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Don't let milk output go extinct: postgrazing sward height shapes dairy cow foraging efficiency

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A B S T R A C T

Postgrazing sward height is a key management factor in dairy cattle grazing systems because it governs bite formation, subsequent canopy structure, and the trade-off between forage selectivity and harvest efficiency. This study evaluated how postgrazing sward height shapes ingestive behaviour across temporal (bite, meal, day) and spatial (feeding station) scales and how these responses relate to grazed forage intake and milk production of grazing cows in mixed-feeding dairy systems. Thirty-two multiparous Holstein cows grazed tall fescue (*Lolium arundinaceum*) under two treatments: Control (5.0–7.0 cm) and High (12.0–15.0 cm) postgrazing residuals, arranged in a randomised complete block design (4 blocks × 2 paddocks of 1.6 ha). Detailed 5-day measurements were performed in winter (Period I) and spring (Period II), when cows grazed for 6.5 and 8.0 h/day, respectively, and received a mixed ration after pasture access. Daily grazing time averaged ~300 min/cow and did not differ between treatments, but was ~1 h longer in Period II. Cows at the High treatment distributed grazing into shorter, more frequent meals (2.6 vs 3.1 meals/d). At the spatial scale, they visited more feeding stations, spent less time per feeding station and took fewer but larger bites, displaying a rapid-sampling grazing strategy. These behavioural adjustments increased the efficiency and selectivity of forage harvesting. In Period I, cows at the High residual achieved a 32% greater grazed forage intake rate and consumed 2.0 kg DM/cow per day more grazed forage and leading to an increased total DM intake without increasing daily grazing time. Across both periods, they selected forage with higher CP (+55 g/kg DM) and lower fibre (–17 g NDF and –31 g ADF/kg DM) than Control cows, resulting in 10% greater milk production at equal supplementation. Postgrazing sward height influences the temporal and spatial behavioural mechanisms by which grazing dairy cows acquire nutrients and highlights the importance of considering these behavioural responses when designing sward management strategies to improve nutrient capture and use efficiency.

Implications

Postgrazing sward height is a key management factor influencing how grazing dairy cows harvest pasture. This study evaluated how contrasting residual heights affect ingestive behaviour, intake, and milk production. Taller residuals led cows to adopt a more selective and efficient foraging strategy, characterised by shorter, more frequent meals, more frequent movement between feeding stations, and fewer but larger bites. These changes increased forage intake and improved diet quality, supporting higher milk yield without increasing grazing time. Managing taller residuals may enhance nutrient capture and efficiency in pasture-based systems, although responses will depend on season, pasture conditions, and overall system management.

Introduction

Pasture remains the foundation of milk production in temperate pasture-based and mixed feeding dairy systems. Yet the extent to which grazing management can enhance nutrient capture from swards while controlling supplementation costs remains under

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debate. Postgrazing sward height (residual) is a key management factor in dairy cattle grazing systems because it determines bite formation, subsequent canopy structure, affecting the trade-off between forage selectivity and harvest efficiency across grazing events, with the magnitude of effects depending on pasture species composition, environmental conditions, and grazing system characteristics (Griffiths et al., 2003; Carvalho, 2013). Residual sward height influences spatial heterogeneity and the distribution of profitable feeding stations, thereby affecting how cows search and sample patches to maintain a high instantaneous intake rate (Chapman et al., 2007). From the sward perspective, residual sward height defines the residual leaf area available for photosynthesis, influencing whether regrowth relies on current photosynthate or stored reserves. Greater residual leaf area promotes faster regrowth (Parsons and Chapman, 2000).

Short-term feed intake control under grazing ruminants emerges from interacting physical and metabolic signals (Mertens, 1994; Allen, 2000). At the bite scale, less-depleted, taller swards generally support larger bite mass and higher intake rates within optimal sward structure ranges and without extending grazing time (Laca et al., 1992; Gibb et al., 1999). At the meal and daily scales, cows may adjust meal frequency, meal duration, and between-meal rumination to manage constraints associated with rumen fill (Chilibroste et al., 2008; Gregorini, 2012). Spatially, animals continually trade off search depth (staying longer within a feeding station) against breadth (moving sooner to a new feeding station), as the marginal value of additional bites declines within feeding stations (Roguet et al., 1998; Searle et al., 2005). Despite this conceptual framework, few studies have linked residual sward height to a multiscale description of ingestive behaviour, from jaw-movement chews and bites to meal structure, to the use of feeding stations in the same cows while concurrently quantifying intake and milk responses. Limited evidence suggests that increasing residual sward height alters dairy cow grazing behaviour, leading to shorter, more frequent meals, reduced time at feeding stations, fewer steps between feeding stations, and higher intake rates and ultimately milk production (Gibb et al., 1999; Menegazzi et al., 2021). However, information remains scarce for modern, high-producing cows managed under supplementation, which may modify how ingestive behaviour responds to residual sward height.

Therefore, our objective was to quantify how contrasting postgrazing sward heights, representative of common practices (5–7 cm) versus a taller, less-depleted target (12–15 cm), affect ingestive behaviour across temporal (bite, meal, day) and spatial scales (feeding station), and how these behavioural responses influence forage and total DM intake (**DMI**) and milk production. We hypothesised that, relative to the common residual, the taller residual would increase bite mass, intake rate and daily DMI without altering daily grazing time, enhance selective behaviour leading to a diet of higher quality, and translate these behavioural shifts into higher milk yield at equal supplementation.

Material and methods

An experiment was conducted at the Research Station "Dr. Mario A. Cassinoni" (EEMAC) of the Facultad de Agronomía – Universidad de la República, located in Paysandú, Uruguay (32° 23′ 08″ S, 58° 03′ 19″ W). This study reports detailed measurements from two strategically selected periods within this larger trial (described in detail by Menegazzi et al., 2025) conducted between 19 April 2023 and 19 November 2023. To enable intensive data collection, these measurement periods were performed in July (Period I; representing autumn–winter) and October (Period II; representing spring-summer) to capture seasonal variation.

The experimental site is located in a region classified as humid subtropical with hot summers (Cfa) according to the Köppen climate system (Beck et al., 2018). The soils correspond to shallow eutric and haplic Brunisols of the San Manuel Series (Altamirano et al.,1976). In the 0–20 cm soil layer, organic matter content averaged 4.1%, with mean concentrations of 17.2 mg/kg phosphorus and 166 mg/kg potassium, and a soil pH of 6.6. The pasture was a 2-year-old tall fescue sward (*Lolium arundinaceum* cv. INIA Fortuna). Prior to treatment implementation, the sward was mechanically mown to 6 cm on 13 March 2023. Grazing treatments commenced on 19 April 2023, once the sward had reached the 2-leaf stage. Nitrogen (**N**) fertilisation totaled 135 kg N/ha, applied as urea in three split applications during May, August, and October.

