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Effect of grazing intensity and dung on herbage and soil nutrients

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Abstract: Dung deposited by grazing animals is a key driver affecting sward structure and nutrient cycling in pastures. We tested herbage and soil properties in three types of tall sward-height patches (> 10 cm): (i) patches with dung under intensive grazing; (ii) patches with dung under extensive grazing; and (iii) patches with no dung under extensive grazing. These patches were compared with grazed swards under intensive and extensive grazing. Analyses indicated no significant effect of different types of patches on plant available nutrients. Herbage nutrient concentrations from the different types of patches differed significantly. The highest concentrations of nitrogen (30.65 g/kg), phosphorus (4.51 g/kg) and potassium (22.06 g/kg) in the herbage dry matter were in the tall patches with dung presence under intensive grazing regime because of nutrients from dung utilized for sward regrowth. Regardless of dung presence, similar herbage nutrient concentrations were revealed in non-grazed tall sward-height patches in extensive grazing regime. The presence of dung did not have any effect on the plant available nutrients in any type of patches, therefore we suppose that non-utilized nutrients were probably leached, volatilised or transformed into unavailable forms and thus soil nutrient enrichment was low.

Keywords: heifer grazing; faeces; grassland; grazing management; plant-soil relationship

Selective defoliation by grazing, which is mainly due to dietary choice, is one of the main mechanisms by which grazing animals contribute to sward heterogeneity. Grazing changes the competitive advantage among plant species through the selective removal of plant biomass (Bullock and Marriot 2000), it opens spaces for gap-colonizing species, and there is contamination of the sward surface by the animals' dung and urine which decreases the amount of forage available for grazing (Bokdam 2001). Furthermore, as the level of contamination increases, there is increased rejection by grazing animals, especially in the immediate vicinity of dung pats (Forbes and Hodgson 1985). Dung deposition, in combination with other grazing-related effects such as trampling, is an important factor that can explain the structure of vegetation in the pasture (Kohler et al. 2004). It also has a significant effect on the chemical status of the soil and serves as a potential source of available nutrients for plants (Aarons et al. 2004).

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Cattle generally show a grazing preference for shorter (< 10 cm) herbage patches rather than taller (> 10 cm) patches, which are mostly left ungrazed as their biomass is usually of lower feed value. This differentiation of patches into short and tall height is commonly observed in temperate grasslands (Ludvíková et al. 2015). Cattle avoid areas with tall-stem herbage where the leafy components of the sward are difficult to graze (De Vries and Daleboudt 1994) and also areas that have been contaminated by dung (MacDiarmid and Watkin 1972b). Several studies have been conducted that have focused on the effects of dung patches about botanical composition and nutrients (MacDiarmid and Watkin 1971, 1972a, Aarons et al. 2009, White-Leech et al. 2013). However, there has been little research focusing on patches of different heights in swards in terms of the concentrations of nutrients in the herbage and the soil, particularly in Central Europe, where only preliminary analyses are available (Pavlů et al. 2018).

Therefore, our goal was to determine the effects of different intensities of grazing by heifers on the nutrient concentrations in the herbage and the soil under tall sward-height patches in Central European *Agrostis capillaris* grassland. We aimed to answer the following questions: (i) what is the effect of the presence of dung on nutrient concentrations of soil beneath tall sward-height patches under intensive and extensive grazing management?; (ii) what is the effect of the presence of dung on dry matter standing biomass, dry matter (DM) content, dead biomass, and nutrient concentrations in the herbage?, and (iii) is there any relationship between soil nutrient concentrations and herbage nutrient concentrations under the tall sward-height patches?

MATERIAL AND METHODS

Study site. The study site of the 'Oldřichov Grazing Experiment' is located in the Jizerské hory (Jizera Mountains) in the northern Czech Republic, 10 km north of the city of Liberec (50°50.34'N, 15°05.36'E; 420 m a.s.l.). The experimental site was established in 1998 and had a mean annual temperature of 7.2°C and average annual precipitation of 803 mm (Liberec Meteorological Station). The site has a medium deep (10–15 cm) brown sandy soil (Cambisol, with less than 10% of clay, i.e., particle size fraction < 0.01 mm) and is underlain by granite bedrock. The sward on the experimental site has a high diversity of plant species, with about 24 vascular plant species per m^2. The dominant species are *Agrostis capillaris*, *Festuca rubra* agg., *Trifolium repens*, and *Taraxacum officinale*.

Experimental design and plot management. The experimental site was established as two completely randomized blocks. Each block consisted of four paddocks with different grazing regimes, and each experimental paddock was approximately 0.35 ha (Ludvíková et al. 2015). For this study, we selected two paddocks in each block, with two contrasting levels of grazing intensity: (i) extensive grazing (EG), with a mean target sward surface height of greater than 10 cm; and (ii) intensive grazing (IG) with a mean target sward surface height of less than 5 cm. Target sward heights were achieved by increasing or decreasing the area available for grazing by moving fences with a set number of stock per plot for IG or EG. All paddocks were grazed under continuous stocking by young heifers (Czech Fleckvieh) of initial live weights of about 200 kg, from early May until late October.

