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Effects of postgrazing sward height on individual and per-hectare milk production of supplemented high-producing dairy cows

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ABSTRACT

Residual sward height management is a key factor influencing milk production and grazed forage utilization per cow and per hectare in pasture-based dairy systems. This study evaluated the effects of postgrazing sward height on forage growth rate and DMI, milk production, and BCS in supplemented, high-producing dairy cows. The study captured cumulative treatment effects on animal performance across nearly an entire lactation, as well as sward dynamics over most of the tall fescue growing season. Thirty-two multiparous Holstein cows were assigned to 2 treatments: the control treatment, with a postgrazing sward height of 5.0 to 7.0 cm (CT), and the high treatment, with a postgrazing sward height of 12.0 to 15.0 cm (HI). The study spanned 215 d of grazing on a *Lolium arundinaceum* sward in a randomized complete block design, with 4 blocks, each measuring 3.2 ha, and consisted of 2 paddocks, each measuring 1.6 ha. Cows had one grazing session between milkings and were supplemented with a mixed ration in the opposite session. Rotational grazing was employed, with new strips allocated once the postgrazing sward height for each treatment was achieved. A new grazing cycle was initiated when plants reached the 2.5 to 3.0-leaf phenological state. Any extra or unused areas within a grazing cycle were always recorded. The postgrazing sward heights were 7.7 and 14.4 cm for the CT and HI treatment, respectively. Forage growth rate tended to be 21% higher in the HI treatment (40 vs. 33 kg DM/ha per day), and cows stayed longer per strip (3.9 vs. 2.9 d) and had 2.5 times more grazing cycles (8.3 vs. 3.3). Total forage disappearance was similar between treatments. Cows in the HI treatment had greater individual grazed forage DMI (+2.0 kg/cow) and BCS throughout lactation compared with CT cows. The HI treatment also increased the individual milk production by 10% (31.5 vs. 34.5 kg milk/d) while reducing concentrate intake per unit of milk by 10%, resulting in a tendency for higher income over feed costs at cow level. However, although we observed a tendency for a higher forage growth rate, this approach required a larger grazing area (1.18 vs. 1.60 ha/4 cows), leading to a trend toward 21% lower milk output per hectare (23,598 vs. 18,528 kg milk/ha). In contrast, the CT treatment supported a higher stocking rate but resulted in lower grazed forage DMI, higher supplemental feed input per hectare and slower BCS recovery. These findings highlight the importance of aligning grazing strategies with system-specific goals. Farmers seeking to maximize land productivity may favor lower postgrazing sward heights, although these must be managed carefully to prevent adverse effects on animal health, reproduction, and long-term productivity due to slower BCS recovery during lactation and lower BCS at the onset of dry off. Conversely, systems aiming to reduce feed costs may benefit from a higher residual sward height, which enhances individual cow performance and BCS while decreasing reliance on supplemental feed.
Key words: high-producing dairy cow, residual sward height, trade-offs, grazing management

INTRODUCTION

Grazing management strategies are critical for the productivity and sustainability of pasture-based dairy systems (van Vuuren and Chilibroste, 2013). A key challenge in these systems is navigating the economic and environmental trade-offs between maximizing milk production per animal and per hectare. Although increased stocking rates and grazing intensities can enhance production per hectare, this often compromises individual animal performance by limiting grazed forage intake (Romera and Doole, 2015), particularly for high-producing dairy cows (>35 kg milk/d at peak) with substantial nutritional de-

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mands (Peyraud and Delagarde, 2013; Dale et al., 2018), unless additional feed is supplied.

Supplementation practices, which are widely used to support individual milk production and manage forage allowance, further complicate the trade-offs between productivity at the animal and system level (Stockdale, 2000; Bargo et al., 2003; Wales et al., 2013), primarily due to the substitution effects of supplements. Although supplementation improves individual performance and may enable higher stocking rates, it reduces forage utilization per unit of milk, increasing costs due to greater reliance on external feed inputs (Stockdale, 2000; Bargo et al., 2003; Wales et al., 2013). Therefore, careful integration with grazing management strategies is required to avoid unnecessary supplementation (Méndez et al., 2020). Grazed forage is usually the most economical nutrient source for dairy cows, and pasture-based systems prioritize maximizing grazed forage intake (Finneran et al., 2010; Fariña and Chilibroste, 2019) while minimizing the consumption of human-edible resources by the cows (Wilkinson, 2011; feeds that could otherwise be directly consumed by humans).

Grazed forage DMI is driven by the grazing process, with sward height being the key factor determining bite mass (Laca et al., 1992), which in turn drives intake rate and daily grazed forage intake (de Faccio Carvalho, 2013). Managing sward height influences DMI potential, milk production performance, and forage regrowth dynamics (van Vuuren and Chilibroste, 2013). Although postgrazing sward height recommendations in Europe and Oceania generally range from 3.5 to 6.0 cm, depending on forage type, season, and management goals, the most common range to balance forage utilization and regrowth is 4.0 to 5.0 cm (Parsons and Chapman, 2000; Fulkerson and Donaghy, 2001; Roche et al., 2017; Delaby and Horan, 2021; Donaghy et al., 2021). However, these guidelines may not universally apply in temperate and subtropical regions of South America, where canopy density (Scheneiter and Améndola, 2012; Jáuregui et al., 2017) is commonly lower than in Europe and Oceania. Indeed, in these regions, postgrazing sward heights below 6.0 cm have been rarely reported (Menegazzi et al., 2021; Stirling et al., 2021; Gareli et al., 2023; Ortega et al., 2024; Rivoir et al., 2025).

Recent studies in South America evaluating grazing strategies for beef cattle and lambs have highlighted the benefits of moderate grazing intensity. These strategies often result in improved individual performance and comparable or higher production per hectare compared with high grazing intensity systems (Savian et al., 2021; Schons et al., 2021; Portugal et al., 2022). In a short-term trial, Menegazzi et al. (2021) evaluated nonsupplemented late-lactation dairy cows grazing tall fescue (*Lolium arundinaceum*) at postgrazing sward heights of 9.0, 12.0, and 13.5 cm. We found that individual milk production improved with increasing postgrazing sward height. Individual grazed forage intake was higher at postgrazing sward heights of 12.0 and 13.5 cm (17.8 kg DMI/d) compared with 9.0 cm (14.8 kg DMI/d). However, despite no difference in DMI between 12.0 and 13.5 cm, daily milk production increased by 2.5 L per cow (16.2 vs. 18.7 L/cow per d) due to differences in the nutritive value of the consumed grazed forage (Menegazzi et al., 2022). Gareli et al. (2023) conducted an 81-d trial with mid-lactation cows grazing *Dactylis glomerata*, comparing 2 grazing strategies: high intake rate (pre- and postgrazing height of 23.5 and 14.4 cm, respectively) and high herbage harvest per hectare (pre- and postgrazing sward height of 28.3 and 10.0 cm, respectively). Cows received 0 or 4 kg DM/d of concentrate. The study revealed a trade-off between individual and per-area performance, regardless of supplementation level, with greater feed intake and milk production per cow in the high intake rate strategy, but greater milk solid production per hectare in the high herbage harvest per-area strategy. Notably, nonsupplemented cows managed under the high herbage harvest per hectare strategy experienced reductions in BW and BCS, indicating that part of their milk production was supported by mobilization of body reserves.

