestating beef cows (Lalman et al., 2000; Lents et al., 2005).

Crossbred cows produced more milk (22%) and greater calf ADG and BWW (Gutiérrez et al., 2013; Do Carmo et al., 2018), which can be explained by a tendency ($P = 0.10$) toward greater (59%) DMI during L2 (Table 3) and by greater cow BCS at calving that was associated to increased BWW (Table 4). Ability of crossbred cows to produce more milk and maintain greater BCS was not associated with greater DMI, increasing their biological efficiency.

Biological efficiency, g of calf weaned/kg DMI, was in the mid to upper range reported by Jenkins and Ferrell (1994) from 20 to 47 g of calf weaned/kg DMI for a DMI level of 4,000 kg/y (Table 5). However, herbage ME affects the efficiency of energy use and in our experiment, herbage was 7.84 MJ (using an equation for C4 plants, CSIRO, 2007) vs. 9.41 MJ of ME in Jenkins and Ferrell (1994) that could underestimate the biological efficiency of our cows. Greater calf BWW and weaning rate in crossbred cows without increasing DMI (Tables 3 and 5) differs from the study of Andresen et al. (2020), probably because the "metabolic flexibility" (Mulliniks et al., 2016) is prevented under "non stressful" conditions, decreasing the expression of behavioral and metabolic differences that could affect DMI, while grazing and efficiency of energy use, that ultimately affects milk production, calf ADG and BWW, anestrus period and weaning rate (Laporta et al., 2014; Do Carmo et al., 2018).

HA and cow genotype affected DMI in opposite directions and during different physiological stages, but both in an additive way improved calf productivity. Thus, cow-calf systems

Table 4. Regression models for calf ADG and BWW, and cow BCS at weaning (cow BCS-W)

Dependent variable	Independent variables[1]	Equation model	R^2	P-value				
				DMI	Cow cycle	Calf age (d)	Sex	BCS-P
Calf ADG	DMI + BCS-P + sex	Y = 0.189(0.21) + 0.00245(0.0012) DMI + 0.07(0.035) BCS-P − 0.06(0.04) for females or zero for males	0.41	0.04			0.15	0.05
Calf BWW	DMI + BCS-P + sex + d	Y = −23.2(29.9) + 0.26(0.16) DMI + 8.3(4.5) BCS-P − 9.25(5.3) for females + 0.73(0.15) d	0.74	0.10		<0.01	0.09	0.07
Cow BCS-W	DMI + BCS-P ± cow cycle	Y = 1.59(0.78) + 0.012(0.004) DMI + 0.29(0.17) BCS-P + 0 (for L2) − 0.6(0.17) for L1	0.61	<0.01	<0.01			0.05

[1]DMI, herbage intake in g/kg MBW/d; BCS-P, cow BCS at calving; sex, sex of the calf; d, calf age in days.
[2]R, amount of variance explained by the model, is the correlation (Pearson) between the predicted value by the model and the actual value of the variable, in every case R was significant P < 0.001 and $n = 42$.
Intercepts and coefficients of regression (SE) are expressed in the "equation model."

Table 5. Effect of HA and CG during CC one on calf BW at 200 d (BWW), biological efficiency (g of calf/kg of DMI) and DMI/cycle (annual basis)[1]

Variable	High	Low	Crossbred	Straightbred	SEM	P-value	
						HA	CG
g of calf/kg DMI	36.0[a]	29.7[b]	40.0[a]	26.2[b]	0.8	<0.05	0.05
BWW (200 d)	198[a]	162.4[b]	196.8[a]	164[b]	8	<0.01	<0.01
DMI/cycle, kg	4,178[a]	3,827[a]	3,984[a]	4,064[a]	33	0.07	0.57

[a,b]Differences in letters means statistical differences within file ($P < 0.05$). Four experimental units, one High and one Low in each block and the same for CG.
[1]CG, cow genotype, crossbred and straightbred; BWW, calf BW at weaning estimated at 200 d; cycle, cycle of the cow from gestation to lactation in 365 d.

in Campos grasslands or other subtropical grasslands have the chance to greatly improve the productivity, increasing the g of calf weaned/kg DMI by using Crossbred cows and High HA, which at the entire country scale could increase beef production with the same pasture resources or, alternatively, maintain current production levels, while reducing the livestock herd in absolute terms to decrease methane and other greenhouse gas emissions.

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Conflict of interest statement

The authors have no conflict of interest to declare.

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6. Foraging strategy of purebred and crossbred beef cows grazing native subtropical grassland differing in herbage allowance

Estrategia de pastoreo de vacas de cría puras y cruzas bajo diferente oferta de forraje de pasturas nativas subtropicales

6.1. Resumen

Estudiamos el efecto de la oferta de forraje (HA, alta HA vs. baja HA, 5 vs. 3 kg MS/kg PC, respectivamente) y raza de la vaca (cruza [F1 Angus-Hereford] vs. pura [Angus y Hereford]) sobre la estrategia de pastoreo en gestación (-90 d hasta el parto) y lactancia (40 d después del parto) en dos años. La masa de forraje (HM), el tiempo diario de pastoreo (GT, min/d) y de rumia (RT min/d) se controlaron mediante registradores automáticos de comportamiento y se expresaron en relación con el consumo de forraje (DMI, kg/vaca/día). El número de estaciones de alimentación (FeSt/min) y las bocados/FeSt se registraron mediante observación directa durante treinta min/día en 2 a 4 vacas por parcela y durante 2 o 3 días consecutivos. El efecto de la HA y la raza de la vaca sobre las variables de comportamiento se analizó mediante modelos mixtos. Una mayor HA se asoció a una mayor HM durante la gestación y la lactación en ambos años. Durante la gestación la HA no afectó al GT, RT, tasa de mordida, FeSt o DMI; sin embargo, durante el segundo período de gestación, las vacas cruza redujeron la tasa de consumo (IR, 8,7 vs. 10,3 ± 0,31 g DMI/min; $P < 0,01$) y el DMI ($P = 0,03$, 6,84 vs. 7,76 ± 0,27 kg/vaca/d). Durante la lactancia, las vacas pastoreando alta HA accedieron a mayor HM y HA, pero mostraron similar GT, RT y tasa de bocados, pero mayor ($P < 0,05$) DMI en ambos años. Las diferencias en IR podrían explicarse por un menor número de bocados/FeSt en vacas pastoreando alta HA (9 vs. 13 ± 2, mordiscos/FeSt, $P = 0,08$), lo que parece

un comportamiento más selectivo que permitió una mayor tasa de ingestión y DMI. Cambios en IR y FeSt sin alterar GT o RT, pero aumentando DMI y DDMI, fueron resultados novedosos durante la lactación, así como la rumia como actividad competidora con el pastoreo a niveles bajos de HM. Sin embargo, la reducción del DMI y el IR de las vacas cruza durante la gestación sin alterar el GT no tiene una explicación clara sobre la estrategia de pastoreo, sino que se produjo cuando el HM tuvo los valores más restrictivos, lo que pone de manifiesto el efecto del estado interno de la vaca sobre la estrategia de pastoreo.
Palabras clave: oferta de forraje, vacas de cría, Campos, carga animal, peso al destete

Foraging strategy of purebred and crossbred beef cows grazing native subtropical grassland differing in herbage allowance

Martin Do Carmo [1*], Andrés F. Cibils [2], Juan P. Damián [3], Teresa C.M. Genro [4], Santiago Scarlato [1], Pablo Soca [1]

[1] *Departamento de Producción Animal y Pasturas, Facultad de Agronomía, Ruta 3 km 363, CP 60000, Paysandú, Paysandú, Uruguay.*

[2] *Southern Plains Climate Hub, USDA, 7207 W. Cheyenne St. El Reno, Oklahoma 73036, USA.*

[3] *Departamento de Biociencias Veterinarias, Facultad de Veterinaria, Ruta 8 km 18, Montevideo, CP 13000, Montevideo, Uruguay.*

[4] *Embrapa Southern Livestock, BR-153 km 633, Bagé, CP 242, RS, Brazil.*

[*] *Present address: Departamento de Sistemas Agrarios y Paisajes Culturales, Centro Universitario de la Región Este, Ruta 9 y Ruta 15, CP 27000, Rocha, Rocha, Uruguay.*

Corresponding author: Martin Do Carmo, Email: martindocarmocorujo@gmail.com

Highlights

Herbage allowance did not affect grazing or ruminating behavior during gestation but affected both grazing and rumination during lactation.

Feeding stations behavior was linked to digestible herbage intake and rumination per kg of herbage intake.

Crossbred cows decreased herbage intake during gestation but foraging strategy was unclear.

Cow breed did not affect grazing or ruminating behavior during lactation.

