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TABLA DE CONTENIDO

RESUMEN

Los objetivos del presente estudio fueron: (i) evaluar el valor nutritivo del forraje, el consumo y la producción de leche de vacas lecheras Holando en respuesta a diferentes estrategias de manejo del pastoreo que priorizan la tasa de consumo de pasto o la cosecha de pasto por hectárea y (ii) evaluar cómo la suplementación con concentrado afecta esta respuesta. El experimento se realizó en Uruguay durante 81 días, con 24 vacas lecheras Holando en lactancia media. El diseño experimental fue en bloques completos al azar con arreglo factorial 2 × 2. Las dos estrategias de manejo del pastoreo fueron: una estrategia de alta tasa de consumo (ATC) de pasto con alturas pre- y pospastoreo de 21 y 13 cm (porcentaje de remoción del 40 %), respectivamente, y una estrategia de alta cosecha de pasto por hectárea (ACH) con un objetivo prepastoreo de 3,5 a 4 hojas por macollo y pospastoreo de 7 a 11 cm de altura remanente. Los niveles de suplementación con concentrado fueron 0 (S0) y 4 (S4) kg de MS por vaca por día. Se midieron altura de la pastura, número de hojas por macollo, composición morfológica y química del forraje, producción de leche, peso vivo y condición corporal de las vacas, consumo y producción por hectárea. Las vacas en ATC lograron un mayor consumo de pasto de mayor valor nutritivo, presentaron mayor producción de leche (+ 6 kg/vaca/d), mantuvieron la condición corporal e incrementaron su peso vivo durante el experimento. Las diferencias en producción de leche entre ambas estrategias de manejo de pastoreo se mantuvieron independientemente del nivel de suplementación. Aunque la producción por hectárea fue mayor en ACH respecto a ATC, esta estrategia de pastoreo debería ser acompañada de suplementación para no comprometer la condición corporal de las vacas.

Palabras clave: altura de la pastura, pastoreo rotativo, número de hojas por macollo.

EFFECTS OF GRAZING MANAGEMENT AND CONCENTRATE SUPPLEMENTATION ON INTAKE AND MILK PRODUCTION OF DAIRY COWS GRAZING ORCHARDGRASS

SUMMARY

The objectives of this study were: (i) to evaluate the herbage nutritional value, intake and milk production of Holstein dairy cows grazing orchardgrass in response to grazing management strategies that prioritize either herbage harvest per hectare or herbage intake rate, and (ii) to assess whether concentrate supplementation affects this response. The experiment was carried out in Uruguay for 81 days, with twenty-four mid-lactation Holstein dairy cows. The experimental design was a randomized complete block with a 2 × 2 factorial arrangement. The grazing management strategies were a high herbage intake rate (HIR) strategy with pre and post-grazing sward heights of 21 and 13 cm (sward depletion of 40 %), and a high herbage harvest per hectare (HHH) strategy with a pre-grazing target of 3.5-4 leaves per tiller and a post-grazing target of 7-11 cm. Concentrate supplementation levels were 0 (CS0) and 4 (CS4) kg DM/cow per day. Measurements of sward height, number of leaves per tiller, herbage morphological and chemical composition, milk production per cow, body condition score, body weight, intake and milk production per hectare were performed. Compared with cows under HHH, cows under HIR achieved a greater herbage intake of greater nutritive value, presented greater milk production (+ 6 kg/cow/day), maintained body condition score and increased body weight throughout the experiment. Differences in milk production between both grazing management strategies were maintained regardless of the concentrate supplementation level. Although production per hectare was greater in HHH than in HIR, this strategy should be combined with concentrate supplementation to not compromise the body condition score of cows.

Keywords: sward height, rotational stocking, number of leaves per tiller.

1. INTRODUCCIÓN

La pastura es el componente de menor costo de la dieta de los sistemas lecheros (Dillon, 2006), con la capacidad de sostener altos niveles de producción (O'Donovan et al., 2015). En Uruguay, las pasturas perennes representan un 30 % de la superficie total de los sistemas lecheros (DIEA, 2020) y son una herramienta para aumentar la estabilidad de la base forrajera. La primavera, que se caracteriza por condiciones que permiten altas tasas de crecimiento de las pasturas (García, 2003), aparece como una oportunidad para disminuir el uso de suplementos e incrementar la producción de leche a partir de pasto.

En un estudio reciente evaluando predios lecheros de Uruguay, se ha reportado que, para incrementar el consumo de pasto, la suplementación debe ajustarse en función de la disponibilidad de forraje a lo largo del año (Méndez et al., 2020). Conjuntamente, el manejo de pastoreo que se implemente afectará de forma directa el consumo y, en consecuencia, el desempeño animal. Mientras que la clave del manejo de pastoreo en sistemas que utilizan el método de pastoreo rotativo se ha establecido en términos de lograr una alta cosecha de pasto por hectárea (Roche et al., 2017), trabajos recientes han presentado nuevas estrategias de manejo del pastoreo, basadas en las respuestas del comportamiento ingestivo de los animales. Dichas estrategias se basan en que el tiempo de pastoreo es limitado y, por tanto, apuntan a ofrecer estructuras óptimas de la pastura para lograr una alta tasa de ingestión y consumo de pasto por animal (Carvalho, 2013). En esta línea, los criterios de ingreso al pastoreo están basados en alturas determinadas para cada especie forrajera, y la intensidad de pastoreo es moderada (40 % de remoción de la altura de forraje disponible; Fonseca et al., 2012) para mantener una alta tasa de consumo durante todo el día de pastoreo.

En vacas lecheras se ha generado información detallada sobre el efecto de la variación en la altura pospastoreo sobre el desempeño individual

(Menegazzi et al., 2021, Dale et al., 2018, Ganche et al., 2014), pero no se han realizado aún estudios en los que se apliquen estrategias con criterios específicos para maximizar la ingestión de pasto por unidad de tiempo, que consideren tanto la altura prepastoreo como el porcentaje de remoción. Por otro lado, aún es poco claro el efecto que dicha estrategia de pastoreo tendría sobre la producción de leche por superficie, en comparación con estrategias orientadas a una alta cosecha de pasto por superficie. Asimismo, es interesante evaluar la respuesta animal ante las estrategias de pastoreo planteadas también en situaciones de suplementación con concentrados, práctica habitual en los sistemas lecheros en Uruguay (Méndez et al., 2020, Fariña y Chilibroste, 2019).

En este contexto, surgió el interés de llevar adelante una investigación con vacas lecheras que contrastara estrategias de manejo de pastoreo durante la primavera, aplicadas sobre una pastura perenne de *Dactylis glomerata*, en combinación con dos niveles de suplementación con concentrados, para evaluar efectos sobre características de la pastura y de los animales. A continuación, se describen los antecedentes recabados, la hipótesis de trabajo y los objetivos. Posteriormente se presenta el artículo «Effects of grazing management and concentrate supplementation on intake and milk production of dairy cows grazing orchardgrass», en el cual se muestran y discuten los principales resultados obtenidos durante esta investigación. Por último, se presentan la discusión y las conclusiones globales de este trabajo.

1.1 CONSUMO DE PASTO EN SISTEMAS LECHEROS

El pasto tiene un rol central en la dieta de vacas lecheras en diversas partes del mundo (Wilkinson et al., 2019). En comparación con otros alimentos como reservas y concentrados, destaca por su bajo costo (Dillon, 2006), por producir productos con una mejor composición nutricional (en perfil de ácidos grasos y concentraciones de vitaminas A y E; Hennessy et al., 2020, Wilkinson et al., 2019) y por asociarse a un mayor bienestar animal al permitir que los animales expresen su comportamiento natural en pastoreo (Hennessy et al., 2020) cuando es manejado de forma adecuada.

En Uruguay, el consumo estimado promedio de pasto por vaca por día ronda los 9,5 kg de materia seca (MS) (Fariña y Chilibroste, 2019). Estudios realizados en algunos sistemas de la cuenca lechera muestran cierta variación interanual en estos valores. Los predios con mayor consumo estimado de pasto por animal registran un promedio anual de 10,1 kg MS/vaca/día, con máximos consumos de pasto de 12,5 y 13,7 kg de MS vaca/día en primavera y verano, respectivamente (Méndez et al., 2020).

Sin embargo, trabajos experimentales realizados a nivel internacional y local, con estrategias de pastoreo de alta asignación por vaca (o baja intensidad de pastoreo) y bajos niveles de suplementación, han reportado valores de consumo de pasto superiores a los citados. En estudios de corta duración, desarrollados sobre pasturas base de *Lolium perenne* (raigrás perenne) de alto valor nutritivo [43 % de fibra detergente neutro (FDN), 25 % de proteína cruda (PC)], se ha reportado un consumo de pasto de 19 kg MS/vaca, que se tradujo en una producción promedio de 29,6 kg leche/vaca en vacas en lactancia temprana (Kolver y Muller, 1998). Un trabajo realizado por Bargo et al. (2002), con vacas de alto potencial manejadas con altas asignaciones diarias de forraje (40 kg MS/vaca), reportó un consumo de pasto de 21 kg de MS/vaca, equivalente a un 3,3 % del peso vivo (PV). McEvoy et al. (2008), trabajando con alta disponibilidad de forraje y asignaciones diarias de 20 kg MS/vaca (por encima de 4 cm) de pasturas de raigrás perenne, registraron consumos de pasto de 17,5 kg de MS/vaca, lo que representó un consumo de alrededor del 3,3 % del PV. A nivel local, vacas lecheras en primavera pastoreando *Festuca arundinacea* (festuca) con mínimos niveles de suplementación (2 kg/vaca/día) presentaron un consumo de pasto equivalente al 3,2 % del PV, que significaron, aproximadamente, 18,5 kg de MS de pasto por animal (Carballo, 2014). Asimismo, Menegazzi et al. (2021)

variando la intensidad de pastoreo, sin suplementación, reportaron consumos de pasto de más de 18 kg de MS/vaca/día (2,8 % del PV) al trabajar con una altura remanente de 12 cm en festuca.

Los antecedentes anteriores permiten observar que los valores de consumo de pasto en vacas lecheras podrían ser incrementados en cierto rango cuando el manejo de pastoreo y la suplementación se manejan de forma conjunta con ese fin.

1.2 MANEJO DEL PASTOREO

El manejo de pastoreo consiste en la manipulación del pastoreo en busca de un objetivo específico o un conjunto de objetivos. De los métodos de pastoreo que pueden aplicarse, el método rotativo, que se caracteriza por períodos recurrentes de pastoreo y descanso entre tres o más potreros (Allen et al., 2011), ha sido ampliamente adoptado en los sistemas lecheros (Roche et al., 2017).

Los objetivos que se persiguen con cada manejo de pastoreo pueden ser diversos (Sollenberger et al., 2020) y de eso dependen, en gran medida, la intensidad y frecuencia de pastoreo. Algunos sistemas se basan en las características de crecimiento de las plantas con el objetivo final de lograr una alta cosecha de pasto por hectárea (Chapman, 2016, Parsons y Chapman, 2000). Por otro lado, estudios recientes enfatizan en la necesidad de basar el pastoreo en las respuestas comportamentales de los animales, ofreciendo una estructura de la pastura óptima para maximizar la tasa de consumo y, con ello, el desempeño animal (Carvalho, 2013). A continuación, se presentan los conceptos principales vinculados con dos estrategias de manejo de pastoreo contrastantes: una orientada a lograr una alta cosecha de pasto por hectárea y otra basada en las respuestas comportamentales de los animales, buscando ofrecer a los animales una estructura de pasto óptima con el objetivo de lograr una alta tasa de consumo de pasto.

1.2.1 Manejo orientado a la cosecha de pasto por hectárea

Una de las claves para comprender el proceso de pastoreo radica en que los componentes cosechados por los animales son los propios órganos fotosintéticos de la planta, principalmente las hojas (Parsons y Chapman, 1998). Esto implica enfrentar el desafío de lograr una alta remoción, en equilibrio con el mantenimiento de suficiente área foliar luego del pastoreo, para lograr una alta cosecha de pasto y un adecuado crecimiento de la planta luego de la defoliación (Parsons y Chapman, 1998). Incrementar la cosecha de pasto permite aumentar la proporción de pasto producido que es utilizado por los animales, lo cual ha mostrado ser determinante en la rentabilidad de los sistemas lecheros basados en pasturas (Hanrahan et al., 2018). En este contexto, el conocimiento de la ecofisiología de las plantas ha permitido el desarrollo de estrategias de pastoreo que optimicen la cantidad de pasto cosechado por los animales (Chapman, 2016), para lo cual tanto la intensidad como la frecuencia de pastoreo son consideradas.

Para lograr una alta cosecha de pasto, la intensidad de pastoreo suele ser alta (Parsons y Chapman, 2000), sin trabajar en extremos que generen situaciones de sub- y sobrepastoreo (Chapman, 2016). En este sentido, pastoreos laxos implicarían mantener un alto índice de área foliar remanente luego de la defoliación, por lo que una baja proporción de las hojas serían cosechadas y, en consecuencia, una alta proporción avanzaría al estado de senescencia sin poder ser utilizada por los animales. En la línea opuesta, en una situación de sobrepastoreo, una muy baja cantidad de lámina remanente se mantendría luego de la defoliación, lo que reduciría el tamaño y crecimiento de nuevas hojas (Chapman, 2016). Nueva área foliar podría ser generada a partir de carbohidratos de reserva, pero el período de crecimiento que estos pueden sostener es limitado (Parsons y Chapman, 1998) y la tasa de crecimiento en las etapas iniciales de rebrote se reduciría, producto de la limitada energía disponible para la formación de nueva área foliar. En la práctica, el largo de rebrote podría ser extendido para aumentar la cosecha de pasto, pero las pérdidas de rendimiento generadas en las primeras etapas de rebrote no son recuperadas y la cosecha de pasto total es menor a la lograda en situaciones donde la severidad de pastoreo es inferior (Chapman, 2016).

Una situación intermedia refiere a mantener un mínimo de área foliar remanente que permita lograr una alta cosecha de forraje por los animales sin comprometer el rebrote posterior de las plantas (Parsons y Chapman, 2000). En la práctica, esto se ha asociado a alturas remanentes bajas (Parsons y Chapman, 2000) pero variables, según la especie forraje en cuestión y su estructura (Davies, 1988).

Para mantener un adecuado crecimiento de la planta en el pospastoreo y lograr una alta cosecha de pasto, además de la intensidad de defoliación, el momento de pastoreo es un criterio clave. Parsons y Chapman (1998), a partir de la clásica curva sigmoidea de crecimiento de las plantas, desarrollaron curvas que permiten identificar el momento óptimo para pastorear una pastura, maximizando la cosecha de pasto sobre pastoreo rotativo (figura 1). Este momento se alcanza cuando la tasa de crecimiento promedio de la pastura es máxima, punto en el cual se logra el balance óptimo entre la cantidad de hojas nuevas que se producen y la cantidad de hojas viejas que mueren (punto *b* de la figura 1). Pastorear antes de este punto (*a* en la figura 1) implicaría interrumpir el crecimiento de la planta en el momento donde la tasa de crecimiento instantánea es máxima. Por el contrario, retrasar el pastoreo más allá del momento donde se alcanza la máxima tasa de crecimiento promedio (*c* en la figura 1) implicaría alargar el período de rebrote de forma innecesaria, ya que, en etapas avanzadas, la tasa de crecimiento será muy baja o nula, producto de la senescencia de las primeras hojas (Parsons y Chapman, 2000).

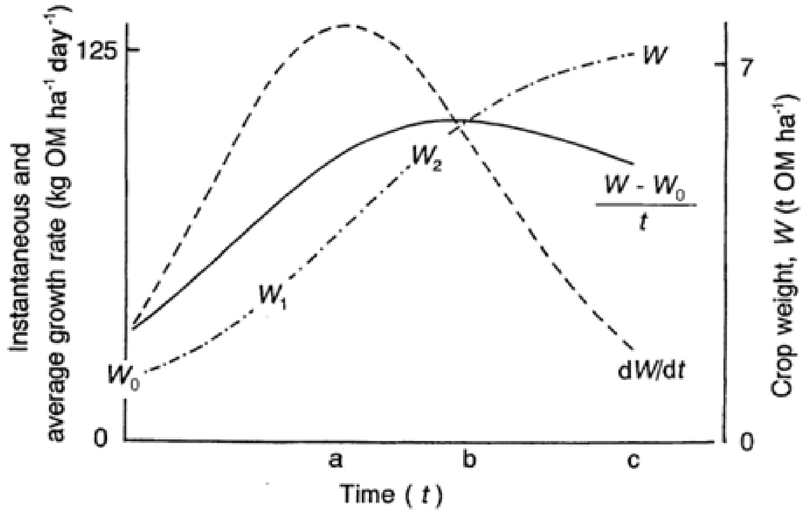

Figura 1. Relación entre el largo del rebrote (t) y la tasa de crecimiento instantánea (dW/dt), masa de forraje (W) y tasa de crecimiento promedio ([W-W_0]/t) de la pastura. Tomado de Parsons y Chapman (1998).

Si bien el momento en el que se logra la tasa de crecimiento promedio máxima no es fácilmente identificable a campo, indicadores más sencillos de medir, tales como el estado foliar, permiten aproximar el pastoreo a este punto (Chapman, 2016). En esta línea, el número de hojas por macollo o estado foliar se ha reportado como un indicador preciso para determinar el momento óptimo de defoliación desde el punto de vista de la planta. Este permite establecer intervalos mínimos y máximos de descanso, llevando en consideración el estatus de reservas energéticas en la planta y el inicio de la senescencia (Fulkerson y Donaghy, 2001).

