Unidad de Posgrados y Educación Permanente

FACULTAD DE AGRONOMÍA
UNIVERSIDAD DE LA REPÚBLICA

UNIVERSIDAD DE LA REPÚBLICA URUGUAY

Estimación del gasto energético en vacas de cría con diferentes ofertas de forraje

María Jimena GÓMEZ ZABALA

Magíster en Ciencias Agrarias
opción Ciencias Animales

Agosto 2022

Estimación del gasto energético en vacas de cría con diferentes ofertas de forraje

María Jimena GÓMEZ ZABALA

Magíster en Ciencias Agrarias
opción Ciencias Animales

Agosto 2022

Tesis aprobada por el tribunal integrado por Ing. Agr. (PhD) Ana Inés Trujillo, Ing. Agr. (PhD) Francisco Dieguez y Zoot. (Dr.) Jean Kássio Fedrigo el 11 de agosto de 2022. Autor/a: Ing. Agr. María Jimena Gómez. Directora Ing. Agr. (PhD) Mariana Carriquiry, codirector DMV. (Dr.) Alberto Casal.

Dedico este trabajo a Atanasio y Adolfo.

AGRADECIMIENTOS

A Mariana Carriquiry, por abrirme las puertas al mundo académico y por su invaluable aporte en mi formación.

A mi cotutor, Alberto Casal, por su incondicional apoyo a lo largo del experimento y en cada paso de mi formación académica.

A Soledad Orcasberro, sin su apoyo hubiera sido imposible realizar mi maestría, a Martín Claramunt, Martín Do Carmo y Pablo Soca, por sus aportes en la realización y discusión de esta tesis. A Fiama Machado, por su apoyo y colaboración a lo largo del ensayo.

A todo el personal de la Estación Experimental Bernardo Rosengurtt que hicieron posible este trabajo, en especial a Dorrel Bentancor, Mauricio Cáceres y un recuerdo especial a Óscar Cáceres, a Xenia Vieira y Carlos Mantero por el apoyo en la realización del trabajo experimental.

A los estudiantes de UTU, a Ezequiel Jorge y a Hernán Bueno que apoyaron en la realización de las medidas.

Al Instituto Plan Agropecuario y, en especial, a Ítalo Malaquín, por valorar mi proceso de formación e impulsarme a cerrar esta etapa.

Finalmente, a mis padres, Gerardo y Sandra, y a mi hermana Agustina, que siempre estuvieron a mi lado cuando elegí lo que me gusta hacer, y un especial agradecimiento a mi esposo Adolfo por ser un gran compañero y apoyarme a lo largo de este proceso; a nuestro hijo Atanasio por ser mi cable a tierra.

TABLA DE CONTENIDO

RESUMEN

La partición de la energía entre la producción total de calor (HP) y la energía retenida (ER) en la eficiencia energética fue evaluada a lo largo del ciclo anual de producción (gestación-lactación) en vacas multíparas (n = 46) pastoreando dos ofertas de forraje (OF), alta (AOF; 7 kgMS/kgPV) y baja (BOF; 4 kgMS/kgPV) en campo natural; además, fue evaluado el gasto energético de la actividad de pastoreo en invierno. La ER fue mayor en vacas de AOF que en BOF, asociado a una mayor ER en leche durante la lactación temprana. La HP por vaca —estimada con la técnica de pulso de O_2 y frecuencia cardíaca— y la energía metabolizable (EM) consumida (CEM) no varió entre tratamientos, pero, en términos de peso metabólico, la HP fue mayor en vacas de BOF que AOF. El CEM durante la lactación temprana en primavera fue mayor en AOF que BOF, mientras que en invierno tendió a ser menor en AOF que BOF, en términos de peso metabólico. La eficiencia energética de todo el ciclo no fue afectada por el tratamiento (0,19 vs. 0,12 ± 0,02 para AOF y BOF, respectivamente), así como tampoco hubo diferencias entre tratamientos en gramos de ternero por MJ de EM consumida. La actividad de pastoreo fue monitoreada con collares MOONITOR. El gasto energético (KJ/ kg $PV^{0,75}$ por h) de la caminata y pastoreo se incrementó un 25 % y 15 %, respectivamente, sobre el descanso. Sin embargo, el gasto energético diario de la caminata no fue significativo debido a que esta actividad ocurrió durante menos de 1 h. A pesar de no haber diferencias en el tiempo destinado a cada actividad entre tratamientos, el gasto energético diario fue mayor en BOF para descanso/rumia y pastoreo. Diferencias en el manejo del pastoreo a través de la OF generaron en otoño una mayor masa y altura del forraje, por lo cual, durante el invierno, a igual OF entre tratamientos, pero con una mayor masa y de forraje y carga animal para AOF, las vacas se encontraron en mantenimiento con un menor consumo de EM comparado con las vacas de BOF, lo cual está probablemente asociado a las diferencias en la actividad de pastoreo.

Palabras clave: vacas de carne, eficiencia energética, campo natural

ESTIMATION OF ENERGY EXPENDITURE OF BREEDING COWS WITH DIFFERENT HERBAGE ALLOWANCE

SUMMARY

The energy partitioning between total heat production (HP) and retained energy (RE) on the efficiency of energy use was evaluated throughout the annual production cycle (gestation-lactation) of 46 multiparous beef cows grazing on two herbage allowances (HA) of Campos grassland (4 vs. 7 kgDM/kgBW; LO vs. HI); energy expenditure of grazing activity in winter was also evaluated. Total RE was greater for HI than LO cows and presented minimum values during early gestation and maximum values during early lactation, associated to the greater RE-milk in the former ones. Whole-animal HP, estimated by the heart rate-O_2 pulse technique, and cow metabolized energy (ME) intake did not differ between HA treatments, but HP relative to $BW^{0.75}$ was greater for LO than HI. Total HP and ME intake were minimum in gestation and maximum in early lactation and ME intake was greater during early lactation for HI than LO, and per unit of $BW^{0.75}$ tended to be less for HI than LO cows in winter. Grazing activities were monitored using MOONITOR collar. The energy efficiency of the annual cycle was not affected by treatments (0.19 vs. 0.12 ± 0.02 for HI and LO, respectively) and there were no differences in terms of grams of calf per MJ of ME intake. Herbage allowance affected total HP along the day but did not affect time spent in each activity. EE for grazing and walking represented a 15 and 25 % increment above resting/ruminating, respectively. Daily HP (kJ/kg $BW^{0.75}$ per day) in resting/ruminating and grazing was greater for LO than HI cows as EE for each activity per unit of time was greater. However, daily EE for walking was not significant as cows spent less than 1 h walking without foraging during the day. Differences in the management of HA between treatments improved in HI-HA greater herbage mass and height in fall, therefore, with equal HA between treatments in winter, but with higher forage mass and stocking rate for HI than LO, it allowed cows to be at maintenance with a lower ME intake compared with LO cows, which could be probably associated to differences in grazing activity.

Keywords: beef cows, energy efficiency, native grassland

1. INTRODUCCIÓN

1.1. PLANTEAMIENTO DEL PROBLEMA

La cría de bovinos de carne en Uruguay involucra 7,6 millones de hectáreas, que significan el 51 % de las hectáreas de pastoreo, principalmente de campo natural, y el 54 % de los productores, en su mayoría del tipo familiar (DIEA, 2015). La producción de carne llevada a cabo en un 89 % del área total con base en campo natural es de gran importancia económica nacional, representando el 19,1 % del ingreso por exportaciones (DIEA, 2015). A pesar de la importancia nacional de la ganadería, hoy compite fuertemente con otros rubros, por lo que, para lograr sustentabilidad de los productores y empresas dedicados a este sector, se debe mejorar la productividad físico-económica, sin incrementar los costos ni deteriorar el medio ambiente.

La producción estacional del campo natural, las variaciones climáticas intra- e interanuales y las diferencias en la calidad y cantidad de la pastura (Berretta et al., 2000) determinan que el consumo de nutrientes y energía resulte la principal limitante del proceso. Esto establece que, durante gran parte del año, las vacas de cría presenten un balance energético negativo (BEN), determinando una baja condición corporal (CC) al parto e inicio del entore (Soca et al., 2013a, Do Carmo et al., 2016). Como consecuencia, se produce un largo período de anestro posparto y baja probabilidad de preñez, reducido peso vivo (PV) de los terneros al destete y de la vaca de refugo, lo que impacta negativamente en el sistema productivo y en el ingreso de los productores (Short et al., 1990, Soca et al., 2013b, Do Carmo et al., 2016). Resultados nacionales muestran que el control de la intensidad de pastoreo del campo natural, a través de la oferta de forraje (OF), permitió mejorar la respuesta productiva y reproductiva de las vacas de cría e incrementar la eficiencia global del sistema criador, al comparar OF alta (AOF) y baja (BOF) (Do Carmo et al., 2018). Esta mejora se asoció a un mejor balance energético a lo largo del ciclo de gestación-lactación, que podría ser el resultado no solo de un mayor consumo, sino también de una reducción en los costos energéticos de mantenimiento (metabolismo basal y actividad) (Do Carmo et al., 2018).

En el ciclo de cría vacuna, más del 70 % de los costos energéticos son debidos al mantenimiento de los vientres, determinando que esta se caracterice como un proceso largo e ineficiente (Ferrell y Jenkins, 1985). Sin embargo, la eficiencia de producción es uno de los componentes que más define la competitividad y resiliencia de los sistemas. La información sobre gasto energético en distintos sistemas de producción es escasa a nivel internacional e inexistente en nuestro país. Generar información que permita identificar estrategias de manejo que logren incrementar la eficiencia energética de las vacas de cría es central en la competitividad de los sistemas y del sector en su conjunto.

En este contexto, el objetivo de esta tesis es cuantificar el gasto energético de vacas de cría pastoreando dos OF de campo natural (AOF vs. BOF) a lo largo del ciclo anual de producción (gestación-lactación), investigando sobre la partición de la energía entre producción total de calor y energía retenida (ternero y reservas corporales) de vacas de cría. Asimismo, se busca estimar el gasto energético para las actividades de caminar y pastorear, y el efecto del manejo del pastoreo sobre estos.

1.2. METABOLISMO ENERGÉTICO

El metabolismo energético, es decir, todas las reacciones químicas de un organismo, son llevadas a cabo por la energía obtenida en el alimento y, en ocasiones, por el tejido movilizado (Mendoza-Martínez et al., 2008).

La energía bruta es la energía liberada como calor cuando una sustancia orgánica es oxidada completamente a dióxido de carbono y agua (Mendoza-Martínez et al., 2008), es la energía que contiene un alimento. La energía digestible se define como la energía bruta menos la energía que se pierde en las heces. Los factores que afecten la digestibilidad del alimento consumido afectarán la energía digestible. La energía metabolizable (EM) es la energía digestible menos la energía que se pierde en la orina (producto de procesos metabólicos y de origen endógeno) y los gases generados en la fermentación microbiana, siendo el principal el metano (figura 1).

La energía neta (EN) es la retenida por el cuerpo del animal en sus tejidos o por alguno de sus productos; se utiliza para cubrir las necesidades de mantenimiento y para la producción. Es la EM menos las pérdidas de calor del metabolismo de los nutrientes y la fermentación; a ese calor se le denomina incremento calórico (IC); entonces, la energía neta es: EN = EM – IC (figura 1). En términos de eficiencia energética, cuanta más energía consumida se pierda en forma de calor, menor será la energía retenida (ER) por los tejidos; por lo tanto, la eficiencia para convertir el alimento en producto será menor.

Factores que afecten el consumo de EM, la producción de calor o la partición de la ER entre proteínas y grasas afectarán la eficiencia para convertir el alimento en producto. Por ejemplo, el consumo de EM se puede ver afectado por aquellos factores que incidan en el consumo de MS y/o la digestión; la producción de calor, por las variables que afectan el costo de mantenimiento, y la ER, por las variables del animal que influyan en la composición corporal (DiMarco, 2006).

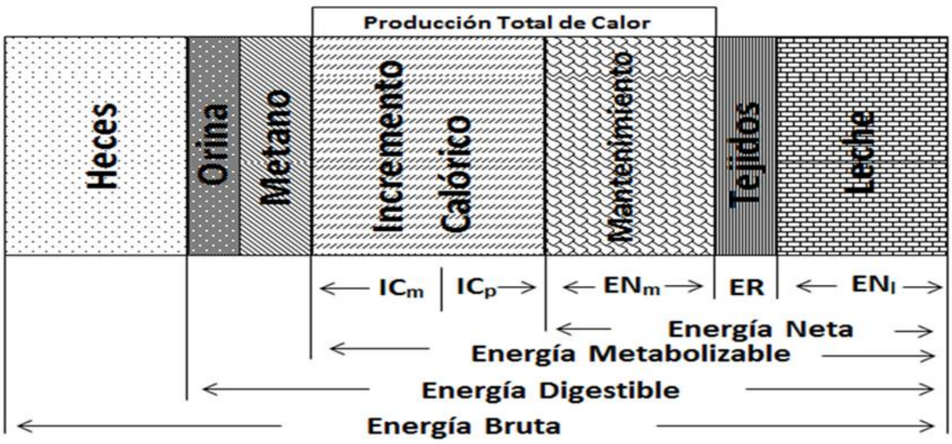

Figura 1. Esquema de partición de energía contenida en los alimentos (Brosh, 2015).

En la partición de la energía requerida para las diferentes funciones, el animal prioriza el mantenimiento de la vida en detrimento de la propagación de la especie.

El orden aproximado en la partición de nutrientes es el siguiente: metabolismo basal, actividad, crecimiento, reservas energéticas básicas, gestación, lactación, reservas energéticas adicionales, ciclos estrales e iniciación de la preñez y, por último, reservas en exceso, y este orden puede variar dependiendo de las funciones que estén presentes y en qué nivel (Short et al., 1990).

La eficiencia de producción en la cría vacuna está fuertemente influenciada por la partición de la energía entre las funciones de mantenimiento y producción, asociada al balance energético de los animales, que se determina por el consumo y los costos energéticos de las funciones nombradas anteriormente (Dickerson, 1978). Hablamos de mantenimiento cuando el balance energético es igual a cero (Baldwin, 1995); es la energía neta consumida la que permite el equilibrio energético del animal, es decir, en mantenimiento se mantienen los tejidos corporales y las actividades vitales básicas, lo cual incluye la energía requerida para el mantenimiento basal, la termorregulación y la actividad (NASEM, 2016). A su vez, el costo de mantenimiento es el principal componente del costo energético total del animal. El porcentaje de la energía consumida destinada a mantenimiento se estima, por algunos autores, entre un 70 y un 75% (Ferrell y Jenkins, 1985), lo que determina que la cría vacuna sea un proceso largo e ineficiente.

Diversos factores inciden sobre el costo de mantenimiento, algunos son inherentes al animal, como son las características del biotipo, el estado fisiológico y corporal, y otros son externos, como el clima, la composición del alimento y la actividad en pastoreo (Aello, 2014). Existe una gran variabilidad en el costo de mantenimiento entre razas (Baker et al., 1991) y entre animales de una misma raza (Solis et al., 1988); si eliminamos las condiciones externas como variable, el mayor costo de mantenimiento se debe a las diferencias de tamaño en el tejido visceral y al mayor contenido de proteínas tisulares (DiMarco, 2006).

Dentro de los factores externos, el costo de la actividad de pastoreo se debe al efecto de la caminata y a la cosecha del forraje. Se ha reportado que los animales bajo condiciones de pastoreo tienen mayor gasto de mantenimiento que los estabulados, reportando necesidades de mantenimiento 50 % superiores (Osuji, 1974, CSIRO, 2007). Este gasto depende del tiempo de pastoreo, condicionado por la disponibilidad de forraje, las distancias recorridas para la cosecha del forraje, el acceso al agua y la topografía del terreno (Rovira, 1996). La caminata incide en menos de un 5 % por ser una actividad de corta duración que se realiza a baja velocidad, teniendo un costo energético bajo a moderado. Sin embargo, el costo energético de mantenimiento puede incrementarse entre un 10 y un 15 % por la actividad extra de pastoreo, y cuando las condiciones de pastoreo son extremas y los animales deben pastorear muchas horas al día a alta tasa de bocado, este costo puede aumentar entre 25 y 30% (DiMarco y Aello, 2001), siendo la tasa de bocado el componente de actividad de mayor costo energético y el de mayor incidencia en el mantenimiento de novillos en pastoreo (DiMarco et al., 1996, DiMarco y Aello, 2001). Diferencias en las estimaciones realizadas sobre el gasto energético de la caminata y cosecha de forraje podrían relacionarse con las distintas metodologías (técnicas utilizadas), así como con las condiciones ambientales donde estas se realizaron.

La información sobre gasto energético en vacas de cría a lo largo del ciclo anual de producción y, como resultado, del manejo de pastoreo es escasa a nivel internacional (Brosh, 2007) y nula en nuestro país.

1.3. METABOLISMO ENERGÉTICO Y PARTICIÓN DE NUTRIENTES DE LA VACA DE CRÍA

Si consideramos una vaca en gestación avanzada, al alto costo energético de mantenimiento bajo condiciones de pastoreo le sumamos el crecimiento fetal y de las membranas fetales, el mantenimiento del útero grávido y el desarrollo de la glándula mamaria, puede llegar a ser 75 % más alto el costo energético de mantenimiento que el de un animal no gestante del mismo peso (Bauman y Currie, 1980, Meikle et al., 2006).

Durante el invierno (gestación avanzada), la restricción en la OF no permite satisfacer estos elevados requerimientos nutricionales, debido, principalmente, a la insuficiente ingestión de energía (Orcasberro, 2000). La baja disponibilidad de forraje produce un alto gasto energético por actividad de pastoreo (McClymont, 1967), por lo cual, cuando los requerimientos de nutrientes son mayores al consumo neto, los animales usan sus reservas corporales para satisfacer este déficit y generan un BEN (Robinson et al., 1999).