We study the effect of herbage allowance (HA, High HA vs. Low HA, 5 vs 3 kg DM/kg BW respectively) and cow breed (Crossbred [F1 Angus-Hereford] vs. Purebred [Angus and Hereford]) on foraging strategy during gestation (-90 d to calving) and lactation (40 d after calving) in two years. Herbage mass (HM), daily grazing time (GT, min/d) and ruminating time (RT min/d) were monitored using

automatic behavior recorders and were expressed relative to herbage intake (DMI, kg/cow/day). Number of feeding stations (FeSt/min) and bites/FeSt were recorded by direct observation for 30 min/day. The effect of HA and cow breed on behavior variables were analyzed using mixed models. During gestation, greater HA was associated to greater HM however, HA did not affect GT, RT, bite rate, FeSt or DMI. During the second gestation period, crossbred cows reduced intake rate (IR, 8.7 vs 10.3±0.31 g DMI/min; $P<0.01$) and DMI ($P=0.03$, 6.84 vs 7.76±0.27 kg/cow/d) without changing GT. During lactation, cows grazing High HA accessed higher HM and HA, exhibited similar GT, RT and bite rate, but greater ($P<0.05$) DMI in both years. Differences in IR could be explained by lower bites/FeSt in cows grazing High HA (9 vs 13±2, bites/FeSt, $P=0.08$) which seems a more selective behavior that allowed greater intake rate and DMI. Changes in IR involved time in FeSt without altering GT or RT but increasing DMI and DDMI were novel results as well as the rumination as a competing activity with grazing at low levels of HM. However, the reduction of crossbred DMI and IR during gestation without altering GT has not clear explanation on foraging strategy, but occurred when the HM has the more restricting values, which highlight the effect of cow 'internal state' on foraging strategy.
Keywords: rangeland, beef cattle, rumination, grazing, feeding station

6.2. Introduction

Native subtropical grasslands, such as those found in the Campos and Pampas regions, are the primary herbage resource for beef production and provide important ecological services, including carbon sequestration, biodiversity, and soil conservation. However, economic sustainability is threatened by low beef productivity, but can be further enhanced through an ecological intensification approach (Ruggia et al. 2021; Soca et al. 2024) that aims to optimize beef production, improve economic returns, and maintain ecosystem services (Soca et al. 2024). A key strategy for improving beef production while reducing the intensity of methane emissions is to increase digestible dry matter intake (DDMI), which could be achieved by increasing dry matter intake (DMI) or by increasing digestible herbage (DMD) of the cow's diet. We postulated an innovative model to improve economic sustainability and ecosystem services based on experimental results that modify herbage allowance (HA), canopy height and cow BCS throughout the cow's gestation-lactation cycle (Do Carmo et al. 2016; Dumont et al. 2020; Soca et al. 2024). The model attempts to couple the spring-summer herbage production of the native grassland with the nutrient requirements of beef cows through the gestation-lactation cycle (Soca et al. 2024), and to do so requires quantification and conceptualization of the foraging strategy under different HA and HM. Herbage intake and selectivity include factors such as forage digestibility and herbage mass (HM), which could be controlled by HA management (Brosh et al. 2004; Do Carmo et al. 2021), as well as by herbage digestion and passage at the rumen, classical rumen fill (Gregorini et al. 2008).

The higher DMD of ingested herbage compared to the grassland mean is the result of selective grazing from feeding site to feeding site (FeSt), which involves all the behaviors of grazing and rumination that collectively could be called "foraging strategy" (Gordon and Lascano 1993).

When grazing, DDMI depends on the cow's foraging strategy, which is the result of grazing and ruminating activities influenced by HM, canopy height, chemical composition, its covariation and resource distribution, as well as the cow's internal state (Gregorini et al. 2008). The herbage ingested and the chewing behavior (during ingestion) and particle size reduction by microorganisms and rumination affect the rumen filling, which in turn affects grazing selectivity and foraging strategy (Gregorini et al. 2008 and 2015).

However, many herbivory studies have focused only on short-term intake rates (Allden and Whittaker 1970; Gonçalves et al. 2009a), few integrate patch and FeSt changes in HM and quality to study cow selectivity and intake rate (IR) (Utsumi et al. 2009), and there is no previous work using native grasslands measuring daily DMI that integrates ingestive and digestive constraints and animal behavior at different temporal and spatial scales (Demment and Greenwood 1988; Baumont et al. 2004; Fryxell 2008).

Although higher HM in Campos grasslands is typically associated with increased DMI during spring-summer (Da Trindade et al. 2016; Do Carmo et al. 2021), we need empirical evidence to investigate how grazing and rumination are related to DMI under different herbage structure. We do not know how native grassland under control of HA, which directly affects HM, contributes to change cow foraging strategy such as FeSt/min, bite rate and daily grazing time and/or rumination, which may affect passage rate and rumen filling and ultimately DMI (Gregorini et al. 2007; Do Carmo et al. 2021).

Previous reports have shown that changes in cow breed modify DMI, herbage selectivity, as well as energy expenditure (Aharoni et al. 2009) and spatial distribution (Dolev et al. 2014). Our previous research showed that crossbred cows (F1 of Hereford and Angus breeds) reduced DMI (g/MBW/d) during gestation compared to purebred cows on the same grassland (Do Carmo et al. 2021). Our research postulated that mechanisms such as larger rumen and liver size and lower adipose tissue mobilization of the crossbred cows could be behind the lower DMI (Casal et al. 2014, 2016). However, it remains unclear if or how breed differences may or may not affect grazing or ruminating behavior, which may help explain the changes in DMI.

The primary objective of this study was to quantify how HA and cow breed influence grazing and ruminating behavior and to determine their relationship with DDMI and DMI during gestation and lactation over a two-year period. We hypothesized that the reduction in DMI during gestation could be explained by lower GT, which cannot be compensated by increased bite rate, while bite mass was controlled by herbage characteristics. In contrast, cows grazing High HA during lactation (with higher HM and HA) will achieve higher DMI through fewer but heavier bites, allowing them to increase intake rate while reducing GT.

5.3. Materials and methods

5.3.1. Animals

The animal procedures used in this research were approved by the Ethics Committee (Comisión de Ética en el Uso de Animales, Universidad de la República, CEUA-CHEA, N° 021130-006374-12). Experimental dams were selected from a herd described by Gutierrez et al. (2013) and Do Carmo et al. (2018). Multiparous cows, 4 to 8 years old, purebred (Angus and Hereford) and crossbred (F1 reciprocal Hereford and Angus crosses) were assigned to one of two herbage allowance (HA) treatments: High HA (average 5 kg DM/kg BW) and Low HA (average 3 kg DM/kg BW). Cows were maintained in the same treatments if they calved and became pregnant each year (Do Carmo et al. 2018). Body weight (BW, kg) and BCS (scale from 1 to 8, Vizcarra et al., 1986) of purebred and crossbred cows were recorded monthly (14 to 48 days interval) in the morning without fasting period.

5.3.2. Experiment design

The experiment was conducted on 95 ha of Campos grassland at the Prof. Bernardo Rosengurtt Experimental Station, Facultad de Agronomía (Universidad de la República), Uruguay (32° 35' S, 54° 15' W) between August 2007 and March 2010. General results of herbage mass, canopy height, herbage accumulation as well as stocking rate, cow BCS and BW and calf BW at weaning and DMI of these cows have been previously reported by Do Carmo et al. (2018, 2021), also cow body tissue mobilization and visceral size and functionality by Casal et al. (2014, 2016), as well as metabolic hormones and gene expression by Laporta et al. (2014) and calf metabolic and endocrine profile by Gutierrez et al. (2013).

The experimental design was a randomized complete block with 2 blocks with different soil characteristics. Block 1 covered 60 ha (two 20 ha pastures for High HA and two 10 ha pastures for Low HA) and its soils were classified as Hapludalfs and Argiudolls. Block 2 covered 35 ha (two 12.5 ha pastures for High HA and two 5 ha pastures for Low HA) and consisted of soils classified as Hapluderts and Argiudolls. Each block consisted of 4 experimental units (pastures) to which the 2 x 2 factorial combinations of HA (High vs. Low, 5 and 3 kg DM/kg BW average) and cow breed (purebred and crossbred) treatments were randomly assigned. However, most of the daily automatic behavior recorders were collected only in block 1 (except for lactation of the second year), so the analysis was performed by factor, herbage allowance or cow genotype due to the lack of spatial replication for most of the behavioral measures. Herbage allowance, the ratio between herbage mass and animal weight (kg herbage DM/kg BW; Sollenberger et al. 2005), varied across seasons as reported by Do Carmo et al. (2018). The average HA achieved across years was 5 and 3 kg DM/kg BW for high and low HA, respectively. However, HA varied seasonally. In High HA pastures, HA was 4.7, 6.0, 5.6, and 3.3 kg DM/kg BW in spring, summer, fall, and winter, respectively, whereas in Low HA pastures, herbage allowance was 2.3, 2.8, 3.6, and 2.9 kg DM/kg BW in each of the four seasons, respectively (Do Carmo et al. 2018). The seasonal herbage allowance levels were based on the management guidelines proposed by Soca and Orcasberro (1992) and tested in subsequent experiments (see Do Carmo et al. 2016), which were designed to manage the body energy balance of dams throughout their annual reproductive cycle in order to significantly improve calving rates. Continuous stocking was applied throughout the year, with monthly stocking rate adjustments beginning in August 2007. Adjustments were made after monthly measurement of herbage mass, which was used together with animal BW/ha to calculate HA.

5.3.3. Behavior monitoring

Grazing behavior was monitored during early gestation (77±9 d of gestation or 205±9 days prepartum), mid-gestation (195±12 d of gestation or 87±12 days prepartum) and early lactation (39□14 d after calving). Each of these periods corresponded to autumn, winter and spring-summer, respectively. Early gestation behavior was monitored during a single year (in seven cows), while mid-gestation (26 cows in both years) and early lactation (38 cows in both years) behavior data were collected in two years of the experiment.

Automatic behavior recorders (IGER, Ultra Sound Advice, London, UK; Rutter et al. 1997) were used to monitor ingestive-ruminating behavior. The IGER records jaw movement to detect grazing, ruminating, resting or other activities. Jaw movement is detected by a ‘nose-band’ via an electrical resistance that occurs as the jaws open and close. The device registers this signal 20 times a second (Rutter et al. 1997).

The IGER system sensors were placed on two to four cows per pasture, which were brought to a cattle handling facility located approximately 600 m from the pastures, walked through a chute to the head gate, and fitted with the recorder and noseband. The entire procedure was typically completed in less than an hour.

