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RAPID COMMUNICATION

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Stocking density adjustment optimises grazing and limits soil ingestion of beef-on-dairy heifers

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ABSTRACT

Grazing conditions that optimise herbage utilisation, together with reduced involuntary soil ingestion by livestock, may improve profitability and lower risks for animal health and food safety. Here, we assessed herbage consumption and selection and soil intake by beef-on-dairy growing cattle managed at low or high stocking densities (StockD, 5.6 and 9.2 livestock units/ha/10 days, respectively) in montane pastures. The cattle were allocated to two sub-herds ($n = 32$ cattle each) that grazed under a rotational grazing system. The percentage removal of grasses, legumes, and forbs was calculated for two successive 10–day grazing periods. Furthermore, *n*-alkanes, ytterbium, and acid-insoluble ash were used as markers for the measurements of herbage and soil intake in eight individual heifers per herd. Soil intake was higher under high versus low StockD ($p < 0.001$; 0.28 *vs.* 0.15 kg DM/day) and in period 1 compared to period 2 ($p < 0.001$; 0.30 *vs.* 0.13 kg DM/day), due to more humid weather conditions. Moreover, the percentage removal of grasses, legumes, and forbs was higher ($p < 0.01$) in period 1 than in period 2 but did not differ between stocking densities. The sire's breed of heifers affected herbage intake, especially under low StockD, with a higher level in Angus than in Limousin crossbreed ($p < 0.001$; 7.39 *vs.* 5.60 kg DM/day), but not the soil intake ($p = 0.61$; on average, 0.22 kg DM/day). Cattle breed selection and stocking density adaptation could represent grazing management strategies for improving herbage utilisation and lowering soil intake.

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Growing cattle; pasture; extreme rainfall; adaptability; feeding selection

1. Introduction

Targeted and site-adapted grazing management is a key to improving the profitability and sustainability of herbage-based ruminant farming systems. This involves finding the right balance between improving the use of available herbage and alleviating overgrazing and nutrient shortage (Hennessy et al. 2020). Furthermore, grazing under harsh conditions, such as when herbage availability is low, can increase involuntary soil ingestion of dairy cows (Jurjanz et al. 2012) or growing bulls (Collas et al. 2019). Soil intake may contribute to livestock exposure to soil-born gastro-intestinal parasites (e.g. nematodes), as well as environmental pollutants (e.g. polychlorinated biphenyls), which pose a threat to animal health (Playford and Besier 2025) and milk and meat safety (Lerch et al. 2024). Grazing management could be adapted to face these challenges by adjusting the stocking density (StockD), that is, the pasture area available to grazing livestock over a specified time, depending on vegetation and weather conditions.

Farmers may also select cattle breeds or strains that have specific grazing behaviours that support the capability to cope with low herbage availability under harsh weather conditions (Heublein et al. 2017). Such effects of StockD and cattle genetic backgrounds have to be considered in the context of climate change in temperate areas, characterised by an increased frequency and intensity of extreme weather events, such as droughts alternating with intense rainfall. These periods affect the productivity and quality (botanical composition and nutritive value) of pasture herbage, as well as the grazing conditions for livestock (Bernabucci 2019).

The aim of this study was to assess herbage consumption and digestibility, percentage of removal of grasses, legumes, and forbs, as well as soil intake by

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heifers from two beef-on-dairy crossbreeds managed at two different StockD in montane pastures. Our hypothesis was that lowering StockD would enhance herbage intake and digestibility and decrease soil intake, and that the intensity of such effects would depend on the cattle's crossbreed.