En los últimos dos meses de gestación, se da el 60 % de la acumulación de masa fetal, período en el que la demanda de nutrientes específicos como glucosa y aminoácidos aumenta significativamente (Bauman y Currie, 1980). Como parte del control homeorético, los diferentes tejidos y órganos, a través de hormonas y metabolitos, coordinan finamente el metabolismo para mantener la gestación (Short, 1990). Estos cambios metabólicos en la vaca permiten enfrentar condiciones de BEN (Bauman y Currie, 1980, Robinson et al., 1999) para lograr obtener un ternero viable, prioridad fisiológica (Short, 1990), en detrimento de la CC al parto, lo que genera consecuencias negativas para el futuro desempeño reproductivo (Trujillo et al., 1996).

1.4. CONTROL DE LA INTENSIDAD DE PASTOREO DEL CAMPO NATURAL

Frente a todos estos cambios en los requerimientos nutricionales, a lo largo del ciclo de la vaca de cría, el manejo del pastoreo es una herramienta fundamental para regular la captación y transformación de energía solar en producto animal, incidiendo en la productividad y resiliencia del recurso (Heitschmidt y Taylor, 1991). La carga animal es la principal medida de manejo del pastoreo que afecta resultados productivos y económicos en los sistemas de producción ganaderos. Los sistemas de producción en nuestro país ocurren bajo condiciones ambientales muy variables, siendo entonces, la producción de forraje, poco estable; por lo que la carga animal fija, definida como la cantidad de animales por unidad de superficie (Allen et al., 2011), cambia la OF a lo largo del año, lo que afecta el desempeño animal.

La principal ineficiencia de los sistemas criadores ocurre porque, durante el año, la OF, definida por una carga animal fija, no acompaña los distintos requerimientos durante el ciclo de la vaca de cría, lo que genera un desbalance energético. Durante el invierno, por ejemplo, no acompaña los altos requerimientos del último tercio de gestación y de la lactogénesis y provoca una baja CC al parto, lo que explica el largo anestro posparto y el porcentaje de destete de los rodeos de cría en Uruguay (Soca y Orcasberro, 1992). Durante la primavera y el verano, la baja relación masa de forraje/carga animal genera un BEN por el insuficiente consumo de energía durante la lactancia, el reinicio de la actividad sexual y el elevado costo energético por actividad de pastoreo.

La OF, definida como los kg de MS por kg de PV animal (Sollenberger et al., 2005), relaciona la cantidad de forraje y la carga animal, siendo la principal herramienta para controlar la intensidad de pastoreo, lo que permite incrementar la productividad de la pastura (Maraschin et al., 1997, Soares et al., 2003), los resultados productivos del rodeo de cría —ganancia diaria, carga animal, producción de carne— (Soares et al., 2003, Stuedemann y Franzluebbers, 2007) y, como consecuencia, los resultados económicos, promoviendo un ecosistema pastoril menos vulnerable a los cambios climáticos dado por una masa y acumulación de forraje superior (Do Carmo et al., 2018).

Experimentos nacionales y extranjeros reportan modificaciones en el comportamiento y el consumo animal en pastoreo frente a cambios en la cantidad de forraje ofrecido (Piaggio, 1995, Kennedy et al., 2007, Thurow et al., 2009). Do Carmo et al. (2018) mostraron la importancia de modificar la OF a lo largo del año por su efecto en la variación en la ganancia diaria de PV, optimizando la ganancia por unidad de superficie y por animal; lo que coincide con experimentos realizados en pastizales nativos en el sur de Brasil durante 20 años (Nabinger et al., 1999).

En este contexto, se llevó a cabo una serie de experimentos en las estaciones experimentales de Bernardo Rosengurtt (EEBR) y de Facultad de Agronomía de Salto (EEFAS) en pastoreo de campo natural, buscando evaluar, a distintos niveles jerárquicos, el efecto del control de la intensidad de pastoreo sobre la respuesta primaria (producción y composición química forraje), física (reproducción y producción de carne), comportamental y fisiológica (consumo de energía, conducta en pastoreo, selectividad, balance de nutrientes, concentraciones de metabolitos, y hormonas metabólicas y expresión génica) y sus posibles interacciones con el genotipo de la vaca (Carriquiry et al., 2013).

Se diseñaron dos experimentos llevados a cabo en la EEBR y en la EEFAS para determinar los efectos de dos OF (AOF y BOF; variable a lo largo del año). En la EEBR se estudió, además, el efecto de dos genotipos (Hereford y Angus puros vs. sus cruzas) en la productividad de vacas multíparas y primíparas (Do Carmo et al., 2018), mientras que en la EEFAS se usaron vacas primíparas Hereford. Los resultados mostraron que la AOF incrementó la acumulación de masa forrajera sin afectar la carga animal en la EEBR (Do Carmo et al., 2013), pero disminuyéndola en la EEFAS. Sin embargo, la producción por hectárea aumentó en AOF con respecto a la BOF en ambos experimentos debido a que se mejoró la producción por animal.

Según las estimaciones de consumo de forraje y energía, con base en los sistemas de alimentación CSIRO (2007), que se fundamenta en la disponibilidad y digestibilidad de la MS de la pastura y el PV de los animales, y NASEM (2016), basado en los requerimientos de energía para mantenimiento, gestación o lactación, y cambios en reservas corporales, se indica que los animales consumían por debajo de sus requerimientos durante gran parte del ciclo productivo anual en ambas OF, consumiendo las de AOF un promedio de entre un 65 y 84 % del consumo de MS potencial o de energía requerida, y las vacas en BOF, entre un 57 y 74 %. A pesar de estas condiciones, se vieron importantes diferencias entre los tratamientos.

Con respecto a la actividad de pastoreo, fue mayor el tiempo destinado en la BOF que en la AOF durante la primavera y el otoño, con un menor consumo, debido a la menor cantidad de masa forrajera y a la altura de la pastura (Wales et al., 1999, Scarlato et al., 2012, Da Trindade et al., 2015). Además, el tiempo de rumia fue mayor en AOF, donde se vio incrementada la energía consumida por las vacas, mejorando su CC y PV, lo cual generó impactos positivos; se alcanzó la CC objetivo en otoño y primavera, mejorando la CC al parto y la probabilidad de preñez por un menor anestro posparto, viéndose maximizada la eficiencia reproductiva (Do Carmo et al., 2018). La AOF incrementó la energía consumida por las vacas, la tasa de destete y PV de los terneros al destete, asociado a una mayor producción de leche, en ambas estaciones experimentales. A su vez, la BOF afectó su composición corporal al destete y a los 380 días de edad (Gutiérrez et al., 2013). Es así que la eficiencia de conversión fue afectada por la OF debido al mayor consumo de las vacas en AOF, siendo mayor el incremento en la productividad que en la energía consumida, lo que determinó una mejor eficiencia biológica del conjunto vaca-ternero en las cruzas. El incremento en la eficiencia de producción al aumentar el consumo se debió a que el coeficiente de ER (0,62) fue mayor que el impacto en la producción de calor (0,38; Brosh et al., 2004).

Los resultados obtenidos en estos experimentos en EEBR muestran, durante la gestación en invierno, una pérdida en la CC, un aumento de los AGNE en sangre —debido a la lipólisis del tejido adiposo— y la disminución de las concentraciones circulantes de las hormonas anabólicas indicadoras de la disponibilidad energética, como son la insulina e IGF-I, evidenciando un BEN y la movilización de reservas corporales. A su vez, en las condiciones de AOF, donde se dio una mejor CC, producción de leche, PV del ternero y menor largo de anestro posparto, se correspondió con un mejor estado metabólico durante el ciclo de gestación-lactación (mayor insulina e IGF-I). Además de verse reflejado el mejor estado nutricional de las vacas de la AOF en los niveles de insulina e IGF-I, las vacas de este tratamiento tuvieron menor deposición de grasa visceral que las de BOF, a pesar de tener mayor deposición de grasa total. Esto se asocia con una baja resistencia a la insulina (Sinclair, 2010). Estos resultados sugieren un mejor perfil anabólico en las vacas de AOF con respecto a las de BOF.

Es así como el manejo de la OF, en conjunto con otras medidas y técnicas como puede ser el cruzamiento, el manejo del destete y el *flushing*, modifican el consumo y la partición de energía en favor de la producción y/o reproducción, lo que resulta en una mayor eficiencia productiva de los sistemas de cría pastoriles (Do Carmo et al., 2016, Soca et al., 2013a).

1.5. HIPÓTESIS Y OBJETIVOS

1.5.1. Hipótesis

La mayor eficiencia productiva de las vacas de cría pastoreando AOF está asociada no solamente al incremento en el consumo de EM, sino también a una disminución en los requerimientos energéticos de mantenimiento, principalmente durante la gestación de invierno, cuando la masa y altura del forraje son limitantes.

1.5.2. Objetivo general

Evaluar el efecto de la intensidad de pastoreo en campo natural, a través del manejo de la OF del campo natural, en la partición de la energía entre la HP y la energía retenida (ER), y en la eficiencia del uso de la EM a lo largo del ciclo productivo (gestación-lactación) de la vaca de cría.

1.5.3. Objetivos específicos

1) Cuantificar la HP, la ER y la eficiencia energética de vacas de cría pastoreando dos OF de campo natural, alta y baja (7 y 4 kg MS/kg PV), a lo largo del ciclo anual de producción (gestación-lactación).

2) Estimar el incremento del gasto energético de la actividad de pastoreo sobre la actividad de descanso para vacas de cría pastoreando campo natural.

1.6. ESQUEMA GENERAL DE TESIS

Esta tesis incluye dos artículos científicos. El primer artículo, titulado «*Estimation of Energy Expenditure in Breeding Cows Grazing Rangelands with Different Herbage allowance*», constituye el segundo capítulo de esta tesis. Presenta la evaluación del efecto de la OF del campo natural sobre la eficiencia del uso de la EM, a lo largo del ciclo de gestación-lactación, a partir de la cuantificación de la producción de calor y la energía retenida (objetivo específico 1). Este artículo fue enviado a la revista *Tropical Animal Health and Production*. El segundo artículo, titulado «*Foraging Energy Expenditure in Breeding Cows*», constituye el tercer capítulo de esta tesis y presenta la estimación del incremento del gasto energético de la actividad de pastoreo sobre la actividad de descanso (objetivo específico 2). Este trabajo será enviado a *Livestock Science* como una comunicación corta. El cuarto capítulo presenta una discusión general y conclusiones del trabajo de tesis.

2. ESTIMATION OF ENERGY EXPENDITURE IN BREEDING COWS GRAZING RANGELANDS WITH DIFFERENT HERBAGE ALLOWANCE

Jimena Gómez[1*], Alberto Casal[1], Martín Do Carmo[1], Soledad Orcasberro[1], Pablo Soca[1], Mariana Carriquiry[1]
[*]Corresponding autor: jgomezabala@gmail.com

[1]*Departament of Animal Production and Pastures, School of Agronomy, Universidad de la República, Uruguay.*
Alberto Casal alcas@adinet.com.uy
Martín Do Carmo martindocarmocorujo@gmail.com
Soledad Orcasberro soleorcasberro@gmail.com
Pablo Soca psocape@gmail.com
Mariana Carriquiry mariana.carriquiry@gmail.com

2.1. ABSTRACT

The energy partitioning between total heat production (HP) and retained energy (RE) on the efficiency of energy use was evaluated throughout the annual production cycle (gestation-lactation) of 46 multiparous beef cows grazing on two herbage allowances (HA) of Campos grassland (4 vs. 7 kg dry matter/kg body weight; BW; LO vs. HI). Total RE was greater ($P < 0.01$) for HI than LO cows and presented minimum values during early gestation and maximum values during early lactation associated to the greater ($P = 0.02$) RE-milk in the former ones. Whole-animal HP, estimated by the heart rate-O_2 pulse technique, and cow metabolized energy (ME) intake, did not differ between HA treatments, but relative to $BW^{0.75}$, HP was greater ($P = 0.04$) for LO than HI cows. Total HP and ME intake were minimum in gestation and maximum in early lactation and ME intake was greater during early lactation for HI than LO cows, and per unit of $BW^{0.75}$ it tended ($P < 0.10$) to be less for HI than LO cows in winter. The energy efficiency of the annual cycle was not affected by treatments (0.19 vs. 0.12 ± 0.02 for HI and LO, respectively; $P > 0.10$) and there were no differences between treatments in terms of grams of calf per MJ of ME intake ($P > 0.10$). Management of grazing intensity of *Campos* grasslands with high herbage allowance improved energy balance of the beef cow-calf system through partitioning of cow ME intake towards RE instead of maintenance.

Keywords energy efficiency, beef cows-calf systems, grazing

2.2. INTRODUCTION

Campos region is the largest ecological unit of native grasslands in South America (Pallarés, 2005), where grassland-based livestock production is one of the most important agricultural activities of the region, having a significant contribution to the world beef industry (FAOSTAT, 2017). Cow-calf operations are often conducted in extensive grazing production systems in which nutrient availability -biomass production and pasture chemical composition- fluctuates with seasonal changes in rainfall and temperature (Berretta et al., 2000). This variation throughout the year affects, among other factors, beef cow energy intake (Aharoni et al., 2013) and maintenance requirements (Brosh, 2007). Particularly, in winter and early spring, when forage availability and production are low and beef cow energy requirements rise due to gestation and early lactation, a negative energy balance is established (Laporta et al., 2014). This negative energy balance is reflected in low body condition score (BCS) at calving and breeding season (Soca et al., 2013a; Do Carmo et al., 2016), resulting in extended postpartum anestrus, early embryonic death and reduced pregnancy and weaning rates (Hess et al., 2005; Soca et al., 2014).

Beef cow-calf systems are long-term energetically inefficient as they use 70-75 % of the energy intake for animal maintenance (Ferrell and Jenkins, 1985; Montaño-Bermudez et al.,1990). The partition of energy between maintenance and production is associated with energy balance (Dickerson, 1978) and when it favors production and reproduction, results in a greater productive efficiency of grazing cow-calf systems (Soca et al., 2013b; Do Carmo et al., 2016). Several factors affect the cost of maintenance, some inherent to animal characteristics such as genotype, physiological stage, BCS and body composition, and others related to external conditions such as climate, pastures chemical composition and grazing activity (NASEM, 2016). The control of energy costs for maintenance has a direct impact on the improvement of feed efficiency as well as environmental sustainability in beef cow-calf operations.

Reducing grazing intensity of native pastures through increased herbage allowance (HA), increased forage mass, height and growth of native pastures in *Campos* enables maintenance of stocking rate and increased cow energy intake, body weight (BW), BCS and kilograms of calf weaned when compared with low HA (Do Carmo et al., 2018). Also, retained energy as a proportion of the total energy intake in cows grazing high HA increased, thus, a dilution of the energy cost of maintenance was expected, which improved biological efficiency (Do Carmo et al., 2018). An increase in HA of native grasslands also affected organ mass, cellularity, or gene expression of mitochondrial proteins of the gastrointestinal tract and liver, which could be related with regulation of energy utilization and efficiency (Casal et al., 2014). In addition, herbage mass and height affected animal behavior and, thus, reduced energy cost in steers grazing cultivated pastures (DiMarco et al., 1996). Previous work in beef cows reported that both average daily energy expenditure and metabolized energy (ME) intake during the annual cycle of gestation-lactation was greater for beef cows grazing at low vs. high stocking rate (Aharoni et al., 2004; Brosh et al., 2006).

In order to correctly estimate energy requirements of grazing breeding cows, more information regarding energy expenditure and efficiency throughout the annual production cycle and the effect of grazing management is needed (Brosh, 2007; NASEM, 2016). Our hypothesis was that the greater production efficiency of beef cows grazing high-HA is associated not only with increased energy intake but also decreased maintenance energy requirements, especially during winter gestation. when forage mass and height decrease when compared with cows grazing low-HA. Therefore, the objective of the present study was to evaluate the effect of grazing intensity of *Campos* grassland, through management of HA, on energy partitioning between total heat production (HP) and retained energy (RE) and on the efficiency of energy use during the annual production cycle (gestation-lactation) of beef cows.

2.3. MATERIALS AND METHODS

2.3.1. <u>Experimental Site</u>

The experiment was conducted on 95 ha of *Campos* grassland located at the Experimental Station Bernardo Rosengurtt (School of Agronomy, Universidad de la

República, Uruguay, 32°S, 54°W) and lasted from March 2017 to May 2018. Average annual rainfall is almost 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 and 18 °C and the warmest is above 22 °C) according to Köppen (Panario and Bidegain, 1997). Native pastures were dominated by summer-growing C4 grasses (*Poaceae*), with few C3 grasses associated with the winter cycle. The main four families included *Asteraceae, Fabaceae, Rubiaceae* and *Umbelliferae*, similar to *Campos* grassland botanical composition (Altesor e*t* al., 1998).

2.3.2. Animals and Experimental Design

Forty-six 5 years old multiparous pregnant beef cows (Hereford, Angus and crossbred; average calving date 11/02/17 ± 13 days) were used in a randomized block design with two blocks (block 1: sandy loam soil, 59 ha and block 2: clay loam soil, 47 ha) and four plots in each block into which two treatments of HA (high and low; HI and LO) were allocated (n = 23 per HA). The HA, defined as the ratio between forage mass and stocking rate (kg of dry matter (DM) per kg of BW; Sollenberger et al., 2005), represented 8 and 5 kg DM/kg BW on average (for HI and LO, respectively) and varied with season of year (table 1). Chemical composition for different herbage allowance treatments did not differ and averaged 89 %, 7.7 %, 60.6 % and 30.6 % for organic matter, crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF), respectively (table 1). Herbage mass (kg DM/ha) was estimated monthly by the comparative yield method (Haydock & Shaw, 1975). A continuous stocking method was applied throughout the year and HA in each plot was adjusted monthly by the 'put-and-take method' (Mott, 1960). Experimental cows were maintained in the same plot throughout the experiment (n = 3 to 5 cows per plot within block) and 'put-and-take' cows were added or removed based on herbage mass available to adjust forage allowance and, thus, stocking rate. Cows did not receive any additional feed throughout the experiment except during the first 20-d of the breeding season during which cows were supplemented 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) and were suckling restricted for 14 d (for details, see Do Carmo et al., 2018). Cows grazed on the same HA (HI or LO) from May 2016 to May 2018.