Dairy grazing systems encompass multiple dimensions, where management decisions influence not only individual cow performance but also forage utilization, affecting overall system productivity and efficiency. Research on grazing dairy cattle has focused on lower sward heights, as managing swards with low-intensity grazing often raises concerns about maintaining sward quality (Peyraud and Delagarde, 2013), leaving limited insights into the potential benefits or trade-offs associated with taller postgrazing sward height (above 7 cm) on both individual and per-hectare performance of supplemented high-producing dairy cows. Additionally, to the authors' knowledge, no detailed studies have evaluated these dynamics over an entire lactation period. The current study aims to address these gaps by evaluating the effects of 2 contrasting postgrazing sward heights on intake, milk production, BCS, and forage production in supplemented, high-producing dairy cows grazing tall fescue. By collecting data at both the individual cow and per-hectare levels over nearly an entire lactation, this study contributes to the understanding of the impacts of grazing strategies on both productivity and sustainability of pasture-based dairy systems, providing essential information for farmers and potentially informing policy decisions to tailor management strategies to specific objectives. It was hypothesized that in comparison to the CT treatment, the HI treatment would increase milk production per cow and sustain a higher BCS, primarily due to higher DMI, while maintaining similar milk production per hectare with lower supplementary feed input (per hectare), as enhanced forage growth was expected with a higher residual sward height.

MATERIALS AND METHODS

An experiment was conducted at the Research Station "Dr. Mario A. Cassinoni" (EEMAC) of the Facultad de Agronomía, Universidad de la República (Paysandú, Uruguay; 32° 23′ 08″ S, 58° 03′ 19″ W). The study was carried out from April 19, 2023, to November 19, 2023, spanning a total experimental period of 215 d. The experimental protocol was approved by the Ethics Committee of the Universidad de la República (protocol number Exp. 311170-000044-23).

The climate is humid subtropical or temperate hot-summer (Cfa in the Köppen classification; Beck et al., 2018). The soils at the experimental site are typical eutric and haplic Brunisols from the San Manuel Series (Altamirano et al., 1976) characterized by shallow depth. Soils had an average OM content of 4.1% (0–20 cm), 17.2 mg/kg of P (0–20 cm), 166 mg/kg of K (0–20 cm), and average pH of 6.6. The pasture consisted of a 2-yr-old tall fescue (*Lolium arundinaceum* cv. INIA Fortuna) sward.

On March 13, 2023, the sward was uniformly cut to a height of 6 cm using mechanical mowing, and cattle began grazing the treatment swards starting on April 19, 2023, when the sward reached 2.0-leaf stage. The sward was fertilized with a total of 135 kg N/ha applied in 3 equal applications during May, August, and October. The monthly rainfall during the experimental year (Appendix Table A1) indicated generally dry conditions. Precipitation was 78% below the 15-yr average for January and February (summer, before the study began), as well as in April (−75%; autumn) and from August to October (−54%; later winter and early spring) during the study. The weekly average temperature ranged between 10.2°C and 21.5°C. On average, throughout the experiment, 86% of the week remained below the threshold of 68 on the temperature-humidity index (**THI**; De Rensis et al., 2015). However, during the last 5 wk of the trial, the THI was between 68 and 72 for 12% of the week and exceeded 72 for 20% of the week (Appendix Figure A1). This increase in THI coincided with the period when cows began grazing at night (see the "Grazing and Feeding Management" section).

Experimental Design, Treatments, and Cows

Two postgrazing sward heights were tested in a randomized complete block design with 4 blocks, each measuring 3.2 ha. Each block was characterized by homogeneous soil conditions and consisted of 2 paddocks, each measuring 1.6 ha. Within each block, paddocks were randomly assigned to either the control treatment, with a postgrazing sward height of 5.0 to 7.0 cm (CT), or the high treatment, with a postgrazing sward height of 12.0 to 15.0 cm (HI). The rationale behind the CT treatment was to represent the common grazing management practices present in pastoral dairy systems of Uruguay (Zibil et al., 2016). The sward height range of the HI treatment was defined based on maximal individual DMI (de Faccio Carvalho, 2013) and milk production observed in previous experiments (Menegazzi et al., 2021).

Each paddock was grazed by 4 milking cows throughout the trial. A total of 32 multiparous Holstein cows, selected from the general experimental grazing herd of the research station, were stratified into groups of 4 based on previous 305-d milk production (9,100 ± 1,560 kg), parity (3.4 ± 1.0 lactations), far-off dry period BW (718 ± 70 kg), far-off dry period BCS (3.3 ± 0.3), and expected calving date (April 5 ± 15 d). Within each group, cows were randomly assigned to one of 4 blocks and then randomly allocated to paddocks within their assigned block. The groups were balanced for previous milk production, parity, BW, BCS and expected calving date. All cows received equal management during both the far-off and close-up periods and were fed an anionic precalving diet in a compost-barn for ~3 wk before their expected calving dates. Cows that calved a few days before the start of the trial were managed together until the trial began. All cows underwent at least 2 clinical examinations by a veterinarian: one on the day of calving and another between 5 and 10 d postpartum to assess their health status and ensure eligibility for continued participation in the study. One cow experienced calving-related complications and was replaced on d 1 of the trial. Nonexperimental fresh lactating cows with similar BW and parity were used as temporary replacements for experimental cows that calved within the first 10 d of the trial (n = 5; 2 on d 2, 2 on d 5, and one on d 10). Cows were cleared by the veterinary staff to enter the study 1 d postpartum.

Grazing and Feeding Management

Rotational grazing was employed, with new strips allocated once the postgrazing sward height for each treatment was achieved. To reach the target postgrazing sward heights, different strip-grazing sizes were implemented using movable fencing, and sward height was monitored daily (details provided in "Sward Measurements" section) to determine when cows should be moved to a new strip. The intended duration per strip was 3 d for the CT treatment and 5 d for the HI treatment. The initial strip size (ha) in each paddock was determined as follows: [intended forage intake per group of 4 cows (kg DM/d) × target duration per strip (d)]/forage mass above the target postgrazing sward height (kg DM/ha). Subsequent strips were kept the same size if the previous one matched the intended grazing duration; otherwise, the strip size was adjusted accordingly. A new grazing cycle was initiated again when the first strip-grazing area reached the 2.5 to 3.0-leaf phenological state (Lawson et al., 2017). When cows grazed the last strip of a paddock, and the first strip had not yet met the criteria to begin grazing again, the cows were temporarily moved to an adjacent area, managed according to their treatment's postgrazing sward height. Conversely, when a new grazing cycle began, any remaining ungrazed area within the paddock was grazed by a group of nonexperimental cows until it met the paddock treatment's postgrazing sward height. Any extra or unused areas within a grazing cycle were always recorded.

From April 19 to September 30, cows had 6.5 h of daily pasture access (0730 to 1400 h) with milking at 0600 h and 1600 h. From October 1 to October 16, pasture access increased to 8 h (0700 to 1500 h) with milking at 0500 h and 1700 h. From October 17 to November 19, cows had 13 h of daily pasture access overnight (1630 to 0530 h) with milking at 0600 h and 1500 h. Outside pasture hours, cows were housed in pens with the same groups of 4 as assigned 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. A single feed bunk, providing 0.75 m of linear space per cow, allowed all 4 cows to be fed simultaneously as a group. The barn featured fans and automatic sprinklers. The sprinklers were activated for 3 min with 10-min intervals without spraying whenever ambient temperatures exceeded 25°C. Cows had ad libitum access to fresh water in the paddock, barn, and milking parlor holding area. A mixed ration (**MR**) of silage and concentrate was fed after the evening milking during day-grazing periods and after the morning milking during night-grazing periods. The amount of MR offered was restricted and varied throughout the trial to complement the variability in forage growth rate to better meet the cows' nutritional requirements; however, both the amount and composition of supplemental feed were standardized across treatments. The ingredients of the MR, as well as its nutrient composition, are presented in Table 1.