Experimental design, treatments, and cows

Within the framework of the larger experiment (Menegazzi et al., 2025), two contrasting postgrazing sward height targets were evaluated using a randomised complete block design. The study comprised four blocks of 3.2 ha, each selected for uniform soil characteristics and divided into two paddocks of 1.6 ha. Within each block, paddocks were randomly allocated to one of two grazing treatments. The Control treatment aimed for a postgrazing sward height of 5.0–7.0 cm, reflecting typical grazing management in Uruguayan pasture-based dairy systems (Zibil et al., 2016). The High treatment targeted a taller residual sward height of 12.0–15.0 cm, based on previous evidence of maximised individual DM intake (Carvalho, 2013) and enhanced milk production (Menegazzi et al., 2021). Each paddock was stocked with the same four lactating cows for the duration of the experiment. In total, 32 multiparous Holstein cows from the experimental herd were enrolled and stratified into groups of four according to previous 305-day milk yield (9 100 ± 1 560 kg), parity (3.4 ± 1.0 lactations), BW during the far-off dry period (718 ± 70 kg), body condition score during the far-off dry period (3.3 ± 0.3 on a 1–5 scale), and expected calving date (April 5 ± 15 d). Cows within groups were randomly assigned to blocks, and subsequently randomly allocated to paddocks within each block (Menegazzi et al., 2025). Throughout the far-off and close-up dry periods, cows were subjected to uniform management and were maintained in a compost-bedded barn, where an anionic diet was offered for approximately 3 weeks preceding the anticipated calving date.

Grazing and feeding management

The grazing, feeding and sward management has been described in detail by Menegazzi et al. (2025). Briefly, rotational grazing was employed, with new strips allocated once the targeted postgrazing sward height for each treatment was achieved. To reach this target, different strip-grazing sizes were implemented using movable fences. The detailed measurements were performed in a random strip inside each paddock, with a 5-day occupation time for both treatments and periods. The total number of grazing cycles was 3.3 for Control and 8.3 for High treatment. During Period I, the Control treatment was in its second grazing cycle and the High in its third. Cows had 6.5 h of daily pasture access (0730–1400 h) with milking at 0600 and 1600 h. In Period II, the Control treatment was in its third grazing cycle, while the High was in its seventh. Cows had 8.0 h of daily pasture access (0700–1500 h) with milking at 0500 and 1700 h. The milking parlour was located 800 m from the paddock. Outside pasture hours, cows were housed in pens with the same four-cow sets as in the pasture. Each pen in the barn included 13.5 m^2 of compost-bedded pack and 6.7 m^2 of concrete area per cow and had a single feed bunk, providing 0.75 m of linear space per cow, allowing all four cows to consume simultaneously as a group. Cows had *ad libitum* access to fresh water in the paddock, barn, and milking parlour holding area. A mixed ration (**MR**) of silage and concentrate was fed after the evening milking. Both the amount and composition of supplemental feed were standardised across treatments but varied between periods. The ingredients of the MR, as well as its nutrient composition, are presented in Table 1.

Sward and animal measurements

Pre- and postgrazing sward heights were assessed on each grazing strip at ground level using a sward stick (Barthram, 1985). Measurements were taken along zigzag lines, with readings recorded every two steps. The extent of sward height depletion was calculated as the proportional reduction between pregrazing and postgrazing heights relative to the initial sward height.

Milk yield for each cow was recorded automatically at every milking. Milk samples were obtained on days 1, 3, and 5 of the strip occupation period during both morning and afternoon milkings and subsequently analysed for fat, protein, lactose, and milk urea nitrogen (**MUN**) using mid-infrared spectroscopy (MilkoScan FossElectric FT2®, Drachten, The Netherlands). For each cow, daily milk composition was calculated as a weighted mean based on milk yield from the two milkings and then averaged across the three sampling days to generate a single value per period. Energy-corrected milk (**ECM**) yield was computed following Sjaunja et al. (1990): ECM (kg) = milk yield (kg) × [38.30 × fat (g/kg) + 24.20 × protein (g/kg) + 16.54 × lactose (g/kg) + 20.7]/3 140. Data from one cow that developed mild mastitis near the end of the measurement period were excluded from the analyses of all response variables.

Mixed ration intake was quantified on days 2 and 4 of the occupation period for each pen by calculating the difference between feed offered and feed recovered as waste. Intake values were averaged across the two measurement days to obtain a single estimate per cow for each period. Feed waste was defined as material displaced from the feed bunk by the cows and was distinguished from voluntary refusals; no voluntary refusals were observed during the study. On each intake measurement day, samples of both offered and wasted MR were collected at the pen level, pooled, weighed, and dried in a forced-air oven at 60 °C to constant weight to determine DM concentration. The dried feed offered samples were milled through a 1-mm screen and stored for subsequent chemical analysis.

Individual forage DMI was determined using the n-alkanes technique (Dove and Mayes, 2006), with hentriacontane (C_{31}) as the internal marker and dotriacontane (C_{32}) as the external marker. For 11 consecutive days, cows were orally dosed twice daily following each milking, with a cellulose pellet (Carl Roth GmbH and Co. KG, Karlsruhe, Germany) impregnated with 292 ± 5 mg of dotriacontane. Dosing began 6 days before the start of the 5-day

Table 1
Ingredients of the mixed ration (MR), nutrient composition of MR, and forage consumed by lactating dairy cows grazing tall fescue swards at two postgrazing sward heights, and proportions and nutrient composition of diet consumed.

	Period (PER) and Treatments[1] (TRT)					Probability			
	Period I		Period II						
Item	Control	High	Control	High	SEM[2]	TRT	PER	TRT × PER	n
Nutrient composition of the MR[3]									
CP, g/kg of DM	179		167						
NDF, g/kg of DM	412		325						
ADF, g/kg of DM	229		182						
Lignin, g/kg of DM	24		18						
Ether extract, g/kg DM	29		45						
Ash, g/kg of DM	77		63						
Starch g/kg of DM[4]	131		143						
Nutrient composition of grazed forage									
CP, g/kg of DM	167[b]	244[a]	118[d]	150[c]	3.0	<0.001	<0.001	<0.001	63
NDF, g/kg of DM	601	589	602	579	4.2	<0.001	0.259	0.199	63
ADF, g/kg of DM	282	249	323	294	2.9	<0.001	<0.001	0.406	63
Lignin, g/kg of DM	24	24	24	21	1.4	0.384	0.202	0.330	63
Ether extract, g/kg DM	27	21	26	28	2.6	0.380	0.203	0.144	63
Ash, g/kg of DM	117	110	92	88	1.8	0.004	<0.001	0.328	63
Proportions of the consumed diet[5]									63
Grazed forage, % DM	41	46	52	52	1.1	0.042	<0.001	0.004	63
MR, % DM	59	54	48	48					63
Nutrient composition of the consumed diet[5]									63
CP, g/kg of DM	174[b]	209[a]	141[d]	159[c]	1.6	<0.001	<0.001	<0.001	63
NDF, g/kg of DM	489[a]	493[a]	468[b]	456[b]	3.5	0.300	<0.001	0.010	63
ADF, g/kg of DM	251	238	255	240	1.8	<0.001	0.110	0.478	63
Lignin, g/kg of DM	24	24	21	20	0.7	0.423	<0.001	0.274	63
Ether extract, g/kg DM	28	25	35	36	1.3	0.389	<0.001	0.153	63
Ash, g/kg of DM	93	92	78	76	0.9	0.090	<0.001	0.555	63
Starch g/kg of DM[6]	77	71	69	68					