2.3.3. Data and Sample Collection

Cows' BW and BCS (scale 1 to 8; Vizcarra et al., 1986) were determined every month by the same observer throughout the experiment. Calf weight was determined at birth and monthly until weaning (05/02/2018; 181 ± 13 days of age). Milk yield and composition were individually measured at 50 and 180 ± 13 days of lactation by machine-milking (Quintans et al., 2010) and milk samples were collected and subsequently analyzed for fat, protein and lactose by a milk analyzer mid-infrared spectrophotometry (NIRS, Milko-Scan, Fross Electric, HillerØd, Denmark).

Table 1. Actual herbage allowance, forage mass, height and chemical composition, and cow physiological status throughout the year for high and low herbage allowance management of *Campos* grasslands

	Season				SE	P-values[1]		
	Fall	Winter	Spring	Summer		S	HA	S x HA
Herbage allowance (kg DM[2]/kg BW)								
High	7.1	3.4	8.1	6.3				
Low	3.2	3.4	4.9	3.1				
Herbage mass (kg DM/ha)						<0.01	<0.01	0.02
High	3808 a	2153 c	1183 d	2985 b	325			
Low	2350 bc	1395 d	1071 d	2346 bc	325			
Height (cm)						<0.01	0.04	0.39
High	9.5 a	4.5 bc	4.1 bc	8.0 a	0.9			
Low	6.1 ab	3.1 c	3.5 c	5.2 bc	0.9			
CP (% of DM)						<0.01	0.16	0.96
High	8.4ab	5.5c	8.2ab	7.0bc	0.5			
Low	9.3a	6.2bc	9.1a	7.8ab	0.6			
NDF (% of DM)						<0.01	0.10	0.19
High	69.0a	51.9b	61.9ab	68.8a	5.0			

Low	79.0a	34.7c	58.9ab	69.8a	5.0			
ADF (% of DM)						<0.01	0.08	0.19
High	37.0a	25.2b	30.4ab	36.6a	2.2			
Low	36.0a	15.0c	28.9b	36.4a	2.2			
Cow physiological status	Pregnant	Pregnant	Lactating	Lactating				
Days relative to calving	-145	-75	50	175				

[1]S = season, HA = herbage allowance
[2]DM = dry matter
[a-d] Means with different literals differed with P <0.05

2.3.4. Heat Production Measurements

At the end of the fall (second third of gestation; -145 ± 4 days relative to calving), end of the winter (last third of gestation; -75 ± 4 days relative to calving), mid-spring (start of breeding season and lactation; +50 ± 4 days relative to calving) and end of summer (breeding season and lactation; +175 ± 4 days relative to calving), heat production (HP; kJ/kg $BW^{0.75}$/d) was determined individually using the heart rate (HR; beats/min) - oxygen (O_2) pulse technique (O_2P; mL O_2/beat per kg $BW^{0.75}$) (Brosh et al., 1998). The HR-O_2P technique was validated to estimate HP for different ruminant species, diets and environmental conditions (Brosh, 2007) and recently used for measuring HP in grazing dairy cows (Jasinsky et al., 2019: Talmon et al., 2020). This technique is based on the indirect estimation of HP by O_2 consumption (VO_2) measurement calculated as VO_2 (mL/min per kg $BW^{0.75}$) = HR × O_2P where O_2P is the amount of O_2 consumed per heartbeat.

Heart rate was measured continuously for 4 d per animal using HR monitors (Polar RCX3, Electro Oy, Kempele, Finland) with a transmitter Polar WearLink® (Polar Electro Oy) and a data logger programmed to record HR at 5 s intervals. The devices were attached to the thorax behind the forelegs by means of a specifically designed elastic belt. To calculate the O_2P (mL O_2/beat per kg $BW^{0.75}$) in a short-term interval (10 to 15 min), the HR and O_2 consumption (mL O_2/kg $BW^{0.75}$ per h) were measured simultaneously, at 1 s intervals, in each cow. Oxygen consumption was measured using a facemask open-circuit respiratory system (Fedak et al., 1981) with a paramagnetic oxygen analyzer (SERVOPRO 1440, Crowborough, East Sussex, United Kingdom). The O_2P was measured immediately after the HR measurement period (2 days between 06:00 and 15:00 h; HI and LO cows belonging to block 1 and 2 were measured randomly during the first and second day of measurement, respectively). The accuracy of the system was checked gravimetrically by nitrogen injection (N_2 recovery) into the facemask (McLean and Tobin, 1990); N_2 recovery testing was performed at least three times in each day of measurement to confirm the entire system calibration and averaged 0.86±0.02 along the experiment.

Daily average HP and HP throughout the day were quantified from the individual HR, O_2P and 20.47 kJ/L constant of O_2 consumed (Nicol and Young, 1990) according to the following equations (Brosh, 2007):

Daily HP (MJ / cow per day) = specific HP (kJ kgBW$^{0.75}$/d) x BW$^{0.75}$ (kg) / 1000; where specific HP (kJ/kg BW$^{0.75}$ per day) = HP (beats/min) x O_2P (mL/beats per kg BW$^{0.75}$) x (20.47 J/mL O_2 consumed) x 60 x 24

During the second third of gestation (-145 ± 4 days relative to calving; end of fall) and the last third of gestation (-75 ± 4 days relative to calving; end of winter), the mean temperature and humidity index was 15.0 ± 2.2 ºC, 83.4 ± 6.5 % and 15.8 ± 2.8 ºC, 78.6 ± 10.9 %, respectively. At the start of breeding season and lactation (+50 ± 4 days relative to calving; mid-spring) and breeding season and lactation (+175 ± 4 days relative to calving; end of summer), the mean temperature and humidity index was 25.7 ± 3.6 ºC, 58.4 ± 10.7 % and 19.2 ± 2.3 ºC, 76.31 ± 10.2 %, respectively. Thus, during spring and summer measurements (+50 and +175 days) if corresponded, O_2P was corrected for the effect of temperature humidity index (THI) on O_2P (Aharoni et al., 2003).

2.3.5. <u>Calculations and Statistical Analyses</u>

Data from -14 to 14 days around HP measurements were used for energy balance calculation. Retained energy for gestation (fetus + gravid uterus; RE-gest) was estimated from calf birth weight and days of gestation (NASEM, 2016) while RE for lactation (RE-milk) was estimated from milk yield and composition using the coefficients of 38.5, 23.8, and 17.5 MJ/kg of fat, protein, and lactose, respectively. The RE in body reserves (RE-tissue) was estimated from the changes in BW and BCS (NASEM, 2016). Total RE was calculated as the sum of RE-gest or RE-milk and RE-tissue. Metabolizable energy (ME) intake was estimated as the sum of total HP and total RE and individual gross energy efficiency was calculated as total RE divided by ME intake (Brosh, 2007).

Data were analyzed using the SAS Systems program (SAS® University Edition, SAS Institute, Inc., Cary, NC, USA) using a mixed model with a repeated measure analysis using the MIXED procedure. The model included HA (HI vs. LO), measurement period (-145, -75, +50 vs. +175 days relative to calving) and their interaction as fixed effects, block, plot within block and cow as random effects and calving date as a covariate. Calf birth weight and cow average milk yield and composition were analyzed with a model that included only HA as fixed effect. The UNIVARIATE procedure was used to identify outliers and verify normality of residuals. The relationships between the different variables were studied through correlation and regression analysis. For all variables, mean separation was performed using Tukey test ($\alpha = 0.05$). Pearson correlation coefficients to describe relationships between variables were estimated using the CORR procedure. Results are presented as least square means ± pooled S.E.

2.4. RESULTS

2.4.1. <u>Productive Responses and Energy Partitioning during the Gestation-Lactation Cycle</u>

During the annual cycle, forage mass and height differed between HA treatments (2532 vs. 1790 ± 237 kg DM/ha; $P = 0.03$ and 6.5 vs. 4.4 ± 0.5 cm; $P = 0.04$ for HI and LO, respectively) and between seasons (table 1) with lower values of forage mass and height for winter and spring. Herbage CP, NDF and ADF showed a low variation along the year with reduced CP, NDF and ADF contents during winter compared with the other seasons, being NDF and ADF less ($P < 0.05$) for LO than HI only during this season (table 1).

In accordance with herbage allowance, cow BW and BCS were low during winter and increased during spring and summer ($P < 0.01$; figure 1A-B). Although BW tended ($P = 0.08$) to be greater for HI than LO cows, BCS did not differ between HA treatments (table 2). However, BW was greater ($P < 0.05$) for HI than LO cows during summer. Herbage allowance treatments neither affected calf birth and weaning weights nor cow milk production ($P = 0.69$; table 2). Milk production and milk fat and lactose contents decreased (*P* ≤ 0.05) from 50 to 180 days (6.9 vs. 4.5 ± 0.3 kg; 3.3 vs. 2.6 ± 0.2 and 5.0 vs. 4.4 ± 0.2, respectively). In addition, milk protein percentage tended (*P* = 0.09) to be less in HI than LO cows, while milk fat percentage was greater (*P* = 0.03) for HI than for LO cows at early lactation (day 50 relative to calving, spring; 3.6 vs. 2.9 ± 0.2).

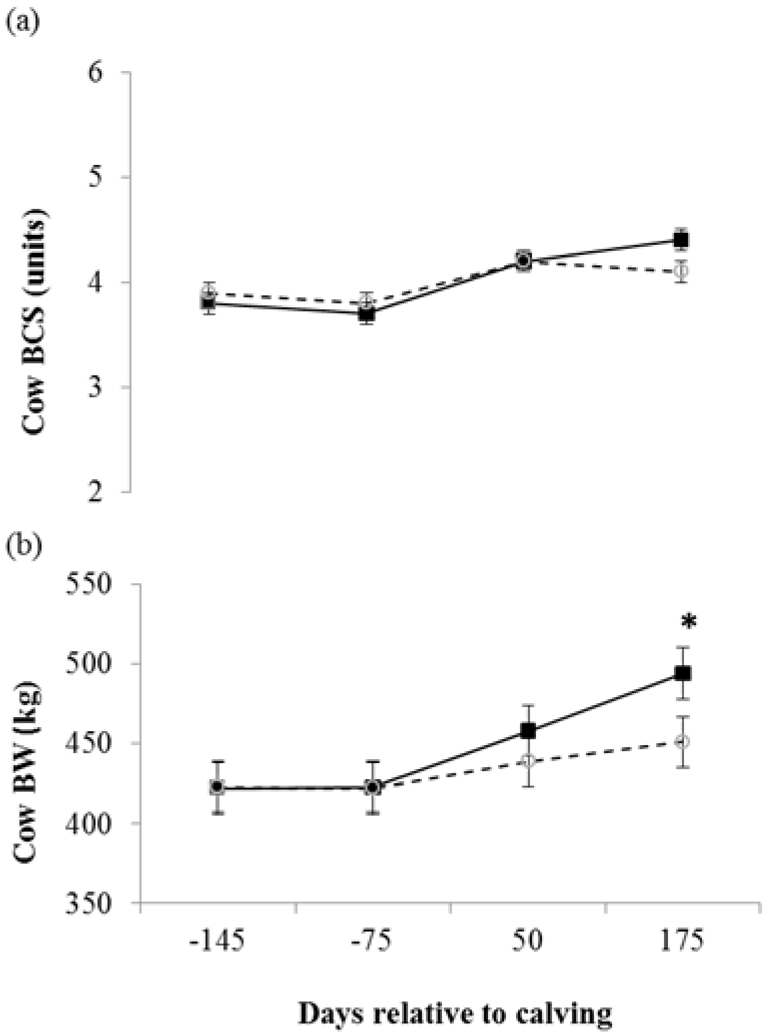

Fig. 1. Least square means and s.e.m. for cow body condition score (BCS; 8-point scoring system, 1 = thin to 8 = obese); (a) and body weight (BW; b) throughout the gestation–lactation cycle (−145 to 175 days relative to calving) in beef cows grazing high (solid symbols and lines) and low (open symbols and dashed lines) herbage allowances (8 and 5 kg dry matter (DM)/kg BW of annual mean, respectively) of native grasslands (n = 46). Asterisks denote days in which cow BCS differed (*P* < 0.05), and crosses denote days in which cow BW tended to differed (*P* < 0.1), between high and low herbage allowances.

Table 2. Productive performance and energy partitioning of beef cows grazing high or low herbage allowance (HA) of native pastures

	Herbage allowance			P-value		
Variable	High	Low	SE	HA	Days	HA x Days
Body weight (kg)	449	434	15	0.08	<0.01	0.22
Body condition score (units)	4.0	4.0	0.1	0.92	<0.01	0.13
Calf birth weight (kg)	30	31	2	0.75	_	_
Calf weaning weight (kg)	178	186	4	0.23	_	_
Milk yield (kg/d)[1]	5.8	5.6	0.4	0.69	<0.01	0.26
Milk composition (%)						
Fat	3.1	2.7	0.2	0.19	<0.01	0.11
Protein	2.9	3.1	0.1	0.09	0.51	0.40
Lactose	4.6	4.8	0.1	0.37	0.05	0.44
Energy partitioning (MJ/d)[1,2]						
Metabolizable energy intake	68.3	65.7	6.4	0.51	<0.01	0.04
Retained energy in gravid uterus	3.4	3.3	0.2	0.63	<0.01	0.40
Retained energy in milk	19.9	14.3	1.6	0.34	<0.01	0.67
Retained energy in body tissue	1.2	1.1	1.3	0.99	0.08	0.32
Total retained energy	13.1	9.3	1.3	<0.01	<0.01	0.07
Measured heat production	55.4	58.2	5.0	0.47	<0.01	0.13

HA = herbage allowance; Days = days relative to calving.
[1]HA: herbage allowance treatments (HA, high and low: 8 and 5 kg DM/kg BW in average, respectively; HI vs. LO).
[2]Data referred to days +50 and +180 postpartum.
[3]Metabolizable energy intake = Total RE + HP; Measured heat production= heart rate (beats/min) x O_2 pulse (L of O_2/beat^{-1}kg BW$^{0.75}$) x (20.47 kJ/1000) x 60 x 24 x BW$^{0.75}$ (kg) / 100 kJ/MJ.

Total RE was greater ($P < 0.01$) for HI than LO cows and was affected by days relative to calving ($P < 0.01$), with minimum values during early gestation in fall (-145 ± 4 days relative to calving) and maximum values during early lactation in spring (50 days relative to calving) (table 2; figure 2A). However, total RE tended ($P = 0.07$) to be affected by the interaction between HA and days as there were no differences between HA treatments during gestation (fall-winter), but it was greater ($P < 0.05$) during lactation (spring-summer) for HI than LO cows, which is associated to their greater ($P = 0.02$) RE-milk (table 2; figure 2A).

Whole-animal HP (MJ/d) and cow ME intake (MJ/d) did not differ between HA treatments and were affected by days relative to calving as they were minimum in gestation (fall-winter) and maximum in early lactation (spring) (table 2; figure 2B). However, ME intake was affected by the interaction between HA and days relative to calving ($P = 0.04$) as differences during early lactation (spring) were more evident for HI than LO cows (figure 2C).

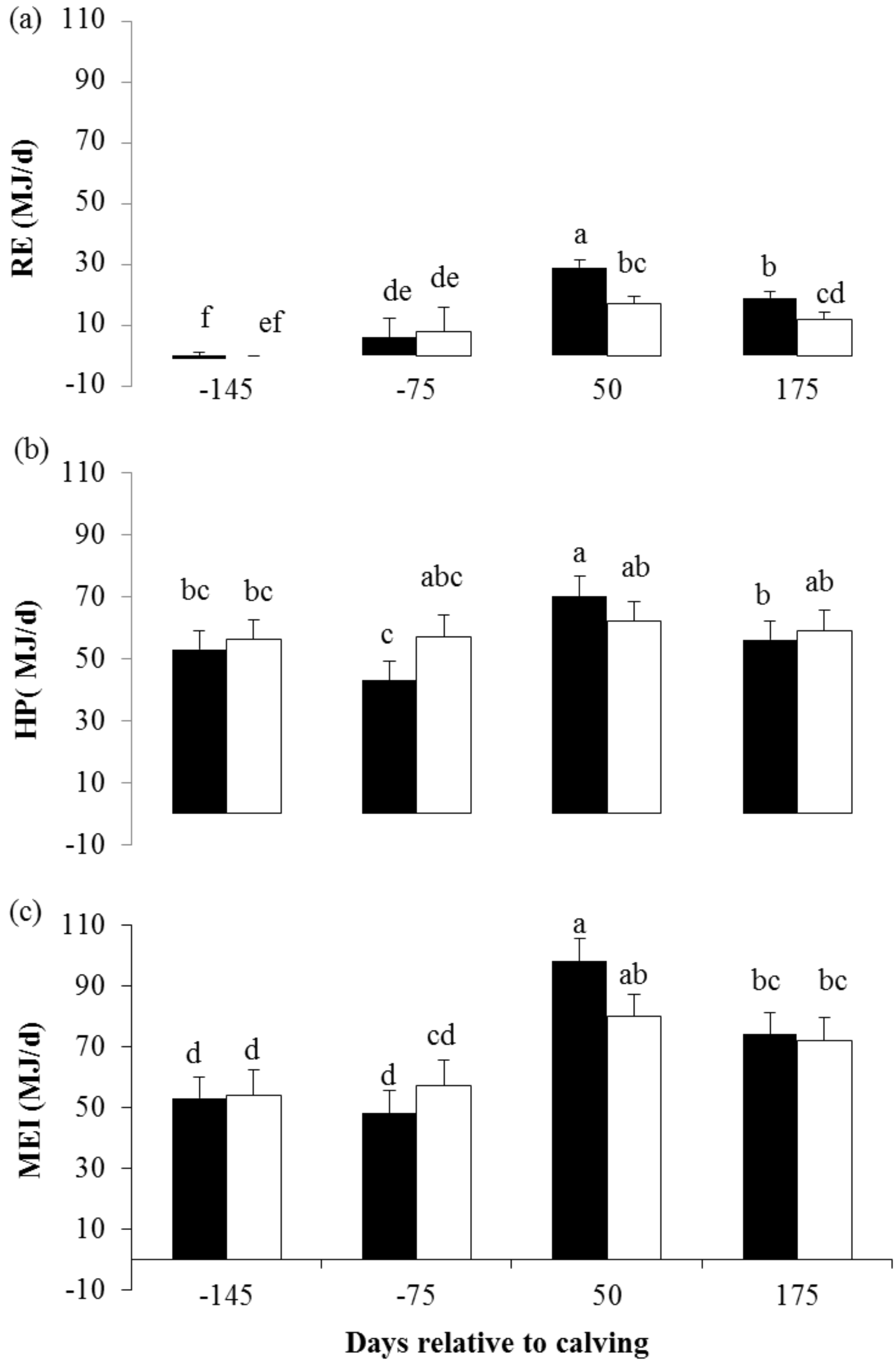

Fig 2. Total retained energy (RE; a), total heat production (HP; b) and metabolized energy intake (MEI = Total RE + HP, c) in beef cows grazing high (black bars) and low (white bars) herbage allowances (8 and 5 kg dry matter (DM)/kg BW of annual mean, respectively) of native grasslands throughout the gestation-lactation cycle. Letters denote least square means differences ($P < 0.05$) and asterisks indicate a tendency ($P < 0.1$) for the interaction between treatments and days relative to calving.