During October, each strip was mowed to its treatment-specific postgrazing sward height after cows grazed the strip to remove flowering stems. Jáuregui et al. (2017) recommended removing flowering stems through short-term, intense grazing or mowing at the end of winter in subtropical regions to reduce tiller mortality in late spring. Mowing was performed at the treatment-specific sward height to maintain treatment conditions while avoiding physical constraints to grazing in subsequent cycles, even though the effectiveness of flowering control itself may not have been fully achieved.

Sward Measurements

Weekly monitoring of the sward's phenological state was conducted by counting the number of leaves per tiller in the first strip-grazing area on 10 randomly selected tillers to determine when a new grazing cycle should begin. Grazed leaves were counted proportionally as a fraction of the length of a fully expanded leaf, following Lawson et al. (2017). Leaves with less than approximately one-quarter of the length of a fully expanded leaf were ignored. On every strip, pre- and postgrazing sward heights were taken from ground level using a sward stick (Barthram, 1985), and forage mass was measured using a rising plate meter (**RPM**; Ashgrove Co., Palmerston North, New Zealand). Sward height was measured daily in all strips to determine when cows should move to a new strip. Measurements were taken along zigzag lines, with readings recorded every 2 steps. On average, 50 sward height and RPM readings were collected per strip in the CT treatment, and 100 readings were collected per strip in the HI treatment during each measurement event. Calibration of RPM was conducted every 45 d separately for each treatment by recording the compressed sward height and forage mass of 3 contrasting sward heights in triplicate. The compressed sward height was measured with the RPM at each of the 9 sites before cutting the forage under the RPM to ground level within a 30 × 34 cm frame. The harvested forage was collected, weighed, and oven-dried at 60°C for 48 h to determine DM content. Individual frame DM forage mass measurements were regressed against the corresponding RPM compressed sward height to develop forage mass prediction equations. Forage disappearance was estimated as the difference between pre-grazing and postgrazing forage mass (kg DM/ha) for each period of stay per strip. Sward height depletion (%) was calculated as the difference between pregrazing and postgrazing sward heights, expressed as a proportion of the pregrazing sward height.

To determine the forage growth rate, 2 measuring areas of 0.28 ha each were defined and physically marked in each paddock: one at the beginning and the other at the middle of the paddock. This arrangement ensured that if one measuring area was under grazing during the measurement day, the other was available for measurements. In these measuring areas, forage mass was estimated weekly using an RPM along the same zigzag

Table 1. Ingredients of the mixed ration (MR), nutrient composition of MR, and forage consumed by lactating dairy cows grazing tall fescue swards at 2 postgrazing sward heights, and proportions and nutrient composition of diet consumed

Item	Treatment[1] CT	HI	SEM[2]	*P*-value
Ingredients of the MR				
Concentrate,[3] % DM	64	64		
Sorghum silage, % DM	22	22		
Corn silage, % DM	10	10		
Grass silage, % DM	4	4		
Nutrient composition of the MR				
CP, g/kg of DM	209	209		
NDF, g/kg of DM	391	391		
ADF, g/kg of DM	216	216		
Lignin, g/kg of DM	23	23		
Ash, g/kg of DM	83	83		
Starch[4] g/kg of DM	159	159		
Nutrient composition of pre-grazed forage				
CP, g/kg of DM	162	189	8.8	0.121
NDF, g/kg of DM	570	564	4.0	0.350
ADF, g/kg of DM	276	263	3.7	0.081
Lignin, g/kg of DM	20	21	1.0	0.698
Ash, g/kg of DM	99	99	2.4	0.905
$NEL_{3\times}$,[5] Mcal/kg DM	1.42	1.46		
Proportions of the consumed diet[6]				
Grazed forage, % DM	40	47	1.4	0.003
MR, % DM	60	53		
Concentrate in diet, % DM	38	34	0.7	<0.001
Conserved forage in diet, % DM	22	19	1.1	0.152
Nutrient composition of the consumed diet[6]				
CP, g/kg of DM	190	200		
NDF, g/kg of DM	463	472		
ADF, g/kg of DM	239	238		
Lignin, g/kg of DM	22	22		
Ash, g/kg of DM	89	90		

[1]CT: postgrazing sward height of 5.0 to 7.0 cm. HI: postgrazing sward height of 12.0 to 15.0 cm.

[2]Average SEM is listed.

[3]Average composition of concentrate (DM basis): corn grain, 24%; soybean hulls, 20%; soybean meal, 16%; corn dried distillers grains with solubles, 12%; sunflower meal, 10%; barley, 7%; wheat bran, 7%; vitamin-mineral mix, 2.4%; salt, 1.0%; calcium carbonate, 1.0%.

[4]Calculated from ingredients composition.

[5]$NEL_{3\times}$ = NEL calculated assuming intake at 3× maintenance, according to NRC (2001).

[6]Calculated based on DMI of Table 3.

lines. On average, a total of 91 readings were taken per measuring area. The forage growth rate was calculated as the difference in forage mass between 2 consecutive weeks with no grazing in between, divided by the number of days that elapsed between readings. A forage sample was collected at the treatment's sward height in each paddock every 45 d, oven-dried at 60°C until reaching a constant weight, stored, and subsequently analyzed for chemical composition.

Animal Measurements

Individual cow milk production was automatically recorded daily. Individual milk samples were collected fortnightly during both morning and evening milkings and analyzed for milk fat, protein, lactose and MUN concentrations using mid-infrared spectroscopy (MilkoScan FT2, FossElectric, Drachten, The Netherlands). The weighted average milk composition per cow per day was calculated based on morning and evening milk production.

The DMI of MR was determined weekly for each pen as the difference between the feed offered and the feed wasted. Wasted feed was defined as the feed that cows tossed out of the feed bunk, making it no longer accessible. This was distinct from voluntary feed refusals. No voluntary feed refusals were observed during the trial. On the same day, the MR offered and wasted were sampled by collecting one subsample per pen, which was pooled into a single sample, weighed, and oven-dried at 60°C until reaching a constant weight (~72 h) to determine

DM content. The dried feed offered samples were pooled based on changes in the MR composition or ingredients, resulting in 6 pooled samples, which were stored for subsequent chemical analysis. Body weight was recorded monthly. Body condition score was assessed weekly from d 1 to 120 of the trial, and then fortnightly until the trial's end, using a 1-to-5 scale (Edmonson et al., 1989).

Chemical Analysis

The MR and grazed forage samples were analyzed for ash (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), and ADF and lignin (method 973.18; AOAC, 2000). The NDF and ADF analyses were performed independently with an ANKOM200 Fiber Analyzer (ANKOM Tech. Corp., Fairport, NY) and were expressed exclusively of residual ash.

Weather Data and Calculations

Air temperature, relative humidity, and rainfall records were obtained from the meteorological station at the experimental site every 30 min. The THI was calculated according to NRC (1971) as follows: (1.8 × AT + 32) − (0.55 − 0.0055 × RH) × (1.8 × AT − 26.8), where AT represents air temperature (°C) and RH represents relative humidity (%).

The Wilmink (1987) exponential function was fitted to daily milk production data for individual lactations, as follows:

$$y_t = a + b \times e^{-kt} + c \times t,$$

where y_t represents the milk production at day t of lactation, a is the initial milk production after calving, b is the parameter determining ascending slope before the peak, c is the parameter determining descending slope after the peak, k is a factor related to the moment of peak yield, and e^{-kt} is an exponentially decreasing component. The regression parameters were estimated for each individual lactation using PROC NLMIXED from SAS (SAS Institute Inc., Cary, NC). Based on the model, 215-d and 305-d milk production (kg/cow) were calculated. Milk solids content (fat plus protein) was obtained by summing the concentrations of fat and protein. Milk solids production was obtained by multiplying milk solids content and milk production. Energy-corrected milk production was calculated according to Sjaunja et al. (1990), as follows: ECM (kg) = milk production (kg) × {[38.30 × fat content (g/kg) + 24.20 × protein content (g/kg) + 16.54 × lactose content (g/kg) + 20.7]/3,140}.

