Patch-differentiation of vegetation and nutrient cycling in an extensive pasture system

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Abstract. In extensive grazing systems, 'patch-grazing' may lead to the development of a mosaic structure consisting of short, frequently defoliated, and tall, infrequently defoliated patches. If spatial patterns of sward structure are stable over time, this may result in a long-term differentiation of botanical composition and matter fluxes between patch types within a pasture. Patch dynamics, botanical composition and topsoil nutrient concentrations of different patch types were investigated in a long-term grazing experiment in the Solling hills, Germany, where differentiated grazing intensities have been applied for 10 years. Continuously stocked beef cattle grazed to target sward heights of 6 or12 cm in a put-and-take system in replicated 1-ha paddocks. Time series of point-specific sward height measurements showed that patches were relatively stable within- and between-seasons. Botanical composition as well as soil phosphorus and potassium concentrations differed between short and tall patches. While grazing intensity influenced the frequency of short and tall patches within a pasture, differences between patch types were larger than those within the same patch type between different grazing intensities. The results highlight the importance of studying biodiversity as well as nutrient dynamics of extensive pastures in a patch-specific way. Through the development of pasture areas with different functionality, extensive grazing systems have the potential to maintain biodiversity while sustaining agricultural production.

Keywords: Patch grazing, heterogeneity, patch stability, botanical composition, soil.

Introduction

Grazing has been shown to increase, maintain or decrease heterogeneity of vegetation and soil at several scales (Adler *et al*. 2001). In extensive grazing systems where herbage growth rates exceed the requirements of grazing animals, one of the contributing processes is 'patch grazing' caused by positive feedbacks between defoliation frequency and forage quality (Adler *et al*. 2001). It results in a mosaic pattern of short, frequently defoliated, and tall, rarely defoliated sward areas, which may be stable within and between seasons (Cid and Brizuela 1998) and may lead to divergent development of vegetation and soil parameters in short and tall patches (Güsewell *et al*. 2005; Marion *et al*. 2010).

Using a 10-year-old grazing experiment, we tested the hypothesis that differences between short and tall sward patches had a greater influence on vegetation and soil parameters than grazing intensity *per se*. We quantified patch stability using two-year transect data from the initial phase of the experiment, and assessed botanical composit-ion and topsoil phosphorus (P) and potassium (K) concentration in tall and short patches after 10 years of continuous cattle grazing at two grazing intensities.

Methods

Experimental site, treatments and management

The grazing experiment was established in 2002 at the experimental farm Relliehausen of the University of Göttingen, located in the Solling Uplands 40 km northwest of Goettingen (51°46'56''N; 9°42'10''E, 180–230 m above mean sea level). The site has a temperate climate with a mean annual temperature of 8.2°C and mean annual precipitation of 880 mm. The soil is a vertic Cambisol. Before the start of the experiment, the site had been used as an extensive cattle pasture without fertilizer application for at least 10 years. The vegetation was a moderately species-rich *Lolio-Cynosuretum*.

The experiment was laid out in a randomized block design with three grazing treatments and three replications, with a paddock size of 1 ha. The two grazing treatments considered in this paper were continuously grazed by Simmental cattle to two different target sward heights: moderate grazing (MG) with a target sward height 6 cm, and lenient grazing (LG) with target sward height 12 cm.

Sward height was measured with a rising plate meter weekly or bi-weekly, and animal number was adjusted in a put-and-take system to maintain swards at target heights. For the period 2002-2011, this resulted in average stocking densities of 1.41 and 0.76 standard livestock units (where one unit corresponds to 500 kg live weight)/ha/year in treatments MG and LG, respectively. Swards were not mown and they received neither fertilizers nor herbicides.

Sward height transect measurements

In 2003, a permanent 100-m transect was installed in each paddock. Along these transects, sward height was measured at 1-m intervals with a rising plate meter of 30 cm diameter. These measurements were performed at approximately one-month intervals during the entire grazing season, from the beginning of May to mid-October, in 2003 and 2004. Each transect point was classified as belonging to one of three sward-height classes based on all sward height measurements for that observation:

- short: sward height ≤ 33rd percentile of sward height measurements (lower third)
- medium: sward height > 33rd and < 67th percentile of sward height measurements (middle third)
- tall: sward height ≥ 67th percentile of sward height measurements (upper third)

Transition frequencies between sward height classes were calculated for both within-season transitions (from one measurement date to the next in both years) and between-season transitions (3 July 2003 to 29 June 2004). The theoretical transition frequencies, *i.e.* if the sward height of a measurement point was independent of its sward height at the preceding measurement date, were assumed to equal the mean proportions of sward height classes in the respective paddocks.

