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Challenges and innovations for grasslands resilience

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Beyond grazing pressure: stocking method and grazing intensity jointly affect grassland plant diversity

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Abstract

Although typically managed intensively, grazed permanent grasslands in dairy systems can support high plant diversity, depending on the management context. While numerous studies have examined the effects of grazing intensity (GI) and stocking method (SM) separately, their interactions are often overlooked. This study tests whether the effects of GI and SM on different diversity measures interact, depending on the regional context. We surveyed 68 grazed grassland sites on dairy farms across Germany. Plant diversity was assessed using species richness (SR) and species evenness (Simpson Equitability, EQ). We analysed the effects of GI (livestock unit grazing days, LUGD), SM (rotational vs. continuous), and region (RG, North vs. South), as well as their interactions. The SR declined with increasing GI, independent of RG and SM. In contrast, species evenness responded more complexly: the effect of GI on EQ was significantly affected by SM and RG. These findings highlight that plant diversity is shaped by complex mechanisms and that considering just one of the factors might not be sufficient.

Keywords: CSR, grazing intensity, phytodiversity, stocking method

Introduction

Grazed permanent grasslands hold considerable potential for supporting plant diversity. In dairy production, these pastures are typically managed intensively. Yet, their contribution to phytodiversity depends on various factors such as climate, soil conditions, topography or grazing management (Gaujour *et al.*, 2012). Among the most important and adjustable management factors are grazing intensity (GI) and stocking method (SM). While the effects of these two factors have often been studied in isolation (e.g. Herrero-Jáuregui & Osterheld, 2018; Pavlů *et al.*, 2003), their combined effects on plant diversity are usually overlooked, especially under real-farm conditions. Moreover, the regional context may further modify these relationships due to underlying differences in climate and vegetation. We therefore hypothesize that the effect of GI on the two diversity components plant species richness and evenness on dairy farm pastures is dependent on the SM and the regional context.

Materials and methods

We selected 68 permanent grassland sites from 34 grass-based dairy farms across different regions of Germany. The sites, exclusively used for grazing with occasional mulching, represented each farm's specific grazing practices: 58% were grazed by lactating dairy cows and 42% by other cattle (e.g. heifers, calves) typical for a dairy system. We applied hierarchical clustering based on the long-term annual means of temperature, precipitation and global horizontal irradiation to classify the sites into the two regional clusters 'North' ($n = 35$) and 'South' ($n = 33$) that reflect natural differences in the vegetation along a climatic gradient. Management data for 2021–2023 were compiled from interviews

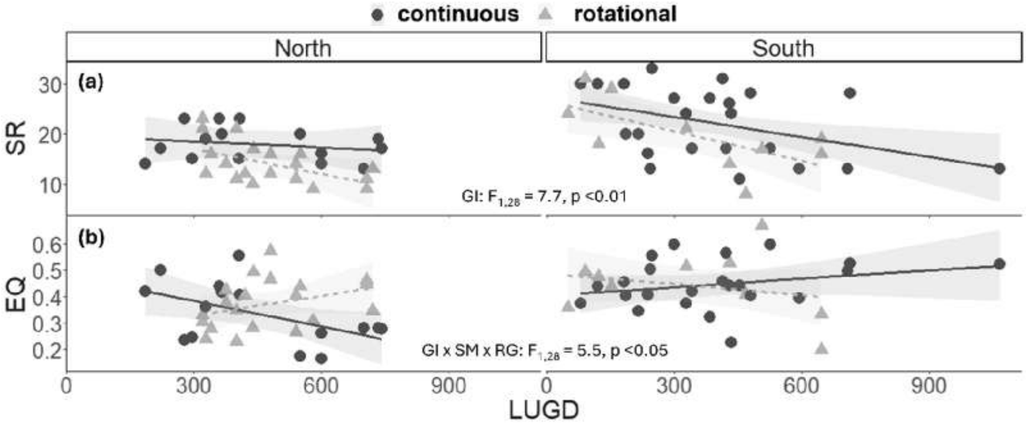

Figure 1. Relationships between GI (grazing intensity) and (a) SR (species richness), and (b) EQ (Simpson equitability), corresponding to the interaction with RG (region) and SM (stocking method). Different point and line shapes represent SM. *F*- and *p*-values are shown for the main effect of GI on SR and the interaction effect of GI × SM×RG on EQ.