Daily time spent either grazing (GT), ruminating (RT), or idling, as well as the number of daily prehension bites, the number of masticatory bites during rumination, and the number of grazing and rumination bouts were quantified from the IGER recorders using procedures developed by Rutter et al. (1997). IGER data were collected on different days depending on the season. The recorders were attached between 08:00 and 10:00 h and removed between 09:00 and 11:00 h the next day; therefore, jaw movement data were recorded over a time interval of 24 h or more. After removal, data were downloaded and recorders were charged in preparation for use the following day. The number of cows with complete data (24 h) varied from one to four days for each cow per period, with 88 complete data sets for gestation and 63 for lactation. Data from the recorders were analyzed using Graze software (Rutter, 2000). Daily grazing and rumination times (minutes/day), number of daily bites, and chewing bites during rumination were calculated for each cow. Daily grazing and rumination time and individual cow DMI (kg/d) were used to estimate intake rate (g/min) and rumination per kg DMI for each cow.

Short-term behavior monitoring. Visual observation of the two to four IGER-equipped cows in each pasture was also conducted in block 1, (24 cows were measured in mid-gestation and lactation in both blocks). Cows were painted with unique visible identifiers on each side of the ribcage. Feeding stations (FeSt), defined as the area available to a cow without moving their forelegs (Bailey et al. 1996), were recorded continuously for 20 min during the morning (9 to 12 am) and afternoon (16 to 19) hours for two consecutive days during gestation. During lactation, the number of FeSt was recorded continuously for 30 min during afternoon (16 to 19) hours only for two to three consecutive days. Cows were familiarized with the observers and seven trained observers counted FeSt using a hand-held herd counter. Observation was conducted at a distance of 6 to 12 m from focal cows to avoid interfering with animal behavior. Before and/or after counting FeSt, observers also counted the time it took each focal cow to reach 100 bites. Feeding station and short-term bite observations were conducted in the first year, during midgestation and lactation, on pastures in both experimental blocks. Data were transformed to FeSt/min and bites/min, and both were used to estimate bites/FeSt.

IGER data were collected only on Block 1 pastures, except during lactation in the second year, when data were collected for cows in both blocks. Visual observations were made on cows in both blocks during midgestation and lactation in the first year of the study.

5.3.4. Herbage intake and digestibility

Herbage intake was assessed during or after cow grazing behavior observations. Three to six beef cows were selected from the core group of cows (the same animal where behavior was measured) in each plot (total n=24 to 36 in the 8 paddocks) and were dosed once a day (at 0700 h) with a cellulose capsule containing 400±1.82 mg of C_{32}-alkane (dotriacontane, 97%, Sigma-Aldrich Corp., St. Louis, MO, USA) for 12 uninterrupted d in each evaluation (Do Carmo et al. 2021). During the periods of herbage intake measurements, the cows were followed in the morning and afternoon to conduct hand plucking of herbage (Coates and Penning 2000) to determine forage acid detergent fiber (ADF) and crude protein (CP) as reported by Do Carmo et al. (2021). Herbage intake and grazing behavior data for each cow were used to investigate the relationship between behavior variables and DMI, and to express behavior variables relative each cow's DMI. To explore differences in dry matter digestibility (DMD) of the diet, we used the n-alkane C31 concentration in herbage and in feces during the first gestation and lactation periods. Herbage n-alkane C31 concentration was determined from a sample pooled for a given pasture, whereas n-alkane C31 concentration in feces was estimated per cow. Both were used to estimate DMD for the first mid-gestation and lactation of the first year.

5.3.5. Vegetation attributes

Monthly herbage mass (kg DM/ha, at ground level) green herbage (GH%) and canopy height (cm, when herbage becomes dense ignoring tall stalks, Stewart et al., 2001) were determined using the comparative yield method (Haydock and Shaw, 1975). Reference quadrats were 0.25 m^2 (50 × 50 cm) and after being assigned a ranking (1, 1.5, 2, 3 and 5), canopy heights were measured and GH% was assessed by visual appraisal and quadrats were harvested to ground level and dried to constant weight at 60ºC, to determine herbage mass (Do Carmo et al. 2020). In each sampling event 51 to 297 were systematically selected (in a straight line and quadrats placed every 10 to 30 steps) on each plot, depending on the size of the plot (5 to 20 ha). The frequency distribution of canopy height (taken from the total number of quadrats in each plot) was divided into two ranges (0 to 3 cm, or +3 cm [thereafter +3 cm], representing a level of herbage mass near the threshold when it limits DMI according to previous reports, Illius and Gordon 1990) that were constructed for each plot.

During each behavioral recording period, hand-plucked forage samples were collected from plot locations where cows grazed (at least 20 locations in each plot during morning and afternoon grazing sessions). These forage samples were dried in a forced-air oven at 60°C, ground in a 1 mm mesh Wiley mill, and stored for chemical analysis. Samples were analyzed at the Laboratory of Animal Nutrition (Embrapa, Bagé, RS-Brazil) for DM, crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) (AOAC, 2005). Herbage samples from reference quadrats (50 × 50 cm) were selected to represent a wide range of herbage mass and GH% and were analyzed at the Laboratory of Animal Nutrition of the Facultad de Agronomia for nitrogen (N) and acid detergent fiber of organic matter (ADFom) (AOAC, 2005).

5.3.6. Statistical analysis

Cow behavior data were pooled per cow and were divided by cow DMI (kg/d). We chose to analyze behavior variables relative to DMI to effectively compare the treatments in their effectiveness of a cow’s foraging strategy. Data were analyzed using the SAS OnDemand for Academics (SAS on demand, 2022, SAS Institute Inc, Cary, NC). Behavior variables were analyzed for daily grazing time (min/day), daily grazing time relative to DMI (intake rate g/min), bites (n/day), bites relative to DMI (bite mass), bite rate, ruminating time (min/day), ruminating time relative to DMI (min/kg), mastication bites during rumination (n/day) and relative to DMI (n/kg) and short-term (30-40 min/day) FeSt (n/min) bites/min and bites/FeSt. All variables were analyzed using the cow as the experimental unit as suggested by Phillips (2002) and Adams et al. (2000) for grazing experiments where cow breed is one factor evaluated. The model included only the fixed effects of HA and breed, with Kenward-Rogers procedure to adjust the degrees of freedom and Tukey procedure for mean separation.

We did not include the interaction of HA and breed because the combination was not spatially replicated as we explained above most of the automatic behavior were recorded only in block 1. We separate the years to see how behavior was affected and due to the large difference in cow physiological status between gestation and lactation we analyzed each period separately. Digestibility of dry matter was estimated using the cow as the experimental unit, using MIXED procedure with fixed effect of cow breed and HA without random effect. In the case of cow behavior at feeding stations and bites/min, block was used as the random effect. Significant differences were considered with an alpha ≤0.05, and P values between 0.05 and 0.10 were declared marginally significant.

Vegetation attributes HM (kg DM/ha), canopy height (cm) and frequency distribution of canopy height (quotient) were analyzed using the MIXED procedure with pasture as the experimental unit. To explore the relationship between herbage mass and ADFom and N at a scale similar to the cow's FS, individual quadrats (50 × 50 cm) were used and PROC REG of SAS was used with green herbage (percentage), N (g/kg) and ADFom (g/kg) as dependent variables and herbage mass as the independent variable.

5.3.7. Model construction

We use Figure 2 as a conceptual model, constructed based on previous works of grazing (Gonçalves et al. 2009a, 2009b; Boval and Sauvant 2019; Garcia et al. 2003; Hirata et al. 2015; Allden and Whittaker 1970; Kenny and Black, 1984; Gibb et al. 1999; de Vries and Dalebout 1994; de Vries et al. 1999; Illius and Gordon 1990; Gregorini et al. 2006) and ruminating (Demment and Greenwood 1988; Gregorini et al. 2007; Beauchemin 2018) behavior in different contexts and added our own results in the variables measured and the behaviors involved to explain the results obtained.

5.4. Results

To provide order between herbage traits, experimental factors and behavioral (grazing and ruminating) response from short-term to daily scale, we present a conceptual model (Figure 2, A, B and C) filled with variables measured (and based on previous research) on how DMI and DDMI could be constructed throughout the day.

5.4.1. Gestation

In both years, HM, canopy height and +3 cm were greater in High than in Low HA (P<0.05); while as expected, herbage traits did not differ between plots grazed by different cow breeds (Table 1, Figure 2A and 2B). Herbage mass was negatively related to green herbage (GH) and N content, whereas it was positively related to ADFom (Figure 1, A, C, and B).

On a short-term scale from bite components (bite rate, FS/min, bites/FS and bite mass) to intake rate and through GT to DMI, no differences were measured between HA, nor between cow breeds during the first year (Figure 2A). Dry matter digestibility did not change between HA or cow breed, so DDMI was not affected (Table 1). However, in both years, cows grazing High HA had greater mastication/kg DMI during rumination compared to Low HA treatment (Table 1).

During the second year, crossbred cows tended to decrease bite mass (P=0.06), while bite rate and GT did not differ and intake rate (P<0.01) and DMI decreased (Table 1, Figure 2B). On the other hand, crossbred cows increased RT and mastication/kg DMI (Table 1, Figure 2B).

5.4.2. Lactation

In both years, HM, canopy height, and frequency of sites with canopy height +3 cm were greater (P<0.05) in High HA than in Low HA (Table 2 and Figure 2C) and, as expected, cow breed did not affect any herbage trait. Herbage mass was not significantly associated with green herbage, ADFom (g/kg) or N (g/kg) (Figure 1, A, B and C).