2.4.2. <u>Energy Partitioning during the Gestation-Lactation Cycle per Unit of Metabolic Body Weight</u>

Heart rate was not affected by HA and increased (*P* < 0.01) during late gestation in winter (at -75 days) and early lactation in spring (at +50 days). Nevertheless, O_2P was lower (*P* < 0.01) for HI than LO cows (table 3) and decreased (*P* < 0.01) during late gestation in winter (at -75 days) when compared with other periods evaluated. When expressed in terms of metabolic BW (kJ/kg $BW^{0.75}$ per day), total RE tended to be greater (*P* = 0.06) for HI than LO cows. In addition, total RE (kJ/kg $BW^{0.75}$ per day) tended (*P* = 0.06) to be affected by the interaction between HA and days relative to calving as it did not differ between HA treatments during gestation (fall-winter) but were greater (*P* < 0.05) during lactation (spring-summer) for HI than LO cows (table 3; figure 3A). Heat production per unit of $BW^{0.75}$ was greater (*P* = 0.04) for LO than HI cows (table 3) and decreased (*P* < 0.05) in winter, especially for cows grazing HI-HA (figure 3B). In addition, ME intake (kJ/kg $BW^{0.75}$ per day) did not differ between HA treatments and was affected by days relative to calving as the differences were minimal during gestation (fall-winter) and maximum in early lactation (spring) (table 3; figure 3C). However, ME intake tended (*P* < 0.10) to be less in winter and greater in spring for HI than LO cows.

2.4.3. <u>Energy Efficiency during the Gestation-Lactation Cycle</u>

Energy efficiency for the gestation-lactation cycle evaluated (320 days), calculated as the relation between the total RE and ME intake, tended to be greater (*P* < 0.10) for HI than LO-HA (0.19 vs. 0.12 ± 0.02). However, biological efficiency did not differ between HA when estimated as either grams of calf weaned, per MJ of ME intake (6.8 vs. 7.6 ± 0.6 g/MJ for HI and LO, respectively) or grams of calf produced per ME intake per unit of cow $BW^{0.75}$ (0.67 vs. 0.73 ± 0.07 grams of calf /kJ of ME intake per kg $BW^{0.75}$ for HI and LO, respectively).

Table 3. Energy partitioning per unit of metabolic weight of beef cows grazing high or low herbage allowance (HA) of native pastures

	Herbage allowance			P-value		
Variable	High	Low	SE	HA	Days	HA x Days
Heart rate (beat/min)	68	69	2.4	0.75	< 0.01	0.36
O_2 pulse (mL/beat per kg $BW^{0.75}$)	0.277	0.304	0.023	< 0.01	< 0.01	0.37
Energy partitioning (kJ/kg $BW^{0.75}$ per day)						
Metabolizable energy intake	685	702	70	0.61	< 0.01	0.11
Retained energy in gravid uterus	36	39	3	0.51	< 0.01	0.24
Retained energy in milk	193	153	16	0.08	0.02	0.94
Retained energy in body tissue	11	11	14	0.95	0.07	0.41
Total retained energy	129	95	12	0.06	< 0.01	0.06
Measured heat production	557	616	56	0.04	0.04	0.28

HA = herbage allowance; Days = days relative to calving.

[1]HA: herbage allowance treatments (HA, high and low: 8 and 5 kg DM/kg BW in average, respectively; HI vs. LO).

[2]Metabolizable energy intake = Total RE + HP; Measured heat production = heart rate (beats/min) x O_2 pulse (L of O_2/beat^{-1}kg $BW^{0.75}$) x (20.47 kJ/1000) x 60 minutes x 24 hour/day.

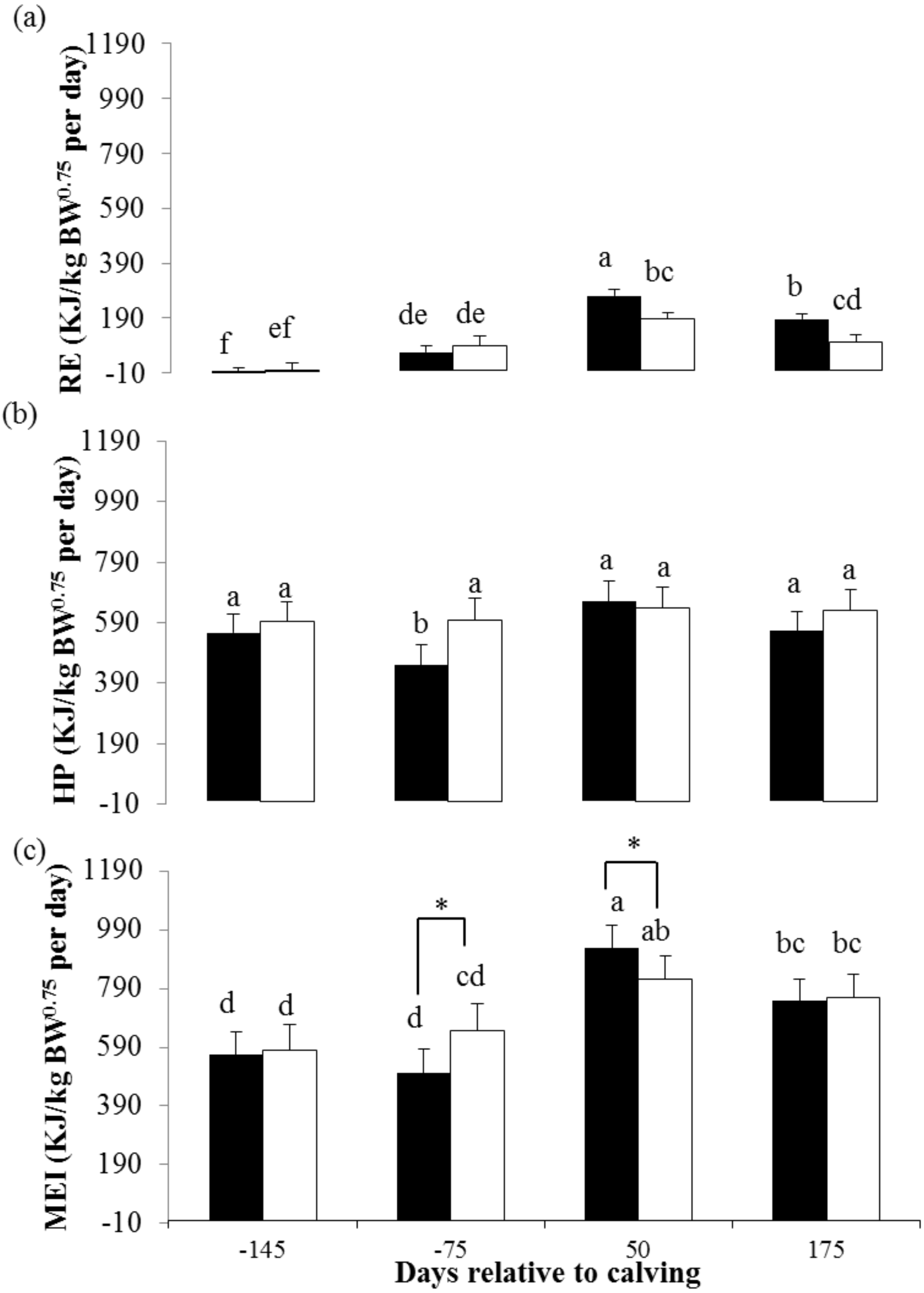

Fig 3. Total retained energy (RE; a), total heat production (HP; b) and metabolized energy intake (MEI = Total RE + HP, c) per unit of metabolic BW in beef cows grazing high (black bars) and low (white bars) herbage allowances (8 and 5 kg dry matter (DM)/kg BW of annual mean, respectively) of native grasslands throughout the gestation-lactation cycle. Letters denote least square means differences ($P < 0.05$) and asterisks indicate a tendency ($P < 0.1$) for the interaction between treatments and days relative to calving.

2.5. DISCUSSION

2.5.1. Energy Partitioning during the Fall and Winter Gestation

Although in winter and early spring, when requirements rise due to gestation and early lactation (NASEM, 2016) and ME intake could be limited (Casal et al., 2014; Laporta et al., 2014), the deferment of herbage from previous growing season to winter through the HA management prevented, in this study, the negative energy balance, as herbage intake increased with herbage mass (Do Carmo et al., 2021). In the present study, losses of BW and BCS in winter were minimal (less than 0.25 units of BCS). Indeed, RE-tissue, either measured as MJ/d or kJ/$BW^{0.75}$ per day, during fall and winter gestation was not different from zero for both, HI and LO cows, indicating that, on average, cows were at maintenance.

When compared with this previous studies performed in the same experimental site (Do Carmo et al., 2018; 2021), the HA level in which grazing intensity was controlled in the present work was 1.6-fold greater (especially in spring), that determined increased herbage mass and height for both HA treatments in fall (2-fold greater) and winter (3-fold greater). Research on *Campos* grasslands has shown that DM intake is a consequence of the greater canopy height and sites of canopy with height > 3cm by probably increasing bite mass, as well as the greater sward heterogeneity, through increased sites of canopy height > 3 cm (Gonçalves et al., 2009; Do Carmo et al., 2021). Therefore, the greater herbage allowance, mass and height would explain the greater DM intake, thus, the minimal BCS loss of cows during gestation (fall-winter). Indeed, ME intake 35 % greater than the reported previously for pregnant beef cows grazing *Campos* grasslands during fall and winter (Laporta et al., 2014) which allowed cows to reach energy maintenance requirements. Although cow ME intake was minimum in mid-late gestation (fall and winter), ME intake per unit of $BW^{0.75}$ for maintenance observed in this study is in agreement with previous research of maintenance requirements of the beef cows during gestation (376 kJ/kg $BW^{0.75}$ per day; Houghton et al., 1990; Freetly et al., 2000). As expected, in agreement with the high correlation between HP and ME intake reported previously (Brosh, 2007), HP during fall and winter (gestation) decreased when compared with spring and summer (lactation). Heat production reported here during gestation (~550 kJ/kg $BW^{0.75}$ per day) was in the range of reported values of HP for beef cows at maintenance (Brosh et al., 2002, 2004).

Reduced HP per unit of $BW^{0.75}$ for HI than LO cows in winter was associated with a reduced O_2P as no differences between HA treatments in HR were observed during this season. Similarly, Brosh (2007) determined increased HP due to greater O_2P, without changes in HR, for grazing vs. confined cows, probably due to short-term effects of exercise. Thus, this could be related to greater animal activity (walking grazing and bite rate) for LO than HI cows as reported by Machado et al. (2017). Moreover, total HP is the sum of HP for maintenance (HPm) and HP for production (HPp) (Miron et al., 2008). As total RE did not differ between HA treatments during gestation in fall-winter but total HP was 25% greater for LO than HI cows, it could be expected that HPp was maintained while HPm increased for LO vs. HI cows. Thus, the trend for a greater ME intake for LO than HI cows during winter was used for maintenance in detriment of greater production (calf birth weight or RE in body tissue).

Previous research has indicated that the energy expenditure for walking and grazing was greater than for ruminating and resting (Susenbeth et al., 1998, 2004). During winter, HI cows walked less than LO cows (5 vs. 24 ± 11 minutes per day, $P \leq 0.05$; Machado et al., 2017) and although they did not present differences in the probability of grazing or in grazing time, they had a reduced bite rate than LO cows (43 vs. 56 ± 4 bite/min, $P = 0.05$; Machado et al., 2017). In fact, DiMarco and Aello (2001) indicated bite rate is considered the most expensive component in grazing activity (DiMarco and Aello, 2001; Brosh et al., 2006) showed in Aberdeen Angus steers grazing cultivated pastures that HP can increase between 8 and 52 % above basal metabolism depending on grazing conditions (herbage mass and height). On the other hand, Piaggio et al. (1995) showed that greater HA increased selectivity that, in turn, increased forage digestibility. Approximately 50 % of maintenance costs are related to the mass and metabolic activity of the gastrointestinal viscera and liver due to the processes of feeding, chewing, fermentation and digestion, as well as the absorption and metabolism of digested nutrients; therefore, as food digestibility increases, maintenance costs decrease (Nkrumah et al., 2006; Reynolds et al., 2011). Thus, it could be suggested that, in winter, the better management of grazing intensity for HI than LO was reflected in a higher herbage mass and sward structure with equal HA (Machado et al., 2017; Do Carmo et al., 2018) that allowed HI cows to decrease grazing time selectivity for higher quality forage, decreasing energy maintenance requirements to retained the same energy in than LO cows.

2.5.2. Energy Partitioning during the Spring and Summer Lactation

Along with the increase in energy requirements for lactation, herbage production and its energy concentration are maximum during spring and summer as *Campos* grasslands are dominated by C4 species (Do Carmo et *a*l., 2018). In the present study, rainfall in early spring was below the historical average (22 vs. 102 mm in November), thus, herbage mass accumulation was delayed, reaching maximum in summer. However, HA (kg of BW/ kg of DM) for both HI and LO treatments were the greatest in spring when compared with the other seasons, which probably allowed cows to maximize herbage intake. Cow BCS and BW were greater in spring and summer than in fall-winter in agreement with greatest HA (Do Carmo et al., 2018). Moreover, RE-tissue, measured as both MJ/d or kJ/$BW^{0.75}$ per day, indicated that cows for both HI and LO were in positive energy balance. Total RE was greater in spring-summer than in fall-winter due to RE-milk as milk peak yield occurred in early lactation for beef cows grazing *Campos* (Espasandin et al., 2016). In agreement with the increased total RE, cow ME intake was almost 42 % greater in spring and summer than in fall and winter as both energy demands due to lactation and HA increased during the former season. In contrast to winter, both, RE- milk and ME intake were greater for HI than LO, especially during spring, and they were greater than the reported previously for Laporta et al. (2014; 62 and 53 MJ/d of ME intake and 4.9 and 4.0 ± 0.3 kg/d of milk with milk production at day +60 for HI and LO cows, respectively).

Although total HP (kJ/kg $BW^{0.75}$ per day) increased as ME intake increased during lactation in spring and summer, it was less than the reported previously for grazing lactating beef cows (Brosh et al., 2004; 2006; Brosh, 2007), associated with a reduced cow HR in the present study but similar values for O_2P. In contrast with Brosh et al. (2006) that determined that grazing at high stocking rate reduced cow energy expenditure, greater intensity of pasture grazing (LO herbage allowance) did not affect total HP in the present work. However, total RE was 1.5-fold greater for HI than LO cows, thus, it could be expected that HPp was increased while HPm was decreased for HI than LO cows during this period, and that greater proportion of the increased ME intake was partitioned towards production –body and milk RE- instead of maintenance. A reduction of energy cost for grazing and walking as HA increases in spring with also an increase in herbage mass and height in summer would explain the decrease in maintenance energy cost (Susenbeth et al., 1998, 2004).

2.5.3. Energy Efficiency during the Gestation-Lactation Cycle

Consistent with the greater total RE and decreased maintenance costs (Ferrell and Jenkins, 1985), gross energy efficiency, calculated as the ratio of total RE to ME intake, tended to be greater in HI than in LO cows, especially during lactation, explained by the greater milk yield of the former ones (Gutierrez et al., 2013). However, the biological production efficiency, calculated as the relationship between the grams of calf with the ME consumption per unit of $BW^{0.75}$, was not different between the treatments.

This discrepancy was probably associated, among other factors, with calf milk consumption vs. cow milk production, either due to calves not being dependent on lactation (Wright and Russel, 1987) or to decreased growth potential (Greenwood and Cafe, 2007). The young calves can start consuming forage at a very young age; they learn foraging skills from their peers, and intake of forage increases with reduced milk supply around weaning (Tedeschi and Fox, 2009). Besides, previous reports indicated biological efficiency was 2.7 and 3.7 g/MJ for Hereford and Aberdeen Angus, respectively, with an intake of 3000 kg DM/year, which represents

77.4 MJ/day (Jenkins and Ferrell, 1994), and between 3.6 and 5.7 g/MJ with an ME intake of 455 and 473 kJ/kg $BW^{0.75}$ per day, respectively (Do Carmo et al., 2016). It could be suggested that the ME intake reported in the present study (1.5 fold greater than Do Carmo et al., 2016) allowed to reach greater efficiencies.