with the farmers. The SM was classified as either rotational or continuous grazing for each site (Allen *et al*., 2011). The GI was measured as livestock unit grazing days (LUGD) to standardise comparisons across different livestock groups and grazing durations (1 LU = 500 kg live weight), calculated as follows:

$$\text{LUGD} = \frac{\text{livestock units} * (\text{grazing hours perday}/24) * \text{grazing days per year}}{\text{hectares}}$$

On-site botanical surveys were conducted during 2023 and 2024 within a representative 3 m × 3 m plot per site, where all vascular plant species were recorded and their dry matter (DM) yield proportions visually estimated (Voigtländer & Voss, 1979). Species richness (SR) quantifies the total species number. Simpson Equitability (EQ), as a measure of species evenness, was calculated by dividing the Gini-Simpson-Index by the SR (Magurran, 2003). For a basic understanding of the ecological context, we classified all species into plant functional types C (competitor), S (stress-tolerant) and R (ruderal), and derived a functional signature for each site based on yield proportions (Grime *et al*., 1988). For analyses of covariance, linear mixed-effects models were computed in R studio to test main and interaction effects of RG, SM and GI on SR and EQ, including the individual farms as random effect. Pearson's product-moment correlation tests were used to test relationships between functional signature components CSR vs. SI, SR and EQ.

Results and discussion

We found a significant negative main effect of GI on SR, without interactions of SM or RG (Figure 1a). The EQ was affected by the interaction of GI×SM × RG (Figure 1b): in the North, EQ decreased significantly under rising GI on continuously stocked and increased on rotationally stocked pastures. Moreover, with increasing GI under continuous stocking, EQ increased significantly in the South and decreased in the North.

An increase in GI was correlated with all three indices of the sites' functional signatures (C: $r = 0.3$, $p < 0.05$; S: $r = -0.5$, $p < 0.0001$; R: $r = 0.3$, $p < 0.05$). Moreover, a higher SR was correlated with significantly higher S- ($r = 0.6, p < 0.0001$) and lower C-components ($r = -0.5, p < 0.0001$), whereas we found no significant correlations between EQ and any component of the CSR signature.

Despite an output-oriented grassland management, mean plant diversity was relatively high, likely supported by certain characteristics of the studied farms, such as low to medium soil phosphorus contents (mean: 0.06 g kg^{-1}) and nitrogen fertilization (mean: 50 kg ha^{-1} $year^{-1}$), reduced concentrate feeding (mean: 83 g kg^{-1} energy-corrected milk), and diversified grassland use as adapted to the needs of different livestock groups. The observed shift from stress-tolerant towards competitive and ruderal species under high GI reflects a functional adaptation of plant communities to nutrient-enrichment and disturbance and corresponds to the observed linear decline in SR (Grime *et al.*, 1988; Marini *et al.*, 2007). In contrast to the species number, species evenness responded in a more complex way, confirming our hypothesis for EQ but not for SR. The EQ was influenced by the interaction of GI and SM, which was further dependent on the regional context, but showed no significant response to the GI-induced change in functional composition. Other research confirms that the mechanisms controlling species composition are more difficult to understand than the mere species number (Klimek *et al.*, 2007). While EQ was already relatively high in the South, GI and SM seemed to have a larger impact in the North, where topographic and pedoclimatic conditions were more uniform.

Conclusion

While high grazing intensity generally reduced the plant species numbers of dairy pastures, the species evenness was shaped by complex interactions between grazing intensity, stocking method and regional context. Both species number and evenness are essential components of plant diversity. Our findings emphasize the importance of considering both grazing intensity and stocking method when evaluating management systems for an effective conservation of biodiverse grassland.

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