Effects of corn silage supplementation strategy and grazing intensity on herbage intake, milk production, and behavior of dairy cows

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ABSTRACT

Effects of corn silage supplementation on milk production of grazing dairy cows depend in part on the substitution rate between the 2 forages, which may be influenced by grazing management. The aim of this study was to compare 2 grazing management strategies for measuring substitution rate between herbage and corn silage, in interaction with grazing intensity. Six treatments were compared, with 2 grazing intensities and 3 supplementation strategies investigated at both grazing intensities. The 2 grazing intensities were severe and light grazing, defined by either (1) herbage allowance (HA) of 15 (severe) or 30 (light) kg dry matter (DM)/cow per d at 3 cm above ground level or (2) postgrazing sward height, depending on the supplementation strategy. The 3 supplementation strategies were as follows: (U) an unsupplemented treatment, (A) 5 kg DM/d of corn silage offered at a similar HA as in U, and (H) 5 kg DM/d of corn silage offered at a similar postgrazing sward height as in U. Thirty-six multiparous Holstein cows were used in a randomized complete block design and divided in 2 groups for the entire experiment, one for each grazing intensity. Within each grazing intensity group, the corn silage supplementation strategy was studied using a 3 × 3 Greco-Latin square design, with 3 periods of 14 d. Supplementing cows with corn silage increased total DM intake only for severe grazing by 1.7 kg DM/d. The substitution rate between corn silage and grazed herbage was lower for severe than for light grazing, averaging 0.63 and 1.23, respectively. Herbage dry matter intake was lower by 1.2 kg/d for strategy H than A, leading to lower substitution rates (0.81 vs. 0.99, respectively), irrespective of grazing intensity. Milk production increased with silage supplementation for severe grazing (+1.0 kg/d milk) and was unaffected by silage supplementation for light grazing (−0.4 kg/d milk). The milk production response to corn silage supplementation averaged +0.23 and −0.08 kg of milk per kg DM of silage for severe and light grazing, respectively. Fat-corrected milk production tended to be lower by 0.4 kg/d for strategy H than A, leading to lower milk production response (+0.00 vs. +0.12 kg of milk per kg DM of silage, respectively). Milk protein concentration increased with silage supplementation for severe grazing (+1.0 g/kg) but decreased with silage supplementation for light grazing (−0.6 g/kg). Milk fat concentration did not differ among treatments. On average, daily grazing time (−47 min/d, i.e., −9%) and herbage intake rate (−4.9 g of DM/min, i.e., −14%) decreased when cows were supplemented, with greater grazing time reduction at severe than light grazing, and greater herbage intake rate reduction at light than severe grazing. In conclusion, the greater substitution rate and the lower 4% fat-corrected milk production when corn silage was provided at a similar postgrazing sward height rather than at a similar HA to those of unsupplemented cows explain why supplementing grazing dairy cows with conserved forages has no strong effect in practice from a production point of view.

Key words: grazing, dairy cow, intake, supplementation, corn silage

INTRODUCTION

Dairy production systems based on grazing can reduce production and labor costs and capital investment and result in environmental benefits (Dillon et al., 2005). However, the amount of grazeable land per cow around the milking parlor is an increasingly limited resource, particularly given the constant increase in herd size (Ramsbottom et al., 2015). This could result in an herbage shortage for several months of the year, including in the spring. Thus, adopting mixed diets of herbage supplemented with conserved forage, with or without additional concentrates, could be useful (Chénais et al., 1997; Kolver et al., 2001).

Effects of forage supplementation on short-term intake and milk production responses of grazing dairy
cows have been known for a long time to depend on many factors, including pasture characteristics (Stockdale 1997; Pérez-Prieto et al., 2011), quality of the supplement (Moate et al., 1984; Bargo et al., 2003; Woodward et al., 2006), and herbage allowance (HA) or grazing intensity (Phillips, 1988; Stockdale 1996; Stockdale 2000; Burke et al., 2008). The literature describes a wide range of substitution rates (e.g., the reduction in herbage DMI per kg of supplement DMI) between grazed herbage and conserved forage, but it remains difficult to predict the effects of forage supplementation on total DMI and milk production (Moate et al., 1984; Bargo et al., 2003; Delagarde et al., 2011).

Effects of grazing management on dairy cow responses to forage supplementation have been known for a long time (Phillips, 1988; Stockdale, 2000; Kolver et al., 2001). One of the reasons that explains the high variability in the effects of forage supplementation on grazing dairy cows may be the experimental management rules chosen by researchers for comparing supplemented and unsupplemented herds. Under intensive strip-grazing management, many studies compare forage supplementation levels at similar HA, with each group of cows receiving daily the same amount of herbage for grazing, irrespective of the amount of forage supplement provided (Moate et al., 1984; Stockdale 1996; Pérez-Prieto et al., 2011; Miguel et al., 2014). This, however, results in greater postgrazing sward height in forage-supplemented cows due to their lower herbage DMI, and thus better postgrazing conditions in supplemented than in unsupplemented cows. Other studies compare forage supplementation levels at similar postgrazing sward height, with forage-supplemented cows receiving voluntarily lower HA than unsupplemented cows, which aims to maintain a similar herbage-use rate, similar postgrazing sward height, and thus similar postgrazing conditions (Pérez-Ramirez et al., 2008; Dall-Orsoletta et al., 2019; Ribeiro-Filho et al., 2021). This is also often related to a desired increase in milk production per ha (Chaves et al., 2002; Woodward et al., 2006; Burke et al., 2008). These 2 experimental strategies may evidently affect cow responses because in the first one, supplemented cows received the same amount of herbage as unsupplemented cows, while in the second one, they received less herbage than unsupplemented cows. At first glance, the first strategy (same HA) may be considered more scientific, and the second one (same postgrazing sward height) may be considered more practical. Comparing supplementation levels at the same postgrazing conditions, however, is similar to forage-feeding management in indoor experiments that investigate the substitution rate between a forage and a concentrate, with the forage supply being managed to allow for 10% of refusal (Faverdin et al., 1991; INRA, 2018). In these studies, the forage supply decreased as the supplementation level increased in order to keep the percentage of refusals similar among treatments. To our knowledge, no indoor experiment has investigated substitution rate at similar forage supply. The effect of these different experimental strategies per se on the calculated substitution rate at grazing has never been investigated in the same study. Therefore, our study might have strong practical implications, as well as implications for modeling herbage intake of grazing cows.