2. Materials and methods

2.1. Experimental design

The grazing trial reported herein was part of a larger experimental set-up on a total of 136 beef-on-dairy growing heifers and steers fed herbage-based diets, described in detail by Lindtke et al. (2024). From the whole herd, two homogenous sub-herds of 24 heifers (Brown Swiss as dam crossed with Angus, Limousin, or Simmental sires; $n = 8$ of each) and 8 steers each (Brown Swiss × Limousin) were composed based on body weight (BW) recorded by double-weighing on 20 and 21 May 2021. On these days, sub-herds A and B had equivalent BW of 262 ± 19 and 261 ± 16 kg (mean ± SD) and ages of 235 ± 7 and 236 ± 9 days old, respectively. Each sub-herd grazed separately and continuously from 25 May to 13 September 2021 at La Frêtaz, 1200 m a.s.l. in the Jura Mountains (Bullet, Vaud, Switzerland).

The site comprises 14.6 ha of permanent mountain grasslands divided into 12 paddocks (mean ± SD of paddock size = 1.2 ± 0.3 ha) that were grazed under a rotational grazing system. The experimental phase took place in the four most productive paddocks (α, β, γ, and δ), which were grazed twice along the season (i.e. in July and September), over two successive periods of 10 days n each month. The present study focuses on successive periods 1 and 2 of July (6^{th} to 15^{th} July and 16^{th} to 25^{th} July, respectively). Within these paddocks, vegetation communities were dominated by *Lolium perenne* L., *Dactylis glomerata* L., *Trifolium repens* L., *Trifolium pratense* L., *Taraxacum officinale* Weber and *Plantago lanceolata* L. The soils were classified as cambisol eutric and had an average depth of 50 cm, an organic content between 4% and 12%, a pH between 5.1 and 6.7, and a clay and silt content between 24% and 45%. During each period, two different StockD (9.17 and 5.62 livestock units/ha/10 days for high and low StockD, respectively) were applied alternatively to the two sub-herds (Figure 1). The high StockD corresponds to the one often applied under similar vegetation and topographic conditions, while the low StockD is a 40% reduction that could be applied under critical conditions, such as dry periods with limited forage availability (Mosimann et al. 2012). Throughout the two experimental periods, the weather conditions were registered by a meteorological

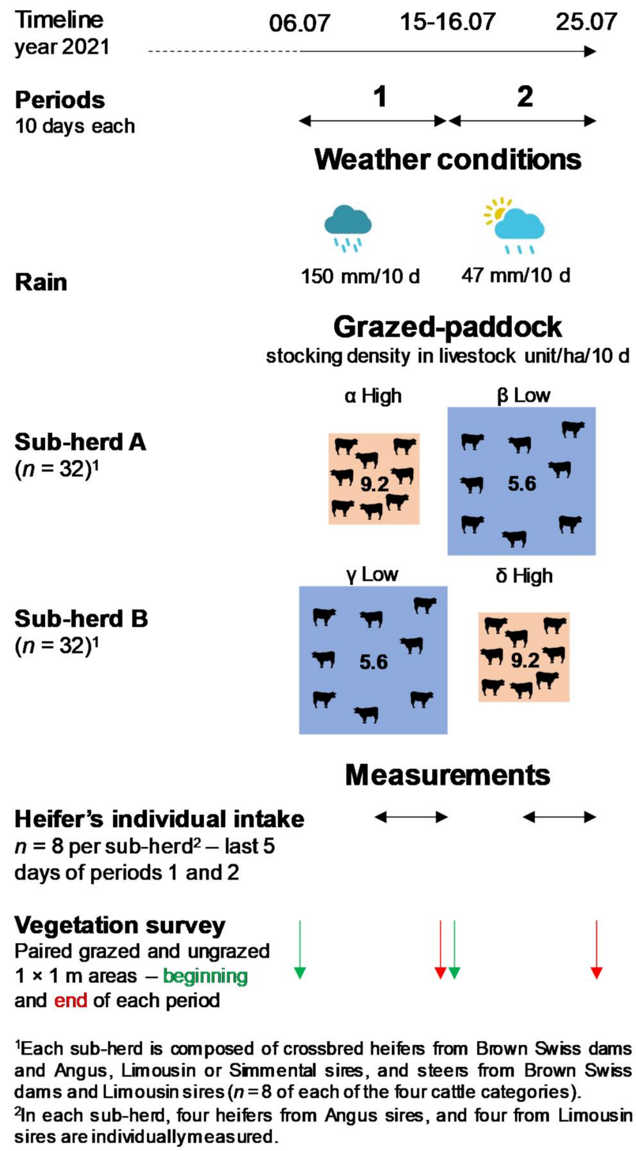

Figure 1. Timeline of the experimental design, procedures, and measurements for the study of herbage and soil intake and selection in beef-on-dairy crossbred cattle at montane pasture.