Después de un pastoreo intenso, la planta dispone de baja área foliar remanente, el crecimiento radicular es detenido y los carbohidratos de reserva almacenados en la base de la planta se destinan a la formación de nuevas hojas (Fulkerson y Lowe, 2017). El nivel de carbohidratos de reserva que la planta presenta luego del pastoreo dependerá, en gran parte, del largo de rebrote. Luego de la defoliación, en la medida en que nueva área foliar es generada, se producen carbohidratos, a partir de la fotosíntesis, que serán destinados a procesos de respiración y crecimiento, y aquellos no utilizados inmediatamente serán almacenados en la planta. Si el pastoreo se produce en etapas de rebrote muy tempranas, los niveles de carbohidratos de reserva acumulados pueden ser bajos, lo que vuelve a la planta más vulnerable y compromete su capacidad de rebrote posterior (Fulkerson y Lowe, 2017).

En el caso de raigrás, ha sido ampliamente reportado que pastorear en el estado de dos a tres hojas permite asegurar un nivel de carbohidratos de reserva adecuados en la planta. Por el contrario, se ha visto que alargar el tiempo de rebrote más allá del estado de tres hojas por macollo implica incrementar las pérdidas por senescencia (Chapman, 2016). Esto se debe a que las hojas poseen una vida media determinada, dependiente del genotipo y la época del año. De esta manera, al alcanzarse un determinado número de hojas por macollo, este se mantendrá estable, ya que al producirse una nueva hoja la más antigua empezará a morir (Robson et al., 1988).

Se ha determinado que el número máximo de hojas por macollo que puede sostener es de tres hojas en el caso de raigrás (Fulkerson y Slack, 1995), mientras que en el caso de *Dactylis glomerata* (dactylis), por ejemplo, es de cinco a seis hojas (Rawnsley et al., 2002). Estudios realizados por Turner et al. (2006) encontraron que, tanto para raigrás como para dactylis, plantas defoliadas en el estado de dos hojas producían menos MS que plantas defoliadas en el estado de tres o cuatro hojas. Para dactylis, si bien se han reportado incrementos en la concentración de carbohidratos de reserva en raíces y pseudotallos hacia el estado de cuatro hojas, conjuntamente se ha observado un incremento en el porcentaje de material senescente que comenzaría a producirse a partir del estado de tres hojas y que en esta etapa representaría más del 10 % de la MS (Rawnsley et al., 2002). Similar a esto, Duru y Ducrocq (2000) reportan un aumento en la cantidad de hojas senescentes a partir del estado de tres hojas por macollo.

Los antecedentes presentados, en su conjunto, permiten inferir que, en situaciones de campo, el momento óptimo de defoliación en dactylis para lograr una alta cosecha de pasto por hectárea estaría en el rango de tres a cuatro hojas por macollo, dejando un mínimo de área foliar remanente luego del pastoreo para no comprometer el rebrote posterior.

1.2.2 Manejo basado en las respuestas comportamentales de los animales

El consumo de pasto se estima como el producto entre el tiempo de pastoreo (h/día) y la tasa de consumo (g/hora), la cual es resultado del producto entre la tasa de bocado (bocados/hora) y el peso de bocado (g/bocado) (Stobbs, 1973, Allden y Whittaker, 1970). Este último, a su vez, depende de la densidad de la pastura y del volumen de bocado que adquiera el animal (Prache y Delagarde, 2011, Laca et al., 1992), el cual, normalmente, es representado como un cilindro con una determinada área y profundidad (Ungar, 1996). En términos generales, los distintos parámetros de consumo tienden a compensarse entre sí como forma de evitar caídas en la ingesta. Frente a situaciones en que el peso de bocado disminuye, pueden incrementarse tanto la tasa de bocado como el tiempo de pastoreo (Allden y Whittaker, 1970). Sin embargo, esta capacidad de compensación es limitada (Laca et al., 1994a).

Los rumiantes tienen una serie de actividades diarias a las que deben asignarles tiempo a lo largo del día y que se producen en momentos puntuales. Las vacas lecheras concentran su período de consumo de pasto durante las horas de luz (Rook et al., 1994), siendo mínima la actividad en pastoreo durante la oscuridad. Los eventos de pastoreo más importantes se producen luego del ordeñe de la mañana y la tarde, siendo este último el de mayor intensidad (Sheahan et al., 2013). La rumia, si bien ocurre durante todo el día, se concentra mayormente en la noche (Sheahan et al., 2013) y el descanso, que puede insumir unas nueve horas diarias, es un comportamiento de alta prioridad para los rumiantes (O’Driscoll et al., 2019). A esto se suma el tiempo destinado a otras actividades como el consumo de agua, la interacción con otros animales y, en los sistemas lecheros, el ordeñe

(Carvalho et al., 2017). Esta situación implica que el tiempo de pastoreo (posible factor de compensación para evitar caídas en el consumo) quede restringido a menos de 10 h diarias (Jamieson y Hodgson, 1979). Adicionalmente, sobre pastoreo rotativo, diversos estudios han encontrado escasos o nulos incrementos en el tiempo de pastoreo frente a condiciones de la pastura limitantes o pastos muy bajos (Ison et al., 2019, Amaral et al., 2013, Wade y Carvalho, 2000), lo que se ha explicado como una espera de los animales a que les sea ofrecida una nueva parcela con mejores condiciones (Jamieson y Hodgson, 1979). En este contexto, algunos autores señalan que para incrementar el consumo de pasto se debe apuntar a aumentar la cantidad de MS ingerida por unidad de tiempo (Carvalho et al., 2017), es decir, la tasa de consumo.

Dentro de las características de las plantas, la estructura de la pastura es un factor determinante de la tasa de consumo por definir la facilidad con la que el pasto puede ser cosechado por el animal (Carvalho et al., 2017). Se sabe que cada especie forrajera tiene una estructura de la pastura ideal, capaz de permitir al animal una cosecha de nutrientes fácil y rápida (Carvalho et al., 2017). La estructura de la pastura ha sido descrita por diversos autores a lo largo de los años (Laca y Lemaire, 2000, Thomas, 1980). Las definiciones más recientes incluyen dentro de este concepto variables como la disponibilidad, la altura del pasto, la densidad, la proporción de hojas, la proporción de tallos y la distribución espacial (Carvalho, 2013).

Es reconocido que, en situaciones de pastoreo, el forraje se modela como un conjunto de horizontes superpuestos (Baumont et al., 2004, Laca et al., 1994a) donde las hojas tienden a predominar en los estratos superiores (Gregorini et al., 2009), mientras que tallos y pseudotallos predominan en la porción inferior (Benvenutti et al., 2015). En etapas tempranas de pastoreo, las hojas en el estrato superior son el primer componente removido por los animales. En la medida en que la defoliación avanza, la cantidad de hojas en el forraje se reduce y en etapas posteriores empiezan a ser removidos los tallos (Chacon y Stobbs, 1976). Los componentes morfológicos y su distribución en el perfil impactan en el proceso de pastoreo, de manera que se ha reportado una correlación alta y positiva entre la relación hoja/tallo y el consumo de pasto, y una correlación alta y negativa entre la cantidad de tallos y el consumo (Chacon y Stobbs, 1976).

La altura, a través de su relación con los distintos componentes morfológicos en el perfil de pastoreo, es una de las variables de la estructura de la pastura con mayor influencia sobre la tasa de consumo (Fonseca et al., 2012, Gibb et al., 1997). En concreto, Mezzalira et al. (2014) reportan que la tasa de consumo se maximiza en alturas de pasto intermedias, con relación a muy bajas o altas.

Por un lado, al disminuir la altura, el peso de bocado se reduce como consecuencia de una menor profundidad de bocado, la cual está estrechamente relacionada con la altura de la pastura (Laca et al., 1992). En esta línea, se ha visto que la presencia de vainas en estratos inferiores actúa como una barrera horizontal que restringe la profundidad de bocado (Prache y Delagarde, 2011, Laca et al., 1992). A medida que la altura y el peso de bocado se reducen, la tasa de bocados aumenta en un intento de evitar caídas en el consumo (Allden y Wittaker, 1970). Sin embargo, en la medida en que la estructura de la pastura se vuelve más limitante, como, por ejemplo, en pastos con alturas muy bajas o en presencia de tallos e inflorescencias (Prache, 1997), el aumento en la tasa de bocados no logra compensar la caída en el peso de bocado y la tasa de consumo se reduce (McGilloway et al., 1999).

La limitada capacidad de aumento de la tasa de bocado ante importantes reducciones en la altura de la pastura se basa en que el tiempo por bocado permanece poco variable al disminuir el peso de bocado (Laca et al., 1994a). En este sentido, Parsons y Chapman (1998) describen al tiempo de manipulación y el tiempo de masticación como los dos determinantes del tiempo necesario por los animales para procesar cada bocado. Mientras que el tiempo de masticación se reduce linealmente al disminuir el peso de bocado, el tiempo de manipulación, que está vinculado con los movimientos mandibulares de los animales para adquirir el bocado, se mantiene poco variable (Laca et al., 1994b). Este tiempo fijo vinculado con la manipulación del bocado explica que la caída en el peso de bocado por pastorear en alturas muy bajas no pueda ser compensada totalmente por un aumento de la tasa de bocado.

En el extremo opuesto, cuando se pastorea en pasturas demasiado altas, que superan la altura óptima de una determinada especie forrajera, la tasa de consumo también se reduce (Mezzalira et al., 2014). En este sentido, Mezzalira et al. (2017) explican que la caída en el peso de bocado en pastos muy altos se produciría por un aumento en la proporción y dureza de los tallos en los estratos superiores. Esto generaría una reducción en el área de bocado, como intento de los animales por captar láminas y evitar los tallos y componentes de menor valor nutritivo, lo que afectaría el peso de bocado y, en consecuencia, la tasa de consumo.

La relación entre las características de la pastura ofrecida y el comportamiento ingestivo de los animales se ha utilizado para el diseño de manejos de pastoreo que apunten a incrementar el consumo de pasto y la performance animal (Carvalho, 2013). En este sentido, se conocen alturas de la pastura óptimas para maximizar la tasa de consumo de los animales sobre distintas especies forrajeras tales como raigrás, *Avena strigosa* (avena) y *Sorghum bicolor* (sorgo), entre otros (Carvalho, 2013). En el caso de dactylis, hasta el momento no se han realizado experimentos de corto plazo evaluando alturas prepastoreo óptimas para maximizar la tasa de consumo. Sin embargo, trabajos previos contrastando el efecto de distintas alturas prepastoreo sobre la tasa de consumo y el consumo de pasto permiten observar que, ante similares niveles de asignación de pasto, altas tasas de ingestión se obtenían cuando vacas ingresaban al pastoreo en alturas próximas a los 21 cm (Cazcarra et al., 1995). Por otro lado, estudios como el de Fonseca et al. (2012) han demostrado que pastorear no más de un 40 % de la altura inicial de pastoreo permite mantener una alta tasa de consumo durante toda la sesión de pastoreo.

1.2.3 Implicancias del manejo de pastoreo

Manejos de pastoreo que aplican conceptos vinculados a ofrecer una estructura de la pastura para lograr una alta tasa de consumo de pasto se han contrastado con otros que toman como referencia la acumulación de forraje y pastorean de forma más intensa promoviendo la alta cosecha instantánea de forraje. Trabajando con ovinos y novillos, el primer manejo generó una mayor ingesta de láminas, que resultó en un mayor consumo de forraje (Savian et al., 2020) y desempeño animal (Portugal et al., 2021, Schons et al., 2021). En tanto sobre vacas lecheras se han realizado estudios que evalúan el efecto de variar la altura pre- o pospastoreo. Por ejemplo, se ha reportado que ingresar al pastoreo con alturas óptimas, que se asocian a estructuras con una mayor disponibilidad de hojas y menor proporción de tallos, genera incrementos en la producción de leche por vaca (Congio et al., 2018). Asimismo, un estudio reciente con vacas lecheras ha reportado una caída en el consumo y la producción de leche a medida que la proporción de la altura inicial pastoreada aumentaba en pasturas de *Medicago sativa* (alfalfa) (Ison et al., 2019).

Estudios locales con vacas lecheras sobre distintos niveles de intensidad de defoliación en festuca (9, 12 y 15 cm durante la primavera) encontraron que disminuir la intensidad de pastoreo permite a los animales lograr una mayor tasa de consumo (Oborsky, 2020), junto con la obtención de una dieta de mayor valor nutritivo, un mayor consumo de pasto y una mayor producción de leche (Menegazzi et al., 2021).

Asimismo, trabajos en otras regiones, con vacas lecheras, pero con alturas pospastoreo menos contrastantes (5,2 a 6,8 cm y 2,7 a 4,2 cm), han reportado aumentos en la producción de leche y sólidos por vaca al disminuir la intensidad de pastoreo en pasturas de raigrás perenne (Dale et al., 2018, Ganche et al., 2014). Los resultados están en línea con estudios de corto plazo que describen que al disminuir la altura pospastoreo se produce una reducción en la relación hoja/tallo y en la disponibilidad de hojas, que explica un menor consumo de MS (Amaral et al., 2013).

Una intensidad de pastoreo alta, asociada a bajas asignaciones de pasto por vaca (20 kg de MS por vaca), se ha vinculado, además, con una pérdida de peso vivo y condición corporal de animales exclusivamente en pastoreo (Dalley et al., 1999). En esta línea, Delaby y Peyraud (2003) reportaron un aumento en la ganancia de peso vivo de vacas lecheras a medida que disminuía la carga y, con ello, la intensidad de pastoreo. Similares resultados han sido reportados por McEvoy et al. (2008), quienes encontraron una disminución en la condición corporal de vacas lecheras de, aproximadamente, 0,15 puntos (en escala de 1 al 5) al reducir la asignación diaria de forraje de 17 a 13 kg de MS por vaca (por encima de 4 cm) en un período de 2 meses.

Las características de la dieta obtenida por los animales también se modifican con el manejo de pastoreo. En pasturas de alfalfa, se ha visto que, al pastorear horizontes inferiores con mayor densidad de tallos, se reduce el valor nutritivo de la dieta ingerida (aumenta el contenido de FDN y se reduce el aporte de energía metabolizable) y el consumo (Ison et al., 2019). Asimismo, Menegazzi et al. (2021), trabajando sobre festuca, reportaron un aumento del contenido de PC y una disminución del contenido de FDN en la pastura cosechada por vacas lecheras que pastoreaban de forma menos intensa. Similares resultados obtuvieron Savian et al. (2020) y Zubieta et al. (2021) sobre *Lolium multiflorum* (raigrás anual). Estos resultados se asocian con la capacidad de selección de los rumiantes, que pueden obtener una dieta con diferentes características a la que les es ofrecida (Poppi, 2011). Este proceso se basa en el consumo preferencial de hojas. Cuando los rumiantes tienen capacidad de seleccionar, tienden a evitar componentes de menor valor nutritivo (Poppi, 2011) y mayor resistencia al corte (Jacobs et al., 2012), como tallos y pseudotallos (Prache y Delagarde, 2011). La distribución de componentes morfológicos en el perfil vertical de pastoreo, con predominancia de tallos-pseudotallos en estratos inferiores y de láminas en estratos superiores, determina que, en la medida en que la intensidad de pastoreo aumenta, el valor nutritivo de la dieta disminuye (Benvenutti et al., 2020).

En cuanto a los resultados en términos de la producción por hectárea, son variables. El trabajo clásico de Mott (1960) muestra que en cargas intermedias existe una compensación entre la producción por animal y por superficie, de modo que a medida que la presión de pastoreo aumenta, la producción por animal se reduce, pero la producción por hectárea se incrementa. En esta línea y trabajando con vacas lecheras, Dale et al. (2018) encontraron una disminución en la producción de leche por vaca, pero un aumento en la producción de leche por superficie a medida que la altura pospastoreo se redujo en un rango de 6,8 a 5,2 cm. Similares resultados reportaron Coffey et al. (2018), quienes trabajando con tres niveles de carga animal contrastantes (1200, 1400 y 1600 kg de PV/ha), asociadas a alturas remanentes de 3,5 a 4,5 cm, encontraron un aumento en la producción de leche y sólidos por hectárea al aumentar la presión de pastoreo e incrementarse la carga.

Sin embargo, los manejos de pastoreo orientados a ofrecer una estructura de la pastura para lograr una alta tasa de consumo de pasto en pastoreo rotativo (trabajando con estructuras de la pastura más contrastantes que en los estudios mencionados previamente) han mostrado generar aumentos en el desempeño individual, acompañados de incrementos en la producción por superficie (Schons et al., 2021). Asimismo, Euclides et al. (2016) y Da Silva et al. (2012), trabajando con novillos en pastoreo continuo y variando la intensidad de pastoreo, reportaron incrementos en la producción de carne por hectárea al trabajar con pastoreos más laxos. Estos resultados serían consecuencia de i) una mayor altura remanente que incrementa la disponibilidad de láminas e intercepción de luz en el pospastoreo, favoreciendo el crecimiento de la pastura y permitiendo aumentar la frecuencia de pastoreo (Portugal et al., 2021, Schons et al., 2021, Carvalho, 2013) y ii) un incremento notorio en la producción individual que permite compensar la reducción en la carga por pastorear de forma moderada (Portugal et al., 2021, Carvalho, 2013).