The aim of this study was to evaluate short-term effects of 2 experimental strategies of corn silage supplementation (i.e., HA or postgrazing sward height similar to that of unsupplemented cows) on herbage intake, milk production, and grazing behavior. The main hypothesis was that corn silage supplementation at a similar postgrazing sward height induces a higher substitution rate and lower milk production than corn silage supplementation at a similar HA. We also hypothesized that the expected differences in substitution rate and milk production between supplementation strategies would be exacerbated at high grazing intensity, compared with low grazing intensity, considering that the substitution rate is well-known to decrease with decreasing HA.

MATERIALS AND METHODS

Treatments and Experimental Design

Six treatments were compared, with 2 grazing intensities and 3 strategies of forage supplementation for both grazing intensities. The 2 grazing intensities were based on HA for unsupplemented cows: 15 and 30 kg DM/d measured at 3 cm above ground level (severe (S) and light (L) grazing, respectively). The 3 supplementation strategies were as follows: (U) unsupplemented cows: only grazing, (A) allowance: 5 kg DM/d of corn silage offered at an HA similar to that in U, and (H) height: 5 kg DM/d of corn silage offered at a postgrazing sward height similar to that in U by providing less HA than in U. The 6 treatments were thus SU, SA, SH, LU, LA, and LH.

In strategies A and H, the corn silage was offered individually once per day after a.m. milking (0800 to 0900 h) before grazing. After p.m. milking (1630 to 1730 h), cows had access to their individual trough and any silage they had refused in the morning. Refused silage was then removed from the trough and weighed individually. No concentrate was provided during the experiment.

The experiment consisted of a randomized complete block design with 36 lactating cows. The cows were divided into 2 homogeneous groups of 18 cows, 1 for
severe grazing treatments and the other for light grazing treatments for the entire experiment. Within each grazing intensity group, the corn silage supplementation strategy was studied using a $3 \times 3$ Greco-Latin square design, which combines 2 orthogonal Latin squares replicated 3 times (Winer et al., 1991). This helps balance potential carryover effects of silage supplementation strategies.

The experiment was performed at the INRAE experimental farm of Méjusseaume (latitude $+48.11^\circ$, longitude $-1.71^\circ$; Le Rheu, Brittany, France) in the spring from April 25 to June 20, 2014. Each experimental period lasted 14 d, with an 8-d adaptation period followed by a 6-d measurement period. All procedures related to the care and management of the cows used in this experiment were approved by an animal care committee of the French Ministry of Agriculture (CREEA, Comité Rennais d’Éthique en matière d’Expérimentation Animale, N°07), in accordance with French regulations (decrees 2001–464, 29 May 2001).

Cows

Thirty-six Holstein-Friesian dairy cows in mid-lactation, 12 of which were primiparous, were allocated to 6 homogeneous groups using an optimization procedure to minimize between-group variability for all recorded variables. Groups were balanced in parity, lactation stage ($175 \pm 43$ d), milk production ($23.6 \pm 3.8$ kg/d), milk fat concentration ($38.1 \pm 3.1$ g/kg), milk protein concentration ($29.1 \pm 1.7$ g/kg), BW ($590 \pm 56$ kg), and BCS ($1.57 \pm 0.30$, scale 0 to 5) measured from April 7 to 20, 2014. During this period, cows grazed as a single herd on nonexperimental paddocks and were individually supplemented with 5 kg DM/d of corn silage and 2 kg DM/d of a compound concentrate with 180 g CP/kg DM. Cows were milked twice daily at 0700 and 1600 h.

Grazing Management and Pasture

The study was performed in a 7.3 ha plot of perennial ryegrass (*Lolium perenne* L., cv. ‘Ohio’) as the predominant species. Proportional botanical composition measured during the experiment averaged 0.89, 0.07, and 0.04 for perennial ryegrass, white clover, and other species, respectively, on a DM basis. At the end of March, 30 d before the start of the experiment, nonexperimental cows grazed the entire plot, with a postgrazing plate meter height of 4.7 cm. The plot was then fertilized with 30 kg of N/ha supplied as ammonium nitrate. The plot was then divided into 12 paddocks to manage pregrazing sward height, with 1 paddock per treatment for periods 1 and 2, which were consecutive. For period 3, the cows were returned to the paddocks grazed in period 1, which were cut at the end of period 1 to homogenize their height. Period 3 started 14 d after the end of period 2 to provide time for herbage to regrow. During this pause between periods 2 and 3, the 36 experimental cows grazed as a single herd on nonexperimental paddocks with perennial ryegrass as the predominant species and were individually supplemented with 5 kg DM/d of corn silage.

Cows were managed in a strip-grazing system throughout the experiment. For treatments SU, SA, LU, and LA, in which HA was fixed, the daily area provided for each treatment was calculated as a function of pregrazing herbage mass, estimated each day in each paddock (see below). For treatments SH and LH, in which HA varied until a postgrazing height similar to that in treatments SU and LU, respectively, was reached, the area was adjusted regularly throughout the experiment thanks to visual observations and daily measurements of postgrazing sward height in the corresponding treatments. In practice, after some days of treatments application and visual observations, we were able to determine which HA should be provided to treatments SH and LH for achieving the targeted height. Area to be offered daily was then managed as in other treatments, just considering lower HA. Subsequently, HA of treatments SH and LH was only marginally changed 2 to 3 times during the experiment.

Fresh herbage was allocated once per day after a.m. milking, and cows had access to pasture from 0900 to 1530 h and 1800 to 0630 h (i.e., 19 h/d). Drinking water and a mineral block were always available at grazing except when measuring grazing time (see below), when the mineral block was removed to avoid misinterpreting the recorded data.