station on site, which recorded a contrast of prolonged and heavy rainfalls in period 1 and drier conditions in period 2 (Table 1).

2.2. Measurements and sampling

2.2.1. Animal individual intake and BW

One herbage sample representative of the pasture botanical composition was sampled at a sward height of 5 cm above ground before grazing in each paddock for nutritional analysis. Individual intakes of herbage and soil and nutrient digestibility were estimated for 16 heifers (in each herd, $n = 4$ of each Brown Swiss × Angus or Limousin crossbreeds) over the last five days of periods 1 and 2 in July, with the n-alkane double indicator

Table 1. Experimental design, climatic conditions and herbage biomass available during the four grazing periods of two sub-herds of beef-on-dairy heifers and steers under two stocking densities.

Period	Dates	Sub-herd	Paddock	Stocking density: Livestock unit /ha/10 days	Stocking density: Total cattle weight /ha/10 days	Precipitation (mm/10 days)	Number of rainy days	Mean temperature (°C)	Soil moisture (% wet weight)[1]	Biomass beginning (kg DM/ha)[2]	Biomass end ungrazed (kg DM/ha)[3]	Biomass end grazed (kg DM/ha)[4]
1	06.07.2021 – 15.07.2021	A	α	9.2	7405	150	8	12.1	59.8	2784	3678	294
		B	γ	5.6	4806				61.2	2861	3692	593
2	16.07.2021 – 25.07.2021	A	β	5.6	4790	47	3	16.1	55.3	2875	4702	1802
		B	δ	9.2	8261				57.8	3042	4531	963

[1]Average of three measurements on days 1, 3 and 5 of the heifer's intake measurements.
[2]Available biomass in the exclusion cages at the beginning of the grazing period.
[3]Available biomass in the exclusion cages at the end of the grazing period in the ungrazed area.
[4]Available biomass in the exclusion cages at the end of the grazing period in the grazed area.

technique ($C_{32}H_{66}$ as external marker, $C_{33}H_{68}$ as raw herbage internal markers) for total raw herbage intake estimation (Mayes et al. 1986), the Ytterbium (Yb) external marker for faecal flow estimation (Ribeiro Filho et al. 2005), and acid-insoluble ash as internal marker for soil intake estimation (Jurjanz et al. 2012).

Heifers were dosed twice a day (around 08:00 and 16:00 h) for 21 days (from one day before the beginning of period 1 until the end of period 2) with gelatine capsules (HGK 17–60 sl; Capsula GmbH, Ratingen, Germany) containing 0.371 g (± 0.01) $C_{32}H_{66}$ (Minakem Beuvry Production S.A.S., Beuvry la Forêt, France) and 0.347 g Yb_2O_3 (Alfa Aesar GmbH & Co KG, Karlsruhe, Germany) on a carrier of 4.6 g dried fruit pomace. Spot samples of faeces were taken with or without stimulus between 07:00 and 09:00 h over the last 5 days of periods 1 and 2 and further pooled by heifer and period before storage at −20 °C. Daily pasture herbage samples representative of the heifer's intake (Heublein et al. 2017), and soil at the same place (top 5 cm depth, Collas et al. 2019) were composited twice a day (around 10:00 and 17:00 h) by sub-herd on days −1 to +4 relative to the start of faeces collection. Further calculations of herbage and soil intake, and apparent nutrient digestibility are provided in sub-section 2.4 below. Individual BW was recorded between 07:00 and 09:00 h over two consecutive days (double-weighing) with an electronic weighing scale at the mid-term of each 5-day period of individual intake measurements.