Brosh et al. (2004) related values of HP, ME intake (with values between 600 and 1900 kJ/kg $BW^{0.75}$ per day) and RE in a prediction equation, where HP = 0.375x + 328 (R^2 = 0.792) and RE = 0.625x – 328 (R^2 = 0.914). When HP and total RE values obtained in this study were used, fasting HP during fall and winter, when cows were on gestation, were 303 and 366 kJ/kg $BW^{0.75}$ per day and k_m of 0.57 and 0.60 for HI and LO, respectively, while for spring and for summer, when cows were on lactation, fasting HP were 312 and 339 kJ/kg $BW^{0.75}$ per day and k_m of 0.66 and 0.68 for HI and LO, respectively. The values reported in the present study are similar to those reported by NASEM (321 kJ/kg $BW^{0.75}$ per day and 0.60 for fasting HP and k_m, respectively) and CSIRO (337 kJ/kg $BW^{0.75}$ per day and 0.72 for fasting HP and k_m, respectively).

2.6. CONCLUSIONS

In the present study, HA did not improve ME intake in the annual production cycle; however, total RE was higher for HI cows, likely explained by a reduction in maintenance requirements. Differences in the management of herbage allowance between treatments improved in HI-HA greater herbage mass and height in fall; therefore, with equal HA between treatments in winter, but with higher forage mass and stocking rate for HI than LO treatment, it allowed cows to be at maintenance with a lower ME intake compared with LO cows, which could be probably associated to differences in grazing activity. The greater gross energy efficiency for HI than LO treatment was not reflected in an increased biological efficiency (g calf per MJ of ME intake) for cows grazing increased herbage allowance. On the other hand, our results would indicate that energy requirements and energy efficiency of breeding beef cows grazing *Campos* grasslands are in agreement with international feeding systems (NASEM and CSIRO).

2.7. ACKNOWLEDGMENTS

The authors thank the staff of the Experimental Station Bernardo Rosengurtt (D. Bentancor, M. Cáceres) and students from Working University of Uruguay for animal care and assistance throughout the field study, and a special thanks to Óscar Cáceres for his dedication. This research was partially funded by the CSIC Groups I+D Research Program (2014; Udelar) awarded to M. Carriquiry and the CAP-Udelar graduate scholarship awarded to J. Gómez (BDMX_2017_1#47570282).

2.8. REFERENCES

Aharoni, Y., Brosh, A., Kourilov, P. and Arieli, A., 2003. The variability of the ratio of oxygen consumption to heart rate in cattle and sheep at different hours of the day and under different heat load conditions. Livestock Production Science, 79(2-3), 107-117.

Aharoni, Y., Brosh, A., Orlov, A., Shargal, E. and Gutman, M., 2004. Measurements of energy balance of grazing beef cows on Mediterranean pasture, the effects of stocking rate and season 1. Digesta kinetics, faecal output and digestible dry matter intake. Livestock Production Science, 90(2-3), 89-100.

Altesor, A., Di Landro, E., May, H. and Ezcurra, E., 1998. Long term species change in a Uruguayan grassland. Journal of Vegetation Science, 9(2), 173–180.

Bell, A. W., 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. Journal of Animal Science, 73(9), 2804–2819.

Berretta, E. J., Risso, D. F., Montossi, F. and Pigurina, G., 2000. Campos in Uruguay. In: G. Lemaire, J. Hogdson, A. de Moraes, C. Nabinger and P.C. Carvalho (eds), Grassland ecophysiology and grazing ecolog, Cambridge: CABI, 2000, 377-394.

Brosh, A., Aharoni, Y., Degen, A., Wright, D. and Young, B.A., 1998. Estimation of energy expenditure from heart rate measurements in cattle maintained under different conditions. Journal of Animal Science, 76, 3054–3064.

Brosh, A., Aharoni, Y. and Holzer, Z., 2002. Energy expenditure estimation from heart rate: validation by long-term energy balance measurement in cows. Livestock Production Science, 77(2-3) 287-299.

Brosh, A., Aharoni, Y., Shargal, E., Sharir, B., Gutman, M. and Choshniak, I., 2004. Energy balance of grazing beef cattle in Mediterranean pasture, the effects of stocking rate and season. 2. Energy expenditure as estimated from heart rate and oxygen consumption, and energy balance. Livestock Production Science, 90, 101–115.

Brosh, A., Henkin, Z., Ungar, E. D., Dolev, A., Orlov, A., Yehuda, Y. and Aharoni, Y., 2006. Energy cost of cows' grazing activity: Use of the heart rate method and the Global Positioning System for direct field estimation. Journal of Animal Science, 84, 1951-1967.

Brosh, A., 2007. Heart rate measurements as an index of energy expenditure and energy balance in ruminants: A review. Journal of Animal Science, 85(5), 1213-1227.

Casal, A., Veyga, M., Astessiano, A. L., Espasandin, A. C., Trujillo, A. I., Soca, P. and Carriquiry, M., 2014. Visceral organ mass, cellularity indexes and expression of genes encoding for mitochondrial respiratory chain proteins in pure and crossbred mature beef cows grazing different forage allowances of native pastures. Livestock Science, 167(1), 195–205.

Chapman, D. F., Parsons, A. J., Cosgrove, G. P., Barker, D. J., Marotti, D. M., Venning, K.J., Rutter, S.M., Hill, J. and Thompson, A. N., 2007. Impacts of spatial patterns in pasture on animal grazing behavior, intake, and performance. Crop Science, 47(1), 399–415.

Dickerson, G. E., 1978. Animal size and efficiency: Basic concepts. Animal Production, 27(3), 367–379.

DiMarco, O. N., Aello, M. S. and Méndez, D. G., 1996. Energy expenditure of cattle grazing on pastures of low and high availability. Animal Science, 63(1), 45–50.

DiMarco, O. N. and Aello, M. S., 2001. Energy expenditure due to forage intake and walking of grazing cattle. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia.

Do Carmo, M., Claramunt, M., Carriquiry, M. and Soca, P., 2016. Animal energetics in extensive grazing systems: Rationality and results of research models to improve energy efficiency of beef cow-calf grazing campos systems. Journal of

Animal Science, 94:1--9.

Do Carmo, M., Sollenberger, L. E., Carriquiry, M. and Soca, P., 2018. Controlling herbage allowance and selection of cow genotype improve cow-calf productivity in Campos grasslands. The Professional Animal Scientist, 34(1), 32–41.

Do Carmo, M., Genro, T. C., Cibils, A. F. and Soca, P. M., 2021. 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.

Espasandin, A. C., Gutierrez, V., Casal, A., Graña, A., Bentancur, O. and Carriquiry, M., 2016. Modeling lactation curve in primiparous beef cattle. Journal of Agricultural Science, 8(4), 116-125.

FAOSTAT, 2017. Food and agriculture data. http://www.fao.org/faostat/en/#home,
661. Accessed 31Oct 2017.

Fedak, M. A., Rome, L. and Seeherman, H. J., 1981. One-step N2-dilution technique for calibrating open-circuit VO2 measuring systems. Journal of Applied Physiology, 51(3), 772-776.

Ferrell, C. L. and Jenkins, T. G., 1985. Cow type and the nutritional environment: nutritional aspects. Journal of Animal Science, 61(3), 725–741.

Freetly, H. C., Ferrell, C. L. and Jenkins, T. G., 2000. Timing of realimentation of mature cows that were feed-restricted during pregnancy influences calf birth weights and growth rates. Journal of Animal Science, 78(11), 2790-2796.

Greenwood, P. L. and Cafe, L. M., 2007. Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. Animal, 1(9), 1283-1296.

Gutiérrez, V., Espasandin, A.C., Astessiano, A.L., Casal, A., López-Mazz, C. and Carriquiry, M., 2013. Calf foetal and early life nutrition on grazing conditions: metabolic and endocrine profiles and body composition during the growing phase. Journal of Animal Physiology and Animal Nutrition, 97 (4), 720–731.

Haydock, K. P. and Shaw, N. H., 1975. The comparative yield method for estimating dry matter yield of pasture. Australian Journal Experimental Agriculture, 15, 663–670.

Hess, B. W., Lake, S. L., Scholljegerdes, E. J., Weston, T. R., Nayigihugu, V., Molle, J. D. C. and Moss, G. E., 2005. Nutritional controls of beef cow reproduction. Journal of Animal Science, 83, 90–106.

Houghton, P.L., Lemenager, R.P., Hendrix, K.S., Moss, G.E. and Stewart, T.S., 1990. Effects of body composition, pre- and postpartum energy intake and stage of production of energy utilization by beef cows. Journal of Animal Science, 68, 1447–1456.

Jasinsky, A., Mattiauda, D. A., Ceriani, M., Casal, A. and Carriquiry, M., 2019. Heat production and body composition of primiparous Holstein cows with or without grazing pastures in early lactation. Livestock Science, 225, 1-7.

Jenkins, T.G. and Ferrell, C.L., 1994. Productivity through weaning of nine breeds of cattle under varying feed availabilities: 1: Initial evaluation. Journal of Animal Science, 72, 2787–2797.

Laporta, J., Astessiano, A. L., López-Mazz, C., Soca, P., Espasandin, A. C. and Carriquiry, M., 2014. Effects of herbage allowance of native grasslands in purebred and crossbred beef cows: Metabolic, endocrine and hepatic gene expression profiles through the gestation-lactation cycle. Animal, 8(7), 1119–1129.

Machado, F., Claramunt, M., Do Carmo, M., Franco, J., Gómez, J., Orcasberro, S. and Soca, P., 2017. Effect of herbage allowance on grazing behavior at different scales of lactating beef cows grazing native grassland. In: M. Parapinski, M.S. Dalle Carbonare and P. Schmidt (eds), Proceedings of the 54th Annual Meeting of the Brazilian Society of Animal Science, Foz de Iguacu, 2017, (The Brazilian Society of Animal Science, ISSN 1983--4357)

McLean, J. A. and Tobin, G., 1990. Animal and human calorimetry. Cambridge University Press.

Miron, J., Adin, G., Solomon, R., Nikbachat, M., Zenou, A., Shamay, A., Brosh, A. and Mabjeesh, S. Y., 2008. Heat production and retained energy in lactating cows held under hot summer conditions with evaporative cooling and fed two rations differing in roughage content and in vitro digestibility. Animal, 2(6),

843–848.
Montaño-Bermudez, M., Nieslen, M.K. and Deutscher, H., 1990. Energy requirments for maintenance of crossbred beef cattle with different genetic potential for milk. Journal of Animal Science, 68(8):2279-88.
Mott, G. O., 1960. Grazing pressure and the measurement of pasture production. In: Proceedings of the eighth international grassland congress. University of Reading, Berkshire, England. pp. 606-611.
NASEM, 2016. Nutrient Requirements of Beef Cattle: Eighth Revised Edition (National Academies Press).
Nicol, A. M. and Young, B. A., 1990. Short-Term Thermal and Metabolic Responses of Sheep to Ruminal Cooling - Effects of Level of Cooling and Physiological State. Journal of Animal Science, 70, 833–843.
Nkrumah, J. D., Okine, E. K., Mathison, G. W., Schmid, K., Li, C., Basarab, J. A., Price, M.A., Wang, Z. and Moore, S. S., 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. Journal of Animal Science, 84(1), 145-153.
Pallarés OR, Berretta EJ, Maraschin GE. 2005. The south american campos ecosystem. En: Suttie JM, Reynolds SG, Batello C (Eds.) Grasslands of the world. Food & Agriculture Organization. (Vol 34). 171-219.
Panario, D. and Bidegain M., 1997. Climate change effects on grasslands in Uruguay. Climate Research, 9, 37-40.
Piaggio, L., Prates, E.R., Rinaldi, C. and Soca, P., 1995. Diet quality and diet selection of steers grazing in a rotational system at four levels of forage allowance on a rangeland. Annales de zootechnie, 44, 119-119.
Quintans, G., Banchero, G., Carriquiry, M., Lpez-Mazz, C. and Baldi, F., 2010. Effect of body condition and suckling restriction with and without presence of the calf on cow and calf performance. Animal Production Science, 50(10), 931–938.
Reynolds, C. K., Crompton, L. A. and Mills, J. A. N., 2011. Improving the efficiency of energy utilisation in cattle. Animal Production Science, 51(1), 6–12.

Soca, P., Carriquiry, M., Keisler, D.H., Claramunt, M., Do Carmo, M., Olivera-Muzante J., Rodríguez, M. and Meikle, A., 2013a. Reproductive and productive response to suckling restriction and dietary flushing in primiparous grazing beef cows. Animal Production Science 53, 283–291.

Soca, P., Claramunt, M. and Do Carmo, M., 2013b. Beef cows breed system on native sward without agricultural financial assistance: Research to sustainable calf production with low cost and easy instrumentation. Avances en Producción Animal 32:3–26.

Soca, P., González, H., Manterola, H., Bruni, M., Mattiauda, D., Chilibroste, P. and Gregorini, P., 2014. Effect of restricting time at pasture and concentrate supplementation on herbage intake, grazing behaviour and performance of lactating dairy cows. Livestock Science, 170, 35–42.

Sollenberger, L. E., Moore, J. E., Allen, V. G. and Pedreira, C. G. S., 2005. Reporting forage allowance in grazing experiments. Crop Science, 45(3), 896–900.

Susenbeth, A., Mayer, R., Koehler, B. and Neumann, O., 1998. Energy Requirement for Eating in Cattle 1. Journal of Animal Science, 76(10), 2701–2705.

Susenbeth, A., Dickel, T., Sudekum, K. H., Drochner, W. and Steingass, H., 2004. Energy requirements of cattle for standing and for ingestion, estimated by a ruminal emptying technique. Journal of animal science, 82(1), 129-136.

Talmon, D., Garcia-Roche, M., Mendoza, A. and Carriquiry, M., 2020. Maintenance energy requirements of two Holstein genotypes managed under pasture-based system. Journal of Dairy Science, 103, 206-206.

Tedeschi, L. O. and Fox, D.G., 2009. Predicting milk and forage in-take of nursing calves. Journal of Animal Science, 87:3380–3391.

Vizcarra, J. A., Ibañez, W. and Orcasberro R., 1986. Repetibilidad y reproducibilidad de dos escalas para estimar la condición corporal de vacas Hereford. Investigaciones Agronómicas 7, 45-47.

Wright, I. A., and Russel, A.J.F., 1987. The effect of sward height on beef cow performance and the relationship between calf milk and herbage intakes. Animal Production, 44:363–370.

3. GRAZING ENERGY EXPENDITURE IN RANGELAND BEEF COWS

Jimena Gómez1*, Alberto Casal1, Martín Claramunt2, Martin Do Carmo1, Pablo Soca1, Mariana Carriquiry1
*Corresponding autor: jgomezabala@gmail.com

[1]*Departament of Animal Production and Pastures, School of Agronomy, Universidad de la República, Uruguay.*
[2]*CENUR.*
Alberto Casal alcas@adinet.com.uy
Martín Claramunt martinclaramunt@gmail.com
Martín Do Carmo martindocarmocorujo@gmail.com
Pablo Soca psocape@gmail.com
Mariana Carriquiry mariana.carriquiry@gmail.com

Highlights

- Increased herbage allowance reduced energy expenditure for grazing and ruminating in beef cows
- Grazing and walking increase by 10 % and 25 % energy expenditure relative to resting activity in beef cows
- A lower EE per activity with a greater herbage allowance suggests that differences in bite rate and selectivity were involved

3.1. ABSTRACT

To estimate energy expenditure (EE) for grazing activity of breeding cows in rangelands, 46 multiparous beef cows (Hereford, Angus and F1 crossbred; in average 422 ± 16 kg and -75 ± 4 days relative to calving) grazing two herbage allowances (HA) of *Campos* rangeland (represented 8 and 5 kg DM/kg BW of annual mean; HI vs. LO, respectively) were evaluated during winter. Total heat production (HP) was determined using the heart rate-O_2 pulse technique and animal activity was monitored with a collar equipped with a three-axis accelerometer which registered resting/ruminating, grazing and walking without foraging. Herbage allowance affected total HP along the day, but did not affect time spent in each activity. Cows spent almost 10 h grazing, 13 h resting/ruminating and less than 1 h walking without foraging. However, daily HP (kJ/kg $BW^{0.75}$ per day) in resting/ruminating and during grazing was greater for LO than for HI cows as EE for each activity per unit of time was greater. The EE for grazing was 2.8 kJ/$BW^{0.75}$ per h for HI cows while it was 4.2

kJ/BW$^{0.75}$ per h for LO cows, which represented a 15 to 20 % increment above resting/ruminating and an increase between 9 and 13 % above basal metabolism. The EE for walking was about 25 % greater than EE for resting/ruminating, but daily EE for this activity was not significant as cows spent less than 1 h walking without foraging during the day. Grazing management through seasonally changes of HA affected EE for physical activity of rangeland breeding cows. Reduced EE for cows grazing high HA would decrease maintenance energy requirements and explain, at least partially, the productive and reproductive responses of cows grazing HI-HA.

Key words: beef cattle, foraging, heat production

3.2. INTRODUCTION

In beef production systems, 70-75 % of the total dietary energy is used for maintenance, which determines their reduced biological efficiency (Ferrell and Jenkins, 1985). In addition, maintenance energy requirement of rangeland breeding cows is increased due to the extra energy demand of the physical activities of grazing and walking (CSIRO, 2007; NASEM, 2016), which could reduce their productivity when compared with confined animals.