Grazed forage DMI was estimated using the back-calculation approach, calculated as the difference between NEL consumed and required, following equations of NASEM (2021). Briefly, this method involved iteratively adjusting grazed forage DMI until the combined total of estimated grazed forage DMI and observed MR DMI met the cows' NEL requirements to achieve a zero net energy balance. The energy concentration of the diet offered to the animals was estimated according to NASEM (2021) based on MR and grazed forage chemical composition. The energy requirements for maintenance, activity (walking plus grazing), pregnancy (where appropriate), BW change, and milk production were calculated on a weekly, per-pen basis. Cows walked 1.60 km/d horizontally and 0.02 km/d vertically, which included the average round-trip distance from the milking parlor to the paddock. Pregnancy days were calculated retrospectively based on the date of the next calving for each cow.

The return on human-edible input was calculated following the human-edible proportions of feed ingredients described by Wilkinson (2011). Each feed's contribution to the human-edible portion was calculated by multiplying the quantity of that ingredient in the diet by the proportion considered edible for humans. Human-edible proportions were 0 for grazed forage, silage, hay, and mineral/vitamin premix; 0.8 for cereal and pulse grains and soybean meal; and 0.2 for cereal byproducts, other oilseed meals, and other byproducts (Wilkinson, 2011). This metric does not account for land use. The efficiency variables, including concentrate intake per unit of ECM, return on human-edible input, and income over feed costs, were calculated using observed 215-d milk production data. The income over feed costs was calculated using milk prices based on solids content (INALE, 2023), set at US$0.30/kg of milk. Feed prices for concentrate, silage, and grazed forage were US$0.55, US$0.14, and US$0.03/kg of DM (INALE, 2023), respectively.

The area used was the average of the actual area grazed by the group of 4 cows in each grazing cycle. The stocking rate was then calculated as the quotient of 4 cows (or their total BW) divided by the area grazed by the group of 4 cows. All other per-hectare, animal-oriented variables were calculated as the product of mean value per cow per day, the stocking rate (in cows per hectare), and the length of the trial.

Statistical Analysis

The cow was considered the experimental unit for milk production and composition, BCS, and BW-related variables, and the pen was considered the experimental unit for the DMI, efficiency, and sward-related variables. Unless stated otherwise, all variables were analyzed

Table 2. Sward characteristics of tall fescue swards grazed to 2 postgrazing sward heights by lactating dairy cows

Item	Treatment[1] CT	HI	SEM[2]	*P*-value
Pregrazing sward height, cm	23.6	22.1	0.51	0.042
Postgrazing sward height, cm	7.7	14.4	0.13	<0.001
Pregrazing forage mass, kg DM/ha	3,792	3,469	360.9	0.539
Postgrazing forage mass, kg DM/ha	1,604	2,640	114.3	<0.001
Sward height depletion,[3] % of PreGSH	66	35	0.8	<0.001
Forage allowance, kg DM/cow per day	16	58	1.2	<0.001
Forage disappearance,[4] kg DM/ha per 215-d	5,960	6,240	520.9	0.729
Forage growth rate,[5] kg DM/ha per day	33	40	2.8	0.094
Period of stay, d/strip	2.9	3.9	0.22	<0.001
Grazing cycles, n	3.3	8.3	0.25	<0.001

[1]CT: postgrazing sward height of 5.0 to 7.0 cm. HI: postgrazing sward height of 12.0 to 15.0 cm.

[2]Average SEM is listed.

[3]PreGSH = pregrazing sward height.

[4]Forage disappearance was estimated as the difference between pre- and postgrazing forage mass for each period of stay per strip.

[5]Forage growth rate was determined weekly in ungrazed representative areas of the plot (for details, see material and methods).

with a general model that included treatment and block as fixed effects. Individual daily milk production and composition, intake, efficiency, sward height and forage mass-related variables were analyzed as repeated measures over time. The repeated variable indicated in the repeated measures procedure was the time unit during which data were collected. Based on the lowest Akaike information criterion, a first-order autoregressive covariance structure provided the best fit for the milk production and sward data, whereas a compound symmetry covariance structure provided the best fit for the intake and efficiency data. Satterthwaite's procedure was used for estimation of degrees of freedom. For the BCS and BW variables, the values at calving were added as covariates. The model assumptions were evaluated using studentized residual plots. All data were analyzed using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC). Differences were considered significant at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

RESULTS

Grazing and Sward Characteristics

The pregrazing sward height was, on average, 1.5 cm higher ($P = 0.042$) in the CT than in the HI treatment (Table 2). Both the CT and HI treatments achieved postgrazing sward heights within or near their respective target ranges, differing by 6.7 cm ($P < 0.001$). As expected, the sward height depletion level was higher and the forage allowance was lower in the CT treatment ($P < 0.001$). The pregrazing sward heights were more stable in the HI treatment, whereas fluctuations were observed in the CT treatment (Figure 1). The postgrazing sward heights were more consistent than the pre-grazing but exhibited greater standard deviation during the spring months (September to November) for both treatments. The pregrazing forage mass was similar between treatments, whereas the postgrazing forage mass was 1,036 kg DM/ha higher for the HI treatment compared with the CT treatment ($P < 0.001$). The forage growth rate tended ($P = 0.094$) to be 21% higher in the HI treatment than in the CT treatment. Forage disappearance over the 215-d grazing season was similar between treatments. Cows grazed on average 1.0 d more per strip in the HI treatment compared with the CT treatment ($P < 0.001$). During the 215-d grazing season, the number of grazing cycles was 2.5-fold greater for the HI treatment compared with the CT treatment ($P < 0.001$).

Individual Performance

The effect of postgrazing sward height on individual milk and solids production, DMI and efficiencies, BW and BCS variables are presented in Table 3.

Milk and Solids Production

Individual daily milk production was 10% higher ($P = 0.028$) for cows in the HI treatment than in the CT treatment. Similarly, ECM production was 8% higher ($P = 0.048$) for the HI treatment. Fat, protein, lactose, and total milk solids concentrations and fat production did not differ between treatments ($P \geq 0.465$). Protein production was 13% higher ($P = 0.029$) for cows in the HI treatment than in the CT treatment. The MUN con-