2.2.2. Vegetation surveys

Within similar vegetation communities, three pairs (3 blocks) of plots (1 × 1 m) were chosen in each paddock, each including one grazed and one ungrazed plot (grazing exclusion cage of 1.5 × 1.5 m), yielding 6 plots per paddock (StockD × period). The botanical composition of the grazed and ungrazed plots was determined at the beginning and end of the grazing period using the vertical point-quadrat method (Daget and Poissonet 1971). At 5-cm intervals along the two diagonals of the plot, the plant species touching a steel needle were identified, and the percent cover of each species was calculated for each plot. Forage biomass was harvested at 5 cm above ground with grass shears in all plots after the grazing period and dried (60 °C, 48 h) to determine forage yield and DM content. For each plot, the biomass of each plant functional group (i.e. grasses, legumes and forbs) was estimated by multiplying the percent cover of each functional group (from botanical surveys) by the forage biomass harvested. The percentage removal of each functional group after the grazing period was then calculated from the forage biomass difference between the ungrazed and grazed plots divided by the forage biomass of the ungrazed plots.

2.3. Chemical analyses

A sub-aliquot of each raw pasture herbage sample harvested for each StockD and period was rinsed with tap water to remove any soil particles and to determine the basal acid-insoluble ash content of the herbage before storage at −20 °C. The individual faeces pooled samples were freeze-dried, whereas the herbage sampled before grazing, as well as raw herbage (not water-rinsed), herbage rinsed with tap water, and soil sampled along the measurement of individual heifer intake, were oven-dried (60 °C, 48 to 72 h, DM determination). Samples were ground to 1 mm and analysed for DM, ash, CP, crude fibre, NDF, ADF (Lerch et al. 2024), *n*-alkanes and Yb (Heublein et al. 2017), and acid-insoluble ash (Jurjanz et al. 2012).

2.4. Calculations and statistical analyses

The *n*-alkane technique described by Mayes et al. (1986) was first used to estimate the daily raw herbage intake (*Raw Herbage Int.*, herbage including soil particles adhering to the vegetation), as follows:

$$\begin{aligned} &\textit{Raw Herbage Int.}(\text{kg DM/day}) \\ &= [C_{33}H_{68\ Faeces}(\text{g/kg DM})/C_{32}H_{66\ Faeces}(\text{g/kg DM}) \\ &\quad \times \textit{Dose}C_{32}H_{66}(\text{g/day})]/[C_{33}H_{68\ Raw\ herbage}(\text{g/kg DM}) \\ &\quad - C_{33}H_{68\ Faeces}(\text{g/kg DM})/C_{32}H_{66\ Faeces}(\text{g/kg DM}) \\ &\quad \times C_{32}H_{66\ Raw\ herbage}(\text{g/kg DM})] \end{aligned} \tag{1}$$

where $C_{33}H_{68\ Faeces}$ and $C_{32}H_{66\ Faeces}$ are the concentrations of the internal and external *n*-alkane markers, respectively, in faeces composited for each heifer for the corresponding period. $C_{33}H_{68\ Raw\ herbage}$ and $C_{32}H_{66\ Raw\ herbage}$ are the concentrations of the internal and external *n*-alkane markers, respectively, in the raw herbage composited for each sub-herd for the corresponding period. *Dose* $C_{32}H_{66}$ is the daily oral dose in the external *n*-alkane marker and equals 0.742 g/day.

The daily faecal flow of DM (*Fec. Flow*) was further estimated assuming a complete faecal recovery of the Yb external marker (Ribeiro Filho et al. 2005), as follows:

$$\begin{aligned} &\textit{Fec. Flow}(\text{kg DM/day}) \\ &\quad = \textit{Dose}\text{Yb}(\text{g/day})/\text{Yb}_{Faeces}(\text{g/kg DM}) \end{aligned} \tag{2}$$

where Yb_{Faeces} is the concentration of the external Yb marker in faeces, and *Dose* Yb is the daily oral dose in the external Yb marker and equals 0.609 g/day.