[a–d]Means within a row with different lowercase letters differ (*P* < 0.05) between period and treatments.
[1] Control: postgrazing sward height of 5.0–7.0 cm. High: postgrazing sward height of 12.0–15.0 cm.
[2] Average SEM is listed.
[3] Concentrate and sorghum silage are in a ratio of 69:31 (Period I) and 70:30 (Period II). Composition of concentrate (% DM) for Period I and Period II, respectively: Soybean hulls (23, 16); Soybean meal (16, 11); Corn grain (15, 39); Corn dried distillers grains with solubles (14, 10); Sunflower meal (11, 8); Barley (8, 6); Wheat bran (8, 6); Vitamin–Mineral mix (2.8, 2.0); Salt (1.2, 0.9); Calcium carbonate (1.2, 0.9).
[4] Calculated from the ingredient composition.
[5] Calculated based on DM intake of Table 2.
[6] Calculated from ingredients composition, assuming starch in the grazed forage was equal to zero.

detailed measurement period. During the last 5 days of dosing, faecal samples were collected per rectum after each milking and immediately stored at −20 °C. At the end of each collection period, faecal samples from each cow were defrosted, homogenised, dried to constant weight in a forced-air oven at 60 °C, milled through a 1-mm screen, pooled per cow and stored until alkane concentration analysis. To characterise the diet selected by the cows, forage samples were collected on days 2 and 4 of each faecal collection period by hand-clipping (Coates and Penning, 2000), while following individual cows for 1 h during the first grazing meal. Forage samples were dried to constant weight at 60 °C, milled through a 1-mm screen, pooled per cow and stored for subsequent analysis of alkane concentrations and chemical composition. Grazed forage intake was then estimated using the ratio of natural odd-chain C_{31} to dosed even-chain C_{32} and was calculated as follows (Mayes et al., 1986):

$$\text{Grazed forage intake (kg DM/cow per day)} = \frac{F_i/F_j \times (D_j + I_M \times M_j) - I_M \times M_i}{G_i - (G_j \times F_i/F_j)}$$

where F_i, M_i, and G_i are the concentrations (mg/kg of DM) of the natural odd-chain n-alkane (C_{31}) in faeces, MR, and grazed forage, respectively; F_j, M_j, and G_j are the concentrations (mg/kg of DM) of the dosed even-chain n-alkane (C_{32}) in faeces, MR, and grazed forage, respectively; I_M is the daily MR intake (kg DM/day), and D_j is the dose rate (mg/day) of the even-chain n-alkane (C_{32}). Given the relatively low concentration of C_{31} in the MR (less than 10% of that in forage), MR intake measured at the pen level was assumed to be equally consumed among the four cows per pen. Daily DMI was then calculated as the sum of MR and grazed forage intake per cow.

Ingestive and ruminating behaviour was registered with a RumiWatch halter with noseband sensor (Itin and Hoch GmbH, Liestal, Switzerland; Rombach et al., 2018; Werner et al., 2018). During the week preceding the measurements, cows first wore ordinary cattle halters for 72 h to allow adaptation, before being fitted with RumiWatch halters for their 5-day measurement period. The device continuously recorded the pressure of jaw movements related to eating and ruminating at a frequency of 10 Hz. RumiWatch Converter software version V0.7.5.05 (ITIN+HOCH GmbH) was used to convert the raw data into 10-min data. Because 20 RumiWatch halters were available, 12 cows were excluded. One cow per paddock was randomly excluded, and in two randomly selected blocks, one additional cow per paddock was excluded. Among the cows equipped with halters, 7 showed measurement errors (5 and 2 in Control and High, respectively). Only complete 5-day periods with 24-h recording were retained, yielding 33 valid observations out of 40 possible. The RumiWatch noseband sensor determined grazing and ruminating time, number and length of grazing meals, grazing prehension bites, grazing manipulation chews, and eating and rumination chews (Rombach et al., 2018; Werner et al., 2018). Behavioural definitions followed Zehner et al. (2014) and Rombach et al. (2018). Prehension bites are defined as bites to gather or sever forage during feed intake. Grazing manipulation chews were classified as chewing movements occurring during and immediately after bite prehension that serve to reduce ingested forage into smaller particles, without involvement of regurgitated material. Eating chews comprised the combined total of prehension bites and manipulation chews recorded during grazing. Rumination chews were defined as masticatory movements performed during rumination to comminute regurgitated boluses using the molars. Rumination time was calculated as the cumulative duration of rumination chewing activity, including brief pauses in chewing of up to 5 s. A grazing meal is defined as a grazing sequence of at least 7 min separated from the next meal by at least 7 min of non-grazing. Daily grazing time equaled the sum of all grazing meal durations. Behavioural variables for each cow and period were averaged across the 5-day period. Bite rate was calculated for the first grazing meal (total bites during first grazing meal divided by meal duration) and per day (total bites per day divided by daily grazing time). Bite mass equaled grazed forage intake divided by the total grazing prehension bites. Grazed forage intake rate equaled grazed forage intake divided by the daily grazing time. Eating chews during grazing was expressed per kg DM of grazed forage intake and per kg NDF of grazed forage intake. Rumination chews were expressed per kg of total DMI and per kg of total NDF intake. The same calculations were applied to rumination time (min per kg of DMI and per kg of NDF intake).