The energy cost of grazing and walking will depend on the energy expenditure (EE) and the relative time spent for each activity, which could be affected by pasture characteristics such as herbage mass, canopy structure and chemical composition, as well as to other external conditions, such as grassland terrain, access to shade and water, weather and day length (DiMarco and Aello, 2001; Brosh et al., 2006). Indeed, previous research estimated that energy requirements of grazing animals on pasture compared with confined animals may increase up to a 50 % (Osuji, 1974; Havstad and Malechek, 1982). However, more recent research in beef cattle using techniques based either on oxygen (O_2) consumption or carbon dioxide (CO_2) production, that do not alter animal behavior on pasture, estimated a reduced magnitude for forage intake and walking on maintenance energy requirements of grazing animals. DiMarco and Aello (2001) indicated EE of grazing cattle may increase by 8 to 30 % depending on grazing conditions, being bite rate the variable of highest effect on maintenance energy cost, while Brosh et al. (2006; 2010) estimated an increase of 5 to 15 % depending on herbage quality as well as walking time and distance.

Low grazing intensity of *Campos* grasslands, through a higher herbage allowance (HA), increased herbage accumulation, mass and canopy height and productive and reproductive performance of cow-calf systems, associated to a greater cow energy intake and a reduction in energy cost of maintenance (Casal et al., 2014; Laporta et al., 2014; Do Carmo et al., 2021). Our hypothesis is that a reduction in energy cost of maintenance in cows grazing high-HA may be associated with reduced EE for grazing and walking when compared with cows grazing low-HA. Thus, the objective of the present study was to estimate, in winter, the EE of grazing and walking activities in breeding cows on *Campos'* rangelands grazing two different herbage allowances along the year.

3.3. MATERIALS AND METHODS

Animal procedures were performed according to protocol approved by the Animal Experimentation Committee of Universidad de la República (CHEA, Udelar, Uruguay; expe #021130-000818-14).

3.3.1. Experimental design, treatments and animals

The study was conducted on a long-term grazing experiment (Do Carmo et al., 2018; 2021) located on 95 ha of *Campos* grassland at the Experimental Station Bernardo Rosengurtt (School of Agronomy, Universidad de la República, Uruguay, 32°S, 54°W). The experimental site presented native pastures dominated by summer-growing C4 grasses (Poaceae), with few C3 grasses associated with the winter cycle. The main for families included Asteraceae, Fabaceae, Rubiaceae and Umbelliferae, similar to *Campos* grassland botanical composition (Altesor et al., 1998). Average annual rainfall is almost 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 and 18 °C and the warmest is above 22 °C) according to Köppen (Panario and Bidegain, 1997).

The experiment had a randomized block design with two blocks (block 1: sandy loam soil, 59 ha and block 2: clay loam soil, 47 ha) and four plots in each block into which two treatments of HA (high and low; HI and LO) were allocated. The HA, defined as the ratio between forage mass and stocking rate (kg of dry matter (DM) per kg of BW; Sollenberger et al., 2005), represented 8 and 5 kg DM/kg BW of annual mean for HI and LO, respectively. Herbage mass (kg DM/ha) was estimated monthly by the comparative yield method (Haydock & Shaw, 1975). Forty-six 5 years old multiparous beef cows (Hereford, Angus, and F1 crossbred) that grazed on the same HA (HI or LO) since May 2016 were used (n = 23 for each HA).

During the measurement period (July-August 2017; winter; 350 mm rainfall and 14.3 ± 4 °C of temperature), HA was 3.4 kg DM/kg BW for both treatments, while herbage mass and height were 2153 and 1395 kg of DM/ha and 4.5 and 3.1 cm for HI and LO treatments, respectively; regarding chemical composition, CP and NDF were 8.4 and 9.3 % of DM and 25 and 15 % of DM for HI and LO treatments. During the measurement period, cows were on the last third of gestation (-75 ± 4 days) and maintained their body weight (BW) and body condition score (BCS; scale 1 to 8; Vizcarra et al., 1986), which were, in average, 422 ± 16 kg and 3.8 ± 0.1 units with no differences between treatments.

3.3.2. Data and sample collection

Total heat production (HP) and cow activity were measured simultaneously for each cow. Total HP was determined using the oxygen (O_2) pulse technique (O_2P; Brosh, 2007), based on measurement of heart rate (HR; beats/min) and O_2 consumption individually in each cow. Heart rate was measured continuously for 4 d per animal using HR monitors (Polar RCX3, Electro Oy, Kempele, Finland) with a transmitter Polar WearLink (Polar Electro Oy) and a data logger programmed to record HR at 5 s intervals. The devices were attached to the thorax behind the forelegs by means of a specifically designed elastic belt. To calculate the O_2P (mL O_2/beat per kg $BW^{0.75}$), in a short-term interval (10 to 15 min), the HR and O_2 consumption (mL O_2/kg $BW^{0.75}$ per h) were measured simultaneously, at 1 s intervals, in each cow. Oxygen consumption was measured using a facemask open-circuit respiratory system (Fedak et al., 1981) with a paramagnetic oxygen analyzer (SERVOPRO 1440, Crowborough, East Sussex, United Kingdom). The O_2P was measured immediately after the HR measurement period (2 days between 06:00 and 15:00 h). The accuracy of the system was checked gravimetrically by nitrogen injection (N_2 recovery) into the facemask (McLean and Tobin, 1990); N_2 recovery testing was performed at least three times in each day of measurement to confirm the entire system calibration and averaged 0.86 ± 0.02 along the experiment. Total HP throughout the day was quantified from the individual HR, O_2P and 20.47 kJ/L constant of O_2 consumed (Nicol and Young, 1990) according to the following equation (Brosh, 2007):

HP (kJ/kg $BW^{0.75}$ per day) = HP (beats/min) x O_2P (mL/beats per kg $BW^{0.75}$) x (20.47 kJ/L O_2 consumed/1000) x 60 x 24

Cow activity was monitored for 4 d, simultaneously with HR measurements, with a collar (Moonitor®, Tel Aviv, Israel; Brosh and Goldberg, 2017) equipped with a three-axis accelerometer programmed to store motion sensor counts at 5-min intervals and powered by solar panels. The system has a software which translates the quantitative algorithms emitted by into three physical activities of the cows: resting/ruminating (resting), eating (grazing), walking without foraging (walking).

3.3.3. Calculations and statistical analyses

Heat production and animal activity data were integrated into a combined data set at 5 min intervals and the daily energy cost of the different activities was calculated as the time spent in each activity (resting, grazing and walking) multiplied by the energy cost per unit of time of that activity (Aharoni et al., 2014). Data were analyzed using the SAS Systems program (SAS University Edition, SAS Institute, Inc., Cary, NC, USA) using a mixed model. The UNIVARIATE procedure was used to identify outliers and verify normality of residuals. Data of HP throughout the day were analyzed as repeated measures using the MIXED procedure with the first-order autoregressive covariance structure (AR (1)) and the Kenward-Rogers procedure to adjust the denominator's degrees of freedom. The model included HA treatment, time of the day (hour) and their interaction as fixed effects, and block, plot within block and cow as random effects and day of gestation as covariate (if $P < 0.20$). Resting, foraging and walking times as well as EE for each activity (daily, per unit of activity and incremental above resting) were analyzed using the MIXED procedure with a model that included HA (HI vs. LO) as a fixed effect and block and plot within block as random effects. The relationships between the different variables were studied through correlation using the CORR procedure. Results are presented as least square means ± pooled S.E.

3.4. RESULTS AND DISCUSSION

Total HP along the day was greater for LO than HI cows ($P < 0.001$) and increased ($P < 0.001$) during daylight hours and decreased at night for both HI and LO cows (figure 1), in agreement with previous studies which reported that grazing activity is largely diurnal with two main sessions, one in the morning after sunrise and other in the afternoon before sunset (Stobbs, 1970; Stricklin et al., 1976; Brosh et al., 2006). However, there was an interaction between HA treatments and the hour of the day ($P = 0.017$) on HP as the increase in HP between daylight hours (6:00 to 18:00 h) was more marked for LO than HI cows, probably indicating an increased requirement for eating, searching and digesting the grazed forage.

Resting, foraging, and walking time during winter did not differ ($P > 0.44$) between HA treatments (table 1). Cows spent almost 10 h foraging and 13 h resting/ruminating while less time was dedicated to walking without foraging (less than 1 h). These spent times were consistent with the light (10 h) and night (14 h) hours of the day with foraging activity associated with light hours and resting/ruminating with night hours, as reported in previous studies (Gibb et al., 1998; Gregorini et al., 2006; Larson-Praplan et al., 2015). Indeed, grazing time was high negatively correlated with resting/ruminating time ($r = -0.90$; $P < 0.001$), since both activities are mutually exclusive (Hodgson, 1990). In agreement with the present study, previous research in breeding cows (Brosh et al., 2006; Aharoni et al., 2014) reported foraging times between 7 and 12 hours per day depending on animal frame and grazing conditions. Also, previous work reported that animals in grazing conditions spent less than an hour per day walking without foraging (Brosh et al., 2006; Aharoni et al., 2014).

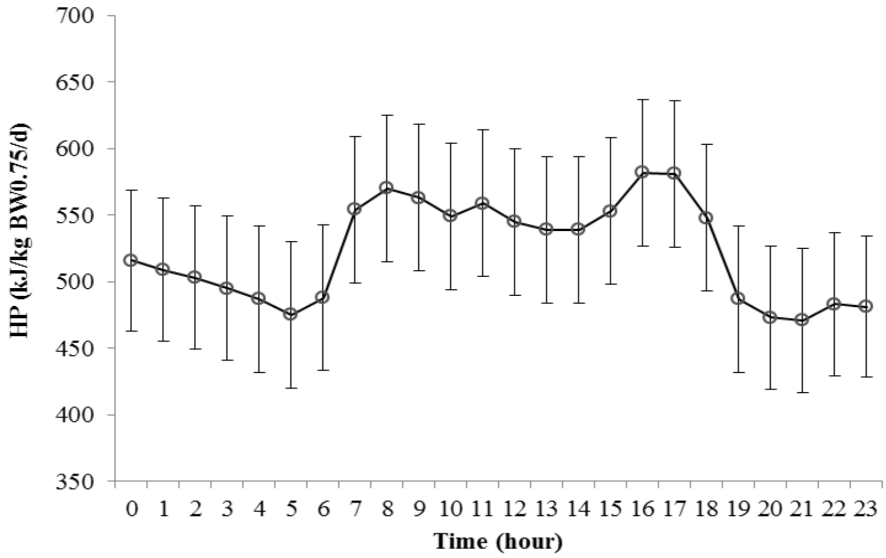

Fig 1. Least square means and s.e.m. for total heat production (HP) per unit metabolic BW in beef cows along the day in winter grazing high (diamonds) and low (squares) herbage allowances (8 and 5 kg dry matter (DM)/kg BW of annual mean, respectively) of native grasslands.

Daily HP (kJ/kg $BW^{0.75}$ per day) during resting/ruminating and during grazing was greater ($P < 0.02$) for LO than for HI cows, while did not differ ($P = 0.41$) for walking (table 1). The energy cost of grazing and walking will depend on the relative time spent by the animal in each activity and the EE required by each activity per unit of time. Indeed, as time dedicated to each activity was not different for HI vs. LO cows, EE per unit of time for resting/ruminating, as well as for grazing, was also greater ($P < 0.01$) for LO than HI cows (table 1). The greater EE could be explained by differences in grazing conditions due to a lower herbage mass and canopy height, determining differences in grazing strategy in LO cows to increment MEI, which probably determined a lower bite mass and, as a result, a greater bite rate in LO cows (56 vs. 43 ± 4 bite/min, $P = 0.05$; Machado et al., 2017) in detriment of selecting a higher quality diet. Although, Brosh et al. (2006) related forage quality with an increase in forage intake and EE, in the present study, estimated metabolizable energy intake was not different between LO and HI (Gómez et al., not published). In addition, Piaggio et al. (1995) showed that greater HA increased selectivity that, in turn, improved forage digestibility. Approximately, 50 % of maintenance costs are related to the mass and metabolic activity of the gastrointestinal viscera and liver due to the processes of feeding, chewing, fermentation and digestion, as well as the absorption and metabolism of digested nutrients; therefore, as food digestibility increases, maintenance cost decreases (Nkrumah et al., 2006; Reynolds et al., 2011), probably reflected in EE for ruminating, the latter being registered as resting/ruminating in our data. Thus, it could be suggested that, in winter, the better management of grazing intensity for HI than LO was reflected in a higher herbage mass and canopy height with equal HA (Machado et al., 2017; Do Carmo et al., 2018) that would allow cows to increased selectivity for higher-quality -more digestible- forage, decreasing EE for grazing and, probably, for ruminating.

Consistent with previous studies, the EE for grazing and walking was greater than for ruminating and resting (Osuji, 1974; Havstad and Malechek, 1982), being the increment of EE due to grazing and walking directly related with the muscular activity that requires high energy compounds (Osuji, 1974). The energy requirement (above resting/ruminating) for grazing was 2.8 kJ/BW$^{0.75}$ per h for HI cows, while it was 4.2 kJ/BW$^{0.75}$ per h for LO cows, representing a 1.15-to-1.2-fold increase. Similarly, Aharoni et al. (2009) and Brosh et al. (2010) reported values of 3.3 to 4.3 kJ/BW$^{0.75}$ per h for EE for grazing activity in rangeland beef cows and DiMarco and Aello (2001) reported for steers grazing cultivated pastures between 2.3 to 7.7 kJ/BW$^{0.75}$ per h for grazing. Considering that, on average, our experiment cows grazed 10 h, the energy cost for grazing represented 6 to 8 % of daily HP and an increase between 9 and 13 % of basal metabolism (322 kJ/BW$^{0.75}$; NASEM 2016).

In contrast, daily EE for walking did not differ (P = 0.41) between HA-treatments (table 1) and EE per unit of activity considered (kJ/kg BW$^{0.75}$ per h) indicated that walking without grazing was the most expensive activity in energy terms. The EE for walking above resting/ruminating was about 25 % greater for both HA and represented 5.5 and 4.9 kJ/kg $BW^{0.75}$ per h. DiMarco and Aello (2001) reported similar values between 2 and 6 kJ/kg $BW^{0.75}$ per h in Aberdeen Angus steers walking on flat and with 6 % grade terrain and different speeds from 1 to 4 km per hour. However, as time dedicated to this activity was less than 1 h per day, in the conditions of this experiment, the daily EE for this activity was not significant, as reported by several authors with estimations obtained under grassland conditions (DiMarco and Aello, 2001; Brosh et al., 2006; Martin et al, 2015). Indeed, several authors reported that walking has no negative effect on animal production if we consider time spent on this activity (Nicholson, 1987; Thomson and Barnes, 1993; Pratumsuwan, 1994; Gemeda et al., 1995).

Table 1. Partition of time spent during the day and heat production (HP) for various activities of beef cows grazing high (HI) or low (LO) herbage allowance of *Campos* rangelands

	Herbage allowance[1]			P-value
Variable	HI	LO	SE	
Time (min per day)				
Resting/ruminating	800	788	56	0.80
Grazing	604	630	50	0.65
Walking without foraging	48	28	24	0.44
Daily HP (kJ/kg $BW^{0.75}$ per day)				
Resting/ruminating	206	271	18	0.01
Grazing	199	271	20	0.02
Walking without foraging	33	18	14	0.41
Daily HP per unit of activity (kJ/kg $BW^{0.75}$ per h)				
Resting/ruminating	15.6	20.9	0.9	< 0.01
Grazing	18.4	25.1	1.6	< 0.01
Walking without foraging	21.1	25.8	1,1	0.01

[1]Herbage allowance treatments had an annual mean of 8 and 5 kg DM/kg BW for HI and LO, respectively.

3.5. CONCLUSIONS

Energy expenditure for physical activity (grazing and walking) of rangeland breeding cows in winter was affected by grazing management through seasonally changes of herbage allowance. Energy expenditure for grazing was greater for cows grazing LO than for HI herbage allowance and represented, in average, about 7 % of daily HP and a 10 % increase above basal metabolism. Reduced EE for cows grazing HI could be explained by improved herbage mass and sward structure that although did not affect time spent grazing, determined a decreased bite rate associated with reduced EE for grazing and, probably, an increased forage digestibility, which could have also reduced EE for ruminating. Lower EE for grazing and ruminating for HI when compared to LO cows would decrease maintenance energy requirements.

3.6. ACKNOWLEDGMENTS

The authors thank the staff of the Experimental Station Bernardo Rosengurtt (D. Bentancor, M. Cáceres) and students from Universidad del Trabajo (UTU; Uruguay), for animal care and assistance throughout the field study, and a special thanks to Óscar Cáceres for his dedication and Fiama Machado for her collaboration. This research was partially funded by the CSIC Groups I+D Research Program (2014; Udelar) awarded to M. Carriquiry and the CAP-Udelar graduate scholarship awarded to J. Gómez (BDMX_2017_1#47570282).

3.7. REFERENCES

Aharoni, Y., Henkin, Z., Ezra, A., Dolev, A., Shabtay, A., Orlov, Yehuda, Y., Brosh, A., 2009. Grazing behavior and energy costs of activity: A comparison between two types of cattle. J. Anim. Sci. 87 (8), 2719-2731. https://doi.org/10.2527/jas.2008-1505.

Aharoni, Y., Dolev, A., Henkin, Z., Yehuda, Y., Ezra, A., Ungar, E.D., Shabtay, A., Brosh, A. 2014. Foraging behavior of two cattle breeds, a whole-year study: I. Heat production, activity and energy costs. J. Anim. Sci. 91:1381-1390. https://doi.org/10.2527/jas.2012-5400.

Altesor, A., Di Landro, E., May, H., Ezcurra, E., 1998. Long term species change in a Uruguayan grassland. J. Vegetation Sci. 9(2), 173–180. https://doi.org/10.2307/3237116.

Brosh, A., Henkin, Z., Ungar, E.D., Dolev, A., Orlov, A., Yehuda, Y., Aharoni, Y., 2006. Energy cost of cows' grazing activity: Use of the heart rate method and the Global Positioning System for direct field estimation. J. Anim. Sci. 84, 1951-1967. https://doi.org/10.2527/jas.2005-315

Brosh, A., 2007. Heart rate measurements as an index of energy expenditure and energy balance in ruminants: A review. J. Ani. Sci. 85(5), 1213-1227. https://doi.org/10.2527/jas.2006-298.