The daily soil intake (*Soil Int.*) was estimated assuming a complete faecal recovery of the acid-insoluble ash internal marker of soil (Jurjanz et al. 2012), as follows:

$$\begin{aligned} \textit{Soil Int.}(\text{kg DM/day}) = {} & [\textit{Fec. Flow}(\text{kg DM/day}) \\ & \times \text{iHCl ash}_{Faeces}(\text{g/kg DM})) \\ & - \textit{Raw Herbage Int.}(\text{kg DM/day}) \\ & \times \text{iHCl ash}_{Herbage}(\text{g/kg DM})]/ \\ & [\text{iHCl ash}_{Soil}(\text{g/kg DM}) \\ & - \text{iHCl ash}_{Herbage}(\text{g/kg DM})] \end{aligned} \tag{3}$$

where iHCL ash_{Faeces}, iHCL $ash_{Herbage}$, and iHCL ash_{Soil} are the concentrations of the soil iHCL ash internal marker in the faeces, herbage clean from soil after tap water rinsing (on average, 5.9 g iHCL ash/kg DM) and soil (on average, 811 g iHCL ash/kg DM), respectively.

Apparent digestibility of nutrients ($Dig_{Nutrient}$) was calculated as follows:

$$\begin{aligned} Dig_{Nutrient}(\%) = 100 \times {} & [\textit{Raw Herbage Int.}(\text{kg DM/day}) \\ & \times \text{Nutrient}_{Raw\ herbage}(\text{g/kg DM}) \\ & - \textit{Fec.Flow}(\text{kg DM/day}) \\ & \times \text{Nutrient}_{Faeces}(\text{g/kg DM})]/ \\ & [\textit{Raw Herbage Int.}(\text{kg DM/day}) \\ & \times \text{Nutrient}_{Raw\ herbage}(\text{g/kg DM})] \end{aligned} \tag{4}$$

where $\text{Nutrient}_{Raw\ herbage}$ and Nutrient_{Faeces} are the concentrations of DM, organic matter, CP, raw fibres, NDF, and ADF in raw herbage and faeces, respectively.

The data were analysed using ANOVA according to the MIXED procedure of SAS (v.9.4, Cary, USA). Individual heifer data were analysed with a model including the fixed effects of period (1 or 2), StockD (low or high), sire breed (Angus or Limousin) and StockD by sire breed interaction; the random effect heifer with period as the repeated statement and a first-order autoregressive variance-covariance matrix. The period by sire breed interaction was never significant ($p > 0.05$) and not retained in the final statistical model. The percentage removal of grasses, legumes and forbs was analysed by including the fixed effects of period and StockD. Logarithmic or arcsine transformations were applied when needed to comply with the assumptions of normality, homoscedasticity and linearity of residuals. This applied to soil intake and proportion, as well as the percentage removal of plant functional groups, for which least squares means and standard error of the means were reported from untransformed data, whereas *p*-values reflected transformed statistical analyses.

3. Results and discussion

Previous reports dissociating herbage and soil intakes at pasture in growing cattle are scarce, and limited to the specific tether-grazing system applied to Creole bulls in the French-West Indies (humid tropical area; Collas et al. 2019). The novelty of the present study lies in reporting the intake of grazing cattle, dissociating herbage and soil, of two beef-on-dairy crossbred growing heifers in a temperate montane system. In our study, herbage yield and quality were similar in all paddocks at the beginning of periods 1 and 2 (Table 1 and Supplementary Table S1). The minimal and maximal individual soil intake levels were 0.07 and 0.56 kg DM/d, corresponding to 1.1 and 10.6% of the total intake, respectively. The minimal intake was observed in an Angus crossbreed heifer during period 2 under low StockD, and the maximal intake was observed in a Limousin crossbreed heifer during period 1 under high StockD. This range of soil intake levels was in accordance with the 1.0–7.3% soil in total DM intake (up to an individual maximum of 11.1%) observed in strip-grazing dairy cows under a temperate climate (Jurjanz et al. 2012), as well as the 2.1–4.7% in tethered-grazing young bulls under a tropical climate (Collas et al. 2019). Stocking density significantly affected soil intake, and the proportions of soil in the total intake, with 1.9- and 2.1-fold higher values under high compared to low StockD, respectively ($p < 0.001$, Figure 2), due to 40% lower pasture allowance. This is in accordance with observations in dairy cows (Jurjanz et al. 2012) and young bulls (Collas et al. 2019), where soil intake increased two- to sixfold due to a shortening of 30–50% of the pasture allowance.