The number of feeding stations visited and the steps taken between them were recorded by visual observation during pasture access time on days 1, 3, and 5 (Menegazzi et al., 2021) of each occupation period for all cows. One trained observer monitored three cows sequentially for 15 min across the entire pasture access time. A feeding station was defined as the hypothetical semicircular area in front of the animal from which bites could be taken without moving the forefeet (Ruyle and Dwyer, 1985). From these data, several spatial grazing behaviour variables were derived. Feeding stations per minute were calculated as the total number of feeding stations divided by the duration of the visual observation. Total feeding stations visited per day were calculated as the product of feeding stations per minute and daily grazing time. Time per feeding station was calculated as observation duration divided by the number of feeding stations visited. Bites per feeding station were calculated as the total number of grazing bites per day divided by the total number of feeding stations visited per day. Grazed forage intake per feeding station was calculated as daily grazed forage intake divided by the total feeding stations visited per day. Displacement rate was expressed as total steps divided by feeding stations visited during the observation. The variables feeding stations per minute, time per feeding station and displacement rate were first calculated per observation and then averaged across the three observation days to yield a single value per cow in each period.

BW and body condition score (**BCS**) (Edmonson et al., 1989) were assessed the day after each 5-day measurement period. During Period I, BW averaged 625 ± 15 kg (Control) and 647 ± 15 kg (High); in Period II, BW was 646 ± 15 and 655 ± 15 kg for Control and High treatment, respectively. Corresponding BCS in Control and High values were 3.17 ± 0.03 and 3.23 ± 0.03 in Period I, and 3.06 ± 0.03 and 3.31 ± 0.03 for the Control and High treatment in Period II, respectively.

Analytical methods

Samples of MR and grazed forage were analysed for ash content (method 942.05; AOAC, 2000), CP (N × 6.25; Kjeldahl method 984.13; AOAC, 2000), NDF using heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991), ADF and lignin (method 973.18; AOAC, 2000), and ether extract (method 920.39; AOAC, 2000). Determinations of NDF and ADF were conducted separately using an ANKOM200 Fiber Analyzer (ANKOM Tech. Corp., Fairport, NY, USA), and the results were reported on an ash-free basis. The n-alkane concentrations of MR, forage and faeces samples were analysed by gas chromatography following the protocol proposed by Dove and Mayes (2006), using a Shimadzu 2 010 gas chromatograph equipped with a flame ionisation detector, a spool autosampler (AOC-20S), and an AOC-20i auto-injector. The extracted n-alkanes were injected (1 μL) into a column containing 5% diphenyl and 95% dimethyl polysiloxane. Nitrogen was used as the carrier gas at a constant flow of 30 mL/min through a Restek Rtx®-5 column (30 m × 0.25 mm × 0.25 μm). Temperature settings were as follows: injector at 270 °C and column at 170 °C for 1 min, followed by ramps of 30 °C/min to 215 °C (held 1 min) and 6 °C/min to 300 °C (held 21 min). The detector temperature was maintained at 340 °C. The chromatographic procedure was calibrated using an external standard solution containing synthetic C_7 to C_{40} n-alkanes (> 99% purity; Sigma-Aldrich Corp., St. Louis, MO, USA) at concentrations similar to those in the extracts. Peak areas for each n-alkane were determined with Shimadzu GC Solution software, and identification of chain lengths from C_{20} to C_{35} was based on comparison with external standards using mean retention time on the column. The quantified peaks were converted to n-alkane amounts using C_{34} as the internal standard, and values were calculated in mg/kg DM of faeces or feed.

Statistical analysis

The experimental unit was defined as the individual cow for all response variables, with the exception of MR intake and sward-related measurements, for which the paddock or pen served as the experimental unit. For variables associated with individual animals, statistical analyses performed using either cow- or pen-level data produced comparable treatment means and resulted in no meaningful differences in statistical inference. All response variables were evaluated using a general linear mixed model that included treatment, period, their interaction, and block as fixed effects. For animal-level traits, the cow was incorporated in the model as a random effect. Degrees of freedom were estimated using Satterthwaite's procedure, and model assumptions were verified through inspection of studentised residuals. Statistical analyses were conducted using the GLIMMIX procedure of SAS software (SAS Institute Inc., Cary, NC, USA). Treatment effects were declared significant at $P \leq 0.05$, with trends discussed when $0.05 < P \leq 0.10$.

Results

Ingestive behaviour

The daily grazing time was not affected by treatment (P = 0.965) and increased by 1 h from Period I to Period II (P < 0.001) (Table 2). Similarly, ruminating time increased by 1 h from Period 1 to Period II (P = 0.014), but did not differ between treatments (P = 0.141). The number of grazing meals was 18% higher in the High treatment compared with the Control (P = 0.009) and increased by 17% from Period I to Period II (P = 0.007). The length of the first grazing meal tended to be 26 min shorter in the High than in the Control treatment (P = 0.067), but did not differ between periods (P = 0.121). The number of grazing prehension bites increased from Period I to Period II by 2 240 bites/day (P = 0.021), with no treatment effects (P = 0.823). A similar pattern was observed for grazing manipulation chews, which increased from Period I to Period II (P = 0.002), with no difference between treatments (P = 0.556). Bite rate during the first grazing meal and average daily bite rate did not differ across treatments or periods ($P \geq 0.355$). Although no significant effects of treatment, period, or their interaction were detected, bite mass was numerically 37% higher in the High treatment compared with the Control during Period I, and numerically similar between treatments during Period II ($P \geq 0.211$). A treatment by period interaction emerged for grazed forage intake rate (P = 0.029), with cows in the High treatment exhibiting a 32% higher intake rate than cows in the Control during Period I, with no significant differences between treatments during Period II. Total eating chews during grazing increased from Period I to Period II (P < 0.001), with no differences between treatments (P = 0.320). However, the number of eating chews per kg of grazed forage DMI was 25% lower in the High treatment than in the Control treatment during Period I, but no differences were observed during Period II (treatment by period interaction; P = 0.022). A similar pattern was observed when expressed per kg of grazed forage NDF, with a 24% reduction in the High compared with the Control treatment only during Period I (treatment by period interaction; P = 0.010). Total rumination chews increased from Period I to Period II (P = 0.009), with no differences between treatments (P = 0.234). Rumination chews per kg of DMI and per kg of NDF tended to be lower in the High treatment (P = 0.052 and 0.089, respectively) and increased from Period I to Period II ($P \leq 0.028$). Rumination time per kg of DMI also tended to be lower in the High treatment (P = 0.078), with no effect of period (P = 0.119). When expressed per kg of NDF, rumination time was higher during Period II (P = 0.011), with no treatment effect (P = 0.141).

Feeding station behaviour

Feeding station behaviour was markedly affected by treatment and its interaction with period (Table 2). The number of feeding stations explored per day was 49% higher in cows under the High treatment compared with the Control during Period II, whereas no differences were observed during Period I (treatment by period interaction; P = 0.013). In line with that, the average residence time per feeding station was shorter and the number of feeding stations visited per min was higher in the High compared with the Control treatment only during Period II (treatment by period interaction; $P \leq 0.006$). The number of bites per feeding station was lower in the High treatment compared with the Control (P = 0.009) and decreased by 16% from Period I to Period II (P = 0.041), with no interaction effect (P = 0.338). The amount of grazed forage DMI per feeding station was greater in the High treatment in Period I compared with Period II, with no difference from Control during Period I and with a tendency (P = 0.075) to be lower than Control in Period II (treatment by period interaction; P = 0.013). Lastly, the number of steps per feeding station (displacement rate) was higher in the High compared with the Control treatment during Period II, while no differences were observed during Period I (treatment by period interaction; P = 0.002).