Feed, Sward, and Grazing Measurements

Corn silage was sampled daily to determine its DM. Samples from d 10 to 13 were combined by period for chemical composition determination. The mean DM concentration of corn silage was $353 \pm 13.6$ g/kg fresh matter. Corn silage contained $959 \pm 2.3$ g of OM, $72 \pm 0.6$ g of CP, $427 \pm 26.3$ g of NDF, $222 \pm 12.3$ g of ADF, and $23 \pm 3.4$ g of ADL per kg of DM, with on average 0.73 of in vivo OM digestibility and 6.44 MJ of NE$_{L}$/kg of DM according to equations of INRA (2007).

Pre- and postgrazing sward heights were measured daily per treatment using an electronic plate meter (30 × 30 cm, 4.5 kg/m$^2$, Aurea Agrosciences) with 30 measurements per treatment, following a W pattern in each paddock. Pregrazing extended tiller and sheath heights were measured per treatment with a ruler on 50 tillers chosen at random on d 11 and 12. Postgrazing extended
Animal Measurements

Body weight was measured after a.m. milking on the last 3 d of each period. Milk production was measured per cow at each milking, but only milk production recorded simultaneously to DMI was used for statistics. Milk fat and protein concentrations were determined on d 11 to 14, and milk urea concentrations were determined on d 11 and 12 via mid-infrared spectrophotometry using a MilkoScan instrument (Foss Electric). Blood urea concentration was determined from blood samples collected in the morning of d 12 via caudal venipuncture into evacuated collection tubes containing lithium heparin. After centrifugation (2,000 × g at 4°C for 15 min), the plasma was stored at −20°C.

Individual herbage DMI was measured on d 10 to 13 using the n-alkanes method (Mayes et al., 1986) and the ratio of herbage C₃₁ (hentriacontane) to dosed C₃₂ (dotriacontane). From d 0 and throughout the experiment, cows were individually dosed twice daily after milking with a cellulose stopper (Carl Roth, GmbH) containing 410 ± 13 mg of C₃₂. From p.m. milking on d 11 to a.m. milking on d 15 (i.e., d 1 of the following period), fecal grab samples were collected manually and stored daily per cow at 4°C in a cold room. On d 15, the samples were combined per cow, oven-dried at 60°C for 72 h, and then milled through a 0.8 mm screen for subsequent chemical analyses (Roca-Fernández et al., 2016).

Total NE₄ and truly digestible protein (PDI) supplies from herbage and supplements were calculated according to INRA (2007) and expressed as a proportion of cow requirements, which were calculated from their milk production and BW (INRA, 2007).

Grazing time was measured using the Kenz Lifecorder Plus device (LCP, Suzuken Co. Ltd.). The Lifecorder Plus is a portable electronic device based on a uniaxial accelerometer that records the average activity level (range 0 to 9) every 2-min period (Ueda et al., 2011). The Lifecorder Plus detects mainly head movements, rather than whole-body movements or locomotion activity, and detects grazing activity accurately (mean prediction error of 5% at the day scale; Delagarde and Lamberton, 2015). The device was placed in a small waterproof plastic box and attached to the cow’s neck via a simple collar. On d 8, 24 cows (4 per treatment) were equipped for 3 d. On d 11, the collars were removed, recorded data were downloaded, and the remaining 12 cows were equipped until d 14, along with half of the cows previously equipped. Thus, each cow had 3 to 6 full-day recordings per period. Since the activity level is near 0 when cows are engaged in activities besides grazing, including rumination, a grazing bout was defined simply as a period whose activity level exceeded 0.5 (Delagarde and Lamberton, 2015). A grazing meal was then defined as a grazing activity period of at least 6 min. Intervals of intrameal inactivity of 2 or 4 min were considered as continued grazing (Gibb, 1998) (i.e., 2 meals were separated by at least 6 min of inactivity). Daily grazing time equaled the sum of the duration of all grazing meals. The mean grazing time per cow and period was calculated by averaging grazing times of the 3 to 6 full-day records. The mean herbage DMI rate (g DM/min) was calculated per cow and period by dividing herbage DMI estimated from n-alkanes (kg of DM/d) by the mean daily grazing time estimated from
the Lifecorders (min/d), both measured simultaneously (wk 2 of each period).

Chemical Analyses

Ash concentration was determined via calcination at 550°C for 5 h in a muffle furnace (AOAC International, 2019). Nitrogen concentration was measured by the Dumas method (AOAC International, 2019) using a LECO instrument (LECO Corp.). Herbage OM digestibility was estimated by regression (INRA, 2007) from herbage pepsin-cellulase digestibility, determined according to Aufrère and Michalet-Doreau (1988). Concentrations of NDF, ADF, and ADL were measured according to Van Soest et al. (1991) using a Fibersac extraction unit (Ankom Technology Corp.). The NDF analysis included α-amylase and residual ash but did not include sodium sulfite. The n-alkanes were determined according to Mayes et al. (1986), following direct saponification (Vulich et al., 1991). The NEL and MP contents of feeds were calculated from their chemical composition according to INRA (2007). Blood urea concentration was determined from a colorimetric enzymatic reaction assessed by a multiparameter analyzer (KONE Instruments 200 Corporation).

Statistical Analyses

Animal data averaged per cow and treatment (i.e., by experimental period) were used as the experimental units (n = 18 per treatment, no data excluded) and were analyzed as a nested Latin square, with cows being nested within grazing intensity using the following model (PROC MIXED; SAS Institute Inc., 1999):

\[
Y_{ijkl} = \mu + P_i + G_j + S_l + (G_j \times S_l) + (G_j \times P_i) + e_{ijkl},
\]

where \(i = 1\) to 3 periods, \(j = 1\) to 2 grazing intensities, \(k = 1\) to 36 cows, \(l = 1\) to 3 supplementation strategies, and \(Y_{ijkl}\), \(\mu\), \(P_i\), \(G_j\), \(S_l\), \((G_j \times S_l)\), \((G_j \times P_i)\), and \(e_{ijkl}\) represent the analyzed variable, overall mean, fixed effect of period, fixed effect of grazing intensity, random effect of the cow nested within grazing intensity, fixed effect of supplementation, fixed effect of the interaction between grazing intensity and supplementation, fixed effect of the interaction between grazing intensity and period, and the residual error term, respectively. The grazing intensity effect was tested using the cow effect as the residual term, as cows were nested within grazing intensity.