Brosh, A., Henkin, Z., Ungar, E.D., Dolev, A., Shabtay, A., Orlov, A., Yehuda, Y., Aharoni, Y., 2010 Energy cost of activities and locomotion of grazing cows: A repeated study in larger plots, J. Ani. Sci. 88(1), 315–323. https://doi.org/10.2527/jas.2009-2108.

Brosh, A., Goldberg, S., 2017. Herd Moonitor Ltd. US Patent 2017/0325426 A1. patentimages.storage.googleapis.com/d9/cc/14/4bb25a0241e40e/US20170325426A1.pdf (accessed 16 December 2021).

Casal, A., Veyga, M., Astessiano, A.L., Espasandin, A.C., Trujillo, A.I., Soca, P., Carriquiry, M., 2014. Visceral organ mass, cellularity indexes and expression of genes encoding for mitochondrial respiratory chain proteins in pure and crossbred mature beef cows grazing different forage allowances of native pastures. Lives. Sci. 167(1), 195–205. http://dx.doi.org/10.1016/j.livsci.2014.06.024.

CSIRO. 2007. Commonwealth scientific and industrial research organization. Feeding Systems for Australian Livestock: Ruminants. Melbourne: CSIRO Publications, Australia.

DiMarco ON. 2006. Eficiencia de utilización del alimento en vacunos [En línea]. Revista Visión Rural 13(61). Consultado en enero 2017. Disponible en: www.produccion-animal.com.ar/informacion_tecnica/manejo_del_alimento/89-eficiencia_utilizacion_alimento.pdf

DiMarco ON, Aello MS. 2001. Energy expenditure due to forage intake and walking of grazing cattle. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia.

https://doi.org/10.1590/S0102-09352001000100017

DiMarco ON, Aello MS, Méndez DG. 1996. Energy expenditure of cattle grazing on pastures of low and high availability. Animal Science, 63(1), 45–50.

Do Carmo, M., Sollenberger, L.E., Carriquiry, M., Soca, P., 2018. Controlling herbage allowance and selection of cow genotype improve cow-calf productivity in Campos grasslands. The Prof. Anim. Sci. 34(1), 32–41. https://doi.org/10.15232/pas.2016-01600.

Do Carmo, M., Genro, T.C.M., Cibils, A.F., Soca, P.M., 2021. Herbage mass and allowance and animal genotype affect daily herbage intake, productivity, and efficiency of beef cows grazing native subtropical grassland. J. Ami. Sci. 99 (10). https://doi.org/10.1093/jas/skab279.

Fedak, M.A., Rome, L., Seeherman, H.J., 1981. One-step N2-dilution technique for calibrating open-circuit VO2 measuring systems. J. App. Phys. 51(3), 772-776. https://doi.org/10.1152/jappl.1981.51.3.772.

Ferrell, C.L., Jenkins, T.G., 1985. Cow type and the nutritional environment: nutritional aspects. J. Anim. Sci. 61(3), 725–741. https://doi.org/10.2527/jas1985.613725x

Gemeda, T., Zerbini, E., Wold, A.G., Demissie, D., 1995. Effect of draught work on performance and metabolism of crossbred cows 1. Effect of work and diet on body-weight change, body condition, lactation and productivity. Ani. Sci. 60(3), 361-367. https://doi.org/10.1017/S1357729800013230.

Gibb, M., Huckle, C., Nuthall, R., 1998. Effect of time of day on grazing behaviour by lactating dairy cows. Grass and Forage Sci. 53(1): 41–46. https://doi.org/10.1046/j.1365-2494.1998.00102.x.

Gregorini, P., Pas, S., Tamminga, S., Gunter, S., 2006. Review: Behavior and Daily Grazing Patterns of Cattle. Professional Animal Scientist, 22(3): 201–209. https://doi.org/10.15232/S1080-7446(15)31095-0.

Haydock, K.P., Shaw, N.H., 1975. The comparative yield method for estimating dry matter yield of pasture. Aust. J. Exp. Agr. 15, 663–516 670. https://doi.org/10.1071/EA9750663.

Havstad, K.M., Malechek, J.C., 1982. Energy expenditure by heifers grazing crested wheatgrass of diminishing availability. J. Range Mgt. 35(4): 447-450.

Hodgson, J. 1990. Grazing management. Science into practice. Harlow: Logman Scientific & Technical. 203 pp.

Laporta, J., Astessiano, A.L., López-Mazz, C., Soca, P., Espasandin, A.C., Carriquiry, M. 2014. Effects of herbage allowance of native grasslands in purebred and crossbred beef cows: Metabolic, endocrine and hepatic gene expression profiles through the gestation-lactation cycle. Ani. 8(7), 1119–1129. https://doi.org/10.1017/S1751731114000986.

Larson-Praplan, S., George, M.R., Buckhouse, J.C., Laca, E.A., 2015. Spatial and temporal domains of scale of grazing cattle. Ani. Prod. Sci. 55(3): 284-297. https://doi.org/10.1071/AN14641.

Machado, F., Claramunt, M., Do Carmo, M., Franco, J., Gómez, J., Orcasberro, S., Soca, P., 2017. Effect of herbage allowance on grazing behavior at different scales of lactating beef cows grazing native grassland. In: M. Parapinski, M.S. Dalle Carbonare and P. Schmidt (eds), Proceedings of the 54th Annual Meeting of the Brazilian Society of Animal Science, Foz de Iguacu, 2017, (The Brazilian Society of Animal Science, ISSN 1983--4357).

Martin, N.P., Hicksona, R.E., Draganovab, I., Horneb, D., Kenyona, P.R., Morrisa, S.T., 2015. Brief Communication: Walking distance and energy expenditure of beef cows grazing on hill country in winter. In: Proc. New Zealand Soc. Ani. Prod. (Vol. 75). DOI: 10.13140/RG.2.1.3061.6164-

McLean, J.A., Tobin, G., 1990. Animal and human calorimetry. Cambridge University Press.

NASEM, 2016. Nutrient Requirements of Beef Cattle: Eighth Revised Edition. National Academies Press.

Nicholson, M. J., 1987. Effects of night enclosure and extensive walking on the productivity of zebu cattle. The J. Agri. Sci. 109(3), 445-452. https://doi.org/10.1017/S002185960008165X.

Nicol, A.M., Young, B.A., 1990. Short-Term Thermal and Metabolic Responses of Sheep to Ruminal Cooling - Effects of Level of Cooling and Physiological State. Can. J. Ani. Sci. 70, 833–843. https://doi.org/10.4141/cjas90-102.

Nkrumah, J.D., Okine, E.K., Mathison, G.W., Schmid, K., Li, C., Basarab, J.A., Price, M.A., Wang, Z., Moore, S.S., 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Ani. Sci. 84(1), 145-153. https://doi.org/10.2527/2006.841145x.

Osuji, P.O. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. J. Range Mgt., v.27, p.437-443.

Panario, D., Bidegain, M., 1997. Climate change effects on grasslands in Uruguay. Climate Res. 9, 37-40. https://doi.org/10.3354/cr009037.

Piaggio, L., Prates, E.R., Rinaldi, C., Soca, P., 1995. Diet quality and diet selection of steers grazing in a rotational system at four levels of forage allowance on a rangeland. Ann. Zootech. 44, 119-119.

Pratumsuwan, S., 1994. Effect of walking extra distances on the performance of grazing dairy cows in early lactation: a thesis presented in partial fulfilment of the requirements for the degree of Master of Agricultural Science, Massey university, Palmerston North, New Zealand (Doctoral dissertation, Massey University).

Reynolds, C.K., Crompton, L.A., Mills, J.A.N., 2011. Improving the efficiency of energy utilisation in cattle. Ani. Prod. Sci. 51(1), 6–12.

Sollenberger, L.E., Moore, J.E., Allen, V.G., Pedreira, C.G.S., 2005. Reporting forage allowance in grazing experiments. Crop Sci. 45(3), 896–900.

Stobbs, T.H. 1970, Automatic measurement of grazing time by dairy cows on tropical grass and legume pastures. Trop. Grass. 4 (3), 237- 244.

Stricklin, W.R., Wilson, L.L., Graves, H.B., 1976. Feeding behavior of Angus and Chrolais-Angus Cows during Summer and Winter. J. Anim. Sci. 43, 721-732. 10.2527/jas1976.433721x.

Thomson, N.A., Barnes, M.L., 1993. Extra walking: Effect on dairy production. Proc. New Zealand Sot. Anim. Prod. 53:69-72.

Vizcarra, J.A., Ibañez, W., Orcasberro R., 1986. Repetibility amd reproductibility of two scales to estimate body condition score in Hereford cows. Inv. Agr. 7, 45-47.

4. DISCUSIÓN GENERAL Y CONCLUSIONES

4.1. DISCUSIÓN

4.1.1. Partición de la energía durante el ciclo anual de la vaca de cría

En Uruguay, el proceso de cría es principalmente llevado a cabo bajo condiciones de pastoreo en campo natural; esto determina que los resultados productivos y económicos dependan del consumo de nutrientes y energía a lo largo del ciclo, el cual presenta fuertes variaciones climáticas intra- e interanuales tanto en cantidad como en calidad de la pastura (Berretta e*t* al., 2000). En invierno, cuando la gestación es avanzada, la tasa de crecimiento del campo natural se vuelve mínima, por lo cual se produce una restricción en la masa y altura del forraje que no permite satisfacer los requerimientos nutricionales, debido, principalmente, a la insuficiente ingestión de energía (Orcasberro, 2000). A su vez, la baja disponibilidad de forraje produce un alto gasto energético por actividad de pastoreo (McClymont, 1967), por lo cual, cuando los requerimientos de nutrientes son mayores al consumo neto y los animales usan sus reservas corporales para satisfacer este déficit, se genera un balance energético negativo (Robinson et al., 1999).

Sin embargo, durante este estudio, las pérdidas de PV y CC durante el invierno fueron mínimas (menos de 0,25 puntos de CC), lo que se reflejó en la ER en los tejidos, con valores cercanos a cero para vacas de AOF y de BOF, indicando que las vacas se encontraban —en promedio— en condiciones de mantenimiento durante este período. Esto se explicaría, probablemente, por el diferimiento de forraje de estaciones con mayores tasas de crecimiento —primavera a otoño— hacia el invierno, que generó una acumulación en la masa de forraje y altura de las pasturas para ambas OF, siendo, en el presente trabajo, 1,6 veces mayor en la primavera, 2 veces mayor en el otoño y 3 veces mayor en el invierno con respecto a estudios anteriores (Do Carmo et al, 2018). Estudios previos en la región demostraron que una mayor masa y altura del forraje y una estructura heterogénea de la pastura generan mayores frecuencias de altura de más de 3 cm, lo cual posibilita una mayor masa de bocado y provoca, como consecuencia, un mayor consumo de EM (Gonçalves et al., 2009, Do Carmo et al., 2021). En acuerdo con estos resultados, la mayor disponibilidad y altura de forraje determinó que, durante la gestación de otoño-invierno, el consumo de EM estimado aumentara 35 %, con respecto a estudios anteriores en vacas de carne preñadas pastoreando campo natural en el mismo período (Laporta et al., 2014), lo que permitió que las vacas alcanzaran los requerimientos de mantenimiento. De hecho, los valores de consumo de EM por unidad de $PV^{0,75}$ estimados en el presente trabajo son similares a los reportados en otros estudios para mantenimiento de vacas de cría de carne durante la gestación (Houghton et al., 1990, Freetly et al., 2000, Brosh et al., 2002, Brosh et al., 2004).

Como era esperado, en acuerdo con la alta correlación entre la HP y el consumo de EM (Brosh, 2007), la HP durante la gestación de otoño-invierno fue menor que durante la lactancia en primavera-verano. A su vez, las vacas de BOF incrementaron la HP en un 25 % con respecto a las vacas de AOF durante el invierno, sin presentar diferencias en la ER. Por lo tanto, el mayor consumo de EM de las vacas de BOF durante el invierno fue utilizado para mantenimiento en detrimento de una mayor producción, lo cual podría ser explicado por las diferencias en los requerimientos energéticos en la actividad de pastoreo, entre otros factores (Osuji, 1974, CSIRO, 2007, Machado et al., 2017). De hecho, las vacas de BOF presentaron mayor HP para rumia/descanso y pastoreo que fueron 35 % mayores que las vacas en AOF. Esta mayor HP de las vacas en BOF puede ser explicado por el mayor gasto energético de cada actividad por unidad de tiempo y no por el tiempo dedicado a cada actividad, ya que no se registraron diferencias en ese sentido. Esto podría ser explicado por las condiciones de pastoreo a la que fueron expuestas las vacas en los diferentes tratamientos, con una menor altura y masa de forraje para las vacas de BOF, lo cual, probablemente, determinó una menor masa de bocado, compensado con una mayor tasa de bocado (56 vs. 43 56 vs. 43 ± 4 bocados/min, P = 0,05; Machado et al., 2017). Por otro lado, el contenido de FDN (% MS) en el tratamiento de AOF es significativamente superior al de BOF (tabla 1), lo cual podría haber limitado el consumo de energía en las vacas de AOF, este menor consumo estar asociado a la menor HP (Brosh, 2007) y, de esta manera, el desempeño productivo, reflejado en la

ER en tejidos. Sin embargo, los animales pueden haber consumido una dieta de mejor valor nutricional que el promedio presentado (Dumont et al., 2002, Hodgson, 1990). Asimismo, Piaggio et al. (1995) demostró que una mayor OF incrementa la selectividad en el pastoreo y, por lo tanto, el consumo de una dieta de mayor digestibilidad. Si se tiene en cuenta que, aproximadamente, el 50 % de los costos de mantenimiento están relacionados a la masa y la actividad metabólica de las vísceras gastrointestinales y el hígado, y a los procesos de ingestión, masticación, fermentación y digestión, así como a la absorción y el metabolismo de los nutrientes, se puede inferir que una mayor digestibilidad de la dieta consumida disminuye los costos de mantenimiento (Nkrumah et al., 2006, Reynolds et al., 2011). La mayor digestibilidad de la dieta consumida probablemente esté relacionada con el menor gasto energético de la rumia, observado en la producción de calor en la actividad de descanso detectado, en las vacas de AOF con respecto a las de BOF.

Estos resultados sugieren que, si bien en invierno la OF fue la misma para ambos tratamientos, un mejor manejo de la intensidad de pastoreo a lo largo del año en el tratamiento de AOF en comparación con la BOF, reflejado en la mayor masa y estructura del forraje durante el invierno (Machado et al., 2017, Do Carmo et al., 2018), permitió a las vacas de AOF, a pesar del mayor contenido de FDN en el forraje, disminuir el gasto energético de la actividad de pastoreo así como de descanso y rumia, lo que redujo los requerimientos de energía para mantenimiento.

La mayor OF en primavera-verano en el presente trabajo determinó que el consumo de EM, en promedio, fue, aproximadamente, un 1,4 veces superior que en otoño-invierno, en concordancia con la mayor OF, la CC y el PV de las vacas (Do Carmo et al., 2018). La ER en los tejidos indica que, durante este período, las vacas de ambos tratamientos se encontraron en balance energético positivo. La ER total fue mayor en primavera-verano que en otoño-invierno debido a la producción de leche (ER-leche), ocurriendo el pico de producción en primavera durante la lactancia temprana (Espasandin et al., 2016).

A diferencia de Brosh et al. (2006), que reporta un menor gasto energético en condiciones de pastoreo a mayor carga animal, en este estudio, la mayor intensidad de pastoreo no afectó la HP al comparar vacas en BOF y AOF. Sin embargo, la ER total fue 1,45 veces mayor en vacas de AOF que BOF, lo que puede sugerir que la HP para producción fue mayor, mientras la HP para mantenimiento fue menor en las primeras, destinando el mayor consumo de EM a producción (ER tejidos y leche). A su vez, la mayor OF en primavera, que generó una mayor masa y altura del forraje en verano, podría explicar el menor gasto energético en las actividades de pastoreo generando una disminución en la HP de mantenimiento.

4.1.2. Eficiencia energética durante el ciclo de gestación-lactación

En el presente trabajo, no se vieron diferencias entre los tratamientos en la eficiencia biológica de producción calculada como la relación entre los gramos de ternero con el consumo de EM por kg de $PV^{0.75}$. Sin embargo, la eficiencia energética bruta calculada como la relación entre la ER total y el consumo de EM tendió a ser mayor en AOF que BOF, principalmente durante la lactación, debido a la producción de leche (Gutierrez et al., 2013).

Las regresiones de los datos individuales de ER, HP y CEM obtenidos en este estudio para las vacas en balance energético positivo y negativo fueron altas y significativas (Carriquiry et al., 2019). La ecuación de regresión generada para las vacas en balance energético positivo fue igual a HP = 323 + 0,43 x CEM (r^2 = 0,84) y para las vacas en balance energético negativo fue igual a HP = 173 + 0,61 x CEM (r^2 = 0,76) (figura 2). La HP estimada para metabolismo basal de las vacas en balance energético positivo (323 kJ/kg $PV^{0.75}$/d) es similar a la propuesta por los modelos de NASEM (2016) y CSIRO (2007) para vacas de carne (321 y 337 kJ/kg $PV^{0.75}$/d, respectivamente). Sin embargo, la EM para mantenimiento es entre 11 y 13 % mayor (567 kJ/kg $PV^{0,75}$/d) que el sugerido por estos modelos (502 y 510 kJ/kg $PV^{0.75}$/d para NASEM y CSIRO, respectivamente) explicado por un menor k_m estimado en este estudio con respecto a los anteriores mencionados (0,57 vs. 0,60 y 0,72 de k_m).