From the bite scale, bite mass differed but bite rate remained similar between HA (Table 2). Cows grazing High HA tended to exhibit greater FS/min and fewer bites/FS than cows grazing Low HA (Table 2). The change in bite mass induced a change in intake rate, which was greater in High HA than in Low HA. There was no difference in GT, which resulted in greater DMI in High HA (Table 2). Digestible DMI was greater in High HA compared to Low HA due to a combination of greater DMI and a tendency for greater DMD (Table 2, Figure 2C). Rumination and mastication/kg DMI were lower in High HA compared to Low HA (Table 2). Any behavior variable was influenced by cow breed.

5.5. Discussion

This is the first report attempting to link cow behavior at different temporal scales from bite to daily DMI, DMD and DDMI of beef cows grazing native subtropical grassland. Changes in the magnitude of IR and FeSt contributed to the explained improvements in DMI and DDM in High HA during lactation. However, changes in DMI of crossbred cows could not be explained by components of foraging strategy.

5.5.1. Gestation

During gestation, the levels of HM and sites +3 cm and the negative relationship between quantity and quality contributed to explain the magnitude of GT and the absence of differences between HA in cow foraging strategy components (GT, RT, FeSt) and finally DMI. However, during the second year, when major limitations in herbage structure occurred, crossbred cows did not change GT or biting rate, but reduced intake rate and DMI, suggesting that the influence of "animal internal state" could affect cow foraging strategy.

Despite equal HA, HM and canopy height were higher in High than Low HA, which can be explained as a consequence of previous higher HA and HM from spring to fall in High HA (Do Carmo et al. 2018). In both HA, canopy height and HM (from 1.6 to 2.8 cm; 700 to 1400 kg DM/ha) were consistent with previous results in subtropical grasslands (Moojen and Maraschin 2002), as well as the negative covariation between HM and N during winter or dormant season (Ogura et al. 2002). Low canopy height and HM, as well as limited forage heterogeneity (sites with canopy height +3 cm) and the negative covariation in the quantity-quality relationship contribute to explain the magnitude of GT and the lack of change in DMI and RT between HA (Figure 2A). Under these limited conditions of herbage structure, GT did not act as a compensatory variable when low IR was established.

The GT was not affected by cow breed and was relatively high (11-13 hr/day, Table 1) compared to GT of growing heifers grazing Campos with the same range of HM (9 to 11 hr/day; Da Trindade et al. 2016) and non-lactating beef cows grazing Mediterranean rangeland (5 to 9 hs/day Aharoni et al. 2009; Brosh et al. 2010). As a consequence of high GT, cow intake rate decreased (from 8.7 to 15 g DMI/min) compared to the intake rate of 16 to 30 g DMI/min reported by Aharoni et al. (2009). The low intake rate was mainly explained by the low bite mass (from 0.16 to 0.25 g DMI/bite), which was below the range derived from the meta-analysis for bite mass in cattle, which varied from 0.25 to 1 g DMI/bite (Boval and Sauvant 2019). Low bite mass should trigger an increase in bite rate or FeSt/min to compensate for the lower bite mass, but neither of these variables changed between HA or cow breed. Possibly because of the high time spent searching for acceptable bites associated with low canopy height and its negative covariation with N, which configure an important ingestive constraint consistent with the models' prediction of IR using bite weight and travel time (as a proxy for search time) when both mean and variation in canopy height and herbage digestibility are low (Demment and Laca 1994). A large number of daily bites, ranging from 39,000 to 43,000, also illustrates the difficulty of finding acceptable bites, even at low bite mass, which also helps to explain GT magnitude and bite mass (Gibb et al. 1999).

During the second mid-gestation, when sites +3 cm decreased strongly from 16 to 3%, showing a very low variability of canopy height, the DMI of cows decreased by 30% compared to the first mid-gestation (Table 1 and Do Carmo et al. 2021), which is consistent with the reduction proposed by mathematical modeling of IR (Laca and Demment 1991). However, crossbred cows reduced bite mass, which was an unexpected result because HM and canopy height are the main factors positively associated with bite mass, but were similar between breeds (Boval and Sauvant 2019). A possible explanation for the reduction in bite mass and intake rate could be a change not measured in our experiment in the selection of FeSt with lower HM than the mean of the paddock, then bite mass should decrease in accordance with HM and canopy height of the selected FeSt (Laca and Demment 1991; Boval and Sauvant 2019). As bite mass decreased, crossbred cows should increase bite rate to maintain intake rate, but bite rate remains similar between breeds. Because intake rate decreased for the crossbred cows, the GT of these cows should increase to some extent to compensate for the decrease in intake rate, but GT remains similar between breeds, decreasing DMI. Probably, the bite rate cannot be increased because, as already explained, acceptable FeSt and bites were very scarce and searching time increases, while GT cannot be increased because it was already high and rumination and resting are necessary.

Lower bite mass could be associated with the active selection of herbage with higher N and possibly higher digestibility, which is associated with better cow energy balance and BCS in crossbred cows (Do Carmo et al. 2018). Cow energy balance could be seen as an expression of the "internal state" of the cow, a complex of animal factors that differed between breeds, as BW, 32 kg heavier and 0.2 units of BCS greater in the crossbred, rumen size (greater in the crossbred) and tissue mobilization (greater protein tissue mobilization in the crossbred with potential reduction in maintenance energy cost) (Casal et al. 2014 and 2016; Do Carmo et al. 2018).

5.5.2. Lactation

Greater canopy height and HM in High HA were similar to those previously reported (Moojen and Maraschin 2002; Da Trindade et al. 2016), and the covariation between HM-N, was consistent with the report of grassland dominated by Paspalum notatum, where herbage digestibility does not change with increasing HM during the spring-early summer period (Ogura et al. 2002).

As expected, cows grazing High HA increased IR and DMI due to improved herbage structure from greater HM, canopy height and +3 cm sites (Boval and Sauvant 2019).

An increase in IR was not associated with a decrease in GT (Figure 2C), as suggested by grazing ecology research (Bergman et al. 2001, Da Trindade et al. 2016). The magnitude of GT was similar to that reported for lactating beef cows grazing Mediterranean rangelands (Brosh et al. 2010), and the lack of decrease in GT could be explained by the physiological state of the cow (lactation), which increases energy demand (Gregorini et al. 2015).

Cows grazing in Low HA were unable to increase the bite rate or GT to compensate the reduction in intake rate, which is in contrast with previous reports (Gibb et al. 1999; Da Trindade et al. 2016). Presumably, searching time prevents the increase in bite rate while rumination competes with grazing as DMD decreases and RT/kg DMI increases.

Cows grazing High HA increased FeSt/min and reduced bites/FeSt as HM increased, which is in contrast to previous grazing experiments (Hirata et al. 2015; Garcia et al. 2003; Roguet et al. 2000). The non-covariation between HM-N concentration could explain an increase in FeSt or a decrease in residence time, because residence time depends not only on the characteristics of the grazed FeSt, but also on the attractiveness of neighboring FeSt (Laca et al. 1993; Searle et al. 2006). We hypothesized that increases in HM at similar N would increase the frequency of "acceptable" FeSt, and therefore cow residence time in each FeSt would likely decrease. The greater HM without change in N concentration and foraging strategy at FeSt could explain the greater IR, DMD and DMI at similar GT of lactating cows. The greater DMD of the diet in High HA could also explain a reduction in mastication prior to swallowing, which decreased the processing time of each bite while searching for the next FeSt, facilitating the greater IR (Kenny and Black 1984).

In contrast, the increase in RT/kg DMI for cows grazing Low HA as DMD decreased is consistent with previous reports (Beauchemin 2018) and was a competing activity with grazing (no change in RT or GT between HA) that limited DMI even at low HM, which was unexpected because models suggest that rumination does not compete with grazing at low HM (Fryxell 2008).

6. Conclusions

During gestation and lactation, despite changes in forage structure and HA, cows did not change GT between treatments, which may reflect a significant limitation in herbage structure (during gestation) and/or an increase in cow energy requirements (during lactation).

During lactation, greater HM, HA and canopy height in High than in Low HA, as well as non-covariation in HM-N relationship and lactating cows contributed to explain the increase in bite mass, intake rate, DMD, DMI and DDMI. Changes in FeSt/min and bites/FeSt seem to be involved in a better selection process as cows in High HA explored more area/min and selected fewer bites/FeSt but yielded the best forage as DMD and DMI were increased.

During lactation, rumination time was a competing activity with grazing in Low HA because as DMD decreased, RT/kg DMI had to be increased, reducing the time to graze to compensate for the decrease in DMI.