Sward height

The pregrazing sward height was 24.2 and 22.6 cm in Period I and 28.1 and 24.4 cm in Period II for the Control and High treatments, respectively (P = 0.052, 0.037 and 0.405 for treatment, period and its interaction, respectively). Postgrazing sward heights were 7.5 and 15.3 cm in Period I and 9.3 and 16.4 cm in Period II for the Control and High treatments, respectively (P < 0.001, 0.057 and 0.613, for treatment, period and its interaction, respectively). As expected, the sward height depletion level was 68% in the Control treatment and 33% in the High treatment (P < 0.001), with no effect of period or treatment by period interaction ($P \geq 0.291$).

Intake, nutrient composition of diet and milk production

The MR intake did not differ between both treatments and averaged 12.5 and 11.3 kg DM/cow per day during Period I and Period II, respectively (period effect; P < 0.001). During period I, cows in the High treatment had greater individual grazed forage intake (+2.1 kg/day) and thus total DMI (+2.0 kg/day) compared with those in the Control treatment, but these did not differ during Period II (interaction, P = 0.005). Consequently, the proportion of grazed forage in the diet followed a similar pattern in Period I (Table 1) and increased for both treatments in Period II (treatment by period interaction; P = 0.004), reaching 52% of total DMI. The nutrient composition of the grazed forage also differed. The CP con-

Table 2
Individual performance, intake and behaviour of lactating dairy cows grazing tall fescue swards at two postgrazing sward heights.

	Period (PER) and Treatments[1] (TRT)					Probability			
	Period I		Period II						
Item	Control	High	Control	High	SEM[2]	TRT	PER	TRT × PER	n
Milk and solids									
Milk, kg/cow/d	34.8	37.5	24.6	27.2	0.99	0.041	<0.001	0.874	63
Energy corrected milk, kg/cow/d	32.8	35.8	24.3	27.1	0.88	0.012	<0.001	0.954	63
Fat, %	3.60	3.44	3.80	3.81	0.107	0.582	<0.001	0.241	63
Protein, %	3.17	3.18	3.32	3.32	0.040	0.887	<0.001	0.707	63
Milk urea nitrogen, mg/dL	22.6^{b}	25.5^{a}	13.5^{c}	13.9^{c}	0.55	0.024	<0.001	0.003	63
Intake									
MR intake, kg DM/cow/d	12.5	12.5	11.3	11.2	0.22	0.494	<0.001	0.338	16
Grazed forage intake, kg DM/cow/d	8.6^{b}	10.7^{a}	12.3^{a}	12.0^{a}	0.45	0.082	<0.001	0.005	63
DM intake, kg DM/cow/d	21.2^{b}	23.2^{a}	23.6^{a}	23.2^{a}	0.45	0.114	0.006	0.003	63
Ingestive Behaviour									
Grazing time, min/d	269	267	330	333	9.9	0.965	<0.001	0.791	33
Ruminating time, min/d	454	439	534	479	22.7	0.141	0.014	0.400	33
Number of grazing meals, n/d	2.3	2.9	2.9	3.2	0.14	0.009	0.007	0.331	33
First grazing meal length, min	171	137	180	163	11.7	0.067	0.121	0.434	33
Total grazing prehension bites, bites/day × 100	109	100	126	128	12.9	0.823	0.021	0.530	33
Total grazing manipulation chews, chews/day × 100	67	66	98	86	9.0	0.556	0.002	0.421	33
Bite rate during first grazing meal, bites/min	41	42	40	41	4.0	0.903	0.693	0.846	33
Bite rate average day, bites/min of grazing	41	38	37	38	3.7	0.788	0.355	0.358	33
Bite mass, g DM/bite	0.83	1.14	1.05	1.07	0.118	0.211	0.506	0.188	33
Grazed forage intake rate, kg DM/h	1.9^{b}	2.5^{a}	2.2^{ba}	2.1^{ba}	0.13	0.078	0.528	0.029	33
Eating chews at grazing, n/day × 100	176	166	225	214	8.7	0.320	<0.001	0.935	33
Eating chews at grazing, n/kg grazed forage DM intake × 10	203^{a}	152^{b}	191^{a}	185^{a}	8.9	0.004	0.252	0.022	33
Eating chews at grazing, n/kg grazed forage NDF intake × 10	339^{a}	257^{b}	316^{ba}	321^{a}	15.1	0.019	0.186	0.010	33
Rumination chews, n/day × 100	244	235	303	269	16.2	0.234	0.009	0.429	33
Rumination chews, n/kg DM intake × 10	116	100	132	118	7.0	0.052	0.028	0.953	33
Rumination chews, n/kg NDF intake × 10	236	202	283	260	15.4	0.089	0.004	0.709	33
Rumination time, min/kg DM intake	22	19	23	21	1.2	0.070	0.119	0.732	33
Rumination time, min/kg NDF intake	44	38	49	46	2.7	0.141	0.014	0.495	33
FS behaviour									
Total FS visited, FS/day × 10	98^{b}	113^{b}	122^{b}	182^{a}	10.6	0.009	<0.001	0.013	33
Time per FS, s/FS	19^{a}	17^{a}	19^{a}	13^{b}	1.1	0.002	0.079	0.037	63
FS per minute, FS/min	3.7^{b}	4.2^{b}	3.8^{b}	5.3^{a}	0.24	0.002	0.002	0.006	63
Bites per FS, bites/FS	11.3	9.2	10.4	6.8	0.85	0.009	0.041	0.338	33
Grazed forage intake per FS, g DM/FS	9.2b^{a}	10.2^{a}	9.9^{ba}	6.6^{b}	0.81	0.169	0.089	0.013	33
Displacement rate, steps/FS	0.58^{a}	0.50^{ba}	0.31^{b}	0.58^{a}	0.056	0.120	0.082	0.002	63

Abbreviations: MR = Mixed Ration; FS = Feeding Station.
[a–c]Means within a row with different lowercase letters differ (P < 0.05) between period and treatments.
[1] Control: postgrazing sward height of 5.0–7.0 cm. High: postgrazing sward height of 12.0–15.0 cm.
[2] Average SEM is listed.

centration was 77 and 32 g/kg DM higher in the High treatment than in the Control during Period I and Period II, respectively (treatment by period interaction; P < 0.001). The NDF concentration was 18 g/kg DM lower in the High treatment than in Control (P < 0.001), with no differences across periods (P = 0.259). The ADF concentration followed a similar pattern, with a 31 g/kg DM difference between treatments (P < 0.001) but increased 43 g/kg DM from Period I to Period II (P < 0.001). Neither lignin nor ether extract concentration differed among treatments or periods ($P \geq 0.144$). Ash concentration was lower in the High treatment than in the Control (P = 0.004) and decreased from Period I to Period II (P < 0.001).