Grazing and herbage data, averaged per treatment and period (n = 3 per treatment), were analyzed using the following model (PROC GLM; SAS Institute Inc., 1999):

\[
Y_{ijl} = \mu + P_i + G_j + S_l + (G_j \times S_l) + e_{ijl}.
\]

Five orthogonal contrasts were used to determine the following mean effects:

1) Contrast G: grazing intensity (SU + SA + SH vs. LU + LA + LH)
2) Contrast A vs. H: supplementation strategy (SA + LA vs. SH + LH)
3) Contrast G × (A vs. H): interaction between grazing intensity and supplementation strategy (G × (SA + LA vs. SH + LH)]
4) Contrast Su: overall supplementation supply (SU + LU vs. other treatments)
5) Contrast G × Su: interaction between grazing intensity and overall supplementation supply

RESULTS

Pregrazing Herbage Characteristics

Pregrazing herbage mass averaged 3,073 and 4,556 kg of DM/ha when measured at 3 cm above ground level and at ground level, respectively (Table 1). Pregrazing plate meter sward height averaged 14.9 cm. Pregrazing herbage mass and sward height did not differ between grazing intensities, nor between supplementation strategies. Pregrazing extended tiller and sheath heights did not differ between treatments, and averaged 28.3 and 12.3 cm, respectively. Extended lamina height averaged 16.0 cm, with slightly shorter heights in supplementation strategy H than A (−0.9 cm; contrast A vs. H: \(P < 0.05\)). Pregrazing herbage OM digestibility and chemical composition were not influenced by treatment except for herbage CP concentration, which was slightly greater at severe than at light grazing (165 vs. 154 g/kg DM, respectively; contrast G: \(P < 0.01\)).

Grazing Management and Postgrazing Pasture Characteristics

For strategies U and A, HA averaged 15.7 and 31.5 kg DM/d for severe and light grazing, respectively (Table 2). The corresponding figures were 23.1 and 47.6 kg DM/d for HA at ground level and 51 and 108 m²/d for offered areas, respectively (\(P < 0.01\)). As planned, strategies U and A had similar HA. Postgrazing sward height was shorter for severe than for light grazing, averaging 5.6 and 8.5 cm, respectively (contrast G: \(P < 0.01\)). Mean postgrazing sward height was shorter
Table 1. Pregrazing herbage characteristics according to grazing intensity (G) and strategies of corn silage supplementation, provided at a similar postgrazing sward height or similar herbage allowance (HA) compared with that of unsupplemented cows.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment 1</th>
<th>Contrast 2 (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe³</td>
<td>Light³</td>
</tr>
<tr>
<td></td>
<td>SU</td>
<td>SA</td>
</tr>
<tr>
<td>Pregrazing herbage mass, kg of DM/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 3 cm</td>
<td>3,107</td>
<td>3,203</td>
</tr>
<tr>
<td>Above ground level</td>
<td>4,588</td>
<td>4,684</td>
</tr>
<tr>
<td>Pregrazing sward height, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rising plate meter</td>
<td>15.0</td>
<td>15.4</td>
</tr>
<tr>
<td>Extended tiller</td>
<td>28.8</td>
<td>28.2</td>
</tr>
<tr>
<td>Extended sheath</td>
<td>12.3</td>
<td>12.2</td>
</tr>
<tr>
<td>Extended lamina</td>
<td>16.5</td>
<td>16.0</td>
</tr>
<tr>
<td>Pregrazing herbage chemical composition, g/kg of DM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, g/kg of fresh matter</td>
<td>175</td>
<td>178</td>
</tr>
<tr>
<td>OM</td>
<td>894</td>
<td>897</td>
</tr>
<tr>
<td>CP</td>
<td>165</td>
<td>166</td>
</tr>
<tr>
<td>NDF</td>
<td>519</td>
<td>514</td>
</tr>
<tr>
<td>ADF</td>
<td>253</td>
<td>249</td>
</tr>
<tr>
<td>ADL</td>
<td>24.5</td>
<td>25.6</td>
</tr>
<tr>
<td>Pregrazing herbage OM digestibility, g/g</td>
<td>0.791</td>
<td>0.787</td>
</tr>
</tbody>
</table>

1Treatments: severe (S): HA = 15 kg DM/d at 3 cm above ground level; light (L): HA = 30 kg DM/d at 3 cm above ground level; unsupplemented (U): 0 kg DM/d of corn silage; A: 5 kg DM/d of corn silage with similar HA as in U; H: 5 kg DM/d of corn silage with similar postgrazing sward height as in U.

2Contrasts: G = effect of grazing intensity (SU + SA + SH vs. LU + LA + LH); A vs. H = effect of supplementation strategy (SA + LA vs. SH + LH); G × (A vs. H) = interaction effect between grazing intensity and supplementation strategy [G × (SA + LA vs. SH + LH)]; Su = effect of supplementation supply (SU + LU vs. other treatments); G × Su = interaction between grazing intensity and supplementation supply.

3Defined by HA or postgrazing sward height depending on the treatment.

4Calculated from pepsin-cellulase digestibility (Aufrère and Michalet-Doreau, 1988).
for strategy H than A (−0.8 cm; contrast A vs. H: \(P < 0.01\)), and this difference tended to be greater for severe than light grazing (contrast G × (A vs. H): \(P = 0.06\)). As planned, strategies U and H had similar postgrazing sward height, regardless of grazing intensity. To achieve this, the area offered daily was 18% smaller for strategy H than U for severe or light grazing (\(P < 0.01\)). This represented a 3.5 and 4.9 kg DM/d decrease in HA for severe and light grazing, respectively, or a 0.7 and 1.2 kg DM/d decrease in HA per kilogram DM of silage consumed, respectively.