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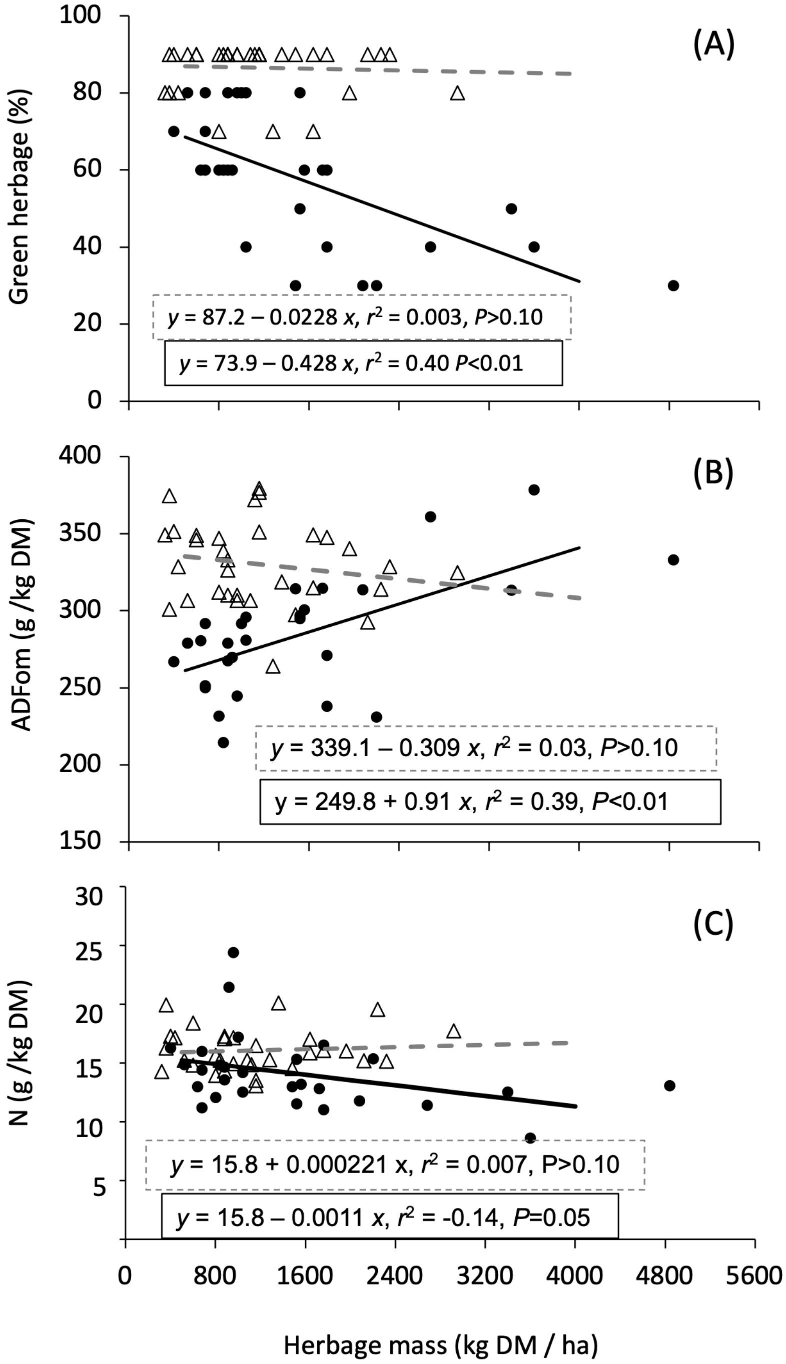
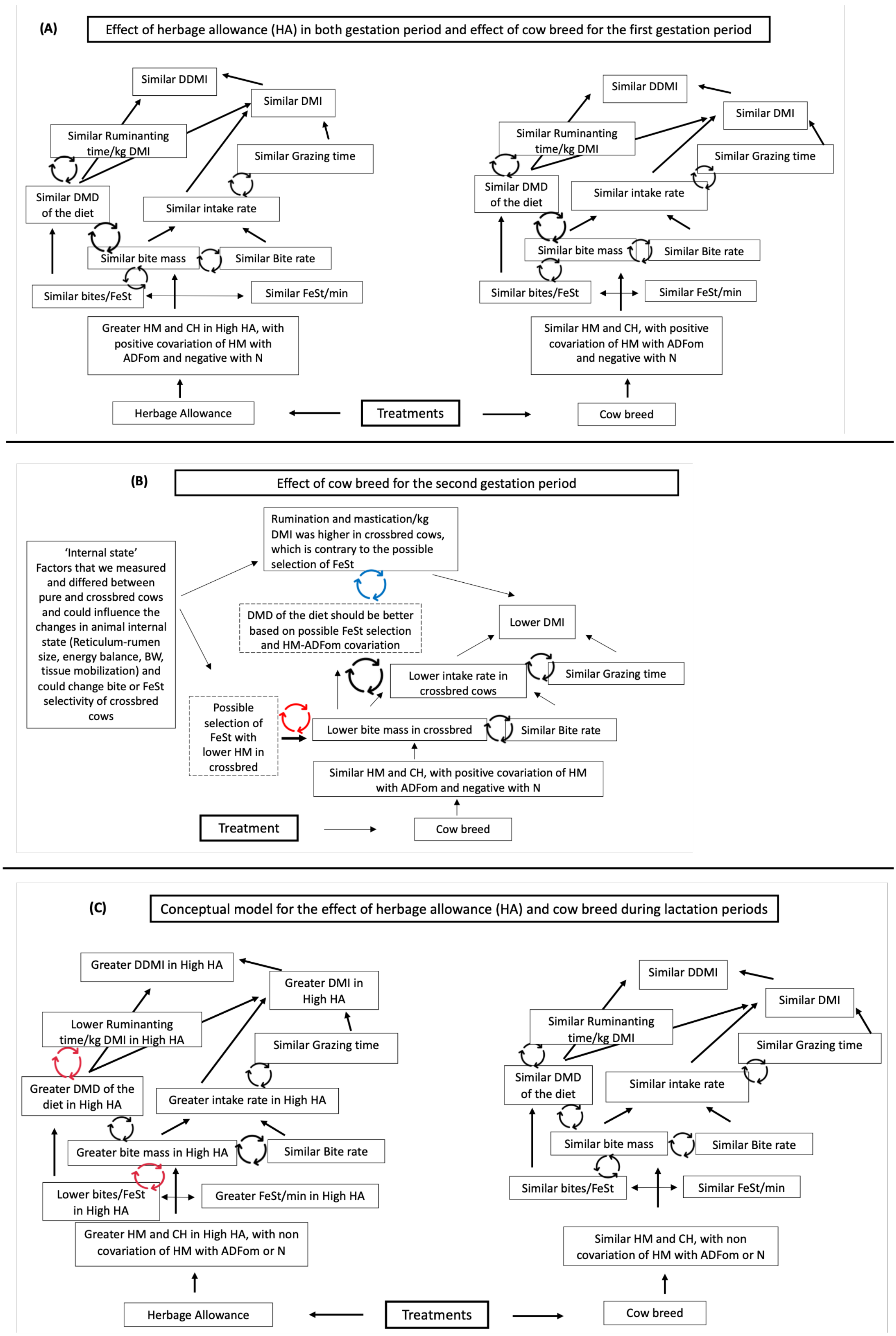
Figure Captions

Figure 1. Relationship between herbage mass and (A) green herbage (GH, %), (B) Acid Detergent Fiber of organic matter (ADFom, g/kg) and (C) Nitrogen (N, g/kg). Open triangles (n=32) and dashed grey line and box correspond to lactation period (spring) while black circles (n=28) and black line and box correspond to gestation period (winter). Intercepts of the regression equations were all different from zero (P<0.01).



(A)
Green herbage (%)
y = 87.2 – 0.0228 x, r2 = 0.003, P>0.10
y = 73.9 – 0.428 x, r2 = 0.40 P<0.01
(B)
ADFom (g /kg DM)
y = 339.1 – 0.309 x, r2 = 0.03, P>0.10
y = 249.8 + 0.91 x, r2 = 0.39, P<0.01
(C)
N (g /kg DM)
y = 15.8 + 0.000221 x, r2 = 0.007, P>0.10
y = 15.8 – 0.0011 x, r2 = -0.14, P=0.05
Herbage mass (kg DM / ha)

Figure 1



(A)
Effect of herbage allowance (HA) in both gestation period and effect of cow breed for the first gestation period
Similar DDMI
Similar DMI
Similar Ruminanting time/kg DMI
Similar Grazing time
Similar DMD of the diet
Similar intake rate
Similar bite mass
Similar Bite rate
Similar bites/FeSt
Similar FeSt/min
Greater HM and CH in High HA, with positive covariation of HM with ADFom and negative with N
Herbage Allowance
Treatments
Cow breed
Similar DDMI
Similar DMI
Similar Ruminanting time/kg DMI
Similar Grazing time
Similar DMD of the diet
Similar intake rate
Similar bite mass
Similar Bite rate
Similar bites/FeSt
Similar FeSt/min
Similar HM and CH, with positive covariation of HM with ADFom and negative with N
(B)
Effect of cow breed for the second gestation period
'Internal state' Factors that we measured and differed between pure and crossbred cows and could influence the changes in animal internal state (Reticulum-rumen size, energy balance, BW, tissue mobilization) and could change bite or FeSt selectivity of crossbred cows
Rumination and mastication/kg DMI was higher in crossbred cows, which is contrary to the possible selection of FeSt
DMD of the diet should be better based on possible FeSt selection and HM-ADFom covariation
Lower DMI
Lower intake rate in crossbred cows
Similar Grazing time
Possible selection of FeSt with lower HM in crossbred
Lower bite mass in crossbred
Similar Bite rate
Similar HM and CH, with positive covariation of HM with ADFom and negative with N
Treatment
Cow breed
(C)
Conceptual model for the effect of herbage allowance (HA) and cow breed during lactation periods
Greater DDMI in High HA
Greater DMI in High HA
Lower Ruminanting time/kg DMI in High HA
Similar Grazing time
Greater DMD of the diet in High HA
Greater intake rate in High HA
Greater bite mass in High HA
Similar Bite rate
Lower bites/FeSt in High HA
Greater FeSt/min in High HA
Greater HM and CH in High HA, with non covariation of HM with ADFom or N
Herbage Allowance
Treatments
Cow breed
Similar DDMI
Similar DMI
Similar Ruminanting time/kg DMI
Similar Grazing time
Similar DMD of the diet
Similar intake rate
Similar bite mass
Similar Bite rate
Similar bites/FeSt
Similar FeSt/min
Similar HM and CH, with non covariation of HM with ADFom or N

Figure 2. Conceptual model of the relationship between herbage traits, behavior variables, components of DMI and DDMI, based in previous works from bibliography and our own results.