Vegetation and soil sampling

In June/July 2012, botanical composition and topsoil P and K concentration were determined in eight patches per paddock visually assessed as representing short or tall sward. In each paddock, two short and two tall patches were chosen in each of two pasture areas characterised by higher or lower utilization by cattle. In each patch, two plots of 30 cm diameter, 2 m apart from each other, were sampled. All vascular plant species were identified, and their share of aboveground biomass was estimated visually. In two cases, determination to species level was not possible in all plots and aggregate values for the genera were used. Soil samples were collected from each plot to a depth of 10 cm and analysed for pH and available P and K after extraction with calcium acetate lactate. Plot sward height was measured with a rising plate meter.

Data analysis

For the soil data analysis, average soil nutrient concentrations per paddock and patch type were used. Linear mixed effects models were fitted with grazing intensity, patch type and their pairwise interaction as fixed effects and block as a random effect. To achieve homogeneity of variance across groups, variance was fitted separately for each patch type in the model analysing K concentrations.

The sward height measurements for each plot were analysed in the same manner, except that variance was fitted separately for each grazing intensity treatment. The nlme package (Pinheiro *et al*. 2012) of R 2.15.0 software (R Development Core Team 2012) was used for all calculations.

Multivariate analysis of species composition was performed using the software Canoco for Windows 4.5 (ter Braak and Šmilauer 1997–2004). Detrended correspondence analysis (DCA, detrending by segments) was performed on untransformed data of the proportions of species yield. The option 'down-weighting of rare species' was chosen. The effects of grazing treatment, patch type and soil variables on species composition were tested using canonical correspondence analysis (CCA) with blocks being used as covariables. Monte Carlo permutations, incorporating pasture areas as split-plots, were used to test whether these factors explained a significant proportion of the variance of the vegetation. Factors were included into the model by manual forward selection based on their *p* values, with a selection threshold of $P<0.05$. Unless mentioned otherwise, default settings were used throughout.

Results

Transect measurements of sward structure

When averaged over all measurement dates, a larger proportion of transect points was classified as 'short' under moderate (46±7%) than under lenient grazing (14±4%; means ± temporal standard deviation). Conversely, the proportion of transect points classified as 'tall' was lower under moderate (19±6%) than under lenient grazing (54±5%). From one measurement date to the next, short patches were 1.6 (MG) and 3.5 (LG) times more likely to remain short patches than expected under temporal independence of sward height between measurement dates (Fig. 1a).

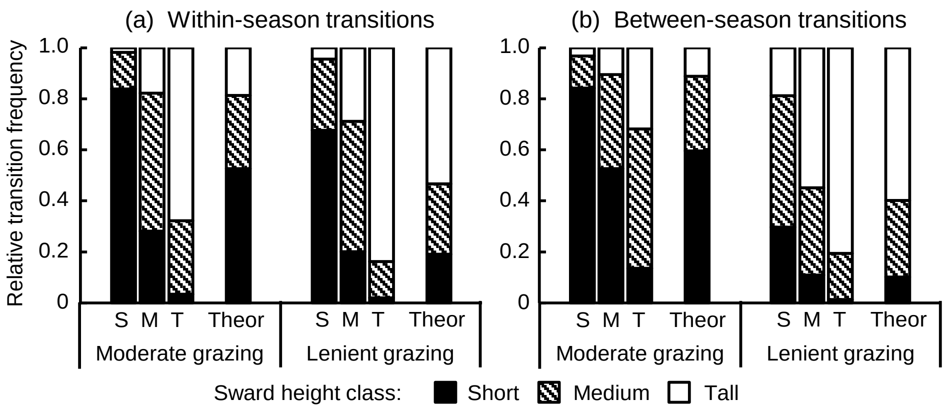
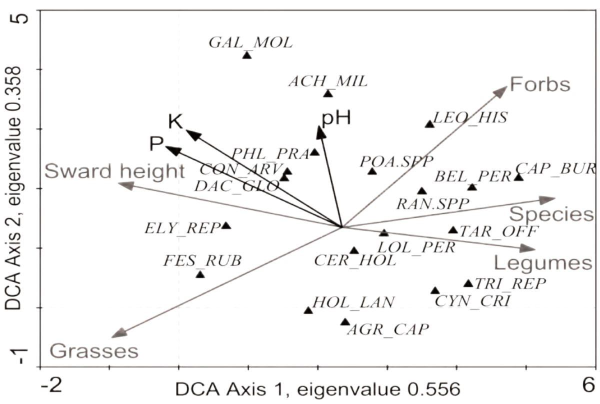