1.3 SUPLEMENTACIÓN CON CONCENTRADOS

La suplementación con concentrados es una práctica habitual en los sistemas lecheros de Uruguay (Fariña y Chilibroste, 2019), en la que las cantidades ofrecidas varían según la intensificación del sistema de producción y la época del año (Méndez et al., 2020). En general, se trata de una mezcla de granos y subproductos que suelen ser ofrecidos en comederos durante el ordeñe (Fariña y Chilibroste, 2019). En vacas lecheras, el suministro de concentrados es una herramienta reconocida para incrementar el consumo de MS total y de energía en relación con el que se obtendría únicamente a pastoreo (Stockdale, 2000).

Diversos estudios han reportado un aumento en el consumo total al incorporar suplementos en la dieta, en muchos casos de manera conjunta con una disminución en el consumo de pasto, sobre todo cuando se trabaja con altos niveles de suplementación (Heublein et al., 2016, McEvoy et al., 2008, Bargo et al., 2003). Este fenómeno se denomina sustitución y tiene importantes implicancias económicas, debido a que se está reemplazando un componente de bajo costo, como la pastura, por uno de mayor costo, como el concentrado (Heublein et al., 2016). Se considera que la sustitución depende tanto de factores del animal, como, por ejemplo, el potencial productivo, la etapa de lactancia o la paridad, como de la pastura (especie forrajera, valor nutritivo) y del manejo, como, por ejemplo, el manejo del pasto, la asignación de forraje y la cantidad de suplemento ofrecido (Baudracco et al., 2010). La reducción en el consumo de pasto en animales que reciben suplementos se ha vinculado con un menor tiempo de pastoreo (Bargo et al., 2003, Rook et al., 1994) que se traduce en aumentos en la altura pospastoreo a medida que aumenta la cantidad de concentrado suministrado (McEvoy et al., 2008). Respecto a esto, se ha observado que la duración del pastoreo matutino está directamente vinculada con la cantidad de concentrado que se haya ofrecido al momento del ordeñe. Esto se asociaría con cambios en la secreción de factores neuroendócrinos que se producen en respuesta a la presencia de comida en el tracto digestivo o por la circulación de distintos compuestos que indican saciedad (Sheahan et al., 2011).

En líneas generales, el suministro de concentrado adicionado a la oferta de pasto genera un incremento en la producción de leche (Sheahan et al., 2011, Berzaghi et al., 1996). La relación entre los kg de leche producidos a partir de los kg de concentrado consumidos se denomina respuesta en leche al concentrado (Bargo et al., 2003), la cual, generalmente, varía de forma opuesta a la tasa de sustitución (Reid et al., 2015). Esta dependerá del déficit energético que enfrenta la vaca (Poole et al., 2019), lo que en sistemas pastoriles está, en parte, relacionado con la cantidad de pasto disponible por animal. En este sentido, se ha reportado que en la medida en que la asignación de pasto es mayor, la tasa de sustitución de pasto por concentrado aumenta y la respuesta en leche al concentrado se reduce (Bargo et al., 2003). Evaluando distintos niveles de asignación de raigrás perene en vacas lecheras, McEvoy et al. (2008) encontraron, al suplementar con 3 kg de concentrado, una respuesta en leche al concentrado de 0,56 y 0,67 kg de leche/kg de concentrado para asignaciones diarias de 17 y 13 kg de MS por vaca (por encima de 4 cm), respectivamente. Resultados similares obtuvieron Bargo et al. (2002) con vacas pastoreando pasturas mezcla de bromus y dactylis, donde reportan una respuesta en leche de 1,36 y 0,96 kg de leche por kg de concentrado para asignaciones de pasto de 25 y 40 kg de MS por vaca, respectivamente.

En la misma línea, Baudracco et al. (2010), a partir de una revisión de trabajos previos, indican que cuando la asignación de pastura es alta, la respuesta al concentrado alcanza una meseta a partir de un consumo de 4 kg de MS de concentrado por animal. Por su parte, Delagarde et al. (2011) desarrollaron un modelo en el cual se estima que, con altas asignaciones de forraje (> 20 kg de MS por encima de 4 cm), la respuesta en leche se mantiene alta cuando el concentrado consumido se ubica próximo a los 3 kg de MS, disminuyendo en la medida en que se trabaja con mayores niveles de suplementación y asignación de forraje.

La suplementación también tiene efectos sobre la composición de la leche y los resultados varían entre los distintos estudios, principalmente con la cantidad de concentrado asignada. En una revisión realizada por Bargo et al. (2003), se observa que, en líneas generales, a medida que aumenta la oferta de concentrado, el porcentaje de grasa de la leche tiende a disminuir mientras que el porcentaje de proteína se incrementa. Por otro lado, trabajos sobre vacas lecheras contrastando cantidades de concentrado moderadas (en el rango de 0 a 6 kg de MS por vaca) no encontraron efecto de la suplementación sobre el contenido de grasa y proteína de la leche (McEvoy et al., 2008; Muñoz et al., 2015).

Más allá de las diferencias en composición, diversos trabajos coinciden en reportar un incremento en la producción de sólidos al incorporar suplementos. En esta línea, McEvoy et al. (2008) y Delaby et al. (2001) encontraron un incremento en la producción de grasa y proteína a medida que la cantidad de concentrado suministrada aumentaba de 0 a 6 kg de MS por animal. Asimismo, Kennedy et al. (2008) trabajando con 0 y 4 kg de concentrado por animal, bajo diferentes niveles de asignación de forraje, si bien no encontraron diferencias en la producción de grasa, hallaron un incremento en la producción de proteína al suplementar.

A nivel de sistema, la inclusión de suplementos permite incrementar la producción por superficie a través de un aumento en la carga animal acompañado de niveles moderados de producción por vaca (Baudracco et al., 2010). Por otro lado, un estudio realizado por Coleman et al. (2010) ha mostrado que cuando los aumentos en la carga animal se acompañan de cantidades crecientes de concentrado, se logra mantener una mayor condición corporal promedio durante la lactancia. En relación con esto, se ha reportado que la incorporación de concentrados permitiría mejorar el balance energético de vacas lecheras, lo que podría observarse a través de la reducción en los niveles de ácidos grasos no esterificados en sangre (AGNE) (Kennedy et al., 2008). En esta línea, Bargo et al. (2002) compararon vacas recibiendo suplementación con concentrados y vacas exclusivamente a pastoreo, y encontraron una mayor concentración de AGNE en estas últimas, lo que reflejaría una mayor movilización de reservas corporales. Similar a esto, Heublein et al. (2016), trabajando con vacas suplementadas con 6 kg de concentrado o sin suplementación, reportan mayores niveles de beta-hidroxibutirato y AGNE en estas últimas. Por otro lado, Delaby y Peyraud (2003) encontraron que el incremento en el nivel de suplementación con concentrados en vacas lecheras estuvo linealmente asociado a un aumento del peso vivo. Estos resultados se relacionan al alto potencial genético de los animales que presentan una alta capacidad de movilizar reservas corporales para mantener la producción de leche (Baudracco et al., 2010).

1.4 HIPÓTESIS Y OBJETIVOS

1.4.1 Hipótesis

Las hipótesis del presente trabajo fueron: i) vacas lecheras pastoreando dactylis durante la primavera, sobre una estrategia de pastoreo para lograr una alta tasa de consumo, lograrán un mayor consumo diario de pasto, de mayor valor nutritivo, y una mayor producción de leche que vacas sobre un manejo para lograr una alta cosecha de pasto por hectárea, ii) la estrategia para lograr una alta tasa de consumo de pasto no comprometerá la producción de leche por hectárea y iii) las diferencias en producción individual de leche entre los manejos de pastoreo serán menores cuando las vacas se suplementen con concentrado.

1.4.2 Objetivos

Los objetivos generales de este estudio fueron: (i) evaluar el valor nutritivo de la pastura, el consumo y la producción de leche lograda por vacas lecheras Holando en respuesta a manejos de pastoreo rotativo que priorizan la tasa de consumo de pasto o la cosecha de pasto por hectárea y (ii) evaluar cómo la suplementación con concentrado afecta esta respuesta.

Los objetivos específicos fueron:

— Describir la proporción de componentes morfológicos de la pastura.

— Estimar el valor nutritivo de la pastura seleccionada por los animales (contenido de FDA, FDN y PC).

— Determinar el consumo de pasto por las vacas.

— Establecer producción, composición de la leche y condición corporal de las vacas.

— Evaluar la respuesta en leche de las vacas al concentrado.

Running head: EFFECTS OF GRAZING MANAGEMENT AND SUPPLEMENTATION

2. EFFECTS OF GRAZING MANAGEMENT AND CONCENTRATE SUPPLEMENTATION ON INTAKE AND MILK PRODUCTION OF DAIRY COWS GRAZING ORCHARDGRASS

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2.1 RESUMEN

El manejo del pastoreo y su combinación con suplementos son determinantes del consumo de pasto y la producción animal. En primavera, las altas tasas de crecimiento de las pasturas permiten incrementar la producción animal a partir de pasto y reducir el uso de suplementos. Tradicionalmente, el manejo de pastoreo se ha orientado principalmente a lograr una alta cosecha de pasto por hectárea, mientras que estrategias de pastoreo orientadas a maximizar la tasa de consumo de pasto de los animales han sido exploradas con mayor énfasis en los últimos años. Los objetivos del presente estudio fueron: (i) evaluar el valor nutritivo de la pastura, el consumo y la producción de leche lograda por vacas lecheras Holando pastoreando dactylis en respuesta a manejos de pastoreo que priorizan la cosecha de pasto por hectárea o la tasa de consumo de pasto, y (ii) evaluar cómo la suplementación con concentrados afecta dicha respuesta. El experimento se realizó en Uruguay usando 24 vacas lecheras Holando en lactancia media pastoreando dactylis en forma rotativa durante un período de 81 días. El diseño experimental fue de bloques completos al azar con arreglo factorial 2 × 2. Se combinaron dos estrategias de manejo de pastoreo [alta tasa de consumo (HIR) con alturas de la pastura pre- y pospastoreo de 21 y 13 cm, respectivamente, vs. alta cosecha de pasto por hectárea (HHH) con un objetivo prepastoreo de 3,5 a 4 hojas por macollo y un objetivo pospastoreo que apuntó a dejar un mínimo de área foliar remanente luego del pastoreo, es decir, alturas remanentes de 7 a 11 cm] y dos niveles de suplementación con concentrado [0 (CS0) y 4 (CS4) kg de MS/vaca por día]. Se midió: altura de la pastura, número de hojas por macollo, composición química y morfológica de la pastura, PV y CC de las vacas y producción de leche por vaca y por hectárea. Los análisis estadísticos se realizaron usando modelos lineales mixtos. Comparadas con las vacas en HHH, las vacas en HIR pastorearon forraje de mayor valor nutritivo (pastura con mayor contenido de PC y menor contenido de FDA), lograron un mayor consumo, mayor producción de leche, e incrementaron su PV durante el experimento. Por su parte, las vacas en

HHH lograron mayor producción de leche y sólidos por hectárea, y perdieron PV y CC cuando fueron manajedas sin suplementación. En conclusión, la estrategia de manejo de pastoreo HIR es una opción efectiva para sistemas lecheros pastoriles que busquen maximizar la producción individual de vacas lecheras de alta producción. Por otro lado, la estrategia de manejo de pastoreo HHH podría ser aplicada en sistemas lecheros donde se apunte a lograr una alta producción por hectárea, teniendo en cuenta que vacas de alta producción bajo esta estrategia perderían PV y CC al ser manejadas sin suplementación.

Palabras clave: altura de la pastura, pastoreo rotativo, número de hojas por macollo, *Dactylis glomerata*, vacas Holando.

2.2 ABSTRACT

Grazing management and its combination with supplements are determinants of herbage intake and animal production. In spring, the high pasture growth rate allows to increase animal production from herbage and reduces the use of supplements. Traditionally, grazing management strategies have focused mainly on achieving a high herbage harvest per hectare, whereas animal-based pasture targets oriented to maximize the intake rate of herbage have been recently explored. The objectives of the present study were: (i) to evaluate the herbage nutritional value, intake and milk production of Holstein dairy cows grazing orchardgrass in response to grazing management strategies that prioritize either herbage harvest per hectare or herbage intake rate, and (ii) to assess whether concentrate supplementation affects this response. The experiment was conducted in Uruguay using twenty-four mid-lactation Holstein dairy cows grazing orchardgrass (*Dactylis glomerata*) managed under rotational stocking over an 81-day period. The experimental design was a randomized complete block with a 2 × 2 factorial arrangement. Two grazing management strategies [i.e. high intake rate (HIR) with pre- and post-grazing sward target heights of 21 and 13 cm, respectively, vs. high herbage harvest per hectare (HHH) with a pre-grazing target of 3.5-4 leaves per tiller and a post-grazing target of minimum leaf area or sward heights between 7-11 cm] and two levels of concentrate supplementation [0 (CS0) and 4 (CS4) kg of dry matter/cow per day] were combined. Sward height, number of leaves per tiller, feed intake, herbage morphological and chemical composition, body weight (BW) and body condition score (BCS) of cows and milk production per cow and per hectare were measured. Statistical analyses were performed using linear mixed models. Compared to cows under HHH, cows under HIR grazed herbage with greater nutritional value (i.e. greater herbage crude protein and lower acid detergent fiber contents), achieved a greater feed intake, greater milk production per cow and increased BW during the experimental period. Conversely, cows under HHH achieved greater milk and milk solids production per hectare and lost BW and BCS when were managed without supplementation. In conclusion, HIR grazing management is an effective option for grazing dairy production systems that seek to maximize individual productivity of high-producing cows. On the other hand, HHH grazing strategies could be applied to dairy farm businesses where farm profit is driven by milk production per hectare, but considering that high-producing dairy cows under this strategy lose BW and BCS when were managed without concentrate supplementation.

Keywords: sward height, rotational stocking, number of leaves, *Dactylis glomerata,* Holstein cows.

2.3 INTRODUCTION

Grasslands provide an inexpensive source of feed for lactating dairy cows (Dillon, 2006) and, if well managed, they can sustain high levels of milk production (Ison et al., 2020; Menegazzi et al., 2021). In subtropical climate regions such as Uruguay, spring (from September to December) is the season when swards such as orchardgrass present high nutritive value and capacity to grow (Peri et al., 2007). This represents an opportunity to increase milk production from herbage in grazing systems. However, realizing this opportunity requires adjustments in supplementation levels to reduce substitution of herbage by concentrate, as well as adjustments in grazing management to increase the intake rate of herbage (Carvalho, 2013).

Under grazing conditions, concentrate supplementation is known to improve milk yield (Bargo et al., 2003). Milk response to concentrate is substantially affected by many factors related to the animal, the sward, and the type of supplement (Baudracco et al., 2010). To maximize productive efficiency under grazing, concentrate supplementation often requires adjustments based on herbage availability (Méndez et al., 2020). When herbage availability is high, recommended supplementation levels are limited to no more than 4 kg per cow per day, thereby minimizing the effects of herbage substitution and maintaining a high milk response to concentrate (Baudracco et al., 2010; Delagarde et al., 2011). On the other hand, for a given level of concentrate supplementation, grazing management tuned for with a high herbage allowance per cow is associated with greater herbage substitution, and thus a smaller milk response to concentrate (Bargo et al., 2003).

In the context of rotational grazing, a commonly-applied principle for pasture management is “to use all the grass-grown” (Roche et al., 2017). Doing so involves optimizing post-grazing residual in order to harvest a relatively high proportion of the available herbage, and pre-grazing targets that insure the replenishment of carbohydrate stores and avoid much leaf senescence (Fulkerson and Donaghy, 2001; Roche et al., 2017). By contrast, recent studies described grazing management strategies based on animal-based pasture targets; these are oriented to maximizing herbage intake per unit of time. This, in turn, implies maximizing animal herbage intake per unit of time over the grazing day (Carvalho, 2013). Indeed, ideal pre-grazing animal-based pasture targets based on sward height are available for various forage species (Carvalho, 2013). Furthermore, moderate levels of sward depletion (at approximately 40 % of the initial sward height) can maintain consistently high intake rate for animals grazing in a strip or paddock (Fonseca et al., 2012; Mezzalira et al., 2014).

In contrast to heavy grazing, moderate grazing intensity practices allow for higher nutritional value of the harvested herbage and greater herbage intake by animals (Savian et al., 2020; Menegazzi et al., 2021). This, in turn, has been shown to result in enhanced milk yield of dairy cows (Dale et al., 2018; Menegazzi et al., 2021). However, to date, no previous studies in dairy cows have compared grazing management strategies where the goal is to offer an optimal sward structure to animals to maximize their herbage intake rate, that consider both ideal pre-grazing sward height and sward depletion level in rotational stocking, as proposed by Carvalho (2013). Furthermore, it is unclear how such grazing management strategy affect milk production per unit area.

Indeed, the few studies that reported on the effect of grazing management on production per hectare present conflicting findings. Dale et al. (2018) reported increases in milk production per hectare following greater grazing intensity, though this study evaluated only a small range of post-grazing sward heights. Conversely, Schons et al. (2021) in lambs and Portugal et al. (2021) in steers using contrasting sward structures of Italian ryegrass and sorghum pastures, respectively, found that in spite of a lower stocking rate, high frequency/low intensity grazing strategies that maximize intake rate also produced greater liveweight gain per hectare.