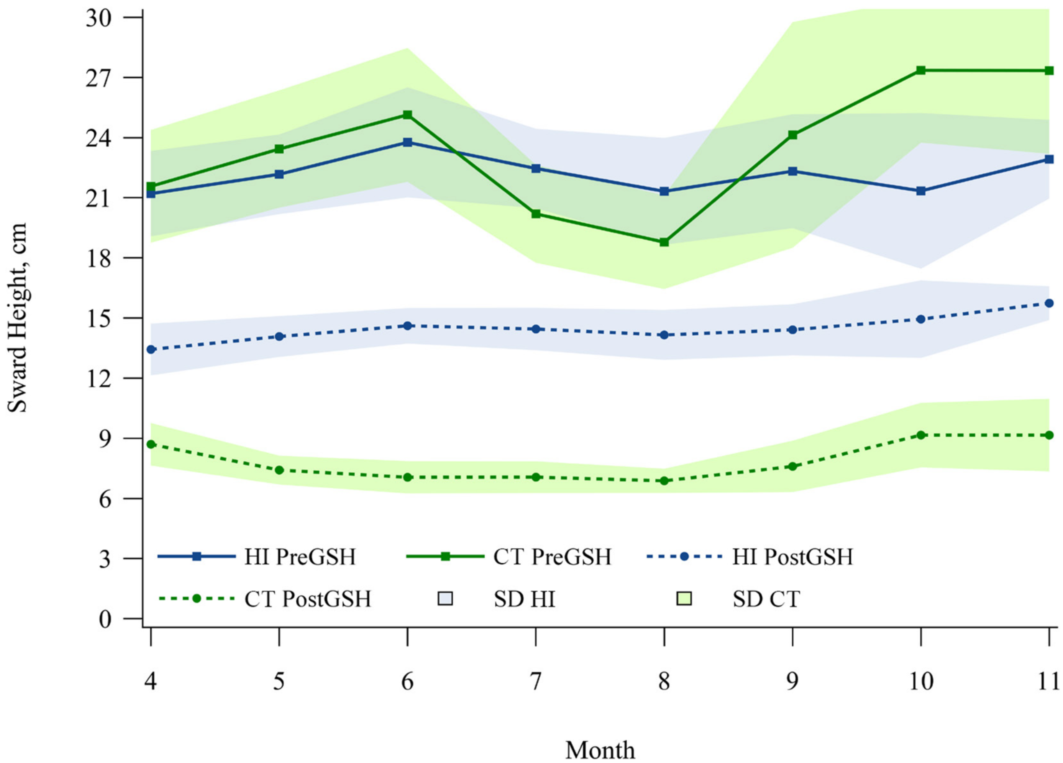

Figure 1. Pre- and postgrazing sward height (PreGSH and PostGSH, respectively) of tall fescue swards grazed at 2 postgrazing sward heights (CT and HI) by lactating dairy cows.

centration was 5% higher ($P = 0.031$) for cows in the HI treatment compared with the CT treatment. Estimated milk production parameters from the Wilmink exponential function are presented in Appendix Table A2. Estimated individual 305-d lactation milk production was 8% higher ($P = 0.044$) for the HI treatment compared with the CT treatment.

DMI and Efficiency

The MR intake averaged 12.3 kg DM/cow per day and did not differ between treatments ($P = 0.519$), although the MR waste was greater ($P = 0.003$) in the HI treatment than in the CT treatment. Cows in the HI treatment had higher individual grazed forage DMI (+2.0 kg/d; $P = 0.001$) and total DMI (+1.7 kg/d; $P = 0.041$) compared with cows in the CT treatment. The proportion of concentrate in the diet (daily DMI; MR plus grazed forage) was lower ($P < 0.001$) for HI cows than CT cows (−11%), whereas the proportion of grazed forage in the diet was greater ($P = 0.003$) for HI cows compared with CT cows (+18%; Table 1). The proportion of conserved forage in the diet did not differ between treatments ($P = 0.152$). The use of concentrate per kilogram of ECM was 10% lower ($P = 0.003$) for HI cows compared with CT cows (Table 3). The return on human-edible input was higher ($P = 0.004$) for HI cows compared with CT cows (+1.0 kg ECM/kg human-edible DM consumed). The income over feed costs tended ($P = 0.059$) to be higher for HI cows than CT cows (+21%).

BW and BCS

The cows calved with an average BW of 670 kg, and BW did not differ between treatments throughout lactation (Table 3). The BCS at calving was 3.39 for both treatments, with no difference in the nadir BCS reached. However, HI cows reached their nadir BCS almost 4 wk earlier than CT cows ($P = 0.048$). The HI cows also began recovering BCS earlier than CT cows and had a postnadir BCS gain 89% higher than CT cows ($P = 0.035$). By the end of the trial, HI cows recovered their initial BCS, with BCS 0.3 units higher ($P = 0.006$) than CT cows.

Per-Area Performance

The stocking rate, milk production, DM intake, and income over feed costs on a per-area basis are presented

Table 3. Individual performance of lactating dairy cows grazing tall fescue swards at 2 postgrazing sward heights

Item	Treatment[1]			
	CT	HI	SEM[2]	*P*-value
Milk and solids				
Daily milk production, kg/cow	31.5	34.5	0.89	0.028
Daily ECM yield, kg/cow	30.5	33.0	0.85	0.048
Fat, %	3.74	3.66	0.082	0.465
Protein, %	3.32	3.31	0.039	0.825
Lactose, %	4.80	4.81	0.027	0.730
Milk solids,[3] %	7.07	6.97	0.108	0.526
Fat, kg/cow	1.17	1.25	0.038	0.137
Protein, kg/cow	1.04	1.14	0.028	0.029
MUN, mg/dL	18.5	19.5	0.30	0.031
Milk production cumulative (Wilmink function)				
215-d daily milk production, kg/cow	31.9	34.3	0.89	0.072
305-d milk production, kg/cow	8,574	9,284	238.1	0.044
Intake and efficiency				
MR intake,[4] kg DM/cow per d	12.5	12.1	0.37	0.519
MR waste, % DM offered	4.8	7.3	0.55	0.003
Grazed forage intake, kg DM/cow per d	8.6	10.6	0.39	0.001
Total DMI, kg DM/cow per d	21.0	22.7	0.55	0.041
Concentrate used per unit milk, g/kg ECM	262	237	4.7	0.001
Return on HE input,[5] kg ECM/kg HE DMI	9.0	10.0	0.23	0.004
Income over feed costs, US$/cow per d	4.05	4.92	0.208	0.059
BW and BCS				
BW calving, kg	672	669	12	0.890
BW nadir, kg	622	639	13.9	0.387
BW average, kg	654	663	9.3	0.520
BW end, kg	676	694	14.4	0.391
BCS at calving	3.39	3.39	0.053	1.000
BCS nadir	2.97	3.05	0.047	0.251
DIM to BCS nadir	74	48	8.9	0.048
Postnadir BCS gain	0.19	0.36	0.055	0.035
BCS end	3.16	3.41	0.058	0.006

[1]CT: postgrazing sward height of 5.0 to 7.0 cm. HI: postgrazing sward height of 12.0 to 15.0 cm.

[2]Average SEM is listed.

[3]Fat plus protein.

[4]MR = mixed ration.

[5]HE = human edible. Calculated following Wilkinson (2011).

in Table 4. The area used by the group of 4 cows was 36% greater ($P = 0.044$) for the HI treatment compared with the CT treatment. Consequently, the stocking rate was 28% lower ($P = 0.050$) for HI compared with CT. The milk ($P = 0.079$) and ECM ($P = 0.054$) production per hectare tended to be higher for CT than for HI. However, the concentrate and conserved forage consumed per hectare were 30% lower for HI compared with CT ($P \leq 0.046$). The grazed forage intake per hectare was not affected by the postgrazing sward height management ($P = 0.347$), whereas the total DMI per hectare tended to be lower for HI than for CT ($P = 0.085$). We found no evidence of differences in income over feed costs per hectare between treatments ($P = 0.245$).