Figure 1. Frequencies with which transect points of different sward height classes (S: short, M: medium, T: tall) transitioned to each of these sward height classes, (a) from one measurement date to the next within each season, (b) between the mid-summer measurements of 2003 and 2004 (n=300). The bar marked 'Theor' shows the theoretical transition frequencies under the assumption that transect point sward height at each measurement date is independent of the sward height at the previous measurement date.



Abbreviations of species names:

Ach_mil: *Achillea millefolium*
Agr_cap: *Agrostis capillaris*
Bel_per: *Bellis perennis*
Cap_bur: *Capsella bursa-pastoris*
Cer_hol: *Cerastium holosteoides*
Con_arv: *Convolvulus arvensis*
Cyn_cri: *Cynosurus cristatus*
Dac_glo: *Dactylis glomerata*
Ely_rep: *Elymus repens*
Fes_rub: *Festuca rubra*
Gal_mol: *Galium mollugo*
Hol_lan: *Holcus lanatus*
Leo_his: *Leontodon hispidus*
Lol_per: *Lolium perenne*
Phl_pra: *Phleum pratense*
Poa.spp: *Poa* spp.
Ran.spp: *Ranunculus* spp.
Tar_off: *Taraxacum officinale* agg.
Tri_rep: *Trifolium repens*

Figure 2. Ordination biplot based on detrended correspondence analysis. Only species with weights of > 5% are shown. Intrinsic variables (grey arrows): yield percentages of grasses, forbs and legumes, sward height, species number (species); environmental variables (black arrows): soil pH, available phosphorus (P), potassium (K).

Similarly, tall patches remained tall patches 3.6 (MG) and 1.6 (LG) times more often than expected under temporal independence of sward heights. The proportion of short patches transitioning to tall patches, and vice versa, was < 5% under both grazing intensities. Similar results were obtained for between-season transitions (Fig. 1b).

Soil nutrient concentration and botanical composition

Sward height of the sampled plots was 6.6±1.9 cm in short patches and 19.1±2.0 cm in tall patches (mean ± standard deviation, n=3). The difference between patch types was significant (F=269.0, P<0.0001), while grazing intensity (F=1.1, P =0.337) and its interaction with patch type (F=0.8, P =0.408) had no effect.

The first two axes of the DCA on species composition explained 13.4 and 8.6 of total variation. The first gradient was closely related to measured sward height and differentiated between tall, grass-rich plots with low species richness, and short, forb- and legume-rich plots with high species richness (Fig. 2). The second gradient was mostly associated with changes in the soil pH. According to the CCA results, patch type explained 34% of total variance of the vegetation (F=8.7; P<0.001), while grazing intensity had no significant effect (F=1.8; P=0.34, 7.3% of total variance explained). Fitted after patch type, pH also had a significant effect (F=3.1; P=0.002), both factors together explaining a total of 45% of variance of vegetation.

Both soil P and K were significantly higher in tall than in short patches (Fig. 3; P: F=8.5, P=0.027; K: F=6.4, P=0.045). Grazing intensity had no significant influence on either soil parameter (P: F=0.4, P=0.570; K: F=2.3, P=0.176), and did not interact with patch type (P: F=0.2, P=0.641; K: F=0.1, P=0.797).

Discussion

Results of the sward height transect measurements indicated that, 1-2 years after establishment of the grazing regime, a relatively stable mosaic pattern of tall and short sward areas had developed. The ratio of tall:short sward areas under lenient grazing was 2.42, compared to 0.27 under moderate grazing. In both treatments, the frequency of measurement points in the 'tall' class transitioning to the 'short' class, and vice versa, was very low. Long-term differentiated development of vegetation and soil under short and tall patches may therefore be expected to have occurred during the 10-year experimental duration.