All the evidence taken together, our hypotheses are that: (a) dairy cows grazing orchardgrass in spring under a high intake rate strategy will achieve a greater herbage intake of high nutritional value and, thus, greater milk production than cows grazing under a high herbage harvest per hectare strategy, (b) the high intake rate strategy will not compromise milk production per hectare and (c) supplementation with concentrate will minimize production differences between grazing management strategies.

The objectives of the present study were: (i) to evaluate the herbage nutritional value, intake and milk production of Holstein dairy cows grazing orchardgrass in response to grazing management strategies that prioritize either herbage harvest per hectare or herbage intake rate, and (ii) to assess whether concentrate supplementation affects this response.

2.4 MATERIALS AND METHODS

All experimental procedures were approved by the committee on Ethics in the Use of Experimental Animals of the National Institute of Agricultural Research of Uruguay (INIA) (number 0009/11).

2.4.1 Site, Climate, and Pasture Management

The experiment was carried out at the dairy unit of the "La Estanzuela" station of the INIA (Uruguay, 34º20'14''S, 57º41'32''W). The experimental area consisted of 18 ha of two to four-year-old pure orchardgrass pastures (*Dactylis glomerata* cv. INIA Perseo). The predominant soil was a typical Eutric Brunisol with pH of 5.5 and OM content of 3.8 %.

The experimental period (also known as stocking season, following Allen et al., 2011) extended from August 11 to October 30, 2020. Previously, in May 2020, the area had been mowed to 5 cm sward height, closed and then fertilized in June (100 kg P/ha as superphosphate, 50 kg N/ha and 8 kg S/ha as sulphur urea and 25 kg K/ha as potassium chloride) and again in July (50 kg N/ha as urea and 25 kg K/ha as potassium chloride). The pasture was fertilized once again in September (106 kg N/ha as urea). This ensured that the stocking season started with similar conditions of pasture management and no deficiencies in fertilization of N, P, K and S. Furthermore, water balance analyses showed that available soil water was near-optimal for most of the stocking season (soil with a holding capacity of 90 mm of plant available water; supplemental figure S1). Overall, the weather during the stocking season seemed to be characterized by mild temperatures and low water deficit, which is well within historical values for the site (supplemental figure S1).

2.4.2 Experimental Design and Treatments

Two grazing management strategies and two levels of concentrate supplementation were arranged in a 2 × 2 factorial treatment structure within a randomized complete block design. A total of three blocks were defined by age of pasture (2, 3 and 4 years of age). Each 6-ha block was composed of four paddocks of 1.5 ha. Within each block, paddocks were randomly assigned to treatments, thus defining the experimental units.

Grazing management strategies are referred to as high intake rate (**HIR**) and high herbage harvest per hectare (**HHH**). Under HIR, the goal was to offer cows a sward structure that allowed maximum herbage intake rate on a per-time unit basis (Carvalho, 2013). Target pre-grazing and post-grazing sward heights were specified at 21 cm (Cazcarra et al., 1995) and 13 cm, respectively. That is, the post-grazing target was only 60 % of the initial sward height, thus implying a sward depletion level of 40 %, as suggested by Fonseca et al. (2012) and Carvalho (2013).

Under HHH, the goal was to achieve high herbage harvest per hectare. The pre-grazing target was set between 3.5 and 4.0 leaves per tiller and was intended to minimize losses by senescence while ensuring replenishment of water-soluble carbohydrate reserves (Fulkerson and Slack, 1994; Duru and Ducrocq, 2000). The target post-grazing criterion consisted of a sward with 15 % of rejected ungrazed patches and 1-2 cm of leaf lamina left in grazed tillers, so that leaf growth zones remained unaffected (Lattanzi et al., 2004). Practical implementation of HHH consisted of target post-grazing sward heights between 7 and 11 cm, and a normalized difference vegetation index (**NDVI**) not smaller than 0.40; the latter corresponds to 10 % interception of photosynthetically active radiation (Oyarzabal et al., 2011).

Concentrate supplementation rate was either nil (**CS0**) or 4 kg of DM/cow per day (**CS4**) (equivalent to 4.5 kg of concentrate per cow on a fresh basis). The latter was selected to minimize herbage substitution effects by concentrate (Baudracco et al., 2010).

2.4.3 Animals and Management

Twenty-four mid-lactation Holstein dairy cows with 116 ± 16 (mean ± SD) days in milk, 550 ± 46 kg, and 2.8 ± 0.1 BCS, on a scale from 1 to 5 (Edmonson et al., 1989), at the beginning of the stocking season and producing 29 ± 3.7 kg of milk/d, were recruited for this study. Cows were first arranged into three groups according to parity and milk yield, namely primiparous (34 ± 4.7 kg/d), medium-producing multiparous (33 ± 2.9 kg/d), and high-producing multiparous (40 ± 3.3 kg/d). Each group was then randomly assigned to a block. Thereafter, individual cows were paired according to pre-experimental daily milk yield, days in milk and BW, and pairs were randomly assigned to paddocks within a block.

In addition, twenty-eight put-and-take Holstein dry cows of 630 ± 113 (mean ± SD) kg were strategically managed in parallel as a single non-experimental herd to maintain appropriate sward height and number of leaves per tiller of each experimental treatment. These animals were not used for any measurement in this study.

During a three-week pre-experimental period, all cows received a transition diet consisting of an estimated per-animal initial intake of 4 kg of herbage, 8 kg of corn silage and 7 kg of a commercial concentrate on a DM basis. Throughout the transition period, herbage intake was doubled, the supply of corn silage was progressively decreased and, for the last week prior to the start of the stocking season, the concentrate supplementation treatment was reduced by 70 % and 40 % for cows assigned to receive 0 (CS0) or 4 (CS4) kg of concentrate/d, respectively.

During the stocking season, CS4 cows received a daily total of 4.5 kg fresh weight of a commercial concentrate (Prolacta 16, Prolesa S.A., Santa Lucía, Uruguay) in the milking parlor. The nutrient content of the concentrate was 191, 97, 268, and 76 g/kg DM of CP, ADF, NDF and ash, respectively.

2.4.4 Grazing Management

Each paddock was divided into daily strips where cow pairs were allowed to graze for one day (stocking period, Allen et al., 2011). Cows were moved to a new fresh strip every day at 1500 h (Gibb et al., 1998). The size of strips was adjusted with electric fences to reach the post-grazing targets corresponding to each grazing management and thus varied between treatments, days, and blocks. The average size of strips across the stocking season was 723 ± 131, 698 ± 142, 207 ± 50 and 186 ± 41 m^2 (mean ± SD) in HIR-CS0, HIR-CS4, HHH-CS0 and HHH-CS4, respectively.

A stocking cycle was defined as the time elapsed between the initiation of successive stocking periods on a specified grazing land area, that is, one stocking period plus one rest period (Allen et al., 2011). Therefore, the cows returned to the first strip-grazing in a paddock when that strip again attained the target pre-grazing height (for HIR) or the target number of leaves per tiller (for HHH). Whenever a new stocking cycle started, the area of the paddock not used during the previous stocking cycle was grazed by the group of non-experimental dry cows to control sward structure following pre- and post-grazing targets of the corresponding treatment.

2.4.5 Sward Measurements

2.4.5.1 Sward Height, Number of Leaves per Tiller and NDVI

Pre- and post-grazing sward heights were measured three times a week on the strip-grazing using a sward stick (Barthram, 1985). A total of 80 random zig-zag readings were taken in the strip-grazing on each measurement event. The number of leaves per tiller was measured twice per week in 10 random tillers collected from the strip-grazing both pre- and post-grazing. The NDVI was measured with a hand-held sensor (Greenseeker, Handheld, Trimble, USA) maintained 1 m above ground and along a zig-zag line in each strip-grazing both pre- and post-grazing.

In addition, the sward height and number of leaves per tiller were measured weekly on the first strip-grazing of the previous stocking cycle to determine when to start the next stocking cycle.

2.4.5.2 Herbage Mass and Morphological Composition

Herbage mass was measured in a subset of samples collected weekly. Specifically, every week, three random quadrats (0.5 × 0.5 m) per strip were measured for sward height using the sward stick (Barthram, 1985) and then clipped at ground level both at pre- and post-grazing. Cuts were made in paddocks of both grazing management strategies, alternating one block per week. Clipped herbage was separated into green and dead material, oven-dried at 55°C until constant weight and green herbage mass was expressed in kg DM/ha. No correction to DM at 105°C was made. At each pre- and post-grazing, non-linear regression was used to fit observed herbage mass (ground level) as a function of sward height (supplemental figure S2). The fitted regression equations were then used to predict herbage mass on a weekly basis for each treatment.

Herbage morphological composition was measured twice, coinciding with measurements of herbage chemical composition and intake by cows (described later). At each measurement period, herbage in three random quadrats (0.5 × 0.5 m) per strip was clipped at ground level in both pre- and post-grazing, in all treatments. Green material was first separated from dead material and then a representative subsample of green material was separated into leaf lamina, stem-pseudostem and inflorescence components. Fresh herbage samples of each component were weighed on a precision scale and then oven-dried at 55°C until constant weight; no correction to DM at 105°C was made. The proportion of each component was computed as a fraction of total green dry mass in each quadrat; the leaf lamina/stem-pseudostem ratio was also computed.

2.4.5.3 Herbage Chemical Composition

Samples for herbage chemical composition were obtained twice during the stocking season by hand-plucking (Johnson, 1978). Timing of sample collection coincided with measurements for intake (described later). Hand-plucking was performed by trained technicians based on close observation intended to mimic cow bites. At each measurement period, hand-plucked samples were collected twice daily, namely after cows entered the strip (**PM**; between 1500 h and 1800 h) and the next morning (**AM**; between 1000 h and 1200 h). Samples were then oven-dried at 55°C for 72 h, ground with a knife mill to pass through a 1 mm screen, and analyzed for DM, OM, CP (AOAC, 1990; methods 934.01, 942.05, and 955.04, respectively), NDF (using heat-stable α-amylase and sodium sulfite) and ADF contents (Van Soest et al., 1991), expressed exclusive of residual ash.

2.4.6 Animal Measurements

2.4.6.1 Milk Production and Composition, Body Condition Score and Body Weight

Individual milk production was recorded (Metatron P21, GEA Ltd., Düsseldorf, Germany) at each milking (0400 h and 1400 h) and summed for the day. Every day, cows were removed from their strips at 0300 h and 1300 h, returning at 0500 h and 1500 h, respectively. Starting on the third week of the stocking season, individual milk samples were collected on each cow 4 times per week for analyses of fat, protein, lactose, BHB and MUN content using transformed infrared spectroscopy (MilkoScan; Foss Electric, Hillerod, Denmark).

Solid-corrected milk (**SCM**) per day was calculated based on measured milk, lactose, fat, and protein production, according to Tyrrell and Reid (1965), as follows:

$$SCM\ (kg/d) = [12.24 \times \text{fat yield}\ (kg/d)] + [7.10 \times \text{protein yield}\ (kg/d)] + [6.35 \times \text{lactose yield}\ (kg/d)] - [0.0345 \times \text{milk yield}\ (kg/d)] \quad (1)$$

Cow BCS was measured every 2 weeks by the same experienced observer using a five-point scale (Edmonson et al., 1989). Cow BW was recorded at the beginning and at the end of the stocking season.

Milk response to concentrate supplementation was calculated as the difference between daily milk production of supplemented vs. unsupplemented cows within a block and grazing management combination. This difference was then divided by the daily amount of concentrate consumed by the supplemented cows and expressed in kg of milk per kg of supplement (see next subsection).

2.4.6.2 Herbage and Total Feed Intake

Intake of the concentrate supplement was measured weekly on individual cows by weighing concentrate offered and refusal. Daily, cows in CS4 were offered 4.5 kg of concentrate on a fresh basis, with the aim of supplying 4 kg of supplement on a DM basis basis (Baudracco et al., 2010). As the average DM content of the supplement during the stocking season resulted in 84.9 %, and no refusals were verified, the actual intake of the supplement by cows was determined at 3.8 kg DM/cow per day for all cows.

Total feed intake was evaluated twice during the stocking season, namely measurement period 1 (from 01 to 10 October 2020) and measurement period 2 (from 20 to 30 October 2020). Intake was estimated from fecal output estimated by the titanium dioxide (TiO_2) marker (Glindemann et al., 2009) and diet digestibility, as estimated by Ribeiro Filho et al. (2005, 2007). Before TiO_2 dosage, rectal fecal samples were collected from the 24 cows recruited for the study. These samples served as reference blanks to correct for possible Ti intake from the soil. Fecal blank samples were pooled by treatment and measurement period, and analyzed for Ti, DM and ash. Content of Ti in the fecal blank samples was not detectable.

For TiO_2 marker dosage, each cow was dosed with a gelatin capsule (A-10 CT, Torpac Inc., Fairfield, NJ) containing 11.6 g of TiO_2 (Glindemann et al., 2009) on a daily basis for 10 days. The purity of the TiO_2 was 93.2 %. The first 5 days of TiO_2 dosage were considered an adaptation to the marker, and the last 5 days of TiO_2 dosage were used for fecal sampling. Rectal fecal samples of each cow were taken twice daily after milking. Immediately after sampling, fecal samples were frozen at -20°C for later lab processing.

Fecal samples were oven-dried at 55°C for 72 h and then ground with a knife mill to pass through a 1-mm screen. For each cow, fecal samples taken during the 5 days were pooled by measurement period, and then Ti content was analyzed according to Myers et al. (2004). Contents of DM, ash, CP, and FDA (expressed exclusive of residual ash) were also determined using the methods described above for the determination of chemical composition of herbage samples.

The diet OM digestibility (**OMD**) was estimated according to Ribeiro Filho et al. (2005, 2007) considering fecal CP content (CP_{feces}), fecal ADF content (ADF_{feces}) and herbage CP content ($CP_{herbage}$):

$$OMD = 1.035 – [24.78 / CP_{feces}\ (g/kg\ OM)] – [0.00027 \times ADF_{feces}\ (g/kg\ OM)] – [0.0571 \times CP_{herbage}\ (g/kg\ OM) / CP_{feces}\ (g/kg\ OM)] \quad (2)$$

Total feed intake per cow was calculated as follows:

$$\text{Total feed intake per cow (kg OM/cow per day)} = \text{Fecal production (kg OM)} / (1 - OMD) \quad (3)$$

Subsequently, herbage OM intake was calculated as the difference between total feed intake per cow and concentrate OM intake per cow. Herbage and concentrate OM intakes were transformed to DM herbage and concentrate intake through herbage and concentrate OM content, as follows:

Herbage DM intake (kg DM/cow per day) = herbage OM intake (kg) / herbage OM content (g/g) (4)

Concentrate DM intake (kg DM/cow per day) = concentrate OM intake (kg) / concentrate OM content (g/g) (5)

The herbage and concentrate DM intake were added to obtain the total DM feed intake per cow. Feed efficiency was calculated on a daily basis as follows:

Feed efficiency (kg SCM/kg DM) = SCM per cow (kg DM/d) / total feed intake per cow (kg DM/d). (6)

2.4.7 Stocking Rate, Milk Production and Herbage Intake per Hectare

Stocking rate (expressed in kg BW/ha per day) was calculated considering the cow's BW (kg), the daily strip area (m^2) and the duration of the stocking cycle (days) (Dale et al., 2018), as follows:

Stocking rate = kg BW per strip / strip area / duration of the stocking cycle × 10000 (7)

Daily milk production per hectare (expressed both as kg milk/ha per day and as kg SCM/ha per day) was calculated as follows:

Milk production per hectare = average milk yield per cow per day × number of cows per strip / strip area / duration of stocking cycle × 10000 (8)

SCM production per hectare = average SCM per cow per day × number of cows per strip / strip-grazing area / duration of stocking cycle × 10000 (9)

Likewise, daily herbage intake per hectare (expressed as kg herbage DM intake/ha per day) was calculated as:

Herbage intake per hectare = average herbage intake per cow × number of cows per strip / strip-grazing area / duration of stocking cycle × 10000 (10)

2.4.8 Statistical Analyses

Cow-level variables collected on a daily basis (i.e. milk production and composition per cow) were summarized weekly. Cow-level variables collected twice during the stocking season (i.e. herbage intake, total feed intake, feed efficiency, estimated diet OM digestibility, total N intake, fecal production and fecal N output) and those collected every two weeks during the stocking season (i.e. BCS) were analyzed without further summarization. Similarly, paddock-level variables collected or estimated on a daily basis (i. e. sward height, number of leaves per tiller, NDVI, estimated herbage mass, stocking rate, herbage intake and milk production per hectare, and milk response to concentrate supplementation) were also summarized weekly. Paddock-level variables collected twice during the stocking season (i.e. herbage chemical and morphological composition) were analyzed without further summarization.

Data were analyzed using general linear mixed models. For cow-level variables, the linear predictor included the fixed effects of grazing management, concentrate supplementation and week or measurement period (1 and 2), and all 2- and 3-way interactions. The linear predictor also included random effects for block and for paddock, the latter identified by the crossproduct of block-by-treatment as the experimental unit for treatments. Furthermore, where applicable, a cow-level covariance structure was specified to recognize repeated measures per cow in the data generation process. For each response variable, alternative covariance structures were tested and the selected one was based on best fit to the data according to Bayesian Information Criterion, after checking model assumptions.