References: HA = herbage allowance, FeSt = feeding station, DMI = dry matter intake, DMD = dry matter digestibility, DDMI = digestible dry matter intake, RT = rumination time, CH = canopy height. Boxes with continuous line represent variables measured. Black unidirectional arrows represent the energy flux from pasture to DDMI and represent the relationship between variables. Bidirectional arrow represent the relationship of the variables (FeSt/min and bites/FeSt). Circular symbol represent the change that could be trigger for one variable on another, or the trade-off made at those points by the animals, based on previous reports, e.g. when bite mass decrease, bite rate could be increased and/or FeSt/min could be increased in order to compensate the bite mass decrease, another example could be that when intake rate decrease daily grazing time could increase and for those reasons the circular symbol is connecting those variables. Red circular symbol, represent the activation of the compensation variable, e.g. to increase bite mass in High HA during lactation the bites/FeSt was modified to encounter more heavy bites and cows have to increase FeSt/min, decreasing bites/FeSt and residence time/FeSt. Blue circular symbol, when the variable response was opposite to the expected or could be a response of the animal, not related to herbage intake selected.

Table 1. Effects of herbage allowance (HA) and cow breed on grazing and ruminating behavior (mean□SE) during gestation.

Mid-gestation 1 (Winter)	Herbage Allowance		Breed			*P*-value	
	High HA	Low HA	Crossbred	Purebred	SE	HA	Breed
Herbage mass (kg DM/ha)	1410	750	1110	1050	160	<0.01	0.80
Canopy height (cm)	2.8	1.6	2.26	2.11	0.33	<0.01	0.85
Quadrats +3 cm	0.26	0.07	0.18	0.15	0.10	0.01	0.60
Daily scale							
Grazing (min/d)	690	713	712	691	20	0.42	0.50
Intake rate (g DM/min)	15	14	14	15	0.55	0.14	0.47
Bites (no./d)	41825	39382	40932	40275	1630	0.32	0.79
Bite rate (bites/min)	61	55	58	58	2	0.08	0.80
Bite mass (g/bite)	0.25	0.26	0.25	0.26	0.01	0.78	0.68
Ruminating (min/d)	476	432	456	452	16	0.07	0.86
Ruminating/kg DMI	45	43	45	44	2.5	0.58	0.81
Mastication (no./d)	26503	20365	24636	22232	764	<0.01	0.05
Mastication/kg DMI	2529	2041	2424	2146	108	<0.01	0.11
DMI (kg/d)	10.5	10.0	10.2	10.4	0.35	0.36	0.73
DMD (%)	54	52	54	52	1.0	0.68	0.71
DDMI (kg/d)	5.7	5.2	5.5	5.4	0.4	0.49	0.91
Short-term (30-40 min)							
FeSt/min	4	5	5	5	0.5	0.21	0.93
Bites/min	51	55	54	53	4	0.55	0.83
Bites/FeSt	13	12	13	12	0.5	0.82	0.61
Mid-gestation 2 (Winter)	Herbage Allowance		Breed			*P*-value	
	High HA	Low HA	Crossbred	Purebred	SE	HA	Breed

Herbage mass (kg DM/ha)	1110	830	950	980	54	<0.01	0.83
Canopy height	2.2	1.6	1.89	1.89	0.04	<0.01	0.97
Quadrats +3 cm	0.06	0.00	0.01	0.05	0.01	0.05	0.13
Daily scale							
Grazing (min/d)	777	757	781	752	12	0.24	0.10
Intake rate (g DM/min)	9.8	9.3	8.7	10.3	0.31	0.36	<0.01
Bites (no./d)	43561	41020	42626	41954	1630	0.29	0.77
Bite rate (bites/min)	56	54	55	56	2	0.50	0.64
Bite mass (g/bite)	0.17	0.17	0.16	0.18	0.008	0.77	0.06
Ruminating (min/d)	374	358	374	359	15	0.44	0.47
Ruminating/kg DMI	50	52	55	46	2.8	0.72	0.05
Mastication (no./d)	19835	15999	18567	17266	750	<0.01	0.25
Mastication/kg DMI	2658	2286	2734	2212	122	0.06	0.01
DMI (kg/d)	7.55	7.05	6.84	7.76	0.27	0.21	0.03

References = DMI: dry matter intake, DMD: dry matter digestibility, DDMI: digestible dry matter intake FeSt: feeding station

Table 2. Effects of herbage allowance (HA) and cow breed on grazing and ruminating behavior (least square mean□SE) during lactation.

Lactation 1 (Spring-Summer)	Herbage Allowance		Breed			*P*-value	
	High HA	Low HA	Crossbred	Purebred	SE	HA	breed
Herbage mass	1330	830	1070	1080	47	<0.01	0.96
Canopy height	2.8	1.5	2.2	2.1	0.33	<0.01	0.91
Quadrats +3 cm	0.27	0.00	0.12	0.16	0.07	0.02	0.60
Daily scale							

Grazing (min/d)	733	757	747	743	19	0.37	0.89
Intake rate (g DM/min)	15	12	13	14	0.73	0.02	0.73
Bites (no./d)	36728	39092	38912	36909	1812	0.37	0.47
Bite rate	50	52	52	50	2	0.65	0.53
Bite mass (g/bite)	0.30	0.23	0.25	0.28	0.018	0.02	0.41
Ruminating (min/d)	524	492	520	496	34	0.12	0.24
Ruminating/kg DMI	48	59	51	56	8	<0.01	0.20
Mastication (no./d)	30253	28230	29580	28903	4230	0.21	0.68
Mastication/kg DMI	2860	3400	2952	3308	633	0.07	0.22
DMI (kg/d)	11.3	8.4	10.3	9.4	1.5	<0.01	0.22
DMD (%)	66	62	63	65	1.3	0.08	0.16
DDMI (kg/d)	7.2	5.7	6.1	6.6	0.32	<0.01	0.31
Short-term (30 min)							
FeSt/min	6.6	4.5	5	6	0.7	0.09	0.44
Bites/min	47	48	48	47	2	0.72	0.81
Bites/FeSt	9	13	9	13	2	0.08	0.11

Lactation 2 (Spring-Summer)	Herbage Allowance		Breed			*P*-value	
	High HA	Low HA	Crossbred	Purebred	SE	HA	breed
Herbage mass (kg DM/ha)	2840	1640	2180	2290	160	<0.01	0.80
Canopy height (cm)	7.1	4.7	5.8	6.1	0.62	<0.01	0.85
Quadrats +3 cm	0.94	0.89	0.91	0.93	0.05	0.47	0.82
Daily behavior							
Grazing (min/d)	679	720	706	693	19	0.14	0.65
Intake rate (g DM/min)	18.3	11.9	15.7	14.5	1.6	0.01	0.61
Bites (no./d)	32307	35368	32042	35633	2600	0.41	0.34
Bite rate	48	49	45	51	3	0.78	0.21
Bite mass (g/bite)	0.39	0.25	0.35	0.30	0.04	0.02	0.32
Ruminating (min/d)	535	525	544	515	20	0.73	0.32
Ruminating/kg DMI	46	64	52	59	4.5	0.01	0.27
Mastication (no./d)	31698	32526	32599	31625	1500	0.70	0.65

Mastication/kg DMI	2762	4001	3104	3659	300	0.01	0.21
DMI (kg/d)	12.2	8.5	10.9	9.7	0.82	<0.01	0.31

References = DMI: dry matter intake, DMD: dry matter digestibility, DDMI: digestible dry matter intake FeSt: feeding station

1

9. Appendix I

Details of vegetation and climatic conditions at the experimental site.

Campos grassland was dominated by *Axonopus affinis* Chase, *Oxalis* sp., *Cyperus* sp., *Cynodon dactylon* (L.) Pers., *Eryngium nudicaule* Lam, *Gaudinia fragilis* (L.) P. Beauv, *Chevreulia sarmentosa* (Pers.) S. F. Blake, *Stipa setigera* (Trin & Rupr.) Backworth, *Paspalum notatum* Flügge and *Coelorhachis selloana* (Hack.) A. Camus (Do Carmo et al. 2018).

Average annual rainfall is approximately 1200 mm and the climate type is classified as Cfa (subtropical, humid, without dry season, where mean temperature in the coldest month is between -3 to 18ºC and the warmest is above 22ºC) according to Köppen (Panario and Bidegain, 1997). During the first year of behavior measurement (year 2008) a drought occurred during the spring-summer when rainfall was 55% below the long-term average (281 mm), in contrast, during the second spring-summer period, rainfall was (1187 mm), 88% above the long-term average.

6. Discusión general

Este es el primer trabajo que cuantificó el consumo de forraje de vacas de cría y su conducta de pastoreo y rumia asociada, a varias escalas de tiempo y durante gestación y lactancia.

Durante primavera, en AOF se incrementó la altura del forraje de 2 cm a 4 cm comparado con BOF, lo cual sería consecuencia de mejoras en la producción de forraje (de 17 a 22 kg MS/ha/d; Do Carmo et al., 2018) y reducción en el consumo de forraje por unidad de superficie (12 a 9 kg MS/ha/d), lo que contribuye a explicar una mejora el consumo de forraje por animal (94,1 vs. 115,6 g/kg MBW/día; Do Carmo et al., 2021). Estos cambios en OF, altura, DMI individual y por unidad de superficie que ocurren simultáneamente constituyen uno de hallazgos centrales de nuestro trabajo, dado que permitieron cuantificar, en forma conjunta, los cambios en el crecimiento y consumo de forraje en función de la masa de forraje, para explicar las mejoras en la masa de forraje, lo cual ha sido postulado como uno de los principales mecanismos para mejorar el flujo de energía en los ecosistemas pastoriles (Noy Meir, 1975). Dichos resultados han contribuido a mejorar los modelos conceptuales que apoyaron las intervenciones prediales para mejorar los resultados productivo y económico con sinergia ambiental de la ganadería sobre campo natural (Do Carmo et al., 2019; Paparamborda et al., 2023; Soca et al., 2024).