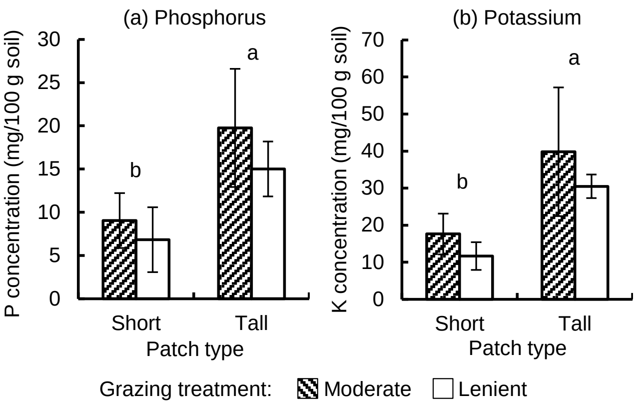


Figure 3. Effect of patch type and paddock grazing intensity on available phosphorus (P) and potassium (K) concentration in topsoil. Different letters indicate significant (*P*<0.05) differences between patch types. Error bars: ± standard deviation (n=3).

The lower P and K concentrations found in topsoil of short patches in this study contrast with other studies that found increased nutrient cycling and soil nutrient concentrations in preferentially grazed areas (Güsewell *et al*. 2005; Augustine *et al*. 2003). In those studies, however, a net import of nutrients into preferentially grazed areas via excrements was observed, an effect connected to the larger spatial scale of those areas. In this study, a net export from, rather than a net import of nutrients into, short patches may be expected since the grazing preference for short patches was most likely not matched by a proportional return of excreta. Excretion also occurs during non-grazing activities, *e.g.* resting, which may take place in either short or tall patches.

Results on botanical composition of tall and short patches confirm the findings of Wrage *et al*. (2012 that plant diversity was influenced by local sward height, but not by paddock grazing intensity. Results presented here show that tall patches were characterized by competitive grasses like *Festuca rubra*, *Elymus repens* or *Dactylis glomerata*, indicating that in these rarely defoliated areas light competition is an important determinant for species composition. Higher species richness and the presence of low-growing dicots like *Bellis perennis, Trifolium repens, Taraxacum officinale*, as well as the ruderal *Capsella bursa-pastoris* in short patches may point towards both lower light competition due to lower resource availability and frequent defoliation, and to better conditions for seedling establishment (Hofmann *et al*. 2004).

Conclusion

Results indicate that within-plot differentiation of sward structure due to spatially heterogeneous grazing was the main factor explaining differences in botanical composition and topsoil nutrient concentrations. Stocking rate, which varied by a factor of two, had no influence on either vegetation or soil in this stratified sampling approach. At the plot-scale level, however, stocking rate influenced both vegetation and soil via treatment differences in the proportion of tall and short sward areas. These findings stress the potential of extensive grazing systems for increasing biodiversity via the creation of, and increase in, spatial heterogeneity. They also highlight the importance of using spatially differentiated approaches based on within-plot differentiation of grazing pressure when investigating nutrient cycling and biodiversity in extensive pasture systems.

References

Adler PB, Raff DA, Lauenroth WK (2001) The effect of gra- zing on the spatial heterogeneity of vegetation. *Oecologia* **128**, 465-479.

Augustine DJ, McNaughton SJ, Frank DA (2003) Feedbacks between soil nutrients and large herbivores in a managed savanna ecosystem. *Ecological applications* **13**, 1325-1337.

Cid MS, Brizuela MA (1998) Heterogeneity in tall fescue created and sustained by cattle grazing. *Journal of Range Management* **51**, 644-649.

Güsewell S, Jewell P, Edwards PJ (2005) Effects of heterogeneous habitat use by cattle on nutrient availability and litter decomposition in soils of an Alpine pasture. *Plant and Soil* **268**, 135-149.

Hofmann M, Isselstein J (2004) Seedling recruitment on agriculturally improved mesic grassland: the influence of disturbance and management schemes. *Applied Vegetation Science* **7**, 193-200.

Marion B, Bonis A, Bouzillé J-B (2010) How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? *Ecoscience* **17**, 229-239.

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Development Core Team (2012) nlme: Linear and nonlinear mixed effects models. R package version 3.1-103. http://cran.r-project.org/src/contrib/Descriptions/nlme.html.

ter Braak, CJF, Šmilauer P (1997–2004) 'Canoco for windows.' (Plant Research International: Wageningen)

R Development Core Team, (2009). 'R: A language and environment for statistical computing, Version 2.10.0.' (Foundation for Statistical Computing: Vienna, Austria, http://www.R-project.org)

Wrage N, Şahin Demirbağ N, Hofmann N, Isselstein J (2012) Vegetation height of patch more important for phytodiversity than that of paddock. *Agriculture, Ecosystems and Environment* **155**, 111-11