As expected, postgrazing extended tiller, sheath, and lamina heights were shorter for severe than for light grazing (contrast G: \(P < 0.01\)), resulting in a greater proportion of lamina-free tillers (0.53 vs. 0.21, respectively; contrast G: \(P < 0.01\)) (Table 2). Mean postgrazing extended lamina height tended to be shorter for strategy H than A (−0.8 cm; contrast A vs. H: \(P < 0.10\)), resulting in a greater proportion of lamina-free tillers (0.40 vs. 0.29, respectively; contrast A vs. H: \(P < 0.01\)). Except for herbage OM concentration that was lower by 5 g/kg DM for severe than light grazing (contrast G: \(P < 0.01\)), the chemical composition and nutritional value of the selected herbage were similar among treatments. In all treatments, selected herbage OM and CP concentrations were close to those of offered herbage, but NDF and ADF concentrations were slightly lower than those of offered herbage.

### Dry Matter Intake and Substitution Rate

Herbage DMI averaged 13.0 and 15.8 kg/d for severe and light grazing, respectively (contrast GI: \(P < 0.01\)) (Table 3). For severe grazing, all the silage offered was consumed, and silage DMI averaged 4.6 kg/d. For light grazing, some of the silage offered was refused, which resulted in lower silage DMI (3.7 kg/d). Total DMI averaged 16.0 and 18.2 kg/d for severe and light grazing, respectively (contrast G: \(P < 0.05\)).

Herbage DMI was lower in supplemented (13.1 kg/d) than in unsupplemented cows (16.8 kg/d) (−3.7 kg/d; contrast Su: \(P < 0.01\)). This represents a mean substitution rate of 0.89. This reduction tended to be lower for severe than for light grazing (2.9 vs. 4.5 kg/d, respectively; contrast G × Su: \(P < 0.06\)), which resulted in a large difference in substitution rate (0.63 vs. 1.23, respectively). Herbage DMI was lower for strategy H than A, averaging 12.5 and 13.8 kg/d, respectively (contrast A vs. H: \(P < 0.05\)), with no interaction with grazing severity. The average subsequent substitution rates for strategies A and H were 0.79 and 1.00, respectively.

### Milk Production, Milk Composition, Body Weight, and Blood Urea

Milk production averaged 20.8 and 23.8 kg/d for severe and light grazing, respectively (contrast G: \(P < 0.05\)) (Table 3). This represented a 0.20 and 0.13 kg increase in milk/d per kilogram DM of HA at 3 cm above ground level and at ground level, respectively. The corresponding values were respectively 19.7 and 21.9 kg/d for 4% FCM production (contrast G: \(P = 0.10\)), 28.9 and 31.8 g/kg for milk protein concentration (contrast G: \(P < 0.01\)), and 600 and 757 g/d for milk protein production (contrast G: \(P < 0.01\)).

On average, mean milk production was similar between supplemented and unsupplemented cows (22.4 vs. 22.1 kg/d; contrast Su: \(P = 0.19\); Table 3). However, the effects of silage supplementation on milk production depended on grazing intensity. For light grazing, silage supplementation did not influence milk production or composition. For severe grazing, silage supplementation increased milk production by 1.1 kg/d, 4% FCM production by 1.0 kg/d, milk fat production by 33 g/d, milk protein concentration by 1.1 g/kg, and milk protein production by 48 g/d (contrast G × Su: \(P < 0.01\)). The 4% FCM production and the milk fat production tended to be lower by 0.4 kg/d and 19 g/d, respectively, for strategy H than A (contrast A vs. H: \(P < 0.08\) and \(P < 0.07\), respectively). Silage supplementation tended to decrease milk fat concentration (−0.4 g/kg; contrast Su: \(P < 0.10\)), and increased body weight (+7 kg; contrast Su: \(P < 0.01\)). Body weight was lower for strategy H than A (−5 kg, contrast A vs. H: \(P < 0.01\)).

Diet CP concentration, averaging 148 g/kg DM, was slightly lower for severe than for light grazing (−5 g/kg DM; contrast G: \(P < 0.01\)) and lower for supplemented than unsupplemented cows (−24 g/kg DM; contrast Su: \(P < 0.01\)) (Table 3). Milk urea N was greater for severe than for light grazing (2.4 vs. 1.8 mmol/L; contrast G: \(P < 0.01\)), despite lower diet CP concentration. Blood urea N concentration averaged 2.0 mmol/L and was not influenced by grazing intensity. Milk and blood urea N concentrations were lower by a mean of 31% and 36%, respectively, for supplemented than unsupplemented cows (contrast Su: \(P < 0.01\)). This reduction was greater (milk urea N; contrast G × Su: \(P < 0.01\)) or tended to be greater (blood urea N; contrast G × Su: \(P < 0.06\)) for severe than for light grazing.

### Grazing Behavior

Grazing time averaged 466 min/d and was not influenced by grazing intensity (Table 3). Grazing time was lower by 47 min/d for supplemented than for unsupplemented cows.
Table 2. Grazing management, postgrazing sward height, chemical composition, and nutritional value of selected herbage according to grazing intensity (G) and strategies of corn silage supplementation, provided at a similar postgrazing sward height or similar herbage allowance (HA) compared with that of unsupplemented cows