Cuantificar el consumo de forraje (DMI) y de forraje digestible (DDMI), conjuntamente con la descripción de la estructura del forraje y la conducta de pastoreo a escala de estación de alimentación (FeSt), sesión y día de pastoreo, constituye un aporte original para comprender la estrategia de pastoreo de vacas de cría en pastoreo de campo natural. La estrategia de pastoreo de vacunos, como respuesta a los cambios simultáneos de la cantidad y calidad de forraje y el estado interno de las vacas, constituye un tema central de la ecología de pastoreo (García et al., 2003; Fryxell et al., 2004). Son escasos los experimentos donde se cuantifica y desagrega la estrategia de pastoreo y el DMI de vacas a escala de parcela, rodeo en producción y con un diseño repetido en el tiempo y espacio (Aharoni et al., 2004; Brosh et al., 2004). Su estudio ha sido prioritariamente orientado con base en experimentos manipulativos en condiciones controladas o empleo de modelos de simulación (Baumont et al., 2004; Laca y Demment, 1991). Existen modelos de predicción de la tasa de consumo ante cambios en la altura de forraje (Boval y Sauvant, 2019; Gonçalves et al., 2009); no obstante, son escasos o inexistentes, en el bioma pampas, los experimentos que cuantifican la conducta en pastoreo a diversas escalas de tiempo y lo relacionan con el DMI diario de vacas de cría. Los experimentos desarrollados en Rio Grande do Sul (Brasil) resultan la base para proponer un modelo de manejo de campo natural basado en los niveles de oferta de forraje variable entre primavera y verano, otoño e invierno (8-12 % del PV o 2-3 kg MS/kg PV; Soares et al., 2005; Cezimbra et al., 2021). Sin embargo, la relación funcional masa de forraje-tasa de consumo de forraje para vacunos en crecimiento, que se maximizó en 12 cm de altura o masa de forraje de 2200-2500 kg MS/ha (Gonçalves et al., 2009; Wallau et al., 2023), no permitiría contribuir a explicar los niveles de producción de carne por animal ni unidad de superficie. La oferta de forraje recomendada como óptima (8-12 % del PV) se asoció con niveles de masa de forraje entre 900 a 1400 kg MS/ha, mientras que la máxima tasa de consumo de forraje se alcanzó a mayores valores (2200-2500 kg MS/ha). Nuestro trabajo cuantificó el consumo de forraje diario y su relación con el resultado productivo, lo que permitió un fructífero diálogo conceptual y numérico entre un experimento que modifica la intensidad de pastoreo con carga variable, el funcionamiento y resultado físico y económico de la ganadería de cría en campo natural (Do Carmo et al., 2019; Ruggia et al., 2021).

A pesar de no poder separar los factores estación del año y estado fisiológico de las vacas, nuestro trabajo contribuyó significativamente al estudio de la relación planta-animal con vacas de cría en pastoreo de campo natural, dado que permitió:

1. Aceptar la primera hipótesis, dado que un incremento en la oferta de forraje se asoció con mejoras de la masa, la altura y el coeficiente de variación (CV) de la masa de forraje y el porcentaje de sitios con altura superior a 3 cm. Dichas mejoras coinciden con lo reportado en experimentos de pastoreo sobre campo natural, donde un aumento en la OF se asoció con mayor frecuencia de sitios menos pastoreados con superior altura (Wallau et al., 2023). La reducción temporal en la carga animal para

incrementar la OF habría permitido un patrón de pastoreo más selectivo entre plantas y zonas de la pastura y explicar el aumento en la frecuencia de las especies con mayor contenido de materia seca y hojas más finas, que son pastoreadas con menor frecuencia e intensidad debido a mayor tensión (dureza) de la hoja, lo cual les permite incrementar su tamaño al disminuir el consumo de materia seca por unidad de superficie en AOF (Caram et al., 2023, 2024).

Cuando, además de estos cambios, se modificó el número de estaciones de pastoreo y bocados dentro de estaciones, lo cual resultaría un indicador de una estrategia de pastoreo más selectiva, se mejoraron simultáneamente el DMI y DMD de vacas lactando pastoreando AOF. Dichos resultados confirman lo planteado en las hipótesis uno y dos: un incremento en la OF, MF y altura del forraje mejora el DMI a través de cambios en la conducta de pastoreo y rumia de vacas lactantes.

2. Cuantificar la relación funcional masa-consumo de forraje para vacas de cría pastoreando campo natural resultó original, dado que, hasta el momento, disponíamos de una relación funcional entre masa-consumo y tasa de consumo de forraje para vacunos en crecimiento en pastoreo de campo natural principalmente en primavera-verano (Da Trindade et al., 2016; Gonçalves et al., 2009; Wallau et al., 2023).

Una mejora de OF al pasar de 3 a 5 kg MS/kg PV se asoció con un incremento de 400 kg de MS en el DMI/vaca/año (4200 vs. 3800 ± 33 kg MS/vaca AOF y BOF, respectivamente; Do Carmo et al., 2021), lo cual resultó similar a la diferencia obtenida para recría vacuna pastoreando campo natural con niveles de OF entre 1 vs. 3 kg MS/kg PV (Cezimbra et al., 2021). La diferencia de niveles de OF a los cuales se obtuvieron similares cambios en el DMI anual pone de manifiesto la importancia de la alometría animal en las relaciones funcionales y confirma la pertinencia de cuantificarla para vacas de cría en pastoreo de campo natural (Illius y Gordon, 1987). La relación funcional obtenida en este trabajo permitió explicar las diferencias en producción individual registradas entre vacas de AOF y BOF y, junto con la ausencia de diferencias en la carga animal anual, la mayor producción por unidad de área en AOF.

Por otra parte, el empleo de vacas cruza no se asoció con incrementos del DMI o DDMI ni con cambios en la conducta de pastoreo, lo cual permitió rechazar la segunda hipótesis: que las vacas cruza en AOF mejoran el consumo, y permite reafirmar que las mejoras en productividad de vacas cruza en ambas OF se explicarían mayoritariamente por cambios en la eficiencia del uso de la energía consumida (Do Carmo et al., 2018, 2021).

3. Cuantificar los atributos de la estructura de forraje y la conducta de las vacas de cría permitió identificar dos modelos de la relación planta-animal ubicados en niveles de masa de forraje contrastantes durante la gestación tardía y lactancia, respectivamente.

Durante el período gestación, las pasturas bajas (1 cm a 4 cm) se asociaron con una reducción en la heterogeneidad (cuantificada en la proporción de sitios con altura +3 cm y el CV de la masa de forraje) y una relación inversa entre cantidad y calidad del forraje, lo cual contribuye a explicar las limitaciones en la estructura del forraje que enfrentaron todos los animales experimentales. El pastoreo entre 1 cm y 4 cm de altura, con una proporción de sitios +3 cm no superior a 20 %, cuando la relación cantidad-calidad resultó negativa, contribuyó a explicar la magnitud promedio de GT (720 minutos/día) y la ausencia de cambios en la tasa de bocados en todas las vacas. Los niveles de GT resultaron similares al rango superior reportado para vacunos en crecimiento en pastoreo de campo natural (Da Trindade et al., 2012). Durante la gestación, con limitados niveles de masa y altura de forraje, las mejoras de estructura del forraje que ocurrieron en AOF no fueron de suficiente magnitud para modificar la conducta en pastoreo, el DMI y DDMI de las vacas. La ausencia de cambios en GT y DMI cuando las vacas pastorean masa de forraje entre 800-1400 kg MS/ha resultó similar a lo reportado por Huber et al. (1995) en pasturas nativas de California, donde el GT resultó inferior (500 a 600 min/día), lo cual sugiere que, aun en pasturas con diferente estructura a la del campo natural evaluado, el costo en tiempo de pastoreo no se modificó con cambios importantes en los niveles de masa de forraje.

Durante la gestación tampoco se modificaron los bocados/kg DMI, FeSt/min o bocados/FeSt, lo que confirmaría que, en ambos niveles de altura, las vacas realizaron un esfuerzo importante de búsqueda para cosechar el forraje con elevados niveles de GT y la ausencia de cambios a escala de elección de FeSt o parches de alimentación.

La ausencia de cambios en las FeSt de vacas pastoreando niveles de altura contrastantes nos permite plantear que los cambios en la estructura del forraje no resultaron de suficiente magnitud para modificar la conducta en pastoreo y que la prioridad en la elección de áreas de pastoreo habría estado en las FeSt y no en los bocados, como habría sucedido en primavera. Dichos cambios contribuyen a explicar los niveles de 12-13 vs. 8 bocados/FeST durante gestación y lactancia, respectivamente. Dichos resultados confirman lo planteado en las hipótesis dos y tres sobre la importancia de comprender la conducta de pastoreo para representar conceptualmente el consumo de forraje y la estrategia de pastoreo de vacas cría en campo natural.

4. La estructura del campo natural resultó determinante para la conducta en pastoreo durante lactancia y, por tanto, las predicciones de DMI deberían incorporar los cambios en la masa, altura, sitios más de 3 cm y calidad del forraje asociada los niveles de OF.