Herbage and soil data collection. Sward height measurement, herbage biomass, and soil samples were taken late in the grazing season on 18 September 2013. For this study, we identified three types of tall sward-height patches and two types of grazed patches: (i) IG_TF – tall patches in IG with presence of residual spring dung; (ii) EG_TF – tall patches in EG with presence of residual spring dung; (iii) EG_T0 – tall patches in EG without presence of residual spring dung; (iv) IG_C – grazed patches in IG; (v) EG_C – grazed patches in EG (for details see Table 1). For the IG regime, we were unable to find any presence of the tall sward-height patches without dung.

Four replications of the presented sward-height patches were randomly taken in each of two paddocks in the block. A total 40 of soil (each in 10 subsamples) and 40 herbage samples were then collected. Since the sward had a canopy height of > 10 cm in the EG regime, visual identification of dung presence was required. In spring, fresh dung deposits were 20–30 cm in diameter and weighed about 1 kg, with 15–20% DM content. The mean values of nutrient concentrations in the spring dung of heifers regardless of treatment were 21.1, 6.6, 7.7, 18.5 and 4.3 g/kg for N, P, K, Ca and Mg, respectively (V. Ludvíková unpublished data). To characterize sward height and patch type distribution in IG and EG, 100 measurements were taken along a transect in four paddocks of both regimes (400 measurements in total). At each sward height measurement, visual identification of the patch type was carried out simultaneously.

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Table 1. Description of the sward height patches and their management

Patch abbreviation terms used in text	Grazing management	Target average sward height (cm)	Patch type	Dung presence	Stocking rate (kg live weight per ha)	Patches percentage of total area
IG_C	intensive grazing	< 5	grazed	–	1000	95.0
IG_TF	intensive grazing	< 5	non-grazed or infrequently grazed tall sward patches > 10 cm	+	1000	5.0
EG_C	extensive grazing	> 10	grazed	–	500	92.5
EG_TF	extensive grazing	> 10	non-grazed or infrequently grazed tall sward patches > 10 cm	+	500	4.5
EG_T0	extensive grazing	> 10	non-grazed or infrequently grazed tall sward patches > 10 cm	–	500	3.0

The height of the sward along a transect in four paddocks and selected patches was measured using a rising plate meter (Correll et al. 2003). Using a circular ring of 30 cm in diameter on each type of patch, the proportion (as %) of dead plant biomass was assessed by visual observation; herbage biomass was then cut to ground level. The harvested herbage was weighed fresh, oven dried at 80°C, and the DM content and dry matter standing biomass (DMSB) were determined. Under each patch, any dung deposits present were removed, and soil samples were taken from the upper 10 cm of the soil profile using an auger, and the biomass residues and roots were removed. The soil samples were air dried and then ground to pass a 2 mm sieve.

The herbage concentrations of N, P, K, Ca, and Mg were determined after digestion of DM herbage in *aqua regia* by inductively coupled plasma-optical emission spectrometry (GBC Scientific Equipment Pty Ltd, Melbourne, Australia). Plant available P, K, Ca, Mg were extracted by Mehlich 3 (Mehlich 1984). Total nitrogen (N_{tot}) was determined by the Kjeldahl method and organic carbon content (C_{org}) by means of colorimetry (AOAC 1984). Determination for pH_{CaCl_2} was done using pH meter acidometer (Sentron, Wellinq, Leek, the Netherlands). All chemical analyses for soil and herbage were performed in an accredited laboratory at the Crop Research Institute in Chomutov.

Data analysis. A linear mixed-effects model with fixed effects of treatment and random effect of the block was used to analyse the effect of different type of patches on concentrations of each individual nutrient in the soil and the herbage, DMSB, sward height (SH), DM content, and proportion of dead biomass. Post hoc comparison using the Tukey *HSD* (honestly significant difference) test was applied to identify significant differences among different types of patches. In some cases, normality and homogeneity in data were achieved by applying the logarithmic transformation. Finally, linear regression analysis was used to identify the relationship between plant available nutrients in the soil and the nutrient contents in the herbage. All univariate analyses were performed using Statistica 13.1 (Dell Inc. 2016).

RESULTS AND DISCUSSION

Frequency of distribution of sward heights during the sampling under IG and EG is shown in Figure 1 and reflected the presence of different patches under the various types of management (Tonn et al. 2019). The highest values for SH, DM content and DMSB were found under EG_T0 and EG_TF patches, and the highest values for dead biomass under EG_T0 and EG_C (Table 2).