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment¹</th>
<th>Contrast² (P-value)</th>
<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe³</td>
<td>Light³</td>
<td></td>
</tr>
<tr>
<td>HA, kg of DM/d</td>
<td>SU SA SH</td>
<td>LU LA LH</td>
<td>SE</td>
</tr>
<tr>
<td>Above 3 cm</td>
<td>15.7 15.7 12.2</td>
<td>31.5 31.5 26.5</td>
<td>0.67 0.01</td>
</tr>
<tr>
<td>Above ground level</td>
<td>23.3 23.0 18.4</td>
<td>46.8 48.4 39.0</td>
<td>1.27</td>
</tr>
<tr>
<td>Offered area, m²/cow per day</td>
<td>51  50  42</td>
<td>103 113  85</td>
<td>4.8 0.68 0.01 0.01 0.30</td>
</tr>
<tr>
<td>Postgrazing sward height, cm</td>
<td>Rising plate meter</td>
<td>5.3 6.5 5.1</td>
<td>0.42 0.01 0.01 0.06 0.29 0.26</td>
</tr>
<tr>
<td></td>
<td>Extended tiller</td>
<td>9.4 11.7 10.1</td>
<td>1.22 0.01 0.01 0.01 0.01 0.30</td>
</tr>
<tr>
<td></td>
<td>Extended sheath</td>
<td>7.3 8.4 7.7</td>
<td>0.79 0.01 0.01 0.01 0.01 0.30</td>
</tr>
<tr>
<td></td>
<td>Extended lamina</td>
<td>2.1 3.3 2.4</td>
<td>0.71 0.01 0.01 0.01 0.01 0.30</td>
</tr>
<tr>
<td></td>
<td>Proportion of lamina-free tillers⁴</td>
<td>0.59 0.42 0.57</td>
<td>0.043 0.01 0.01 0.01 0.01 0.30</td>
</tr>
<tr>
<td>Chemical composition of selected herbage,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/kg of DM</td>
<td>OM</td>
<td>895 895 894</td>
<td>3.55 0.01 0.36 0.43 0.88 0.02</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>159 167 165</td>
<td>6.05 0.74 0.67 0.36 0.28 0.43</td>
</tr>
<tr>
<td></td>
<td>NDF</td>
<td>497 501 495</td>
<td>9.40 0.24 0.59 0.64 0.93 0.83</td>
</tr>
<tr>
<td></td>
<td>ADF</td>
<td>242 243 240</td>
<td>8.75 0.48 0.84 0.67 0.76 0.36</td>
</tr>
<tr>
<td></td>
<td>ADL</td>
<td>24.2 25.5 26.1</td>
<td>2.49 0.95 0.62 0.88 0.88 0.02</td>
</tr>
<tr>
<td>Nutritional value of selected herbage</td>
<td>NE,U, MJ/kg of DM</td>
<td>6.50 6.53 6.55</td>
<td>0.120 0.22 0.98 0.77 0.76 0.76</td>
</tr>
<tr>
<td></td>
<td>PDIE,⁵ g/kg of DM</td>
<td>93 95 94</td>
<td>95 94 94</td>
</tr>
</tbody>
</table>

¹Treatments: severe (S): HA = 15 kg DM/d at 3 cm above ground level; light (L): HA = 30 kg DM/d at 3 cm above ground level; unsupplemented (U): 0 kg DM/d of corn silage; A: 5 kg DM/d of corn silage with similar HA as in U; H: 5 kg DM/d of corn silage with similar postgrazing sward height as in U.

²Contrasts: G = effect of grazing intensity (SU + SA + SH vs. LU + LA + LH); A vs. H = effect of supplementation strategy (SA + LA vs. SH + LH); G × (A vs. H) = interaction effect between grazing intensity and supplementation strategy [G × (SA + LA vs. SH + LH)]; Su = effect of supplementation supply (SU + LU vs. other treatments); G × Su = interaction between grazing intensity and supplementation supply.

³Defined by HA or postgrazing sward height depending on the treatment.

⁴Tillers with main lamina completely defoliated.

⁵Truly digestible protein, with energy-limiting microbial synthesis in the rumen (INRA, 2007).
Table 3. Intake, milk production, and composition, BW, milk and blood urea N, and grazing behavior in dairy cows according to grazing intensity (G) and strategies of corn silage supplementation, provided at a similar postgrazing sward height or similar herbage allowance (HA) compared with that of unsupplemented cows

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment&lt;sup&gt;1&lt;/sup&gt;</th>
<th>G A vs. H</th>
<th>G × (A vs. H)</th>
<th>Su</th>
<th>G × Su</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SU</td>
<td>SA</td>
<td>SH</td>
<td>LU</td>
<td>LA</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbage</td>
<td>14.9</td>
<td>12.7</td>
<td>11.3</td>
<td>18.8</td>
<td>14.8</td>
</tr>
<tr>
<td>Corn silage</td>
<td>0.0</td>
<td>4.5</td>
<td>4.7</td>
<td>0.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Total</td>
<td>14.9</td>
<td>17.2</td>
<td>16.0</td>
<td>18.8</td>
<td>18.1</td>
</tr>
<tr>
<td>NE&lt;sub&gt;l&lt;/sub&gt; supply, MJ/d</td>
<td>100</td>
<td>113</td>
<td>106</td>
<td>127</td>
<td>120</td>
</tr>
<tr>
<td>PDIE&lt;sup&gt;5&lt;/sup&gt; supply, kg/d</td>
<td>1.4</td>
<td>1.5</td>
<td>1.4</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>NE&lt;sub&gt;l&lt;/sub&gt; balance&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0.97</td>
<td>1.05</td>
<td>1.01</td>
<td>1.09</td>
<td>1.04</td>
</tr>
<tr>
<td>PDIE balance&lt;sup&gt;7&lt;/sup&gt;</td>
<td>1.06</td>
<td>1.09</td>
<td>1.06</td>
<td>1.08</td>
<td>1.02</td>
</tr>
<tr>
<td>Milk production, kg/d</td>
<td>20.1</td>
<td>21.5</td>
<td>20.8</td>
<td>24.0</td>
<td>23.7</td>
</tr>
<tr>
<td>Milk fat concentration, g/kg</td>
<td>36.7</td>
<td>36.4</td>
<td>36.5</td>
<td>35.1</td>
<td>34.7</td>
</tr>
<tr>
<td>Milk protein concentration, g/kg</td>
<td>28.2</td>
<td>29.5</td>
<td>29.1</td>
<td>32.2</td>
<td>31.4</td>
</tr>
<tr>
<td>4% FCM production, kg/d</td>
<td>19.1</td>
<td>20.4</td>
<td>19.7</td>
<td>22.2</td>
<td>21.8</td>
</tr>
<tr>
<td>Milk fat production, g/d</td>
<td>740</td>
<td>783</td>
<td>759</td>
<td>837</td>
<td>822</td>
</tr>
<tr>
<td>Milk protein production, g/d</td>
<td>568</td>
<td>633</td>
<td>600</td>
<td>773</td>
<td>746</td>
</tr>
<tr>
<td>BW, kg</td>
<td>559</td>
<td>571</td>
<td>566</td>
<td>592</td>
<td>600</td>
</tr>
<tr>
<td>Diet CP concentration, g/kg of DM</td>
<td>1.59</td>
<td>1.41</td>
<td>1.37</td>
<td>1.69</td>
<td>1.41</td>
</tr>
<tr>
<td>Milk urea N, mmol/L</td>
<td>3.1</td>
<td>2.0</td>
<td>2.0</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Blood urea N, mmol/L</td>
<td>2.8</td>
<td>1.9</td>
<td>1.6</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Grazing behavior</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total grazing time, min/d</td>
<td>496</td>
<td>447</td>
<td>434</td>
<td>499</td>
<td>452</td>
</tr>
<tr>
<td>First grazing bout duration, min</td>
<td>177</td>
<td>170</td>
<td>180</td>
<td>115</td>
<td>106</td>
</tr>
<tr>
<td>Mean grazing bout duration, min</td>
<td>98</td>
<td>79</td>
<td>75</td>
<td>80</td>
<td>72</td>
</tr>
<tr>
<td>Number of grazing bouts</td>
<td>5.2</td>
<td>5.8</td>
<td>5.8</td>
<td>6.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Herbage intake rate, g of DM/min</td>
<td>30.2</td>
<td>28.5</td>
<td>26.1</td>
<td>37.8</td>
<td>32.8</td>
</tr>
</tbody>
</table>