Las mejoras del DMI y DDMI de vacas de cría cuando se incrementó la OF de 3 a 5 kg/kg durante la lactancia permitieron aceptar lo planteado en las hipótesis uno, dos y tres: una mejora en la MF y en la heterogeneidad de la pastura asociada con un aumento de OF contribuye a explicar las mejoras de DMI y DDMI. Una mejora de la MF, altura de +3 cm y la ausencia de covariación entre cantidad y calidad del forraje contribuyó a explicar que las vacas de AOF mejoraron simultáneamente la tasa de consumo y la DMD, lo cual se asoció con un incremento en las FeS/min y una reducción en los bocados/FeSt. Los cambios en la estrategia de las vacas a escala de bocado y estación de alimentación parecerían haber constituido un escenario donde las vacas de AOF priorizaron la elección de bocados de manera de mejorar la tasa de consumo de material digestible, en contraste con la elección de FeSt que parecerían haber realizado en BOF. Esto permitiría aceptar lo planteado en las hipótesis dos y tres: que la conducta en pastoreo a diversas escalas de tiempo está involucrada en el control del DMI, lo cual resultó dependiente de la estructura de la pastura asociada a la OF. El aumento en las FeSt/min y la disminución en los bocados/FeSt al incrementar la masa de forraje en primavera resultó contrario a los antecedentes internacionales

(Hirata et al., 2015; Roguet et al., 2000) y regionales (Gonçalves et al., 2009), donde en general se reportó una asociación negativa entre la masa de forraje y las FeSt/min.

Sumado a la mayor frecuencia de mejores sitios de pastoreo, el comportamiento resultó más selectivo en AOF, al tomar menos bocados por FeSt y recorrer mayor número de FeSt/min, lo que sería señal de menor distancia a la próxima FeSt comparado con BOF, algo similar a lo reportado por experimentos manipulativos (Laca et al., 1993; Utsumi et al., 2009) cuando la distancia al próximo parche disminuye. Los cambios estructurales de la pastura entre BOF y AOF resultaron de suficiente magnitud para mejorar simultáneamente la IR y la DMD de la dieta, sin cambiar el GT. Dichos resultados, que resultan novedosos en pastoreo de campo natural, confirmarían las predicciones de selectividad y tasa de consumo derivadas de modelos de simulación, donde un incremento en la heterogeneidad (CV) de la altura del forraje sin cambios en la calidad del forraje (relación neutra al aumentar la masa de forraje) generó un incremento en la tasa de consumo respecto de una comunidad con menor CV de la masa de forraje (Laca y Demment, 1991).

Resulta novedoso que, comparado con la mayoría de los antecedentes y modelos donde un incremento en la tasa de consumo por lo general condujo a una reducción de la tasa de bocados o el GT (Hodgson, 1990), dicho comportamiento no se registró durante la lactancia. Para que un aumento en la masa de bocado reduzca la tasa de bocado, la búsqueda de forraje debería mantenerse sin cambios y, por lo tanto, mayor masa de bocado conduce a mayor masticación antes de la deglución y, entonces, la prehensión (tasa de bocados) debería verse disminuida.

El resultado obtenido donde se igualaron la tasa de bocado y GT, pero se incrementa la tasa de consumo permite hipotetizar que el mayor tiempo de masticación derivado de bocado con superior masa de forraje en AOF se igualó con el mayor tiempo de búsqueda de sitios de pastoreo en BOF, lo que llevó a igual tasa de bocados, pero con cambios entre AOF y BOF en la tasa de consumo de forraje (Utsumi et al., 2009). Por otra parte, la búsqueda de forraje en AOF estaría facilitada por la mayor masa y altura de forraje, pero también por una reducción en la competencia por el forraje disponible por un incremento en la OF.

La ausencia de covariación entre cantidad y calidad facilitaría el proceso de selección del forraje (Spalinger y Hobbs, 1992). Al mismo tiempo, la mejora en la DMD de la dieta podría asociarse a una disminución del tiempo para procesar los bocados previó a la ingestión, lo que también podría explicar el incremento de la IR, en este caso a través de menor tiempo de masticación, pero de bocados de mayor masa y DMD comparado con BOF. Esto resultaría en acuerdo con Kenney y Black (1984), donde la oferta de distintos forrajes con diferente DMD resultó en diferencias de IR, pero no debidas solamente al cambio en la DMD, sino que los alimentos con mayor incremento en la IR fueron preferidos, lo que podría asociarse a la selección de forraje con superior altura de similar o mayor DMD en este trabajo.

Por otra parte, dentro de cada período, se confirmó cierta inelasticidad del GT ante cambios de la altura de forraje, lo cual estaría indicando que la magnitud de las diferencias en altura, el sentido de la covariación cantidad-calidad de forraje y estado interno de la vaca, que se asoció en parte al momento fisiológico, contribuyen a explicar que en todos los escenarios el GT representó un elevado costo fijo de la estrategia diaria de pastoreo. A escala diaria, parece haberse priorizado la ingestión de materia seca digestible, lo cual resultaría de la integración que la vaca realizó del estado interno con la estructura de la vegetación sin grandes modificaciones del GT diario, lo que resulta coincidente con un incremento del tiempo de búsqueda de los elementos más digestibles del forraje (García et al., 2003) y con el elevado tiempo de pastoreo diario en vacas de cría lactantes en pasturas nativas (Brosh et al., 2010).

La reducción del DMI en vacas de BOF y la igualdad de tiempo de rumia entre vacas de AOF y BOF y mayor RT/kg DMI de las vacas de BOF podrían explicarse porque las vacas de BOF podrían haber incrementado el tiempo de retención ruminal con el fin de aumentar la degradación de la fibra, lo cual habría provocado un incremento del llenado ruminal y una reducción en la producción fecal. Dicha hipótesis ha sido postulada a partir de los experimentos base de los modelos clásicos de control de consumo (Weston, 1996), donde el llenado ruminal ejerce una señal de reducción del DMI. La reducción de la producción fecal y en la DMD de las vacas de BOF coincide con lo reportado por Aharoni et al. (2004), donde el tiempo de retención en el rumen de partículas y solutos de forraje de vacas en pastoreo de pastura nativa mediterránea se incrementó en la medida en que disminuyó la DMD de la dieta y contrario a lo propuesto por Demment y Greenwood (1988), donde vacas sometidas a una restricción en la DMD aumentarían la tasa de pasaje para incrementar el DMI, lo que incrementaría de esta forma la producción fecal con el objetivo de mantener el DDMI.

El mayor RT/kg DMI de las vacas BOF serviría para aumentar el tiempo de retención a través de un mayor empaquetado del forraje y estaría muy relacionado con reducciones de la OF, lo cual resultó similar a lo planteado por Piaggio (1994): ante un aumento de la OF entre 7,5 % y 10 % del PV, el tiempo de retención del forraje de vacunos en crecimiento pastoreando campo natural mejorado se redujo de 50 a 45 horas, respectivamente. En nuestro caso, la RT/kg DMI aumentó en BOF en ambas lactancias, aun cuando la masa de forraje en BOF pasó de 800 a 1600 el RT/kg DMI se mantuvo entre años (59 y 64 min/kg DMI en año uno y dos, respectivamente) y el DMI se mantuvo casi sin cambios. Sin embargo, el mayor empaquetado y mayor retención generarían un mayor llenado ruminal a pesar del menor DMI, lo cual podría explicar la reducción en la FeSt/min, en la masa de bocado y DMI/FeSt. Esto coincide con lo reportado por Gregorini et al. (2007), quienes evaluaron los cambios en la tasa de consumo y comportamiento de pastoreo de vacas de carne pastoreando *Cynodon dactylon* con diversos niveles de llenado ruminal.

7. Conclusiones

Un aumento en la OF anual y durante la primavera permitió mejorar el consumo de forraje anual y estacional (durante la lactancia) y contribuyó a explicar las mejoras de producción por unidad animal de la cría vacuna pastoreando campo natural cuando se incrementó la OF. Para aumentar la OF fue necesario reducir temporalmente la carga animal durante primavera, lo cual redujo el consumo de forraje por unidad de superficie, pero permitió mejorar la producción de forraje y altura del campo natural, lo que contribuyó a explicar las mejoras en la producción por unidad de superficie de la cría en AOF a escala anual debido a la ausencia de diferencias en la carga animal.

Los cambios en la OF de primavera permitieron incrementar la masa de forraje, lo que modificó la distribución vertical y horizontal del campo natural durante gestación y lactancia. No obstante, la magnitud de los cambios en la estructura de la pastura no resultó suficiente para cambiar el DDMI durante la gestación, sin cambios en la IR, GT, la tasa de bocados, las FeSt/min o los bocados/FeSt de vacas entre AOF y BOF.

Sin embargo, durante lactancia las vacas de AOF mejoraron la IR y DDMI a través de cambios en el DMI y la DMD, asociados a cambios en las FeSt/min y bocados/FeSt, pero sin cambios en el GT. Las mejoras en DMI y DDMI en lactancia de vacas pastoreando AOF estuvieron asociadas a mejoras en IR, menor tiempo de rumia/kg de DMI y mayor DMD de la dieta seleccionada, lo cual podría explicarse por el comportamiento a escala de FeST (más estaciones de pastoreo) y bocados/FeSt (menos bocados/estación) que resultaron en un patrón de pastoreo más selectivo en AOF que en BOF.

El modelo de construcción del consumo de forraje a escala diaria muestra que es posible construir de diversas formas el DDMI, a través de cambios en las FeSt y bocados/FeSt, que la rumia resultó un competidor del pastoreo aun en pasturas bajas y que los mecanismos clásicos (tasa de bocados y tiempo de pastoreo) no presentaron cambios cuando el DDMI cambió significativamente.

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