Based on the average amount of dung, their nutrient concentrations and area of coverage, the amounts of nutrients supplied in individual dung patches were calculated as follows: 40–60 g N/m^2, 14–20 g P/m^2, 16–25 g K/m^2, 40–60 g Ca/m^2 and 10–14 g Mg/m^2. These values are approximately half than those reported for cows by Whitehead (2000), differences which may be explained by the different types of grazed sward, supplementary feeding, weight, and age of animals and breed. However, this over-fertilization by faeces had a significant effect on herbage but not on soil properties.

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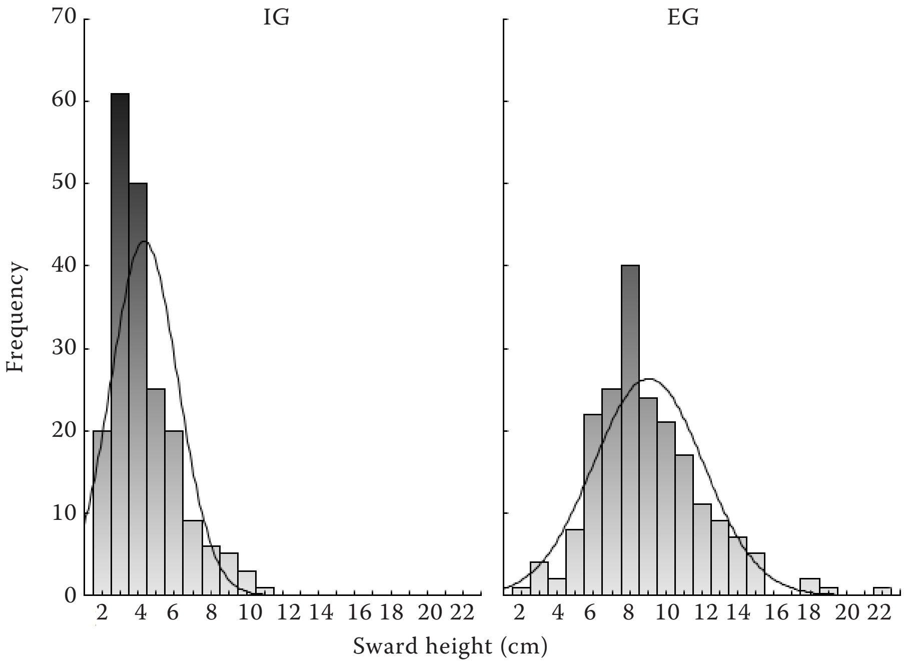

Figure 1. Frequency of distribution showing sward height variation in intensive grazing (IG) and extensive grazing (EG) treatments

Table 2. Sward characteristics and herbage nutrient concentrations of different sward height patches