Individual daily milk and ECM production were about 10% higher (P = 0.041) for cows in the High treatment than in the Control treatment (Table 2). Milk production was about 10 kg/day lower in Period II compared with Period I (P < 0.001). Fat and protein concentrations did not differ between treatments ($P \geq 0.582$) but increased from Period I to Period II (P < 0.001). The MUN concentration was 13% higher (P = 0.031) for cows in the High treatment compared with the Control during Period I, but was lower in both treatments during Period II, with no difference between them (treatment by period interaction; P = 0.003).

Discussion

Regardless of lactation stage or milk production level, the overall effects of residual sward height on behaviour, grazed forage intake, and milk production were consistent. Regarding the temporal-scale behaviour, the daily grazing time varied according to total time on pasture but was not affected by postgrazing sward height. In contrast, the distribution of grazing time throughout the day was influenced by treatments. Cows in the High treatment performed shorter but more frequent grazing meals, whereas cows in the Control treatment performed fewer but longer meals each day. A clear pattern also emerged in spatial exploration behaviour: cows in the High treatment adopted a "rapid sampling" strategy, taking fewer but larger bites of higher-quality forage at each feeding station, thereby exploring a greater number of feeding stations per unit of time. As a result of this behavioural strategy, cows in the High treatment achieved higher intake rates (Period I) and greater grazed forage DMI. The combination of higher intake of better-quality grazed forage enabled cows under taller residual management to produce more milk.

Raising the postgrazing sward height from 8.4 to 15.9 cm increased milk and ECM yield by ~10% across periods. As MR was standardised across treatments, the primary effect of the High treatment originated from grazed forage intake dynamics and diet quality rather than consumption of the MR supplement. In Period I, the High treatment increased grazed forage intake (+2.0 kg/day) and total DMI through a higher intake rate (+32%) relative to Control, with no change in daily grazing time. These patterns are consistent with classic bite-scale mechanisms where less-depleted swards support larger bite mass (Ungar et al., 2001; Laca et al., 1992) and faster ruminal fill, resulting in shorter and more frequent grazing meals, increasing DMI without requiring more time at pasture (Gibb et al., 1999). The jaw movement behaviours further support a harvest-efficiency interpretation in Period I. Cows in the High treatment required fewer eating chews per kg of grazed forage DM (−25%) and per kg of forage NDF (−24%), and tended to require fewer rumination chews and min per kg of DMI during Period I (Table 2). Such reductions in chewing requirement per unit intake are expected when cows consume a diet that is less fibrous, lowering the time cost of particle size reduction (White et al., 2017). The chemical composition of the consumed grazed forage aligns with this: High cows consumed higher CP and lower NDF and ADF than Control in both periods, with particularly large CP differences in Period I. The higher quality and intake of the grazed forage for High cows in Period I were achieved by selecting fewer but likely larger, more digestible bites at each feeding station, with no major differences in the number of feeding stations visited or the time spent at each one in Period I.

Compared with Period I, in Period II (spring-summer), grazed forage intake was higher in both treatments, and differences in DMI and grazed forage intake rate between treatments disappeared, although ingestive behaviour still suggested greater selectivity. Indeed, cows in the High treatment continued to consume grazed forage of higher quality, characterised by greater CP and lower fibre concentration. The shorter and more frequent meal behaviour pattern observed for High cows is often associated with higher intake rates, as cows reach ruminal fill earlier and cease the grazing meal (Chilibroste et al., 1997). In the present case, because grazed forage intake rate and DMI did not differ between treatments, elevated ruminal ammonia concentrations - arising from the higher CP concentration of the grass - likely also contributed to determining when grazing meals ended (discussed below). The behavioural evidence supporting this interpretation is described below. During Period II, cows in the High treatment visited more feeding stations per day, spent less time per feeding station, took fewer bites per feeding station, and almost doubled their search steps until proceeding to the next feeding station. This "rapid sampling" pattern is characteristic of selective grazing in mosaics where cows switch patches more frequently to maintain an instantaneous intake rate, trading off search depth for breadth (Chapman et al., 2007). While moving, it would be expected that cows increase the number of manipulation chews, thereby reducing the particle size of forage in the bites taken while searching for the next feeding station. In contrast to our expectations, the number of grazing manipulation chews did not differ between treatments, but there was a tendency for fewer rumination chews and shorter rumination time per unit of intake, consistent with greater processing of forage during ingestion (Gibb et al., 1999) and less fibrous forage (White et al., 2017). Such processes likely contribute to comminution of the forage prior to ruminative mastication. This behaviour, combined with the higher-quality grazed forage consumed, may have accelerated the release of soluble and rapidly degradable organic matter in the rumen (Chilibroste et al., 2008) of High cows compared with Control. In line with this, the early termination of grazing meals of High cows in the present study is more plausibly linked to increased ruminal ammonia concentrations resulting from the higher CP concentration of the grazed forage, rather than to fermentation end products or rumen fill (lower fibre concentration in High treatment). This interpretation is consistent with Taweel et al. (2004), who reported that cows ended their initial grazing meals well before reaching rumen capacity and without marked changes in volatile fatty acid concentrations, whereas ruminal ammonia levels increased markedly. Similarly, Chilibroste et al. (1998) suggested that elevated ruminal ammonia may play a regulatory role in meal cessation by signalling metabolic feedback associated with excess degradable N. Therefore, the response observed here likely reflects the effects of ruminal N dynamics, with ammonia accumulation acting as a key factor influencing meal termination. Moreover, the greater CP concentration of the High treatment likely enhanced the supply of metabolisable protein (Menegazzi et al., 2022), contributing to the higher milk production observed, particularly in Period II. This response was likely reinforced by differences in ruminal fermentation end products associated with the altered pattern of intake and forage quality, which could also help explain the variation in milk production between treatments. The higher MUN in High treatment during Period I is unsurprising, given the higher CP concentration of consumed grazed forage and likely reflects greater rumen-available N relative to fermentable energy (Dijkstra et al., 2013) when MR was held constant.