In this study, the apparent digestibility of DM, organic matter, CP, and fibres were also 2–4 points lower under high vs. low StockD ($p \leq 0.03$; Supplementary Table S2). Such an effect of a higher StockD on increased soil intake and decreased digestibility corresponds to our initial hypothesis, despite StockD having no effect on herbage (without soil) intake ($p \geq 0.18$). Differences in intake and digestibility were even higher between grazing periods. Indeed, when compared to period 2, we measured 1.2-fold lower herbage intake, as well as 2.3- and 2.8-fold higher soil intake and proportion, respectively ($p < 0.001$), in period 1 (Figure 2). The digestibility also exhibited an increase of 2–6 points from period 1 to period 2 ($p < 0.01$; Supplementary Table S2). When compared to period 2, the more humid period 1 led to higher trampling and soiling of the pasture, which could at least partly explain such effects on herbage and soil intake and nutrient digestibility. Similar results were found by Collas et al. (2019), who observed 1.5-fold higher soil

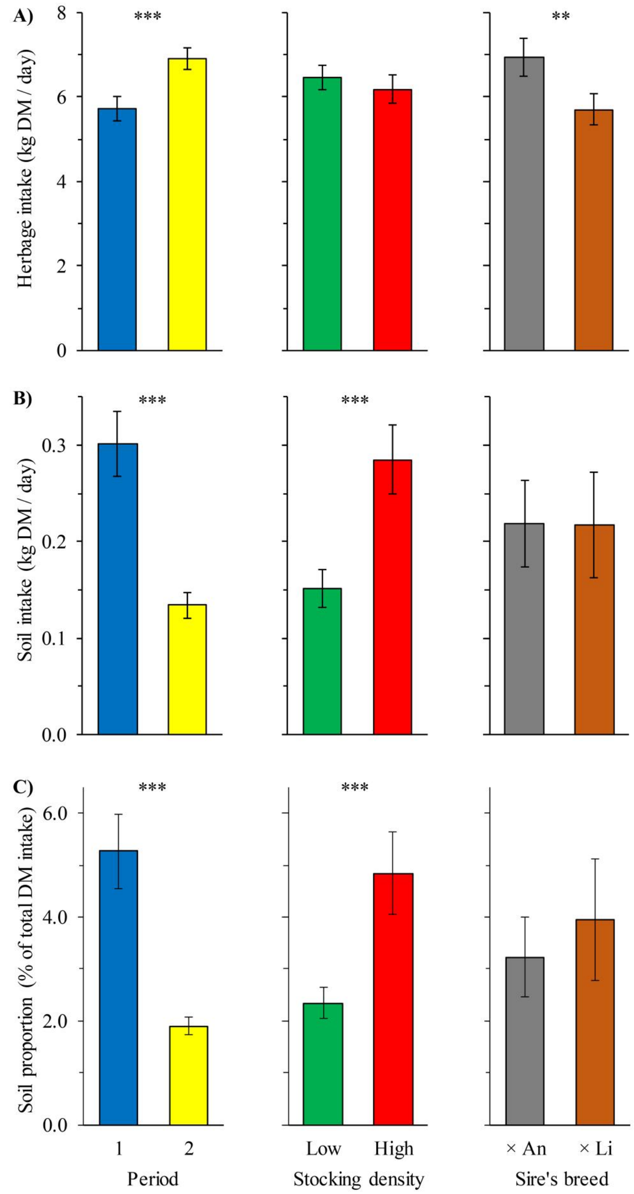

Figure 2. Herbage intake (A), and soil intake (B) and proportion (C) in beef-on-dairy heifers, depending on the grazing period (P1 extremely wet or P2 moderately wet; left panel), stocking density (StockD, low or high; middle panel), or sire's breed (× Angus or × Limousin; right panel). ** and *** highlight high ($p < 0.01$) and very-high ($p < 0.001$) statistical differences between periods, StockD or sire's breeds. Detailed statistical analyses are available in Supplementary Table S2.

ingestion for young bulls on water-saturated soil surfaces compared to those on dried soil surfaces.

The percentage removal of grasses, legumes and forbs, which accounted for, on average, 49%, 23% and 28% of total plant biomass across paddocks, was higher for all the functional groups under more humid period 1 compared to period 2 ($p < 0.05$, Figure 3). Moreover, the percentage removal of grasses, legumes and forbs relative to the offer did not differ between StockD. Considering that herbage intake was higher in