Este menor valor del k_m podría estar asociado a la peor calidad de la dieta y a la actividad de pastoreo.

De acuerdo con lo reportado por Houghton et al. (1990), la HP para metabolismo basal se redujo en un 50 % cuando las vacas se encontraban en balance energético negativo (173 kJ/kg $PV^{0.75}$/d) provocado por la restricción alimenticia, que reduce los requerimientos de mantenimiento a través de la reducción de los requerimientos de las vísceras gastrointestinales e hígado.

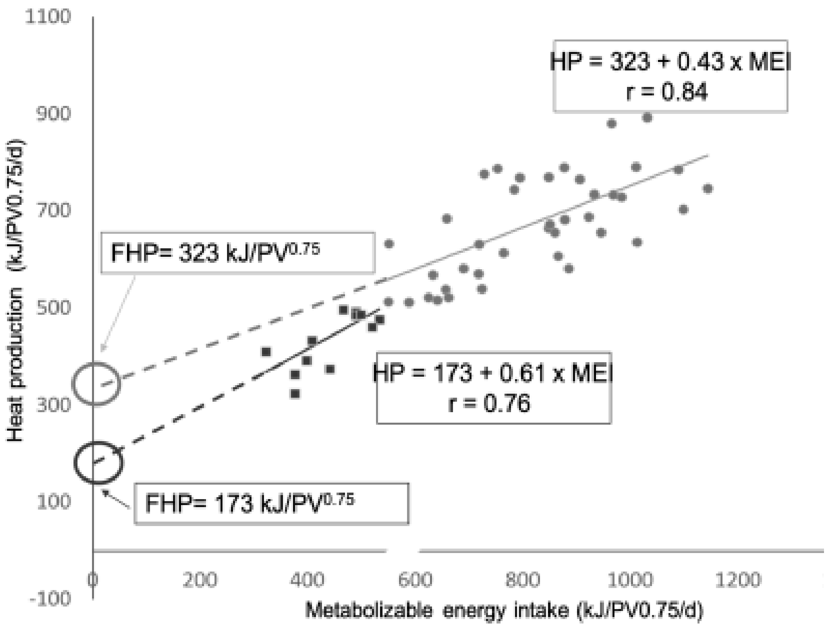

Figura 2. Regresiones para HP sobre CEM (MEI) para vacas en balance energético positivo (gris claro; círculos) y negativo (gris oscuro; cuadros) (Carriquiry et al., 2019).

4.2. CONCLUSIONES

El presente estudio presenta, por primera vez para los sistemas extensivos en campo natural, la estimación de requerimientos energéticos en la vaca de cría a lo largo de su ciclo, que concuerda con los sistemas de alimentación y literatura internacional. Con respecto a la eficiencia en uso de la energía metabolizable para mantenimiento, es menor a la propuesta por los sistemas de alimentación, probablemente debido a la actividad de pastoreo y la calidad de la dieta. El diferimiento de forraje desde las estaciones con mayor tasa de crecimiento hacia el invierno, a través del manejo de una mayor oferta de forraje, permitió una reducción del costo energético del pastoreo mediante una menor tasa de bocado y, probablemente, la selectividad de una dieta de mayor digestibilidad que, además, redujo el gasto energético de la rumia. Generar información con mayor número de animales y en diferentes condiciones de pastoreo y ambientales resulta de importancia para contribuir en esta línea de investigación.

5. BIBLIOGRAFÍA

Aello MS. 2014. Índice de conversión alimenticia en la cría vacuna: factores que lo afectan. Nutrición animal aplicada, 106.

Allen VG, Batello C, Berretta EJ, Hodgson J, Kothmann M, Li X, Mcivor J, Milne J, Morris C, Peeters A, Sanderson M. 2011. An international terminology for grazing lands and grazing animals. Grass and Forage Science, 66, 2-28.

Baker JF, Buckley BA, Dickerson GE, Nienaber JA. 1991. Body composition and fasting heat production from birth to 14 months of age for three biological types of beef heifers. Journal of Dairy Science, 69, 4406.

Baldwin RL. 1995. Modeling Ruminant Digestion and Metabolism. London, UK. Chapman and Hall, p. 585.

Bauman DE, Currie B. 1980. Partition of nutrients During Pregnancy and Lactation: A Review of Mechanisms Involving Homeostasis and Homeorhesis. Journal of Dairy Science, 63, 1514-1529.

Berretta EJ, Risso DF, Montossi F, Pigurina G. 2000. Campos in Uruguay. En: Lemaire G, Hogdson J, de Moraes A, Nabinger C, Carvalho PC (Eds), Grassland ecophysiology and grazing ecology, Cambridge: CABI, 2000, 377-394.

Brosh A. 2015. Heart Rate O_2 Pulse Method for Measuring Heat Production: from theory to application.

Brosh A. 2007. Heart rate measurements as an index of energy expenditure and energy balance in ruminants: A review. Journal of Animal Science, 85(5), 1213-1227.

Brosh A, Henkin Z, Ungar ED, Dolev A, Orlov A, Yehuda Y, Aharoni Y. 2006. Energy cost of cows' grazing activity: Use of the heart rate method and the Global Positioning System for direct field estimation. Journal of Animal Science, 84, 1951-1967.

Brosh A, Aharoni Y, Shargal E, Sharir B, Gutman M, Choshniak I. 2004. Energy balance of grazing beef cattle in Mediterranean pasture, the effects of stocking rate and season. 2. Energy expenditure as estimated from heart rate and oxygen

consumption, and energy balance. Livestock Production Science, 90, 101–115.
Brosh A, Aharoni Y, Holzer Z. 2002. Energy expenditure estimation from heart rate: validation by long-term energy balance measurement in cows. Livestock Production Science, 77, 287-299.
Carriquiry M, Gómez J, Casal A, DoCarmo M. Soca P. 2019. Maintenance energy requirements of beef cows grazing Campos grasslands. European Federation for Animal Science Scientific Series: 138, 277 - 278
Carriquiry M, Espasandín A, Soca P, Astessiano A, Bielli A, Casal A, Guitérrez V, Laporta J, López- Mazz C, Meikle A, Naya H, Quintans G.; Scarsi A, Pérez-Clariget R, Viñoles C. 2013. Metabolismo de la vaca de carne y su cría en pastoreo de campo nativo: un enfoque endócrino-molecular. FPTA N° 43. INIA
CSIRO (Commonwealth Scientific and Industrial Research Organization). 2007. Feeding Systems for Australian Livestock: Ruminants. Melbourne: CSIRO Publications, Australia.
Da Trindade JK, Neves FP, Pinto CE, Bremm C, Mezzalira JC, Nadin LB, Genro TCM, Gonda HL, Carvalho PCF. 2015. Daily Forage Intake by Cattle on Natural Grassland: Response to Forage Allowance and Sward Structure. Rangeland Ecology & Management, 69:59–67.
Dickerson GE. 1978. Animal size and efficiency: Basic concepts. Animal Production, 27(3), 367–379.
DIEA (Dirección de Estadísticas Agropecuarias). 2015. Producción [En línea]. En: Anuario estadístico agropecuario 2015. Montevideo: MGAP (Ministerio de Ganadería, Agricultura y Pesca). Consultado 20 diciembre 2021. Disponible en: http://www.mgap.gub.uy/unidadejecutora/oficina-de-programacion-y-politicas-agropecuarias/publicaciones/anuarios-diea/anuario2015
DiMarco ON. 2006. Eficiencia de utilización del alimento en vacunos [En línea]. Revista Visión Rural 13(61). Consultado en enero 2017. Disponible en: www.produccion-animal.com.ar/informacion_tecnica/manejo_del_alimento/89-eficiencia_utilizacion_alimento.pdf
DiMarco ON, Aello MS. 2001. Energy expenditure due to forage intake and walking of grazing cattle. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia, 53,

105-110.

DiMarco ON, Aello MS, Méndez DG. 1996. Energy expenditure of cattle grazing on pastures of low and high availability. Animal Science, 63(1), 45–50.

Do Carmo M, Genro TC, Cibils AF, Soca PM. 2021. 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.

Do Carmo M, Sollenberger LE, Carriquiry M, Soca P. 2018. Controlling herbage allowance and selection of cow genotype improve cow-calf productivity in Campos grasslands. The Professional Animal Scientist, 34(1), 32–41.

Do Carmo M, Claramunt M, Carriquiry M, Soca P. 2016. Animal energetics in extensive grazing systems: Rationality and results of research models to improve energy efficiency of beef cow-calf grazing campos systems. Journal of Animal Science, 94, 1-9.

Do Carmo M, Carriquiry M, Soca P. 2013. Effect of forage allowance on native pasture traits, stocking rate and beef cow body condition. Proceedings of the 22nd International Grassland Congress.

Dumont B, Carrère P, D'Hour P. 2002. Foraging in patchy grasslands: diet selection by sheep and cattle is affected by the abundance and spatial distribution of preferred species. Animal Research, 51(5), 367-381.

Espasandin AC, Gutierrez V, Casal A, Graña A, Bentancur O, Carriquiry M. 2016. Modeling lactation curve in primiparous beef cattle. Journal of Agricultural Science, 8(4), 116-125.

Ferrell CL, Jenkins TG. 1985. Cow type and the nutritional environment: nutritional aspects. Journal of Animal Science, 61(3), 725–741.

Freetly HC, Ferrell CL, Jenkins TG. 2000. Timing of realimentation of mature cows that were feed-restricted during pregnancy influences calf birth weights and growth rates. Journal of Animal Science, 78(11), 2790-2796.

Gonçalves EN, Carvalho PCF, Kunrath TR, Carassai IJ, Bremm C, Fischer V. 2009. Plant-animal relationships in pastoral heterogeneous environment: process of herbage intake. Revista Brasileira de Zootecnia 38:1655-1662.

Gutiérrez V, Espasandin AC, Astessiano AL, Casal A, López-Mazz C, Carriquiry M. 2013. Calf foetal and early life nutrition on grazing conditions: metabolic and endocrine profiles and body composition during the growing phase. Journal of Animal Physiology and Animal Nutrition, 97 (4), 720–731.

Heitschmidt RK, Taylor CA. 1991. Grazing Management: an Ecological Perspective. En: Heitschmidt RK, Stuth JW (Eds.). Livestock Production. Portland, Oregon: Timber Press, Inc. (7) 259.

Hodgson J. 1990. Grazing management: science into practice. Longman Group UK Ltd., London, 200 p.

Houghton PL, Lemenager RP, Hendrix KS, Moss GE, Stewart TS. 1990. Effects of body composition, pre- and postpartum energy intake and stage of production of energy utilization by beef cows. Journal of Animal Science, 68, 1447–1456.

Kennedy E, O´Donovan M, Murphy JP, Delaby L, O´Mara F. 2007. Effect of Spring Grazing Date and Stocking Rate on Sward Characteristics and Dairy Cow Production During Midlactation. Journal of Dairy Science, 90, 2035–2046

Laporta J, Astessiano AL, López-Mazz C, Soca P, Espasandin AC, Carriquiry M. 2014. Effects of herbage allowance of native grasslands in purebred and crossbred beef cows: Metabolic, endocrine and hepatic gene expression profiles through the gestation-lactation cycle. Animal, 8(7), 1119–1129.

Machado F, Claramunt M, Do Carmo M, Franco J, Gómez J, Orcasberro S, Soca P. 2017. Effect of herbage allowance on grazing behavior at different scales of lactating beef cows grazing native grassland. En: Parapinski M, Dalle Carbonare MS, Schmidt P (Eds), Proceedings of the 54th Annual Meeting of the Brazilian Society of Animal Science, Foz de Iguacu, 2017, (The Brazilian Society of Animal Science, ISSN 1983--4357)

Maraschin GE, Moojen EL, Escoteguy CMD, Correa L, Apezteguia ES, Boldrini II. 1997. Native pasture, forage on offer and animal response. En: Buchanan-Smith JG, Bailey LD, McCaughey P. (Eds). Proceeding of the XVIII International Grassland Congress, 8 - 19 June 1997; Winnipeg and Saskatoon, Canada. Calgary, Canada. p. 27-29.

McClymont GL. 1967. Selectivity and intake in the grazing ruminant. En: Cole CE

(Ed), Handbook of Physiology, Alimentary Canal, Food and Water Intake. (Vol III). Washington D.C: Amer, Physiology Society. p. 129-137

Meikle A, Mattiauda D, Soca P, Bruni M, Uriarte G, Adrien L, Cavestandy D, Chilibroste P. 2006. Perfiles metabólicos durante el pre y posparto de vacas lecheras primíparas sometidas a cantidades diferenciales de forraje. XXXIV Jornadas Uruguayas de Buiatría. p.171-173.

Mendoza-Martinez FD, Plata-Pérez FX, Espinosa-Cervantes R, Lara-Bueno A. 2008. Manejo nutricional para mejorar la eficiencia de utilización de energía en bovinos. Universidad y Ciencia. Universidad Juárez Autónoma de Tabasco. Méjico. p. 75-87.

Nabinger C, De Moraes A, Maraschin GE. 1999. Campos in southern Brazil. En: Lemaire G, Hodgson J, de Moraes A, Nabinger C, Carvalho P. (Eds.). Grassland Ecophisiology and Grazing Ecology. Cambridge, United Kingdom: University Press. p 355-376

NASEM (National Academies of Sciences, Engineering, and Medicine). 2016. Nutrient Requirements of Beef Cattle. 8th rev. ed. Washington (DC): National Academies Press, 494p.

Nkrumah JD, Okine EK, Mathison GW, Schmid K, Li C, Basarab JA, Price MA, Wang Z, Moore SS. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. Journal of Animal Science, 84(1), 145-153.

Orcasberro R. 2000. Manejo nutricional del rodeo de cría en las condiciones pastoriles del país. Jornada sobre cría vacuna. Centro Veterinario de Salto y Comisión de Reproducción de la Sociedad de Medicina Veterinaria de Uruguay. Gran Hotel Salto.

Osuji PO. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. Journal of Range Management, 27, 437-443.

Piaggio L, Prates ER, Rinaldi C, Soca P. 1995. Diet quality and diet selection of steers grazing in a rotational system at four levels of forage allowance on a rangeland. Annales de zootechnie, 44, 119-119.

Reynolds CK, Crompton LA, Mills JAN. 2011. Improving the efficiency of energy utilisation in cattle. Animal Production Science, 51(1), 6–12.

Robinson JJ, Sinclair KD, Randel RD, Sykes AR. 1999. Nutritional management of the female ruminant: mechanistic approaches and predictive models. Nutritional Ecology of Herbivores. Proceedings of the Vth International Symposium on the Nutrition of Herbivores. American Society of Animal Science. Savoy, Illinois, USA.

Rovira J. 1996. Manejo nutritivo de los rodeos de cría en pastoreo. Montevideo, Hemisferio Sur. 288 p.

Scarlato S, Carriquiry M, Do Carmo M, Faber A, Genro TCM, Laca EA, Soca P. 2012. Foraging behavior of beef cows grazing native grassland: Effect of herbage allowance on temporal and spatial grazing patterns. Journal of Animal Science, 90(3), 502.

Short RE, Bellows RA, Staigmiller R, Berardinelli JG, Custer EE. 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. Journal of Animal Science, 68, 799-816.

Sinclair KD. 2010. Declining fertility, insulin resistance and fatty acid metabolism in dairy cows: Developmental consequences for the oocyte and pre-implantation embryo. Acta Scientiae Veterinariae, 38(2), 545–s557.

Soares AB, Carvalho PCF, Nabinger C, Frizzo A, Pinto CE, Junior JAF, Semmelmann C, Da Trindade J. 2003. Effect of changing herbage allowance on primary and secondary production of natural pasture. Proceedings of the 7th International Rangeland Congress. 26, 966-968.

Soca P, Carriquiry M, Keisler DH, Claramunt M, Do Carmo M, Olivera-Muzante J, Rodríguez M, Meikle A. 2013a. Reproductive and productive response to suckling restriction and dietary flushing in primiparous grazing beef cows. Animal Production Science, 53, 283–291.

Soca P, Claramunt M, Do Carmo M. 2013b. Beef cows breed system on native sward without agricultural financial assistance: Research to sustainable calf production with low cost and easy instrumentation. Avances en Producción Animal, 32:3–26.

Soca P, Orcasberro R. 1992. Propuesta de manejo del rodeo de cría con base en estado corporal, altura del pasto y aplicación de destete temporario. En: Jornada de producción animal. Evaluación física y económica de alternativas tecnológicas en predios ganaderos, Estación Experimental Mario A. Cassinoni Facultad de Agronomía. Universidad de la República Oriental del Uruguay. 54-56 p.

Solis JC, Byers FM, Schelling GT, Long CR, Greene LW. 1988. Maintenance requirements and energetic efficiency of cows of different breed types. Journal of Animal Science, 66:764-773

Sollenberger LE, Moore JE, Allen VG, Pedreira CGS. 2005. Reporting forage allowance in grazing experiments. Crop Science, 45(3), 896–900.

Stuedemann JA, Franzluebbers AJ. 2007. Cattle performance and production when grazing Bermudagrass at two forage mass levels in the southern Piedmont. Journal of Animal Science 85, 1340-1350.

Thurow J, Nabinger C, De Souza C, Carvalho P, Oliveira C, Machado M. 2009. Estrutura da vegetação e comportamento ingestivo de novilhos em pastagem natural do Rio Grande do Sul. Revista Brasileira de Zootecnia, 38, 818-826.

Trujillo A, Orcasberro R, Beretta V, Franco J, Burgueño J. 1996. Performance of Hereford cows under conditions of varied forage availability during late gestation. Proc. Development of feed supplementation strategies for improving ruminant productivity on small-holder farms in Latin America through the use of immunoassay techniques. International Atomic Energy Agency. Mayo 1996. pp 6979.

Wales WJ, Doyle PT, Stockdale CR, Dellow DW. 1999. Effects of variations in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. Australian Journal of Experimental Agriculture, 39(2), 119-130.