The cost of selectivity may be reflected in the intake rate (Chilibroste et al., 2015). This pattern was observed during Period II, when cows in the High treatment consumed forage of superior quality but were unable to sustain the greater intake rate observed in Period I, in which they selected higher-quality forage without a negative effect on intake rate. According to Roguet et al. (1998) and Searle et al. (2005), grazing herbivores tend to utilise feeding stations in such a way as to remove more digestible forage before moving on; then operating decisions in a constant trade-off between forage quality and quantity ingested. The decision to move to a new feeding station then depends of the profitability of each bite: trade-off between the benefit and cost of moving on (Searle et al., 2005), which is highly connected to the animals' perception of resource availability (Roguet et al., 1998). In this regard, strength of this research is that cows were submitted to treatments over a long period, and its behavioural response may include carry-over effects of foraging style (Roguet et al., 1998).

The differences in grazing behaviour and intake-related variables between periods are the result of both animal- and sward-related factors. Daily milk production was approximately 10 kg/cow lower in Period II, with concomitant lower nutrient requirements. In addition, sward structure and quality reflected the cumulative effects of treatments and seasonal progression. In Period II, High cows explored 63% more feeding stations than all other treatment × period combinations, suggesting that profitable bites were less abundant and required greater search effort. This aligns with the observed decline in canopy quality over the grazing season in the present study (Dorao et al., unpublished), with a greater reduction in the High than in the Control treatment. In addition, greater spatial heterogeneity is expected when managing for a higher residual sward height. It is noteworthy that the sward structure in a grazing system is both a cause and a consequence of grazing behaviour (Carvalho, 2013).

Collectively, these results highlight the importance of examining dairy cows' behaviour across different temporal and spatial scales to better understand the grazing strategies they employ, thereby improving our knowledge of how nutrient capture from pasture can be enhanced. However, some limitations of the present study should be acknowledged. First, the achieved postgrazing sward height in both treatments was slightly higher than the target range. Although this deviation may have influenced the magnitude of the responses, a clear contrast between treatments was maintained throughout the experiment. In addition, behavioural data were obtained from a reduced number of animals due to equipment availability and data quality filtering, which may have limited statistical power for some variables. Furthermore, interpretations related to rumen processes (e.g., ammonia dynamics and meal termination) remain speculative, as no direct rumen measurements were performed. Future research should investigate whether combining taller residual sward heights with adjustments in supplement composition could better capitalise on differences in selected forage quality by aligning rumen energy and protein supply, thereby improving nutrient use efficiency at the cow and system level.

Conclusion

Contrasting postgrazing sward heights primarily reshaped grazing behaviour, which then determined intake and ultimately milk production. Managing for a taller, less-depleted sward residual prompted cows to redistribute grazing into shorter, more frequent meals and to sample feeding stations more rapidly, taking fewer but larger bites per feeding station. This behaviour strategy increased nutrient intake rate without extending daily grazing time. Cows under taller sward residuals selected higher-quality forage (greater CP, lower fibre) in both periods and, in Period I, achieved higher grazed forage DM intake and higher total DM intake. These behavioural and dietary shifts translated into greater milk production at equal supplementation across periods. Overall, these results demonstrate that postgrazing sward height influences the temporal and spatial behavioural mechanisms by which grazing dairy cows acquire nutrients and highlight the importance of considering these behavioural responses when designing sward management strategies to improve nutrient capture and use efficiency.

Ethics approval

The experimental protocol was approved by the Ethics Committee of the Universidad de la República (protocol number Exp. 311170-000044-23).

Data and model availability statement

None of the data were deposited in an official repository. Data may be available upon request by contacting the corresponding author.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to enhance the English language. The authors reviewed and edited the content as necessary and took full responsibility for the accuracy and integrity of the publication.

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Declaration of interest

None.

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References

Allen, M.S., 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. Journal of Dairy Science 83, 1598–1624. https://doi.org/10.3168/jds.S0022-0302(00)75030-2.

Altamirano, A., Da Silva, H., Durán, A., Echevarría, A., Panario, D. and Puentes, R., (ed.)1976. Clasificación de suelos. In Carta de reconocimiento de suelos del Uruguay, Tomo I. Dirección de Suelos y Fertilizantes, Ministerio de Agricultura y Pesca, Montevideo, Uruguay, pp. 1–96.

AOAC, 2000. Official methods of analysis. Association of Official Analytical Chemists, Washington, DC, USA.

Barthram, G.T., 1985. Experimental techniques: the HFRO sward stick. In: Alcock, M. M. (Ed.), The Hill Farming Research Organization Biennial Report 1984/1985. HFRO Publishing, Midlothian, UK, pp. 29–30.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5, 180214. https://doi.org/10.1038/sdata.2018.214.

Chapman, D.F., Parsons, A.J., Cosgrove, G.P., Barker, D.J., Marotti, D.M., Venning, K.J., Rutter, S.M., Hill, J., Thompson, A.N., 2007. Impacts of spatial patterns in pasture on animal grazing behavior, intake, and performance. Crop Science 47, 399–415. https://doi.org/10.2135/cropsci2006.01.0036.

Chilibroste, P., Tamminga, S., Boer, H., 1997. Effects of length of grazing session, rumen fill and starvation time before grazing on dry-matter intake, ingestive behaviour and dry-matter rumen pool sizes of grazing lactating dairy cows. Grass and Forage Science 52, 249–257. https://doi.org/10.1111/j.1365-2494.1997.tb02355.x.

Chilibroste, P., Tamminga, S., Van Bruchem, J., Van der Togt;, P.L., 1998. Effect of allowed grazing time, inert rumen bulk and length of starvation before grazing on the weight, composition and dermentative end-products of the rumen contents of lactating dairy cows. Grass and Forage Science 53, 146–156. https://doi.org/10.1046/j.1365-2494.1998.5320146.x.

Chilibroste, P., Dijkstra, J., Robinson, P.H., Tamminga, S., 2008. A simulation model 'CTR Dairy' to predict the supply of nutrients in dairy cows managed under discontinuous feeding patterns. Animal Feed Science and Technology 143, 148–173. https://doi.org/10.1016/j.anifeedsci.2007.05.009.

Chilibroste, P., Gibb, M.J., Soca, P., Mattiauda, D.A., 2015. Behavioural adaptation of grazing dairy cows to changes in feeding management: do they follow a predictable pattern? Animal Production Science 55, 328–338. https://doi.org/10.1071/an14484.

Coates, D.B., Penning, P., 2000. Measuring animal performance. CABI, Wallingford, UK, pp. 353–402. https://doi.org/10.1079/9780851993515.0353.

de F. Carvalho, P.C., 2013. Harry stobbs memorial lecture: can grazing behavior support innovations in grassland management? Tropical Grasslands - Forrajes Tropicales 1, 137. https://doi.org/10.17138/TGFT(1)137-155.

Dijkstra, J., Oenema, O., van Groenigen, J.W., Spek, J.W., van Vuuren, A.M., Bannink, A., 2013. Diet effects on urine composition of cattle and N_2O emissions. Animal 7, 292–302. https://doi.org/10.1017/S1751731113000578.