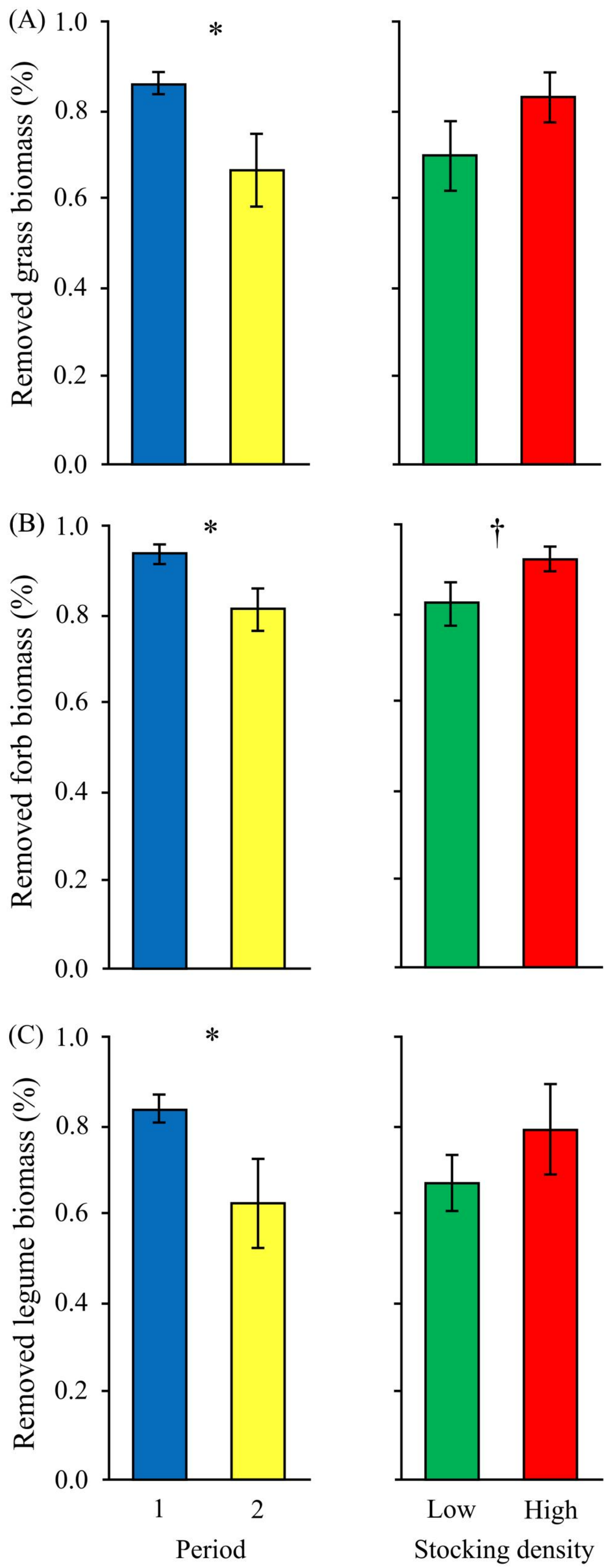

Figure 3. Estimated forage percentage removal of (A) grasses, (B) forbs, and (C) legumes depending on the grazing period (P1 extremely wet or P2 moderately wet; left panel), and the stocking density (StockD, low or high; right panel). † and * highlight marginal ($p < 0.1$) and significant ($p < 0.05$) statistical differences between periods or StockD.

period 2 compared to period 1, while herbage removal followed an opposite trend, we can interpret this difference as related to both a higher herbage growth during period 2 because of higher temperatures and solar radiation (Table 1) and to the higher herbage loss due to livestock trampling under extremely wet weather conditions during period 1. Together, these results highlight the essential role that weather conditions play in influencing livestock forage consumption and removal, and the related impacts on grassland communities.

Under low StockD, Angus crossbreed heifers ingested 1.3-fold more herbage and total intake (herbage plus soil) than Limousin crossbreeds ($p \leq 0.001$), whereas only a tendency ($p = 0.07$) for 1.1-fold higher level was observed under high StockD ($p \leq 0.05$ for the StockD × sire breed interaction; Supplementary Table S2). Such crossbreed effect and range in intake level of pasture estimated by the *n*-alkane double indicator technique were in agreement with the direct DM intake measurements in contemporary heifers of the same crossbreeds and similar BW (in our study Angus crossbreds 294 kg and Limousin crossbreds 286 kg) fed at weighing-troughs in barn with a grass silage-based diet (Angus 7.5 kg DM/day and Limousin 6.4 kg DM/day, respectively; I. Morel et al., personal communication). Despite the relevant effect on herbage intake, crossbreed had no effect on the amount of soil intake ($p = 0.61$). This highlights a presumably higher capability of Angus crossbreeds in selecting herbage with a lower level of soiling than the Limousin crossbreeds (e.g. grazing in less trampled areas, or at higher sward height). This presumption is consistent with a numerically 1.2-fold lower ($p = 0.16$) soil proportion in the total DM intake in Angus crossbreeds compared to Limousin crossbreeds (Figure 2 and Supplementary Table S2).