For variables collected at the paddock level, the linear predictor included fixed effects of grazing management, concentrate supplementation, week or measurement period, moment of measurement (AM and PM, for herbage chemical composition) and all 2-, 3- and 4-way interactions. The linear predictor also included random effects for block and for paddock, the latter being identified by the crossproduct of block-by-treatment in order to recognize the experimental unit for treatments despite subsampling in the data generation process (i.e. multiple quadrants per strip). For milk response to concentrate supplementation, the linear predictor included grazing management, week and their interaction, as well as the random effects of block and paddock, the latter being identified as an experimental unit by the crossproduct of block-by- grazing management.

In all cases, model assumptions were evaluated using studentized residual plots. Variance components were estimated using restricted maximum likelihood. Kenward-Roger's procedure was used for estimation of degrees of freedom and adjustments to estimated standard errors. Least square mean treatment estimates and corresponding standard errors are presented at the appropriate level of inference. Pairwise comparisons were used to characterize effects of treatments. Tukey-Kramer (for marginal effects) or Bonferroni (for simple effects) procedures were used for multiplicity adjustment in order to avoid inflation of the type I error. All statistical analyses were performed using PROC GLIMMIX (SAS 9.4; SAS Institute Inc., Cary, NC, USA). Results were declared significant at $P < 0.05$ and marginally significant at $0.05 < P < 0.10$.

2.5 RESULTS

2.5.1 Stocking Cycles and Sward Characteristics

The number of stocking cycles was greater under HIR (estimated mean of 5 ± 0.2 stocking cycles) compared to HHH (estimated mean of 2 ± 0.2

stocking cycles) ($P < 0.001$), whereas the rest period duration was estimated at 15 ± 1 and 38 ± 1 days, respectively ($P < 0.001$).

Table 1 shows estimated means (and corresponding standard errors) for pre- and post-grazing sward height, sward depletion level, as well as for pre- and post-grazing number of leaves per tiller and NDVI of orchardgrass pastures for each combination of grazing management and concentrate supplementation, averaged across the stocking season. In turn, table 2 shows estimated means (and corresponding standard errors) for pre- and post-grazing estimated herbage mass and morphological composition of orchardgrass pastures for each combination of grazing management and concentrate supplementation, averaged across the stocking season (for herbage mass) or measurement periods (for herbage morphological composition).

Table 1. Estimated means and corresponding standard errors for pre- and post-grazing sward height, sward depletion level, as well as for pre- and post-grazing number of leaves per tiller and NDVI of orchardgrass pastures grazed by lactating dairy cows managed under two grazing management strategies[1] and two levels of concentrate supplementation[2].

	Treatments[1,2]						
	HIR		HHH		*P*-values[3]		
Item	CS0	CS4	CS0	CS4	GM	CS	GM × CS
Sward height, cm							
Pre-grazing	22.9 ± 1.5	24.1 ± 1.5	27.7 ± 1.5	28.9 ± 1.5	.	0.388	0.969
Post-grazing	13.9 ± 0.6	14.9 ± 0.6	9.6 ± 0.6	10.4 ± 0.6	< 0.001	0.075	0.862
Sward depletion level (%)	39.2 ± 1.6	37.8 ± 1.6	65.3 ± 1.6	63.7 ± 1.6	< 0.001	0.373	0.951
Number of leaves per tiller							
Pre-grazing	2.5 ± 0.1	2.6 ± 0.1	3.3 ± 0.1	3.4 ± 0.09	.	0.326	0.881
Post-grazing	1.3 ± 0.1	1.3 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	< 0.001	0.747	0.796
NDVI[4]							
Pre-grazing	0.63 ± 0.01	0.66 ± 0.01	0.72 ± 0.01	0.73 ± 0.01	< 0.001	0.403	0.873
Post-grazing	0.55 ± 0.02	0.56 ± 0.02	0.46 ± 0.02	0.49 ± 0.02	< 0.001	0.181	0.402

[1]Grazing management strategy: HIR = high intake rate; HHH = high herbage harvest per hectare.

[2]Concentrate supplementation level: CS0 = 0 kg DM/cow per day; CS4 = 4 kg DM/cow per day.

[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), main effect of concentrate supplementation (CS) and their interaction (GM × CS). *P*-values corresponding to statistical tests on the main effect of grazing management are not shown (.) when an interaction between grazing management and week was significant ($P < 0.05$).

[4]NDVI, normalized difference vegetation index.

Table 2. Estimated means and corresponding standard errors for pre- and post-grazing herbage mass and morphological composition of orchardgrass pastures grazed by lactating dairy cows managed under two grazing management strategies[1] and two levels of concentrate supplementation[2].

	Treatments[1,2]						
	HIR		HHH		*P*-values[3]		
Item	CS0	CS4	CS0	CS4	GM	CS	GM × CS
Herbage mass, kg DM/ha							
Pre-grazing	2430 ± 143	2562 ± 143	2959 ± 143	3079 ± 143	.	0.399	0.967
Post-grazing	1693 ± 70	1832 ± 70	1128 ± 70	1241 ± 70	.	0.070	0.828
Leaf lamina (%)							
Pre-grazing	53.3 ± 2.6	57.0 ± 2.9	54.2 ± 2.6	51.0 ± 2.9	0.393	0.927	0.254
Post-grazing	45.2 ± 2.1	42.8 ± 2.3	32.8 ± 2.1	36.1 ± 2.4	0.005	0.833	0.255
Stem/pseudostem (%)							
Pre-grazing	45.4 ± 2.6	41.5 ± 2.9	43.4± 2.6	44.8 ± 2.9	0.808	0.645	0.330
Post-grazing	54.2 ± 2.1	56.2 ± 2.4	66.5 ± 2.1	63.6 ± 2.5	0.005	0.845	0.311
Inflorescence (%)							
Pre-grazing	1.29 ± 0.62	1.71 ± 0.76	2.37 ± 0.62	4.46 ± 0.76	.	0.120	0.274
Post-grazing	0.68 ± 0.32	0.92 ± 0.39	0.69 ± 0.32	0.37 ± 0.43	0.492	0.918	0.474
Leaf lamina/stem-pseudostem ratio							
Pre-grazing	1.23 ± 0.17	1.50 ± 0.17	1.43 ± 0.17	1.46 ± 0.17	0.662	0.413	0.510
Post-grazing	0.80 ± 0.05	0.78 ± 0.06	0.52 ± 0.05	0.58 ± 0.06	0.005	0.726	0.494

[1]Grazing management strategy: HIR = high intake rate; HHH = high herbage harvest per hectare.

[2]Concentrate supplementation level: CS0 = 0 kg DM/cow per day; CS4 = 4 kg DM/cow per day.

[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), main effect of concentrate supplementation (CS) and their interaction (GM × CS). *P*-values corresponding to statistical tests on the main effect of grazing management are not shown (.) when an interaction between grazing management and week or measurement period was significant ($P < 0.05$).

No evidence for any interactions between grazing management and concentrate supplementation was observed for any of the sward characteristics considered for orchardgrass pastures (*P* > 0.10 in all cases). In turn, a marginally significant effect of concentrate supplementation was detected on post-grazing sward height (table 1) and on post-grazing herbage mass (table 2), both of which were marginally greater under CS4 compared to CS0 (estimated difference of 0.94 ± 0.47 cm, *P* = 0.075; and 126 ± 56 kg DM/ha, *P* = 0.070, respectively), regardless of grazing management strategy. There was no evidence of any additional effect of concentrate supplementation on other sward characteristics (*P* > 0.10 in all cases).

The effects of grazing management on pre-grazing sward characteristics of sward height, number of leaves per tiller and herbage mass were apparent from weeks 4 or 5 of the stocking season (interaction between grazing management and week: *P* < 0.001 in all cases; supplemental figure S3 and S4). Specifically, HHH had a greater pre-grazing sward height at weeks 5, 6, 7, 9 and 10 of the stocking season relative to HIR, with estimated means of 31.5 ± 1.7 cm and 22.9 ± 1.6 cm for HHH and HIR, respectively, during this period (supplemental figure S3). Similarly, the pre-grazing number of leaves per tiller was greater under HHH relative to HIR in weeks 4, 5, 6, 7 and 8 (*P* < 0.045) (supplemental figure S3). Pre-grazing estimated herbage mass was also greater under HHH relative to HIR in weeks 5, 6, 7, 10 and 11 (estimated means of 3407 ± 164 kg DM/ha and 2459 ± 164 kg DM/ha, respectively, during this period; *P* < 0.01; supplemental figure S4). The effect of grazing management on pre-grazing NDVI was apparent throughout the stocking season and was greater under HHH compared to HIR (*P* < 0.001; table 1). For the pre-grazing herbage morphological composition, there was no evidence for any effect of grazing management, except for inflorescence proportion. Specifically, the effect of grazing management on pre-grazing inflorescence proportion varied depending on the measurement period (interaction: *P* = 0.027). Grazing management showed no evidence for any effect during measurement period 1 (*P* = 0.754), whereas during measurement period 2, HHH registered a greater pre-grazing inflorescence proportion than HIR (estimated means of 6.60 % ± 0.96 for HHH and 2.82 % ± 0.96 for HIR; *P* = 0.024).

For post-grazing sward assessments, HIR had a greater sward height relative to HHH throughout the stocking season and regardless of concentrate supplementation level (estimated means of 14.4 ± 0.4 cm and 10.0 ± 0.4 cm, respectively; *P* < 0.001; table 1; supplemental figure S3). Sward depletion levels were consistently greater (*P* < 0.001) in HHH relative to HIR throughout the stocking season, with estimated means of 64.5 % ± 1.2 and 38.5 % ± 1.2, respectively. Post-grazing number of leaves per tiller was greater under HIR compared to HHH throughout the stocking season (estimated means of 1.3 ± 0.1 and 0.8 ± 0.1 leaves per tiller, respectively; *P* < 0.001; table 1; supplemental figure S3). Similarly, NDVI post-grazing measurements were greater under HIR compared to HHH throughout the study (estimated means of 0.56 ± 0.02 and 0.47 ± 0.02; *P* < 0.001; table 1). Post-grazing estimated herbage mass was greater under HIR compared to HHH in weeks 1, 2, 3, 4, 5, 6, 7, 8, 9 and 11 (estimated means of 1769 ± 99 kg DM/ha and 1157 ± 99 kg DM/ha respectively, during this period; *P* < 0.05; interaction: *P* = 0.070; supplemental figure S4). Grazing management under HIR yielded a greater post-grazing leaf lamina proportion compared to HHH, with estimated means of 44.0 % ± 1.5 and 34.4 % ± 1.6, respectively (*P* = 0.005). Post-grazing stem-pseudostem proportion was greater under HHH compared to HIR (estimated means of 65.0% ± 1.6 and 55.2% ± 1.6, respectively; *P* = 0.005). Post-grazing leaf lamina/stem-pseudostem ratio was greater under HIR compared to HHH, with estimated means of 0.79 ± 0.04 and 0.55 ± 0.04, respectively (*P* = 0.005).

Table 3 shows estimated means (and corresponding standard errors) for herbage chemical composition of the orchardgrass pastures for each grazing management and moment of measurement averaged across concentrate supplementation levels and measurement periods. As expected, there was no evidence for any effect of concentrate supplementation nor interaction between concentrate supplementation and grazing management on herbage chemical composition (results not shown).

Table 3. Estimated means and corresponding standard errors for chemical composition (expressed as %DM) of orchardgrass pastures grazed by lactating dairy cows managed under two grazing management strategies[1] at two moments of measurement after a new strip allocation[2].

	Treatments[1,2]						
	HIR		HHH		*P*-values		
Item	PM	AM	PM	AM	GM	Moment	GM × Moment
Ash	8.9 ± 0.2[c]	9.7 ± 0.2[b]	9.1 ± 0.2[bc]	11.6 ± 0.2[a]	.	.	< 0.001
NDF	59.5 ± 0.5	59.2 ± 0.5	58.6± 0.5	59.3 ± 0.5	0.354	0.597	0.300
ADF	23.3 ± 0.6[by]	23.7 ± 0.6[b]	24.4 ± 0.6[bx]	27.7 ± 0.6[a]	.	.	0.003
CP	25.9 ± 0.8[a]	25.9 ±0.8[a]	23.6 ± 0.8[b]	19.5 ± 0.8[c]	.	.	< 0.001

[a–c] Mean values in the same row with different superscript letters are different ($P < 0.05$).
[x-y] Mean values in the same row with different superscript letters are different ($P < 0.10$).
[1]Grazing management strategy: HIR = high intake rate; HHH = high herbage harvest per hectare.
[2]Moment of measurement after a new fresh strip allocation: PM = after cows entered the strip; AM = at the next morning.
[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), moment of measurement (Moment) and their interaction (GM × Moment). *P*-values corresponding to statistical tests on the effect of grazing management or moment of measurement are not shown (.) when an interaction between grazing management and moment of measurement was significant ($P < 0.05$).

For NDF content in the herbage, there was no evidence for any effect of grazing management nor interaction between grazing management and moment of measurement (table 3). However, for ADF and CP contents in the herbage, the effect of grazing management varied depending on moment of measurement after a new fresh strip-grazing allocation (AM or PM) ($P = 0.003$ and $P < 0.001$, respectively; table 3). Specifically, ADF content was marginally greater under HHH compared to HIR in the PM (estimated difference of +1.2

± 0.6 percentage points; *P* = 0.081) and largely greater under HHH compared to HIR in the AM (estimated difference of +4.0 ± 0.6 percentage points; *P* < 0.001). The content of CP in the herbage was greater under HIR compared to HHH, both in PM (estimated difference of +2.3 ± 1.0 percentage points; *P* = 0.033) and AM (estimated difference of +6.4 ± 1.0 percentage points; *P* < 0.001), though the magnitude of the difference was larger in the latter.

Herbage in measurement period 2 presented greater NDF content (estimated means of 60.3 % ± 0.5 and 58.1 % ± 0.5 for measurement periods 2 and 1 respectively; *P* < 0.001) and ADF content (estimated means of 25.6 % ± 0.7 and 23.9 % ± 0.7 for measurement periods 2 and 1, respectively; *P* = 0.003), compared to measurement period 1, thus reflecting the advancing phenological stage of the sward throughout the stocking season.

2.5.2 Animal Performance on a Per-Animal Basis

Table 4 shows estimated means (and corresponding standard errors) for milk production and milk composition for each combination of grazing management and concentrate supplementation, averaged across the stocking season. Also, the change of BW of cows during the stocking season (expressed as the difference between final and initial BW) for each combination of grazing management and concentrate supplementation is shown.

No evidence for any interaction between grazing management and concentrate supplementation was identified for milk, SCM, milk fat, milk protein, milk lactose and total milk solids per cow, milk composition and BW change (*P* > 0.10). As expected, SCM and total milk solids per cow were greater under CS4 compared to CS0 (estimated means of 24.6 ± 1.0 kg/cow vs. 21.0 ± 1.0 kg/cow, respectively, *P* = 0.020, and 1.8 ± 0.1 kg/cow vs. 1.6 ± 0.1 kg/cow, respectively, *P* = 0.025), and these effects were apparent regardless of grazing management. No evidence for any effects of concentrate supplementation level was apparent on any other indicators of milk production or composition (*P* > 0.10).

Table 4. Estimated means and corresponding standard errors for milk production and composition, and body weight change of lactating dairy cows grazing orchardgrass pastures managed under two grazing management strategies[1] and two levels of concentrate supplementation[2].

	Treatments[1,2]						
	HIR		HHH		*P*-values[3]		
Item	CS0	CS4	CS0	CS4	GM	CS	GM × CS
Milk production, kg/cow per day							
Milk	23.9 ± 1.6	28.7 ± 1.6	19.3 ± 1.6	21.7 ± 1.6	.	0.104	0.523
SCM[4]	23.0 ± 1.4	27.9 ± 1.4	18.9 ± 1.4	21.2 ± 1.4	.	0.020	0.369
Milk fat	0.92 ± 0.07	1.11 ± 0.07	0.82 ± 0.07	0.84 ± 0.07	.	0.147	0.217
Milk protein	0.78 ± 0.07	0.92 ± 0.107	0.59 ± 0.07	0.70 ± 0.07	.	0.120	0.793
Milk lactose	1.09 ± 0.13	1.39 ± 0.13	0.87 ± 0.13	1.01 ± 0.13	.	0.128	0.551
Total milk solids (fat + protein)	1.69 ± 0.11	2.03 ± 0.11	1.40 ± 0.11	1.55 ± 0.11	.	0.025	0.353
Milk composition							
Fat (%)	4.03 ± 0.19	3.94 ± 0.19	4.33 ± 0.19	4.11 ± 0.19	0.245	0.428	0.747
Protein (%)	3.36 ± 0.10	3.26 ± 0.10	3.27 ± 0.10	3.33 ± 0.10	0.828	0.671	0.104
Lactose (%)	4.82 ± 0.10	4.93 ± 0.10	4.78 ± 0.10	4.91 ± 0.10	0.748	0.281	0.937
MUN, mg/dL	28.0 ± 2.27	27.0 ± 2.27	25.5 ± 2.27	23.9 ± 2.27	0.206	0.545	0.878
BHB, mmol/L	0.071 ± 0.004	0.068 ± 0.004	0.072 ± 0.004	0.070 ± 0.004	0.683	0.595	0.972
Cows conditions							
BW change[5], kg	18.7 ± 11.4	18.6 ± 11.8	-19.7 ± 11.8	-0.17 ± 11.4	0.020	0.330	0.325

[1]Grazing management strategy: HIR = high intake rate; HHH = high herbage harvest per hectare.