DISCUSSION

The novel aspect of this study was examining how postgrazing sward height affects DMI and performance of supplemented high-producing dairy cows, both at the cow and per-hectare levels. The study captured cumulative treatment effects on animal performance across nearly an entire lactation, as well as sward dynamics over most of the tall fescue growing season. It was hypothesized that the HI treatment would increase milk production per cow and sustain a higher BCS, primarily due to higher DMI, while maintaining similar milk production per hectare with lower supplementary feed input per hectare, as enhanced forage growth was expected with a higher residual sward height. Results partially supported this hypothesis, indicating that the HI treatment enhanced milk production per cow while also allowing cows to begin recovering BCS earlier than those in the CT treatment and finish the trial with a higher BCS. However, despite a tendency for greater forage growth rate, this individual-level increase did not fully offset the lower stocking rate under the HI treatment, and milk and ECM yield per hectare tended to be lower. Although

Table 4. Performance per area of lactating dairy cows grazing tall fescue swards at 2 postgrazing sward heights

Item	Treatment[1]		SEM[2]	*P*-value
	CT	HI		
Area used, ha/4 cows	1.18	1.60	0.087	0.044
Stocking rate, cows/ha	3.47	2.51	0.214	0.050
Stocking rate, kg BW/ha	2,264	1,661	146.5	0.062
Milk, kg/ha per 215-d	23,598	18,528	1,366.0	0.079
ECM, kg/ha per 215-d	22,841	17,813	1,151.8	0.054
Concentrate DMI, kg/ha per 215-d	5,946	4,184	378.4	0.046
Conserved forage DMI, kg/ha per 215-d	3,479	2,449	221.1	0.002
Grazed forage DMI, kg/ha per 215-d	6,452	5,678	492.0	0.347
Total DMI, kg/ha per 215-d	15,887	12,310	993.6	0.085
Income over feed costs, US$/ha per 215-d	3,077	2,698	186.1	0.245

[1]CT: postgrazing sward height of 5.0 to 7.0 cm. HI: postgrazing sward height of 12.0 to 15.0 cm.

[2]Average SEM is listed.

both grazed forage and total DMI per cow were higher in the HI treatment, total grazed forage DMI per hectare remained similar, but the supplementary feed input per hectare was reduced in the HI treatment due to the lower stocking rate. A similar pattern was observed for income over feed costs, which tended to be higher for the HI treatment at the cow level but showed no significant differences at the hectare level.

Grazing Management

Although the ideal comparison would involve equal strip occupation durations across treatments, cows in the HI treatment grazed each strip for 1.0 d longer due to practical reasons. This difference was not expected to influence outcomes (Menegazzi et al., 2024), given the relatively low sward height depletion characteristic (thus ample forage allowance) of this treatment. Similarly, the use of a phenological criterion to determine grazing initiation led to slightly different average pregrazing sward heights between treatments, which may have influenced the results. Conversely, using a fixed pregrazing sward height would have standardized sward height but introduced variability in the phenological state of the sward at grazing onset (Fulkerson and Donaghy, 2001).

Defoliation intensity and regrowth period strongly affect forage growth and senescence rate. A higher residual sward height is expected to result in more grazing cycles, as higher residual leaf area after each grazing promotes faster recovery (Chapman, 2016; Schons et al., 2021). In contrast, under intensive defoliation, plants have less leaf area to intercept light and produce carbohydrates, particularly during the initial phase of regrowth, which limits their ability to allocate energy to growth and requires longer intervals between grazing events. This likely explains why the forage growth rate tended to be 21% higher in the HI treatment compared with the CT treatment. Despite this, the postgrazing sward height in the CT treatment was slightly above the target, as a result of maintaining a minimal leaf area for regrowth. Therefore, regrowth may not have been as negatively affected as it would have been under even more severe defoliation (Parsons et al., 1988). Although the differences in grazing frequency, total forage disappearance over 215 d was similar between treatments, indicating that both strategies were equally efficient in terms of total forage harvested. However, the characteristics of the grazed forage consumed likely differed between treatments, with HI cows accessing higher-quality forage in the upper sward layers (Delagarde et al., 2000). Furthermore, the HI treatment maintained a lower and more consistent pre-grazing sward height throughout the growing season. Increased grazing frequency has been morphologically linked to more compact sward structures, characterized by reduced leaf elongation and lower variation across grazing cycles (Duru and Ducrocq, 2000). In contrast, the lower grazing frequency in the CT treatment likely promoted greater leaf elongation and a less uniform sward structure, leading to taller and more variable pregrazing heights over time. Additionally, the lower grazing frequency likely allowed more flowering stems to develop during spring, resulting in a taller average sward. The greater SD observed during the spring months in both treatments was also likely associated with structural changes in the sward caused by flowering induction (Scheneiter and Améndola, 2012).

Grazing behavior is closely linked to animals' perception of resource availability (Roguet et al., 1998) and their internal state (Gregorini et al., 2009; Chilibroste et al., 2015), reflecting trade-offs that optimize intake rate and food quality (Searle et al., 2005). Indeed, cows in the HI treatment consumed more grazed forage, leading to higher total DMI. Although feed intake is the primary driver of grazing animal performance (Wales et al., 2005), grazed forage quality may have also influenced performance. The ADF content of grazed forage tended to be higher in the CT treatment, whereas CP content, although not significantly different, was numerically 3 percentage points higher in the grazed forage in the HI treatment (19% vs. 16%). Lower ADF and higher CP contents of grazed forage are typically associated with increased digestibility (Stergiadis et al., 2015).

Managing swards with low-intensity grazing often raises concerns about maintaining sward quality (Peyraud and Delagarde, 2013), leading to the traditional recommendation of lower postgrazing sward heights to enhance forage quality. Alternatively, de Faccio Carvalho (2013) proposed a grazing management approach grounded in animal behavior, prioritizing intake rate through higher sward residuals. Although this strategy may not necessarily improve sward quality, it promotes selective grazing aligned with the "take the best, leave the rest" concept (Provenza et al., 2003; de Faccio Carvalho, 2013).

Individual Intake and Performance

Pasture-based milk production is heavily influenced by factors that regulate grazed forage intake and ruminal digestion (Peyraud and Delagarde, 2013). Grazed forage intake, in turn, is a matter of time, and hence the intake rate is a critical factor, especially for high-producing dairy cows with substantial energy requirements. Maximizing grazed forage intake depends on sward structure, particularly sward height and density, which primarily determine bite mass (McGilloway et al., 1999). Bite mass directly influences intake rate and daily forage consumption (de Faccio Carvalho, 2013). The lower sward height depletion observed in the HI treatment aligns with the range that optimizes intake rate (Fonseca et al., 2012; Mezzalira et al., 2014). This led to a 2.0 kg/cow per day higher grazed forage DMI compared with the CT treatment, a 23% increase in one of the most economical nutrient sources for dairy cows (Fariña and Chilibroste, 2019). Consequently, higher grazed forage intake and lower concentrate intake per kilogram of ECM in the HI treatment resulted in a tendency for higher income over feed costs at cow level. Additionally, cows in the HI treatment produced more ECM per kilogram of human-edible DM consumed, an outcome that is particularly relevant for reducing feed-food competition (Zira et al., 2023).

Maintaining an average daily ECM production of 33.0 kg/cow over 215 d, with nearly half of the diet (47% DM) derived from grazed forage, demonstrates a high level of productivity for a mixed feeding system. For example, Fajardo et al. (2015) reported similar ECM production (34.3 kg/cow per day), but only during the first 10 wk of lactation, with cows consuming 14.5 kg/cow per day of a MR (45:65 forage to concentrate ratio) and 5.5 kg/cow per day of grazed forage (second-year sward of *Festuca arundinacea*, *Trifolium repens* and *Lotus corniculatus*; Uruguay). Similarly, Bargo et al. (2002) reported ECM production of 34.2 kg/cow per day for cows fed a TMR and 28.8 kg/cow per day for cows on a mixed diet (30% grazed forage, mostly *Bromus inermis* and *Dactylis glomerata*, 61% TMR, 9% concentrate) during a 21-wk mid-lactation trial in Pennsylvania. The HI treatment in this study resulted in 8% greater ECM production than the CT treatment, which averaged 30.5 kg/cow per day with 40% of diet DM coming from grazed forage. These findings align with previous research showing that reducing postgrazing sward height and increasing stocking rates negatively affect individual cow performance (McEvoy et al., 2008; McCarthy et al., 2014; Dale et al., 2018).