Dove, H., Mayes, R.W., 2006. Protocol for the analysis of n-alkanes and other plant-wax compounds and for their use as markers for quantifying the nutrient supply of large mammalian herbivores. Nature Protocols 1, 1680–1697. https://doi.org/10.1038/nprot.2006.225.

Edmonson, A.J., Lean, I.J., Weaver, L.D., Farver, T., Webster, G., 1989. A body condition scoring chart for Holstein dairy cows. Journal of Dairy Science 72, 68–78. https://doi.org/10.3168/jds.S0022-0302(89)79081-0.

Gibb, M.J., Huckle, C.A., Nuthall, R., Rook, A.J., 1999. The effect of physiological state (lactating or dry) and sward surface height on grazing behaviour and intake by dairy cows. Applied Animal Behaviour Science 63, 269–287. https://doi.org/10.1016/S0168-1591(99)00014-3.

Gregorini, P., 2012. Diurnal grazing pattern: its physiological basis and strategic management. Animal Production Science 52, 416. https://doi.org/10.1071/an11250.

Griffiths, W.M., Hodgson, J., Arnold, G.C., 2003. The influence of sward canopy structure on foraging decisions by grazing cattle. II. Regulation of bite depth. Grass and Forage Science 58, 125–137. https://doi.org/10.1046/j.1365-2494.2003.00361.x.

Laca, E.A., Ungar, E.D., Seligman, N., Demment, M.W., 1992. Effects of sward height and bulk density on bite dimensions of cattle grazing homogeneous swards. Grass and Forage Science 47, 91–102. https://doi.org/10.1111/j.1365-2494.1992.tb02251.x.

Mayes, R.W., Wright, I.A., Lamb, C.S., McBean, A., 1986. The use of long-chain n-alkanes as markers for estimating intake and digestibility of herbage in cattle. British Society of Animal Production 107, 161–170.

Menegazzi, G., Giles, P.Y., Oborsky, M., Fast, O., Mattiauda, D.A., Genro, T.C.M., Chilibroste, P., 2021. Effect of post-grazing sward height on ingestive behavior, dry matter intake, and milk production of Holstein dairy cows. Frontiers in Animal Science 2, 1–12. https://doi.org/10.3389/fanim.2021.742685.

Menegazzi, G., Giles, P.Y., Mattiauda, D.A., Elizondo, F., Genro, T.C.M., Gerrits, W.J.J., Dijkstra, J., Chilibroste, P., 2022. Diurnal variation in water-soluble carbohydrate contents of pasture affects milk production of dairy cattle: a simulation approach. Elsevier B.V., Sardinia, Italy, pp. 579–580. https://doi.org/10.1016/j.animal.2023.101067.

Menegazzi, G., Dorao, C., Loza, C., Talmón, D., Mattiauda, D.A., Genro, T.C.M., Gerrits, W.J.J., Dijkstra, J., Chilibroste, P., 2025. Effects of postgrazing sward height on individual and per-hectare milk production of supplemented high-producing dairy cows. Journal of Dairy Science 108, 13326–13343. https://doi.org/10.3168/jds.2025-26767.

Mertens, D.R., 1994. Regulation of forage intake. In: Fahey, G.C. (Ed.), Forage Quality, Evaluation and Utilization. American Society of Agronomy, Madison, WI, USA, pp. 450–493. https://doi.org/10.1201/9781351070218.

Parsons, A., Chapman, D.F., 2000. The principles of pasture growth and utilization. In: Hopkins, A. (Ed.), Grass: Its Production and Utilization. Blackwell Science, London, UK, pp. 31–89.

Roguet, C., Dumont, B., Prache, S., 1998. Selection and use of feeding sites and feeding stations by herbivores: a review. Animal Research 47, 225–244.

Rombach, M., Münger, A., Niederhauser, J., Südekum, K.-H., Schori, F., 2018. Evaluation and validation of an automatic jaw movement recorder (RumiWatch) for ingestive and rumination behaviors of dairy cows during grazing and supplementation. Journal of Dairy Science 101, 2463–2475. https://doi.org/10.3168/jds.2016-12305.

Ruyle, G.B., Dwyer, D.D., 1985. Feeding stations of sheep as an indicator of diminished forage supply. Journal of Animal Science 61, 349–353. https://doi.org/10.2527/jas1985.612349x.

Searle, K.R., Thompson Hobbs, N., Shipley, L.A., 2005. Should I stay or should I go? Patch departure decisions by herbivores at multiple scales. Oikos 111, 417–424. https://doi.org/10.1111/j.0030-1299.2005.13918.x.

Sjaunja, L.O., Baevre, L., Junkkarinen, L., Pedersen, J., Setälä, J., 1990. A Nordic proposal for an energy corrected milk formula. In: Proceedings of the 27th Biennial Session of the International Committee for Recording the Productivity of Milk Animals (ICRPMA), 2–6 July 1990. Paris, France, pp. 156–157.

Taweel, H.Z., Tas, B.M., Dijkstra, J., Tamminga, S., 2004. Intake regulation and grazing behavior of dairy cows under continuous stocking. Journal of Dairy Science 87, 3417–3427. https://doi.org/10.3168/jds.S0022-0302(04)73477-3.

Ungar, E.D., Ravid, N., Bruckental, I., 2001. Bite dimensions for cattle grazing herbage at low levels of depletion. Grass and Forage Science 56, 35–45. https://doi.org/10.1046/j.1365-2494.2001.00244.x.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2.

Werner, J., Leso, L., Umstatter, C., Niederhauser, J., Kennedy, E., Geoghegan, A., Shalloo, L., Schick, M., O'Brien, B., 2018. Evaluation of the RumiWatchSystem for measuring grazing behaviour of cows. Journal of Neuroscience Methods 300, 138–146. https://doi.org/10.1016/j.jneumeth.2017.08.022.

White, R.R., Hall, M.B., Firkins, J.L., Kononoff, P.J., 2017. Physically adjusted neutral detergent fiber system for lactating dairy cow rations. I: Deriving equations that identify factors that influence effectiveness of fiber. Journal of Dairy Science 100, 9551–9568. https://doi.org/10.3168/jds.2017-12765.

Zehner, N., Hürlimann, M., Hoch, M., 2014. User Guide RumiWatch Converter Version 0.7. 3.2 and higher. CIGR-AgEng, Bennwil, Switzerland.

Zibil, S., Zanoniani, R., Bentancur, O., Ernst, O., Chilibroste, P., 2016. Control de intensidad de defoliación sobre la producción de forraje estacional y total en sistemas lecheros. Agro Sur 44, 45–53. https://doi.org/10.4206/agrosur.2016.v44n2-06.