[2]Concentrate supplementation level: CS0 = 0 kg DM/cow per day; CS4 = 4 kg DM/cow per day.

[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), main effect of concentrate supplementation (CS) and their interaction (GM × CS). *P*-values corresponding to statistical tests on the main effect of grazing management are not shown (.) when an interaction between grazing management and week was significant ($P < 0.05$).

[4]SCM = solids corrected milk (Tyrrell and Reid, 1965).

[5]Cows BW change expressed as the difference between the final and initial BW of cows.

For milk, SCM, milk fat, milk protein, milk lactose and total milk solids production per cow, the effect of grazing management changed over weeks of the stocking season ($P < 0.001$, $P < 0.001$, $P = 0.039$, $P < 0.001$, $P = 0.006$, and $P = 0.005$, respectively; figure 1 and supplemental figure S5). Specifically, HIR had greater milk (+6.2 ± 1.3 kg/cow), SCM (+5.9 ± 1.6 kg/cow) and total milk solids (+0.43 ± 0.11 kg/cow) production per cow relative to HHH for most of the weeks during the stocking season (2 to 6, 8, 9 and 11 for milk production; 4 to 6, 8, 9 and 11 for SCM and total milk solids production; $P < 0.01$; figure 2). Similarly, HIR had greater milk fat, milk protein and milk lactose production per cow compared to HHH at weeks 5, 6, 8, 9 and 11 ($P < 0.01$; supplemental figure S5). Changes in cow BW during the stocking season were affected by grazing management, with an estimated overall reduction of 10 ± 9 kg for cows under HHH and an estimated increase of 19 ± 9 kg for cows under HIR ($P = 0.020$; table 4) relative to initial BW.

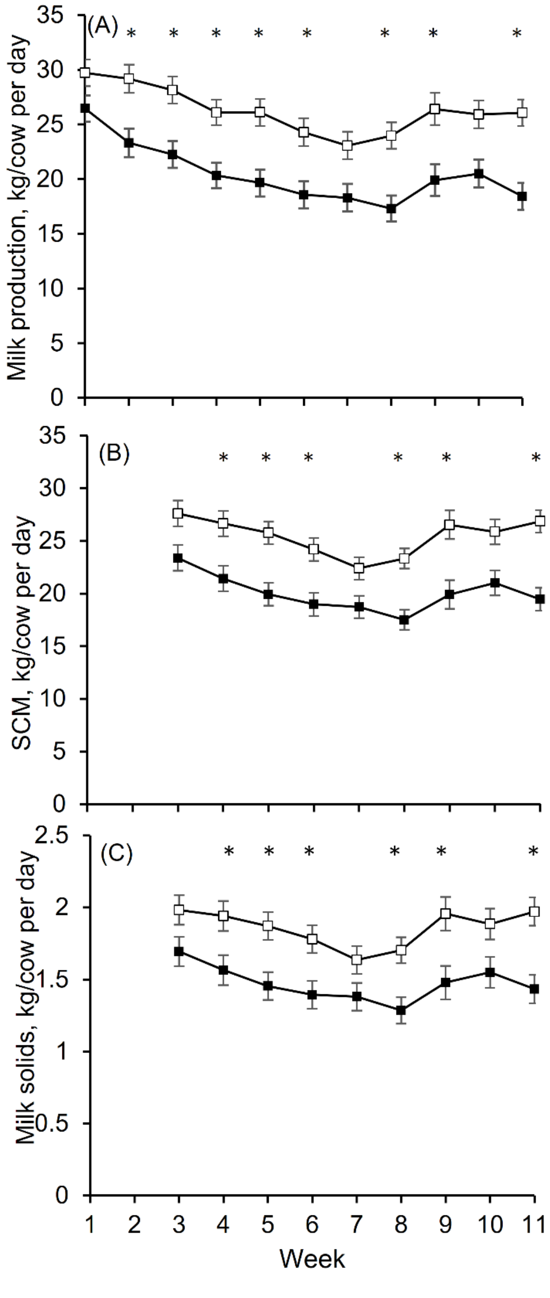

Figure 1. Estimated mean (± SEM) (A) milk, (B) SCM (solids corrected milk) and (C) total milk solids production by dairy cows grazing orchardgrass pastures managed under two grazing management strategies (☐ HIR, high intake rate; ■ HHH, high herbage harvest per hectare) on a weekly basis during the study. Estimates shown have been marginalized over (i.e. averaged for) concentrate supplementation. Panel A and B: interaction grazing management × week, P < 0.001. Panel C: interaction grazing management × week, P = 0.005. * Indicates significant effects at selected weeks of the stocking season (P < 0.05).

For BCS, an interaction was apparent between grazing management and concentrate supplementation (P = 0.027), and between grazing management and week (P < 0.001; figure 2). At the beginning of the stocking season, there was no evidence for any differences in BCS between treatment groups (P > 0.279). Throughout the study, most cows seemed to maintain BCS, except for cows under HHH without any supplementation (i.e. HHH-CS0), which did show a decrease in BCS throughout the 11 weeks of the study (P < 0.001). This group also finalized the stocking season with significantly lower BCS than the remaining treatments (P < 0.002).

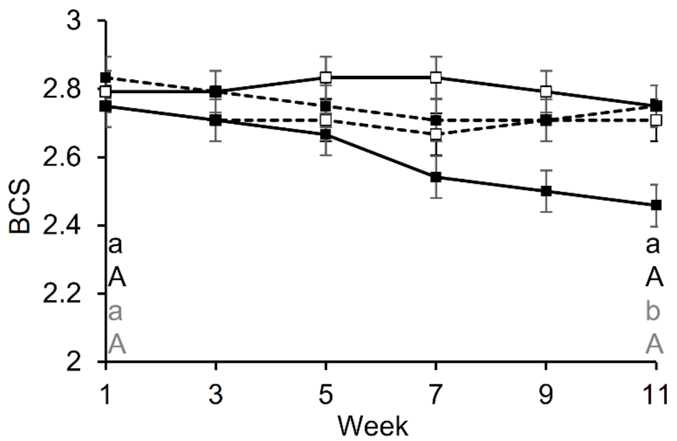

Figure 2. Estimated mean (± SEM) body condition score (BCS) by dairy cows grazing orchardgrass pastures managed under two grazing management strategies (☐ HIR, high intake rate; ■ HHH, high herbage harvest per hectare) and two levels of concentrate supplementation (CS0, 0 kg DM/cow per day: solid lines; CS4, 4 kg DM/cow per day: dashed lines) on a weekly basis during the study. Different letters along the x-axis represent significant differences (P < 0.01) in BCS between weeks 1 and 6 for HIR-CS0 and HIR-CS4 (black letters, uppercase and lowercase, respectively) and for HHH-CS0 and HHH-CS4 (grey letters, uppercase and lowercase, respectively).

For milk response to concentrate supplementation, we identified a marginal effect of grazing management (P = 0.097) with estimated means of

1.2 ± 0.5 and 0.6 ± 0.5 kg milk per kg DM of concentrate consumed by cows under HIR and HHH, respectively.

2.5.3 Herbage and Total Feed Intake

Table 5 shows herbage and total feed intake, feed efficiency, total N intake, diet OM digestibility, fecal production and fecal N output by cows for each combination of grazing management and concentrate supplementation averaged across the measurement periods. No evidence for any interaction between grazing management and concentrate supplementation was observed for total or herbage intake by cows, diet digestibility and fecal output results ($P > 0.10$; table 5). After adjusting for grazing management, herbage intake was lower for CS4 cows compared to CS0 (estimated means of 13.2 ± 0.8 kg DM/cow and 15.1 ± 0.8 kg DM/cow, respectively; $P = 0.025$), but, for total feed intake, concentrate effects were reversed, with greater estimates under CS4 than CS0 (estimated difference of 1.8 ± 0.7 kg DM/cow; $P = 0.033$). The total feed and herbage intake were marginally affected by an interaction between grazing management and measurement period ($P = 0.065$; figure 3). No evidence for any effect of grazing management was found for herbage and total feed intake during measurement period 1 ($P = 0.530$). However, in measurement period 2, the herbage and total feed intake were greater under HIR compared to HHH (estimated difference of 3.2 ± 0.9 kg DM/cow; $P = 0.003$ for both herbage and total feed intake).

A marginally significant effect of grazing management was found for feed efficiency, which was marginally greater under HIR compared to HHH (estimated means of 1.52 ± 0.06 kg SCM/kg DM and 1.32 ± 0.06 kg SCM/kg DM, respectively; $P = 0.066$). Total N intake was affected by grazing management and was, approximately, 172 ± 26 g/cow greater under HIR compared to HHH ($P < 0.001$).

Table 5. Estimated means and corresponding standard errors for herbage and total feed intake, feed efficiency, total N intake, diet digestibility, fecal production and fecal N output by lactating dairy cows grazing orchardgrass pastures managed under two grazing management strategies[1] and two levels of concentrate supplementation[2].

	Treatments[1,2]						
	HIR		HHH		*P*-values[3]		
Item	CS0	CS4	CS0	CS4	GM	CS	GM × CS
Herbage intake, kg DM/cow per day	16.3 ± 0.9	13.9 ± 0.9	14.0 ± 0.9	12.5 ± 0.9	.	0.025	0.535
Total feed intake, kg DM/cow per day	16.3 ± 0.9	17.7 ± 0.9	14.0 ± 0.9	16.3 ± 0.9	.	0.033	0.535
Feed efficiency[4]	1.39 ± 0.11	1.65 ± 0.11	1.34 ± 0.11	1.31 ± 0.11	0.066	0.239	0.137
Total N intake, g/cow per day	681 ± 44	688 ± 44	472 ± 44	554 ± 44	0.001	0.142	0.208
Diet OM digestibility	0.73 ± 0.01	0.74 ± 0.01	0.72 ± 0.01	0.73 ± 0.01	.	0.549	0.872
Fecal production, kg OM/cow per day	4.0 ± 0.3	4.3 ± 0.3	3.5 ± 0.3	4.0 ± 0.3	0.064	0.051	0.525
Fecal N output, g/cow per day	133 ± 8	143 ± 8	106 ± 8	124 ± 8	0.005	0.038	0.407

[1]Grazing management strategy: HIR0 = high intake rate; HHH = high herbage harvest per hectare.

[2]Concentrate supplementation level: CS0 = 0 kg DM/cow per day; CS4 = 4 kg DM/cow per day.

[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), main effect of concentrate supplementation (CS) and their interaction (GM × CS). *P*-values corresponding to statistical tests on the main effect of grazing management are not shown (.) when an interaction between grazing management and measurement period was significant ($P < 0.05$).

[4]kg SCM/ kg DM intake, where SCM refers to solids corrected milk (kg/d) (Tyrrell and Reid, 1965).

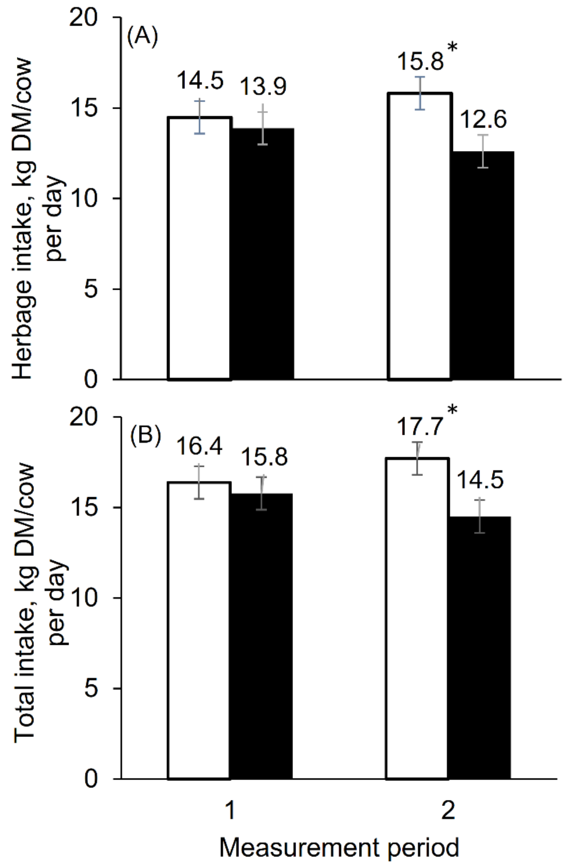

Figure 3. Estimated mean (± SEM) (A) herbage and (B) total feed intake by dairy cows grazing orchardgrass pastures managed under two grazing management strategies (HIR, high intake rate: white bars; HHH, high herbage harvest per hectare: black bars) in two measurement periods (measurement period 1, from 01 to 10 October 2020; and measurement period 2, from 20 to 30 October 2020). Estimates shown have been marginalized over (i.e. averaged for) concentrate supplementation. Panel A and B: interaction grazing management × measurement period, P = 0.065. * Indicates significant effects at measurement period (P = 0.003).

For estimated diet OM digestibility, an interaction between grazing management and measurement period was found (P < 0.001). Specifically, during measurement period 1, there was no evidence for differences between HIR and HHH (P = 0.639), but during measurement period 2, the diet OM digestibility was greater under HIR compared to HHH (estimated means of 0.73 ± 0.006 units and 0.71 ± 0.006 units, respectively; P = 0.008). Diet OM digestibility was 0.01 ± 0.005 units and 0.03 ± 0.005 units greater for measurement period 1 than for measurement period 2 for HIR and HHH, respectively. Regardless of grazing management, fecal N was greater for CS4 compared to CS0 (estimated means of 134 ± 7 g/cow and 119 ± 7 g/cow under CS4 and CS0, respectively; $P = 0.038$) and, even after adjusting for concentrate supplementation level, fecal N was greater under HIR compared to HHH (estimated means of 138 ± 7 g/cow and 115 ± 7 g/cow, respectively; $P = 0.005$).

2.5.4 Animal Performance and Herbage Intake on a Per-Area Basis

Table 6 shows herbage intake, stocking rate, milk production, SCM and total milk solids when assessed on a per-hectare basis, for each combination of grazing management and concentrate supplementation averaged across the stocking season.

No evidence for any interaction between grazing management and concentrate supplementation was observed for herbage intake, stocking rate, milk production, SCM and total milk solids per hectare ($P > 0.10$ in all cases; table 6). Regardless of concentrate supplementation level, grazing management affected herbage intake per hectare (estimated means of 37.5 ± 1.9 kg DM/ha and 28.3 ± 1.9 kg DM/ha for HHH and HIR, respectively; $P < 0.001$) and stocking rate (estimated means of 1569 ± 73 kg/ha and 1089 ± 73 kg/ha for HHH and HIR, respectively; $P < 0.001$), which were greater under HHH compared to HIR. Similarly, SCM and total milk solids per hectare were greater for HHH compared to HIR (estimated means of 59.5 ± 3.1 kg/ha vs. 48.0 ± 3.1 kg/ha for SCM, and 4.36 ± 0.22 kg/ha vs. 3.49 ± 0.22 kg/ha for total milk solids under HHH and HIR, respectively; $P < 0.003$). A marginally significant effect of grazing management was found for milk production per hectare ($P = 0.093$), whereby, regardless of concentrate supplementation level, HHH produced greater yields compared to HIR (estimated means of 58.6 ± 3.3 kg/ha and 49.8 ± 3.3 kg/ha, respectively; $P = 0.093$). There was no evidence for any main effect of concentrate supplementation on stocking rate and herbage intake per hectare ($P > 0.30$, in both cases). However, after accounting for grazing management effects, milk and SCM per hectare were greater under CS4 compared to CS0 (estimated means of 59.7 ± 3.3 kg/ha vs. 48.7 ± 3.3 kg/ha for milk and 59.4 ± 3.1 kg/ha vs. 48.1 ± 3.1 kg/ha for SCM, under CS4 and CS0 respectively; $P < 0.05$). Similarly, total milk solids production per hectare was greater for CS4 compared to CS0 (estimated means of 4.32 ± 0.22 kg/ha and 3.53 ± 0.22 kg/ha, respectively; $P = 0.033$).

Table 6. Estimated means and corresponding standard errors for herbage intake per hectare, stocking rate, milk, SCM and milk solids production per area by lactating dairy cows grazing orchardgrass pastures managed under two grazing management strategies[1] and two levels of concentrate supplementation[2].

	Treatments[1,2]				*P*-values[3]		
	HIR		HHH				
	CS0	CS4	CS0	CS4	GM	CS	GM × CS
Herbage intake, kg DM/ha per day	30.1 ± 2.5	26.5 ± 2.5	37.8 ± 2.5	37.2 ± 2.5	0.010	0.390	0.537
Stocking rate, kg BW/ha per day	1076 ± 103	1103 ± 103	1473 ± 103	1667 ± 103	< 0.001	0.302	0.430
Milk production, kg/ha per day	44.8 ± 4.6	54.8 ± 4.6	52.7 ± 4.6	64.6 ± 4.6	0.093	0.045	0.843
SCM[4], kg/ha per day	42.5 ± 4.4	53.4 ± 4.4	53.8 ± 4.4	65.3 ± 4.4	0.026	0.029	0.946
Total milk solids, kg/ha per day	3.11 ± 0.32	3.86 ± 0.32	3.95 ± 0.32	4.77 ± 0.32	0.020	0.033	0.926

[1]Grazing management strategy: HIR = high intake rate; HHH = high herbage harvest per hectare.
[2]Concentrate supplementation level: CS0 = 0 kg DM/cow per day; CS4 = 4 kg DM/cow per day.
[3]*P*-values corresponding to statistical tests on the main effect of grazing management (GM), main effect of concentrate supplementation (CS) and their interaction (GM × CS).
[4]SCM = solids corrected milk (Tyrrell and Reid, 1965).