Milk composition showed no differences in solids content between treatments. Despite variations in forage CP and ADF content, the relatively high level of supplemental feed consumed by cows resulted in similar total diet composition, with treatment differences remaining below 5%. However, MUN concentration was 5% higher in the HI treatment, likely due to the greater intake of rumen-degradable protein from higher grazed forage intake, which also had a numerically higher CP content. Additionally, the total ration CP content was numerically higher in this treatment, further contributing to the increased MUN levels. Milk urea nitrogen concentration depends mainly on dietary CP content and degradability, along with the quantity and type of dietary energy (Spek et al., 2013). An imbalance between nitrogen and energy substrates in the rumen can elevate ammonia concentrations (Dijkstra et al., 2013), leading to increased excretion of nitrogen as MUN or urinary nitrogen (Nousiainen et al., 2004). In this study, both the individual amount and composition of supplemental feed were standardized across treatments to distinguish differences in grazed forage nutrient intake. However, a practical implication of managing swards with higher residual sward heights could be reducing the CP content of supplemental feed due to the higher CP levels in the upper sward layers (Delagarde et al., 2000; Menegazzi et al., 2021). Such adjustments could reduce N excretion and environmental losses (Dijkstra et al., 2018) while also lowering supplementation costs, as protein is often the most expensive nutrient in dairy diets. The MR waste was greater in the HI treatment. A speculative explanation for this differential behavior is that cows in the HI treatment had greater ruminal fill due to the higher grazed forage intake. This may have reduced their drive to consume the MR and increased their motivation to engage in sorting behavior at the feed bunk, resulting in more waste of feed. In TMR systems, evidence suggests that cows with higher DMI, driven by greater feed availability, engage more in sorting behavior (Miller-Cushon and DeVries, 2010, 2017). In grazing cows, ruminal fill and metabolic status are well-documented factors influencing feeding behavior, modulating both motivation and voracity to graze, and leading to variable degrees of selectivity and intake rate (Chilibroste et al., 1997; Gregorini et al., 2008).

Body condition score data indicate that cows in the HI treatment sustained better energy balance during lactation. Although CT cows mobilized body reserves to maintain milk production during a longer period, finishing the trial with a lower BCS than at the start, HI cows recovered their initial BCS by the end of the trial. In pasture-based systems, cows often reach their BCS nadir at mid-lactation (100–200 DIM; Menegazzi et al., 2025; Washburn et al., 2002; Lucy et al., 2009) and struggle to regain BCS by drying off (Roche et al., 2006; McCarthy et al., 2007; Patton et al., 2008; McClearn et al., 2019). Failing to recover BCS during lactation can negatively affect reproductive performance (Roche et al., 2007). This is especially critical in pasture-based seasonal calving systems, where cows must resume ovarian cyclicity and conceive within 90 DIM to align peak energy demands with forage growth.

Per-Hectare Intake and Performance

Managing a higher postgrazing sward height improved individual milk production by 10%; however, the 28% lower stocking rate associated with this strategy resulted in a trend toward 21% lower milk production per hectare. Although the HI treatment tended to achieve a 21% higher forage growth rate, this increase was insufficient to offset the 36% greater area required to maintain the targeted specific sward height for this treatment. Similar findings were reported by Gareli et al. (2023) in a short-term study with mid-lactation dairy cows grazing *Dactylis glomerata* under 2 contrasting strategies: one favoring high intake rate (postgrazing height: 14.4 cm), and another favoring high herbage harvest per hectare (postgrazing height: 10.0 cm). A trade-off emerged between individual and per-hectare milk production, solids-corrected milk yield was 27% higher per cow in the high intake strategy (25.5 vs. 20.1 kg/d), whereas milk production per hectare was 19% lower (48.0 vs. 59.6 kg/ha per day). Additionally, cows without supplementation in the high-harvest strategy showed declines in BW and BCS, mobilizing body reserves to sustain milk output. Similarly, Dale et al. (2018) observed that low grazing intensity in *Lolium perenne* in Northern Ireland (postgrazing sward height of 6.8 cm) resulted in higher individual milk production but lower per-hectare output compared with high grazing intensity (postgrazing sward height of 5.2 cm). Furthermore, cows under the low grazing intensity treatment were heavier than those in the high grazing intensity group by the end of the 141-d study. In the present study, although the cows' BW at the end of the trial was numerically ~20 kg higher in the HI treatment, the difference was not significant.

Different grazing strategies may be effective depending on system goals, emphasizing either individual animal performance or per-hectare productivity; or, in many cases, a combination between both (Fariña and Chilibroste, 2019). When land availability is limited, maximizing milk output per hectare becomes a priority. Conversely, for high-producing cows with significant genetic potential, supplementation can enhance economic returns when substitution effects are minimized (Bargo et al., 2003). In pasture-based dairy systems, maximizing DMI from grazed forage remains a key objective (Finneran et al., 2010; van Vuuren and Chilibroste, 2013; Fariña and Chilibroste, 2019). Strong positive correlations have been demonstrated between grazed forage per hectare and economic performance (Romera and Doole, 2015; Fariña and Chilibroste, 2019), as well as between the proportion of forage in cows' diets and total milk production costs (Dillon et al., 2008).

In this study, a similar amount of grazed forage harvested per hectare was achieved using different grazing strategies, with 30% lower supplemental feed input per hectare in the HI treatment (6,633 vs. 9,425 kg DM) due to the lower stocking rate. This resulted in no significant difference in income over feed costs between treatments (though numerically 14% lower in HI), even with one fewer cow per hectare under the HI treatment. It is noteworthy that our experimental design may not have been adequately powered to detect significant differences in income over feed costs at the per-hectare level. The limited number of experimental units constrains the ability to draw conclusions about economic outcomes, despite the observed numerical difference of 14% between treatments. Increasing stocking rates and grazing intensity to boost grazed forage per hectare (Doole and Romera, 2013; Romera and Doole, 2015) often involves greater feed supplementation (Patton et al., 2016; Evers et al., 2021). However, in high-producing cows, forcing them to graze lower sward strata negatively affects individual grazed forage intake and may compromise performance (Peyraud and Delagarde, 2013; Dale et al., 2018). Although higher stocking rates can compensate for lower individual milk production by increasing per-hectare output, prolonged mobilization of body reserves, or delayed recovery from a negative energy balance may negatively affect reproduction (Roche et al., 2009; Doole and Romera, 2013).

Balancing Trade-Offs in Grazing Systems

This study over nearly a full lactation highlights the trade-offs between individual animal performance and per-hectare productivity in pasture-based dairy systems, offering insights into grazing strategies tailored to various goals. The debate over optimizing production per animal versus per area has persisted for decades (Mott, 1960; Jones and Sandland, 1974; Wade and Carvalho, 2000; Romera and Doole, 2015). Traditionally, as stocking rates increase, both per-animal and per-area productivity peak before declining, but in modern dairy systems with supplementation, these relationships may follow a different trajectory due to external feed inputs.