4. Conclusion

In the context of a montane full grazing system, this study highlights the potential of lowering StockD to improve ingested forage quality and digestibility and to reduce involuntary soil ingestion of beef-on-dairy crossbred cattle. The sire breed of the crossbred heifers was identified as an additional factor. The wide effect of the successive period of measurements, characterised by contrasted weather conditions, was also pointed out. Indeed, intense rainfall and extremely wet conditions recorded during period 1 were presumably responsible, at least in part, for higher trampling and pasture soiling, concomitant with lower herbage intake and digestibility, and higher soil intake, when compared to drier period 2. Such conclusions were established over short period of herbage and soil intake measurements, and on a limited number of cattle. Therefore, further studies are needed to extend and generalise the results for longer grazing periods (up to several months), and other pedoclimatic context and cattle categories and breeds. Despite such limitations, this study highlights that adapting livestock StockD and selecting animals able to face extreme weather events will become essential management options. This could reduce the productivity per unit of land (e.g. kg BW gain/ha) in the short term but would limit the risk of overgrazing. In turn, this would improve competition from good forage plants, reduce soil compaction and soil gaps that can be rapidly colonised by weeds, with beneficial long-term effects on livestock and grassland management. Moreover, it will decrease soil intake and the concomitant risk of exposure to soil-borne parasites and contaminants entering the animal food chain.

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Ethical approval

Animal experimentation was set under authorisation no. 2020_45_FR (Fribourg, Switzerland).

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

The authors did not use any AI-assisted technologies while writing.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

Data can be obtained from the authors upon reasonable request.

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