2.6 DISCUSSION

Compared to a grazing management strategy aimed at achieving high herbage harvest per hectare, offering dairy cows grazing orchardgrass a sward structure aimed at achieving high intake rate improved herbage nutritive value, milk production per cow and increased cow's BW. However, such grazing management implied a lower stocking rate, lower herbage intake and milk production per hectare. Thus, there was a trade-off between individual milk production and BW of cows vs. production per hectare in response to grazing management. Notably, differences between both grazing management strategies operated regardless of concentrate supplementation level. Despite this, the reduction of BCS observed for non-supplemented cows under HHH, should be considered when deciding on supplement that animals in high grazing intensity strategies such as HHH.

2.6.1 Grazing Management Achieved Sward Targets in all Treatments

Pre- and post-grazing sward height and the number of leaves per tiller were well within the targets of each treatment (table 1; supplemental figure S3). Specifically, pre-grazing sward height under HIR was close to 21 cm (table 1) according to the objective of achieving high intake rates in orchardgrass (Cazcarra et al., 1995). Under HHH, the pre-grazing sward height registered was a consequence of starting grazing with no less than 3.5 leaves per tiller (Duru and Ducrocq, 2000). The post-grazing sward height achieved in HIR (14.4 ± 0.4 cm) was consequence of the target of 40 % of sward depletion (table 1; Fonseca et al., 2012), while the post-grazing condition registered in HHH (mean sward height of 10.0 ± 0.4 cm and NDVI of 0.48 ± 0.02) was the result of keeping a minimal leaf area for regrowth and implied a 65 % of sward depletion. Therefore, we considered that grazing management targets were consistently achieved throughout the stocking season (supplemental figure S3). Sward control was also considered adequate in paddocks where cows received supplementation, as there was no evidence for any effect of concentrate supplementation on sward depletion level, number of leaves per tiller, herbage morphological composition and nutritive value.

As a result of the interaction of sward targets and regrowth rate, the HIR treatment had a greater grazing frequency and thus a greater number of stocking cycles than HHH. These results are consistent with previous studies on temperate (Schons et al., 2021) and tropical (Da Silva et al., 2013; Portugal et al., 2021) pastures. Shorter rest periods when residual sward height is greater are well documented in rotational stocking (Phelan et al., 2013), as the post-grazing sward state has a high quantity of leaves that result in greater light interception (NDVI data, table 1; Zanini et al., 2012) and faster sward regrowth (Gastal and Lemaire, 2015; Merino et al., 2019). Low-intensity and high-frequency grazing strategy (Schons et al., 2021; Portugal et al., 2022) reduces the regrowth interval required for the sward to be optimally grazed again (Parsons and Chapman, 2000).

2.6.2 Grazing Management Affected the Herbage Nutritional Value and Intake

Cows under HIR treatment grazed an herbage with greater nutritive value (table 3), which, unlike HHH, was maintained high until the end of the stocking period (daily strip-grazing). These results can be explained by both lower pre-grazing herbage mass and sward height, and thus less structural tissue (Lemaire and Belanger, 2019), and greater post-grazing herbage mass and sward height, and thus a more leafy residual in HIR (Benvenutti et al., 2020). Benvenutti et al. (2016) and Savian et al. (2020) also found that when animals grazed at a moderate level of sward depletion, the ingested herbage nutritive value remains relatively constant over the stocking period. By contrast, heavy grazing intensities in rotational stocking are associated with a progressive lesser availability of leaves (table 2; Amaral et al., 2013), reduced herbage selection by animals (Chacon and Stobbs, 1976), decreased CP and increased ADF contents as reported here, and less metabolizable energy as reported by Zubieta et al. (2021).

The high level of depletion registered under HHH likely resulted in cows offered swards with a high proportion of pseudostems during the middle and end of the stocking period (strip-grazing; table 2). As a result, one may expect a reduced bite depth, bite mass (Tharmaraj et al., 2003), intake rate (Laca et al., 1992) and, consequently, daily herbage intake (Savian et al., 2020; Zubieta et al., 2021). However, we found evidence of lower herbage intake under HHH relative to HIR only during measurement period 2 (figure 3). In this regard, it is probably that cows under HHH presented an increase in bite rate and grazing time during measurement period 1, which allowed them to prevent decreases in herbage intake (Allden and Whittaker, 1970). Conversely, during measurement period 2, the more restrictive sward structure, with greater inflorescence proportion, ADF and NDF contents relative to measurement period 1, could have limited these mechanisms of compensation. Specifically, on reproductive swards, an increase in bite rate could be constrained due to an increase in the time per bite expended to avoid stems and select leaves, and to chewing more fibrous herbage (Prache, 1997; Amaral et al., 2013). Moreover, animals usually stopped grazing when faced with very restrictive sward conditions, waiting to enter a new strip-grazing (Amaral et al., 2013). In addition, we observed that during measurement period 2, cows under HIR were able to select herbage with greater nutritional value and, consequently, achieved a diet with greater digestibility compared to cows under HHH. Lower herbage digestibility is known to increase rumen fill and, consequently, decrease bite mass and intake rate (Gregorini et al., 2009), and could be an additional factor explaining our results.

To ensure a high herbage harvest, cows under HHH were forced to graze also the bottom stratum of the sward, with lower nutritional value. High levels of sward depletion impair the diet nutritive value in growing sheep (Savian et al., 2020). Therefore, this should be avoided especially in high-producing dairy cows that should eat a high quantity of nutrients in a more limited period of time. In addition, the herbage CP content observed under HIR was well above 23 %, which is the concentration that maximizes milk yield according to NRC (2001). Hence, this could represent an opportunity to reduce the CP content of concentrates and consequently the feed cost in dairy systems.

2.6.3 Cows under HIR Treatment Achieved Greater Individual Milk Production, Regardless of the Concentrate Supplementation Level

Decreasing grazing intensity has been shown to increase animal performance in beef cattle (Da Silva et al., 2013), dairy cows (Ganche et al., 2014; Dale et al., 2018; Menegazzi et al., 2021) and sheeps (Schons et al., 2021). In agreement, HIR induced greater milk and milk solids production per cow than HHH during most of the stocking season (figure 1). This could primarily reflect the greater herbage nutritional value and greater herbage intake observed under HIR, but differences in energy expenditure at grazing could also have played a role (Di Marco et al., 1996; Tharmaraj et al., 2003). Specifically, we expected that during measurement period 1, cows under HHH increased bite rate to prevent falls in herbage intake. A greater bite rate has been linked to an increase in energy expenditure (Di Marco et al., 1996), thus resulting in less energy available for milk production. These possible differences between HIR and HHH in terms of energy expenditure at grazing added to the greater herbage nutritional value observed under HIR would explain the greater feed efficiency registered in this grazing management (table 5). Similarly, Schons et al. (2021) reported that animals under grazing management strategies oriented to achieve a maximum herbage intake per unit time required less DM per kg of BW gain compared to animals under heavy grazing intensity. The greater conversion efficiency was related to a more selective grazing and an increased feed intake by animals under moderate grazing intensity.

Concentrate supplementation is a well-known alternative to increasing the amount of energy consumed by cows, which often results in increased milk production (Delaby et al., 2001). In the present study, SCM and milk solids per cow were greater under CS4 compared to CS0 (table 4). These results are consistent with the greater DM intake observed in CS4 (table 5), which may have allowed a greater nutrient supply to the mammary gland.

Contrary to expectations, we found no evidence of an interaction between grazing management and concentrate supplementation for milk production, and differences in milk yield between HIR and HHH were considered maintained even on supplemented cows. Although previous studies have consistently reported an increase in milk production response to concentrate with reduced herbage allowance (Bargo et al., 2002; McEvoy et al., 2008), in our experiment, the milk response to concentrate was marginally greater under HIR compared to HHH. It may be possible to explain this result based on an underlying mechanism related to the genetic merit of cows. On one hand, the high genetic merit of the cows used in this experiment allowed for a high average milk response to concentrate, even in a moderate grazing intensity situation, as in HIR (1.2 ± 0.5 kg milk/kg concentrate). A similar response was observed by Bargo et al. (2002) and Kennedy et al. (2007) with high-producing Holstein cows grazing at high levels of herbage allowance. On the other hand, it is possible that cows under HHH partitioned a greater part of the consumed energy from the concentrate to maintain body reserves and, therefore, a smaller proportion may have been allocated to milk production, resulting in a lower milk response to concentrate (Baudracco et al., 2010). In this regard, we observed that under HHH, cows without concentrate supplementation did show a decrease in BCS throughout the stocking season, while cows receiving 4 kg DM of concentrate seemed to maintain BCS. Conversely, cows under HIR maintained their BCS throughout the stocking season regardless of the concentrate supplementation level. Previously, combinations of low herbage allocation without supplementation have shown the greatest levels of non-esterified fatty acids, indicating a higher mobilization of body reserves (Bargo et al., 2002). Nonetheless, we did not observe any increase in BHB concentration, as would be expected for animals in negative energy balance, with concentrations below 0.1 mmol/L in all treatments and, thus, within normal levels (Benedet et al., 2019).

2.6.4 Trade-off between Individual and Per Unit Area Performance Was Found

Our results show that there was a trade-off between individual milk production and BW of cows vs. production per hectare in response to grazing management. The greater individual milk production on animals grazing under the HIR strategy came at the expense of a lower stocking rate required to maintain swards that maximized cow's intake rate. Thus, although HIR had a greater number of stocking cycles and shorter rest periods, this was insufficient to compensate for the greater strip size needed daily, required to attain the lower level of sward depletion imposed (table 1). Therefore, stocking rate, herbage intake, milk and solids production per hectare were greater under HHH than under HIR, respectively (table 6).

Trade-offs between individual and per unit area productivity have been reported previously in beef cattle managed under continuous stocking (Kunrath et al., 2020), and in response to stocking rate in dairy cows (Coffey et al., 2018; Dale et al., 2018). Conversely, Schons et al. (2021) and Portugal et al. (2021) working with lambs and beef cattle, respectively, did not find such trade-off when comparing the HIR grazing management vs. grazing strategies analogous to HHH. Schons et al. (2021) reported greater animal production per hectare for HIR grazing management strategy, already Portugal et al. (2021) stated that the BW gain per area was not impaired by the different grazing management strategies. Differences between our study and Schons et al. (2021) and Portugal et al. (2021) may be explained in part by the fact that when faced with a restrictive sward structure as in HHH, high-producing dairy cows were able to mobilize body reserves to sustain milk production in the short term (Roche et al., 2009), as occurred in the present study (table 4), but this compensation mechanism may not be present to sustain BW gain in beef cattle and sheep. For example, the loss of BCS for cows under HHH-CS0 during the stocking season would provide enough energy to produce 1.6 kg of additional milk per cow per day (NRC, 2001). Another possible cause for the discrepancy is that while in the present experiment pre- and post-grazing targets under HHH were based on the number of leaves per tiller and residual leaf, respectively, fixed pre- and post-grazing sward heights were used by Schons et al. (2021) and Portugal et al. (2021). Our results shows that optimal pre- and post-grazing sward height for HHH varied (supplemental figure 3) during the stocking season. Therefore, fixed sward heights under HHH would lead to underestimated carrying capacity due to (i) short or too long regrowth periods, and (ii) damagingly low post-grazing residuals that impair herbage regrowth capacity.

Finally, it should be noted that HHH treatment needed to maintain a 44 % greater stocking rate to increase milk and milk solids production per hectare by 17 % and 25 %, respectively, relative to HIR (table 6). In pasture-based systems, a greater stocking rate could be linked to higher exposure to seasonal variations in pasture growth, greater use of supplementary feeds (Patton et al., 2016), greater greenhouse emissions per unit area (Savian et al., 2018) and higher grazing intensity involving lower herbage production in the long term (Schons et al., 2021). Moreover, the greater stocking rate and milk production per hectare observed under HHH was also accompanied by a decrease in the BW and BCS of non-supplemented cows. The loss of BW and BCS in cows managed at high grazing intensity is consistent with the results reported by Dalley et al. (1999) and could be associated with future reproductive problems (Roche et al., 2009). In this context, it is important to seek a balance between milk production per cow and per hectare, and the welfare of cows in a long term. This is pivotal to achieving sustainable production in the dairy sector in the near future (Britt et al., 2021). In this way, we suggest that new studies should be performed to understand how grazing management strategies can affect the welfare of cows and reproduction, greenhouse gas emissions, herbage production and persistence of perennial grasses such as orchardgrass over time.

2.7 CONCLUSIONS

Grazing management and concentrate supplementation greatly affected the productive performance of Holstein dairy cows grazing orchardgrass in spring. Our study highlights that grazing orchardgrass sward structures prioritizing intake rate results in a greater daily herbage intake of a greater nutritive value which led to a greater milk and milk solids production per cow and increases in cow's BW. The greater individual milk production for cows under this grazing management came at expense of a lower stocking rate, and consequently lower milk and milk solids production per hectare. Specifically, there was a trade-off between individual milk production and BW of cows vs. production per hectare, in response to grazing management. Therefore, cows under HHH achieved a greater milk production per hectare, but lower individual milk production and decreased BW during the stocking season. Notably, although differences in milk production between both grazing management strategies were maintained regardless of concentrate supplementation level, cows under heavy grazing intensity lost BCS when are managed without concentrate supplementation. Based on our results, strategies oriented to achieving a high intake rate could be applied to grazing dairy production systems that seek to maximize individual productivity of high-producing cows. On the other hand, strategies oriented to achieving a high herbage harvest per hectare could be applied to dairy farm businesses where farm profit is driven by milk production per hectare, but considering that high producing dairy cows under this strategy lose BW and BCS when are managed without concentrate supplementation.