<sup>1</sup>Treatments: severe (S): HA = 15 kg DM/d at 3 cm above ground level; light (L): HA = 30 kg DM/d at 3 cm above ground level; unsupplemented (U): 0 kg DM/d of corn silage; A: 5 kg DM/d of corn silage with similar HA as in U; H: 5 kg DM/d of corn silage with similar postgrazing sward height as in U.

<sup>2</sup>Standard error for G effect.

<sup>3</sup>Contrasts: G = effect of grazing intensity (SU + SA + SH vs. LU + LA + LH); A vs. H = effect of supplementation strategy (SA + LA vs. SH + LH); G × (A vs. H) = interaction effect between grazing intensity and supplementation strategy [G × (SA + LA vs. SH + LH)]; Su = effect of supplementation supply (SU + LU vs. other treatments); G × Su = interaction between grazing intensity and supplementation supply.

<sup>4</sup>Defined by HA or postgrazing sward height depending on the treatment.

<sup>5</sup>Truly digestible protein, with energy-limiting microbial synthesis in the rumen (INRA, 2007).

<sup>6</sup>Proportion of NEL requirements met by NE<sub>l</sub> supply.

<sup>7</sup>Proportion of PDIE requirements met by PDIE supply.
unsupplemented cows (i.e., −11 min/d per kg DM of silage consumed; contrast Su: P < 0.01). This reduction tended to be greater at severe than light grazing (contrast G × Su: P < 0.06). On average, there was no effect of supplementation strategy on grazing time. However, grazing time was lower on strategy H than A for severe grazing and greater on H than A for light grazing (contrast G × (A vs. H): P < 0.01). The duration of the first grazing bout and the mean grazing bout duration were greater for severe than for light grazing (176 vs. 117 min (contrast G: P < 0.01) and 84 vs. 75 min/bout (contrast G: P < 0.05), respectively). The duration of the first grazing bout was greater by 16 min on strategy H than A (contrast A vs. H: P < 0.01). The number of grazing bouts per day was lower for severe than for light grazing (5.6 vs. 6.5 bouts/d, respectively; contrast G: P < 0.05). Mean grazing bout duration decreased by 14 min (−16%) with supplementation (contrast Su: P < 0.01). This decrease was greater for severe than for light grazing (−21 vs. −7 min/bout, respectively; contrast G × Su: P < 0.01).

The herbage DMI rate was lower for severe than for light grazing (−5 g of DM/min; contrast G: P < 0.05), and lower on strategy H than A (−3 g of DM/min; contrast A vs. H: P < 0.01) (Table 3). The herbage DMI rate was lower for supplemented than unsupplemented cows (−5 g of DM/min; contrast Su: P < 0.01), with a greater reduction for light than for severe grazing (−7 vs. −3 g of DM/min, respectively; contrast G × Su: P < 0.05).

**DISCUSSION**

The main aim of the study was to evaluate how the grazing management affects the substitution rate and milk production response of grazing dairy cows, under severe or light grazing intensity (strategy A: same HA, or strategy H: same postgrazing sward height, between supplementation levels). As strategy H implies a reduction of HA in supplemented compared with unsupplemented cows, the main hypothesis was that the substitution rate would be higher and milk production per kilogram of supplement lower for strategy H than A.

The 2 supplementation strategies were successful, since strategies U and A had similar HA and strategies U and H had similar postgrazing sward heights. Moreover, the structural, botanical, and chemical characteristics of the offered herbage were similar among treatments, which enabled us to analyze and interpret effects of silage supplementation strategies and their interactions with grazing intensity.

This study quantified only short-term nutritional, productive, and behavioral responses of dairy cows to corn silage supplementation strategy. No direct extrapolation of our results should be done on herd lactation or BCS management, nor on pasture management at the scale of the grazing season, which would require long-term experiments without change-over experimental design.