Our findings demonstrate that the HI treatment enhanced individual cow performance, leading to a 10% increase in milk production per cow, a 10% reduction in concentrate use, and a 10% improvement in the return on human-edible input, primarily due to higher grazed forage intake. Additionally, the improved energy balance facilitated faster BCS recovery. However, this strategy required 36% more grazing area, despite a tendency for 21% greater forage growth, leading to a tendency of 21% reduction in milk output per hectare. In contrast, the CT treatment supported higher stocking rates and tended to increase total milk output per hectare but resulted in 42% more supplemental feed inputs per hectare and led to slower BCS recovery compared with the HI treatment. Although increased per-cow performance and improved human-edible protein efficiency are meaningful (Wilkinson and Lee, 2018), these benefits must be weighed against the broader consequences of reduced output per hectare (Battheu-Noirfalise et al., 2023). This reduction implies that more land is needed to sustain overall production, which in turn may amplify the global competition for arable land (Mottet et al., 2017). The concept of sustainable intensification, which focuses on maximizing output per hectare while minimizing input, remains critical in addressing global food demands (Gerssen-Gondelach et al., 2017). Therefore, a sustainable dairy system must also consider land use efficiency and the implications for global food security.

These results also highlight the need to align grazing strategies with system-specific goals. Farmers seeking to maximize land productivity may favor lower postgrazing sward heights, though these must be managed carefully to prevent adverse effects on animal health, reproduction, and long-term productivity due to slower BCS recovery. Conversely, systems aiming to reduce feed costs may benefit from a higher residual sward height, which enhances individual cow performance and BCS while decreasing reliance on supplemental feed, though requiring substantially greater grazing area. Higher sward residuals may also benefit the environment (Aguirre-Villegas et al., 2017; Zubieta et al., 2021b) by reducing nutrient inputs and improving milk production per unit of inputted nutrients; however, balancing supplemental feed composition with improved sward quality is essential to prevent increased nitrogen excretion as indicated by the higher MUN content in the HI treatment. Additionally, this approach may enhance milk quality (e.g., increased polyunsaturated fatty acids; Joubran et al., 2021) by increasing the proportion of grass in the diet (Provenza et al., 2019), as well as support animal welfare by reducing periods in which body reserves need to be mobilized and positively influence nutritional status and immune response (Zubieta et al., 2021a). Future research should explore the long-term effects of these strategies under varying supplementation levels, environmental conditions and pregrazing height criteria, to further refine sward management recommendations.

CONCLUSIONS

This study highlights the trade-offs between individual animal performance and per-hectare productivity in pasture-based dairy systems under 2 contrasting postgrazing sward height strategies. Managing higher postgrazing sward heights (HI treatment) improved individual cow performance, increasing milk production, forage and total DMI per cow, and improving BCS, while reducing supplemental feed use per unit of milk produced. However, despite a tendency for higher forage growth rate in the HI treatment, these benefits were offset by a lower stocking rate and a tendency for reduced milk production per hectare and required more grazing area. Conversely, the lower postgrazing sward height (CT treatment) increased milk production per hectare but required greater supplemental feed inputs per hectare and resulted in slower BCS recovery.

NOTES

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Nonstandard abbreviations used: CT = control treatment, postgrazing sward height of 5.0 to 7.0 cm; HE = human edible; HI = high treatment, postgrazing sward height of 12.0 to 15.0 cm; max. = maximum; min. = minimum; MR = mixed ration; $NEL_{3\times}$ = NEL calculated assuming intake at 3× maintenance; PostGSH = postgrazing sward height; PreGSH = pregrazing sward height; RPM = rising plate meter; THI = temperature-humidity index.

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APPENDIX

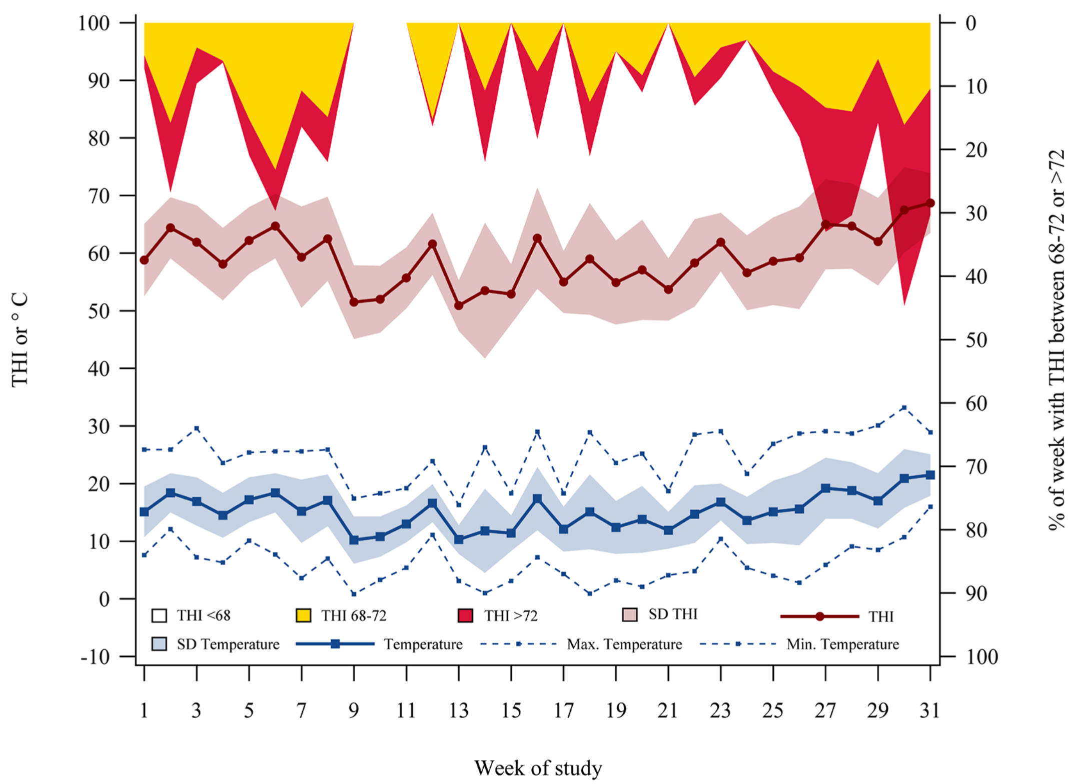

Figure A1. Monthly average, minimum (min.), and maximum (max.) air temperature and temperature-humidity index (THI) during the whole experimental period at the research site.

Table A1. Average monthly and total rainfall during the years of study and during the last 15 yr (2008–2022) at the research site

	Rainfall, mm		
Month	Average year of study	Average last 15 yr[1]	Difference (Study vs. last 15 yr)
January	39	173	−134
February	47	225	−177
March	143	121	23
April	38	155	−117
May	121	106	15
June	57	59	−2
July	91	75	16
August	21	111	−91
September	73	101	−27
October	60	122	−62
November	123	123	0
December	312	146	166
Total	1,125	1,517	−392

[1]No records available for April and May of 2018, March 14–15 of 2019, and August 2–8 of 2019 due to technical problems at the meteorological station.

Table A2. Estimated milk production parameters from the Wilmink exponential function[1] by lactating dairy cows grazing tall fescue swards at 2 postgrazing sward heights

	Treatment[2]			
Item	CT	HI	SEM[3]	*P*-value
a	44.0	49.2	1.85	0.057
b	−17.3	−25.9	2.00	0.005
c	−0.099	−0.112	0.0074	0.253
k	0.097	0.111	0.0235	0.686

[1]The Wilmink (1987) exponsential function was fitted to daily milk production data for individual lactations as $yt = a + b \times e^{-kt} + c \times t$, where yt represents the milk production at day t of lactation, a is the initial milk production after calving, b is the parameter determining ascending slope before the peak, c is the parameter detrmining descending slope after the peak, k is a factor related to the moment of peak yield, and e^{-kt} is an exponentially decreasing component.

[2]CT: postgrazing sward height of 5.0 to 7.0 cm. HI: postgrazing sward height of 12.0 to 15.0 cm.

[3]Average SEM is listed.