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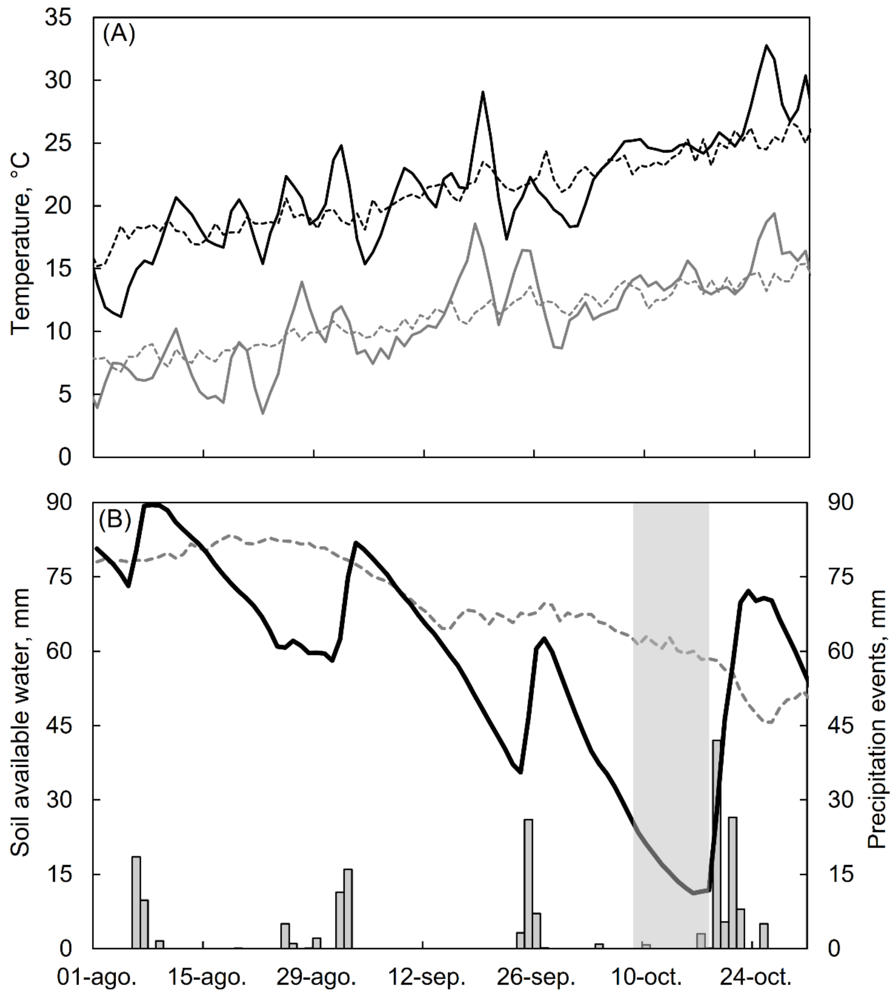
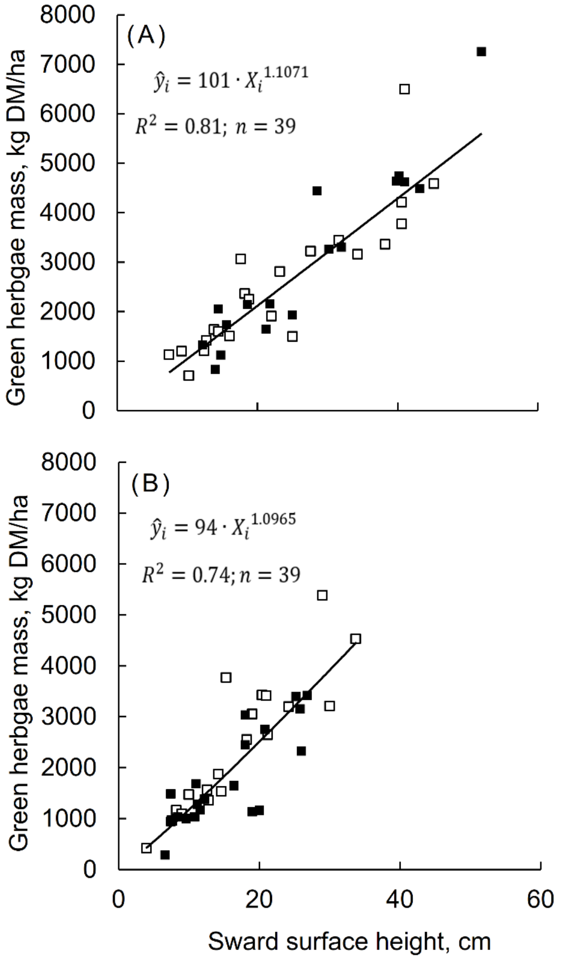
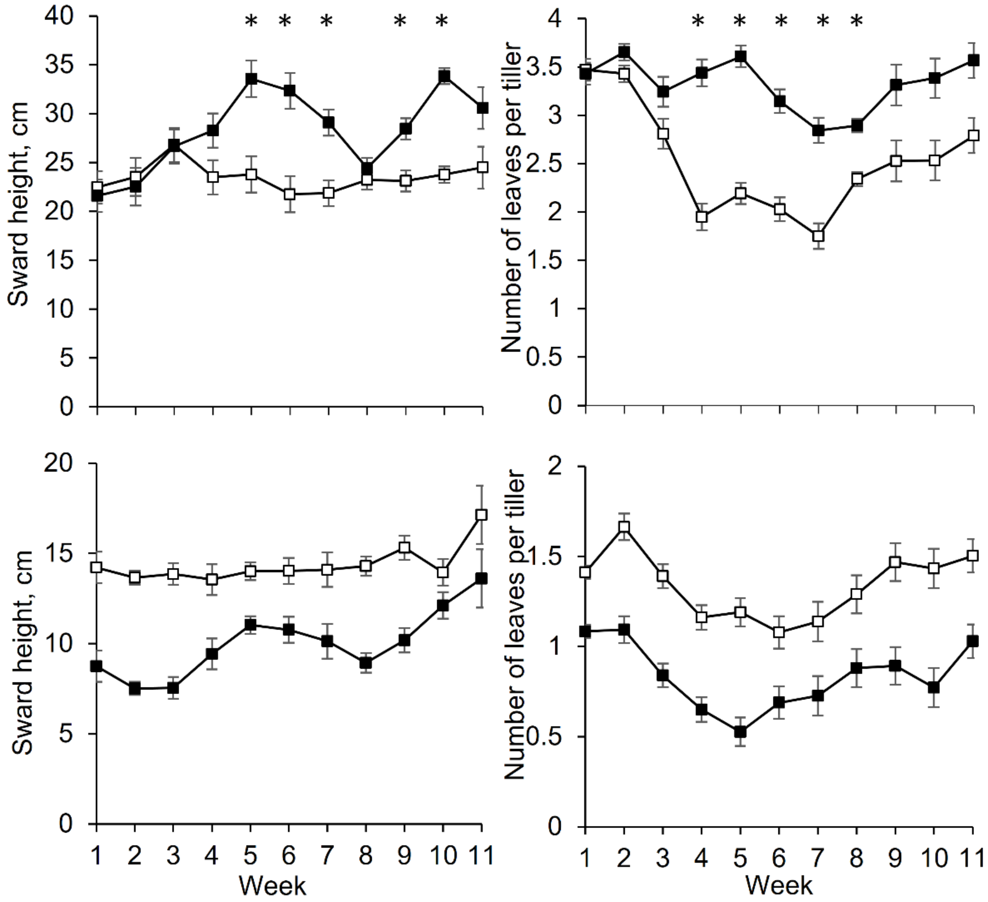
2.10 SUPPLEMENTAL FIGURES



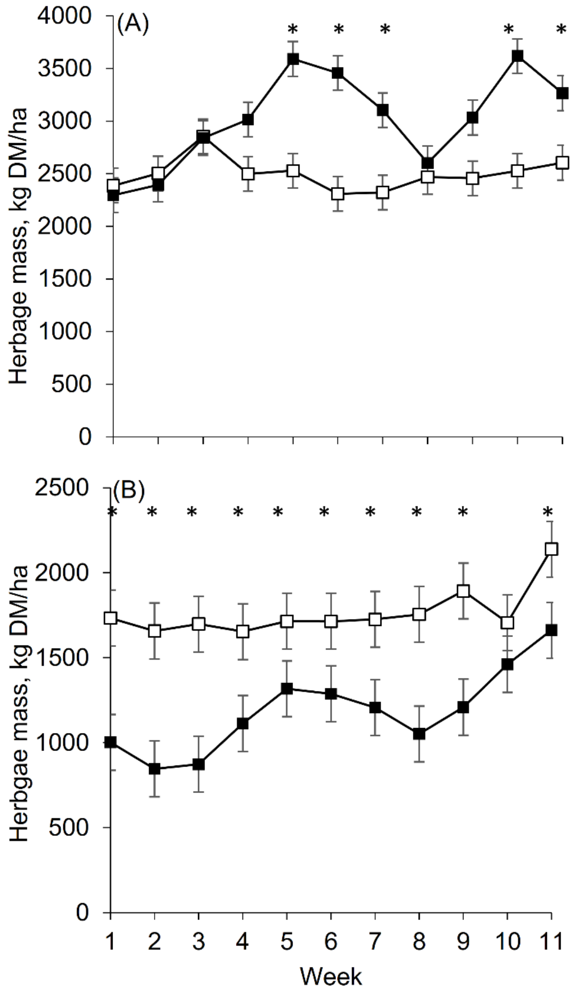
Supplemental figure S1. Evolution of (A) daily temperature (maximum and minimum presented in solid lines), (B) daily precipitation (bars) and soil water balance (solid line) during the stocking season. Period of (mild) water deficit is shown in grey. Historical medians (1967-2021) are shown for comparison (dashed lines).



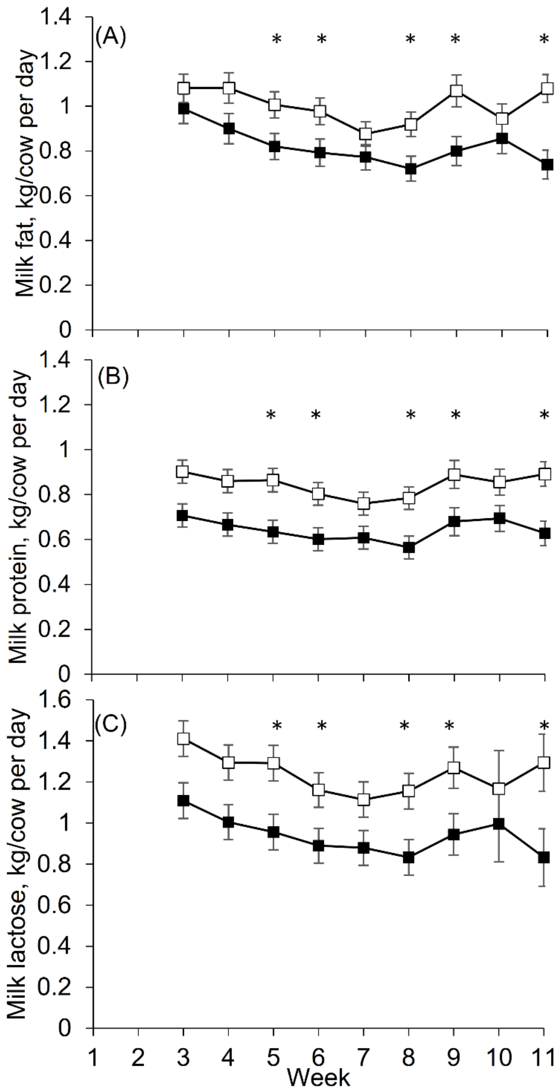
Supplemental figure S2. Observed and estimated standing green herbage mass (y-axis) obtained from calibration equations as a function of swards height (x-axis) for pre- (A) and post-grazing (B) swards of orchardgrass under two grazing management strategies (☐ HIR, high intake rate; ■ HHH, high herbage harvest per hectare).



Supplemental figure S3. Estimated mean (± SEM) sward height (left panels), and number of leaves per tiller (right panels) of orchardgrass at pre- (top panels) and post-grazing (bottom panels) under two grazing management strategies (□ HIR, high intake rate; ■ HHH, high herbage harvest per hectare) on a weekly basis during the stocking season. Estimates shown have been marginalized over (i.e. averaged for) concentrate supplementation. Top panels: interaction grazing management × week, $P < 0.001$; * Indicates significant effects at selected weeks of the stocking season, $P < 0.01$. Bottom panels: grazing management, $P < 0.001$; interaction grazing management × week, $P > 0.268$.



Supplemental figure S4. Estimated mean (± SEM) pre- (A) and post- (B) grazing green herbage mass of orchardgrass pastures managed under two grazing management strategies (☐ HIR, high intake rate; ■ HHH, high herbage harvest per hectare) on a weekly basis during the study. Estimates shown have been marginalized over (i.e. averaged for) concentrate supplementation. Top panel: interaction grazing management × week, $P < 0.001$. Bottom panel: interaction grazing management × week, $P = 0.070$. * Indicates significant effects at selected weeks of the stocking season ($P < 0.01$).



Supplemental figure S5. Estimated (mean ± SEM) (a) milk fat, (b) protein and (c) lactose production by dairy cows grazing orchardgrass pastures managed under two grazing management strategies (☐ HIR, high intake rate; ■ HHH, high herbage harvest per hectare) on a weekly basis during the study. Estimates shown have been marginalized over (i.e. averaged for) concentrate supplementation. Panel A: interaction grazing management × week, P = 0.039. Panel B: interaction grazing management × week, P < 0.001. Panel C: interaction grazing management × week, P = 0.006. * Indicates significant effects at selected weeks of the stocking season (P < 0.01).

3. <u>DISCUSIÓN GENERAL Y CONCLUSIONES GLOBALES</u>

El presente trabajo tuvo como objetivos: (i) evaluar el valor nutritivo de la pastura, el consumo y la producción de leche lograda por vacas lecheras Holando en respuesta a dos estrategias de manejo en pastoreo rotativo que priorizaban la tasa de consumo de pasto (ATC) o la cosecha de pasto por hectárea (ACH) y (ii) evaluar cómo la suplementación con concentrado afectaba dicha respuesta. Nuestros resultados muestran que tanto el manejo de pastoreo como el nivel de suplementación con concentrados afectaron en gran medida el desempeño de vacas lecheras Holando pastoreando *Dactylis glomerata* durante la primavera. Para sintetizar la relación entre ambos factores y las principales variables de estudio, a continuación, se presenta el siguiente modelo conceptual:

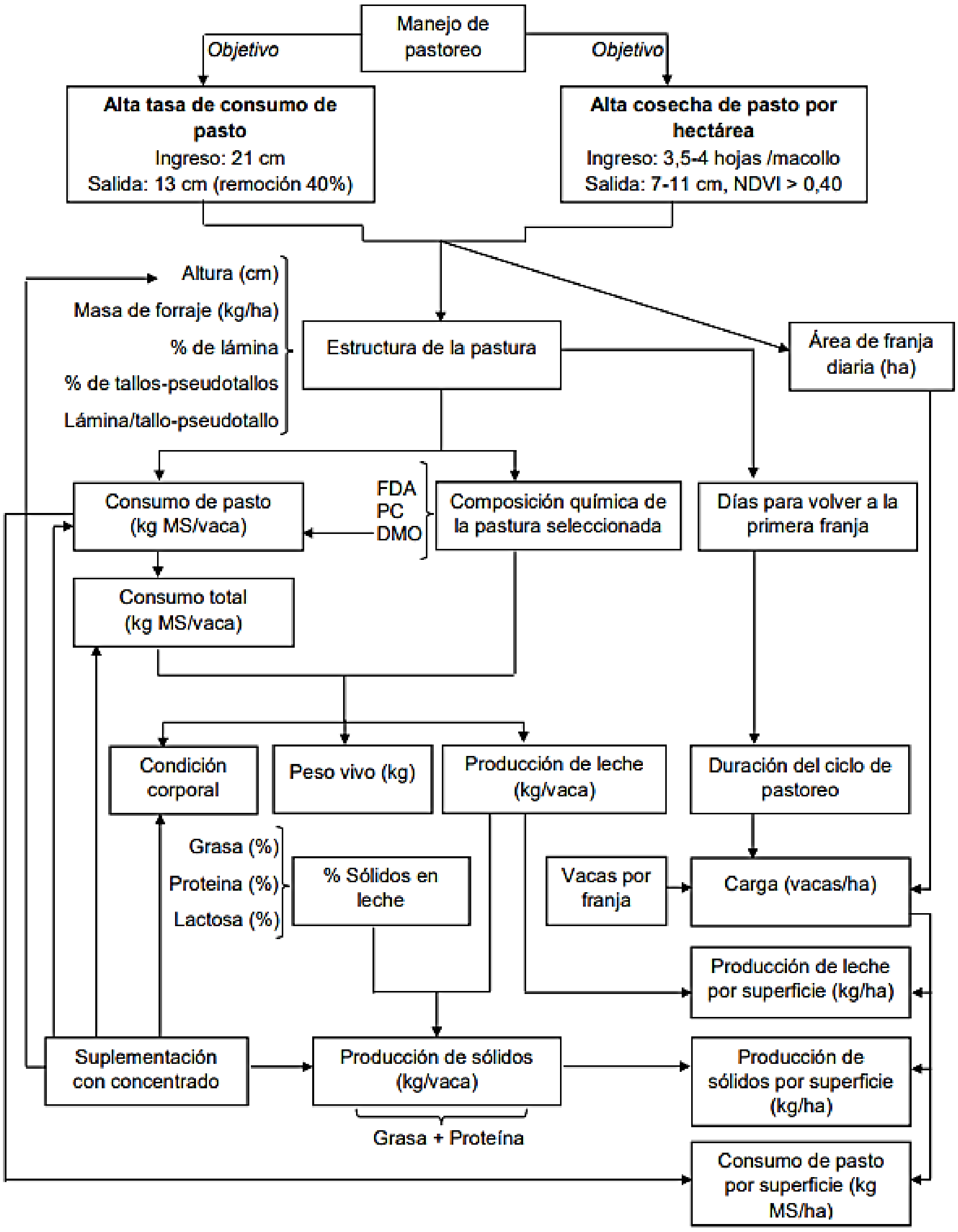


Figura 2. Modelo conceptual que describe las relaciones encontradas entre el manejo de pastoreo, la suplementación con concentrado y las principales variables de estudio.

En concreto, implementar un manejo de pastoreo basado en las respuestas comportamentales de los animales permitió a los animales lograr una dieta de mayor valor nutritivo e incrementar su producción de leche (+ 6 kg/vaca/día) en comparación con un manejo orientado a lograr una alta cosecha de pasto por hectárea. Es interesante notar que bajo el manejo ATC la suplementación podría ser reducida de 4 a 0 kg de MS por vaca durante la primavera sin que se afecte la CC de los animales. Por otro lado, mantener la suplementación en 4 kg de MS en combinación con el manejo ATC resultó en una alta respuesta en leche al concentrado (1,2 kg de leche/kg de concentrado). Asimismo, el mayor contenido de proteína cruda en la pastura adquirida por los animales bajo ATC, podría representar una oportunidad para, en el futuro, incorporar suplementos concentrados con un menor aporte proteico, y por tanto eventualmente menos costosos. En el caso del manejo ACH, por su parte, la suplementación con 4 kg de MS por vaca implicó una menor respuesta en leche al concentrado. Aun así, en ACH, la suplementación (al menos a niveles bajos) sería una alternativa recomendable para no comprometer la condición corporal de vacas de alto potencial.

La superioridad en producción de leche y sólidos por vaca encontrada en el manejo ATC se dio a expensas de una menor carga animal, lo que derivó en una menor producción de leche y sólidos por hectárea. Esto refleja que ambos componentes (el aumento en la frecuencia de pastoreo y el incremento en la producción por vaca registrados en ATC) no fueron suficientes para igualar la producción por hectárea lograda en ACH. En este sentido, si bien la diferencia en producción de leche individual entre ambos manejos fue notoria, el hecho de trabajar con vacas lecheras de alto potencial explica que la producción por vaca se haya mantenido en niveles moderados aun en situaciones limitantes, aunque a expensas de movilizar reservas corporales. Esto último determina que la mayor producción de leche por hectárea encontrada en el manejo ACH se asociara también a una pérdida de PV de los animales y a una reducción en la CC de las vacas en los tratamientos sin suplementación, durante el período experimental.

Nuevas interrogantes vinculadas con el efecto de estas estrategias de pastoreo sobre la producción de forraje y su impacto ambiental en el mediano y largo plazo podrían ser abordadas en el futuro para complementar los resultados obtenidos.

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