**Overall Effect of Grazing Intensity**

The large decreases in herbage DMI (2.8 kg/d) and milk production (3.0 kg/d) for severe compared with light grazing agree well with the predicted responses from a meta-analysis of the literature (Pérez-Prieto and Delagarde, 2013). They clearly indicate restrictive pasture conditions with severe grazing (Stockdale, 2000; Ribeiro-Filho et al., 2005). This nutritional contrast between the 2 grazing intensities is good for studying effects of the interaction between the corn silage supplementation strategy and grazing intensity on dairy cows.

**Overall Interaction of Corn Silage Supplementation by Grazing Intensity**

The lower substitution rate between herbage and corn silage for severe than for light grazing and the positive effects of corn silage supplementation on total DMI and milk production only for severe grazing are consistent with many previous silage supplementation studies under different HA (Moate et al., 1984; Stockdale, 1996; Pérez-Prieto et al., 2011; Dall-Orsoletta et al., 2019; Ribeiro-Filho et al., 2021). At low HA, intake capacity of the cows is not reach from herbage alone, which explains why silage supply has less effect on herbage intake than at high HA (Phillips, 1988).

The mean 18% reduction in herbage DMI after corn silage supplementation was mediated through a 10% reduction in grazing time and 9% reduction in herbage DMI rate, as previously shown for grazing time (Phillips and Leaver, 1985; Graf et al., 2005; Pérez-Prieto et al., 2011; Dall-Orsoletta et al., 2019; Ribeiro-Filho et al., 2021) and herbage DMI rate (Pérez-Ramírez et al., 2008; Pérez-Prieto et al., 2011) for cows supplemented with corn silage. This suggests that supplying corn silage may decrease the motivation to graze or the ability to graze rapidly. It also highlights that the relative change in grazing time due to changes in forage supplementation level cannot be used directly as an indicator of the relative change in herbage DMI.

The response of milk production to corn silage supplementation agreed with the variations in substitution rate, as a positive milk production response
was observed only when total DMI increased, similar to previous work (Phillips, 1988; Bargo et al., 2003). Under severe grazing (i.e., low HA), milk production can increase to 0.68 kg of milk per kg DM of corn silage (Stockdale, 1996; Woodward et al., 2006; Burke et al., 2008). Conversely, at high HA, corn silage supplementation generally does not influence milk production (Stockdale, 1996; Chénais et al., 1997; Dall-Orsöletta et al., 2019; Ribeiro-Filho et al., 2021). This may be particularly true for high-quality herbage, as in our experiment, because the nutritional value of the diet can decrease when corn silage replaces high-quality herbage (Stockdale, 1996; INRA, 2018). The increase in milk protein concentration with corn silage supplementation followed the increase in energy supply (Coulon and Rémond, 1991), with the same magnitude of responses found by Pérez-Prieto et al. (2011) and Miguel et al. (2014) under high grazing intensity.

**Effects of Corn Silage Supplementation Strategy on Animal Responses**

The main and new result of this experiment is that effects of corn silage supplementation on herbage intake and milk production depend on the experimental strategy used to compare levels of corn silage supplementation.

As expected, the reduction in HA for strategy H, which aimed for similar postgrazing sward height in all treatments, decreased herbage intake, resulting by calculation in a higher substitution rate and lower milk production response than in strategy A. These changes in substitution rate and milk production response between strategies have to be related only to the changes in HA and not to the supplement supply per se, which confirms the main hypothesis tested in this experiment. This highlights that changing the paradigm from offering the same amount of forage (strategy A) to refusing the same amount of forage (strategy H), as in indoor studies investigating substitution rate, increases absolute values of substitution rate and decreases absolute values of milk production response simply through the definitions (reduction of herbage intake and increase in milk production per kilogram of supplement eaten). For light grazing (e.g., no intake restriction due to HA), the relative reduction in HA for strategy H compared with that of A was probably not sufficient to interact with effects of silage supplementation on herbage intake, which resulted in similar substitution rates. In this situation, herbage intake is assumed to be regulated by metabolic or energy constraints rather than by feed availability (Poppi et al., 1987), as in indoor feeding systems (Faverdin et al., 1991).

**Practical Implications**

On good-quality pastures and under light grazing, corn silage supplementation did not influence milk production per cow due to the high substitution rate. Conversely, corn silage supplementation increased milk production under severe grazing due to the low herbage intake by unsupplemented cows and the low substitution rate. In practice, grazing management objective on farm is often to achieve a high herbage-use rate and a low postgrazing sward height regardless of the level of corn silage supplementation. Our results showed that the substitution rate between herbage and corn silage was high (strategy H) due to reduced HA to achieve similar postgrazing sward height, and milk production per cow did not increase due to corn silage supplementation. Obtaining a similar postgrazing sward height (i.e., similar herbage-use rate) for supplemented and unsupplemented herds requires reducing the HA at ground level by approximately 1 kg DM/d for each kilogram DM of corn silage consumed.

It is worth stating that the results observed in the current study could differ in scenarios with other types of supplements or animals. For instance, a literature review showed greater substitution rate at grazing with hay than with corn or grass silage and greater milk production response with corn silage than with grass silage or hay (Miguel et al., 2016). Additionally, it is known that milk production may decrease when forage supplements having lower quality compared with herbage is offered to dairy cows at high HA (Phillips, 1988). To our knowledge, the effects of breed, genetic merit, parity, and stage of lactation on the substitution rate between herbage and a conserved forage supplement have not been yet investigated in grazing dairy cows.

**CONCLUSIONS**

The main highlight of this study is that the method used to compare supplementation levels influences short-term dairy cow responses. Indeed, the substitution rate is higher and corn silage has less influence on milk production when studied using similar postgrazing sward height than when using similar HA, which is directly due to the reduction of HA of supplemented cows when low postgrazing sward height is wanted. In practice, maintaining similar herbage-use rate regardless of the supplementation level implies an increased calculated substitution rate and little influence of corn silage supplementation on milk production for dairy cows that graze good-quality temperate pastures, particularly at light grazing intensity. At severe grazing intensity, silage supplementation still may remain interesting due to restricted herbage intake.
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Miguel et al.: CORN SILAGE SUPPLEMENT FOR GRAZING DAIRY COWS


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