	Tall sward-height patches			Grazed patches		*F*-ratio	*P*-value
	IG_TF	EG_TF	EG_T0	IG_C	EG_C		
SH (cm)	10.00 ± 0.46[b]	14.00 ± 0.98[a]	15.37 ± 0.98[a]	3.63 ± 0.26[c]	10.38 ± 0.63[b]	39.00	< 0.001
DM (%)	18.09 ± 0.68[b]	24.13 ± 0.72[a]	27.41 ± 1.27[a]	10.48 ± 0.32[c]	18.53 ± 1.14[b]	58.46	< 0.001
DMSB (g/m^2)	358.58 ±77.93[b]	548.29 ± 57.42[a]	707.43 ± 90.73[a]	79.03 ± 8.18[c]	254.91 ± 12.23[b]	47.37	< 0.001
Dead biomass (%)	8.38 ± 2.38[c]	24.38 ± 2.58[b]	32.50 ± 0.94[a]	1.63 ± 0.26[c]	28.75 ± 1.83[ab]	53.28	< 0.001
Herbage nutrient							
N (g/kg DM)	30.65 ± 2.96[a]	18.68 ± 0.40[cd]	16.68 ± 0.34[d]	25.49 ± 0.67[ab]	22.56 ± 0.39[bc]	21.48	< 0.001
P (g/kg DM)	4.51 ± 0.28[a]	2.75 ± 0.08[bc]	2.40 ± 0.09[bc]	2.96 ± 0.05[b]	2.75 ± 0.07[bc]	34.89	< 0.001
K (g/kg DM)	22.06 ± 1.66[a]	14.73 ± 1.30[b]	11.87 ± 0.63[b]	11.79 ± 0.92[b]	12.53 ± 0.68[b]	12.25	< 0.001
Ca (g/kg DM)	6.14 ± 0.37[b]	7.24 ± 0.63[ab]	6.12 ± 0.46[b]	9.14 ± 0.70[a]	6.92 ± 0.51[ab]	4.97	0.003
Mg (g/kg DM)	2.69 ± 0.17[a]	1.97 ± 0.15[b]	1.75 ± 0.11[b]	2.84 ± 0.19[a]	2.01 ± 0.12[b]	11.41	< 0.001
N:P	6.81 ± 0.57[c]	6.83 ± 0.20[c]	6.98 ± 0.22[bc]	8.62 ± 0.22[a]	8.27 ± 0.32[ab]	6.82	< 0.001
N:K	1.39 ± 0.09[b]	1.34 ± 0.11[b]	1.43 ± 0.07[b]	2.28 ± 0.22[a]	1.84 ± 0.10[ab]	9.62	< 0.001
K:P	4.97 ± 0.41	5.41 ± 0.54	4.97 ± 0.28	3.98 ± 0.29	4.56 ± 0.26	2.23	0.086
Ca:P	1.38 ± 0.08[b]	2.64 ± 0.23[a]	2.54 ± 0.15[a]	3.09 ± 0.23[a]	2.52 ± 0.18[a]	12.27	< 0.001
Total amount of nutrients in herbage per area							
N (g/m^2)	10.66 ± 2.76[ab]	10.30 ± 1.18[a]	11.82 ± 1.58[a]	2.01 ± 0.20[c]	5.74 ± 0.27[b]	30.52	< 0.001
P (g/m^2)	1.52 ± 0.27[a]	1.49 ± 0.14[a]	1.72 ± 0.26[a]	0.24 ± 0.03[c]	0.70 ± 0.04[b]	24.82	< 0.001
K (g/m^2)	8.10 ± 2.33[a]	7.97 ± 1.13[a]	8.42 ± 1.19[a]	0.92 ± 0.11[c]	3.22 ± 0.26[b]	33.59	< 0.001
Ca (g/m^2)	2.16 ± 0.44[b]	3.97 ± 0.52[a]	4.37 ± 0.73[a]	0.73 ± 0.10[c]	1.77 ± 0.16[b]	21.76	< 0.001
Mg (g/m^2)	0.95 ± 0.20[ab]	1.11 ± 0.17[a]	1.23 ± 0.17[a]	0.23 ± 0.04[c]	0.51 ± 0.04[bc]	13.65	< 0.001

Numbers represent average values of patches; ± values represent standard error of the mean. *F*-ratio – *F*-statistics for the test of a particular analysis; *P*-value – corresponding probability value. Significant differences ($P < 0.05$) between patches according to Tukey's post-hoc test are indicated by different letters in the row. Abbreviations for the type of patches see Table 1. SH – sward height; DM – dry matter content; DMSB – dry matter standing biomass

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The highest N, P, K concentrations in the herbage were revealed in IG_TF patches, whereas the highest Ca and Mg concentrations were found in IG_C patches (Table 2). The presence of dung under tall sward-height patches in extensive grazing had no influence either on the DM content and DMSB or on N, P, K concentrations in the herbage (Table 2). We can suppose that released nutrients from dung were predominantly leached from the sandy soil and partly volatized as NH_3 from this type of dung patch. The youngest sward was under IG_C patches with the lowest SH, DM, DMSB, and dead biomass. Although herbage at early stages of maturity usually has very high nutrient concentrations (Duru and Ducrocq 1996, Pavlů and Velich 1998), the highest N, P, K concentrations in the herbage were found not in IG_C but IG_TF patches. It was caused by the nutrients released from dung under the IG_TF patches. Therefore, regardless of maturity, the key driver for N, P, K concentrations in the herbage under intensive grazing was the presence of faeces.

The highest concentrations of Mg in the herbage in both patches under intensive grazing regardless of dung presence (IG_C and IG_TF) as well as the highest Ca concentration in IG_C patches could be connected to a higher proportion of white clover (*T. repens*) and dandelion (*T. officinale*) in the sward (Ludvíková et al. 2015). These prostrate herbs have been reported to have high concentrations of Mg and Ca in the herbage (Whitehead 2000). Therefore, higher uptake of Mg and Ca by plants could also be the reason for the tendency of lower Ca and Mg concentrations in the soil under IG_C patches. Herbage in all tall sward-height patches accumulated more nutrients (N, P, K, Mg) on a per-m^2 basis (Table 2) than herbage in frequently grazed patches as nutrients were removed from tall patches by grazing animals only marginally.

Type of patch did not show any significant effect on the concentrations of N_{tot}, C_{org}, and plant available nutrients P, K, Ca, and Mg in the soil (Table 3). The higher C:N ratio and lower pH in the soil, and ratios of N:P and N:K in the herbage of both types of grazed patches is probably connected with higher amounts of nitrogen used for sward regrowth after grazing. The regression analysis showed no relationship between the concentrations of nutrients in the soil and the herbage. Similarly, Dickinson and Craig (1990) suggested nutrient losses from dung are not necessarily associated with increases in nutrients in the soil and argued that the nutrients might have been used immediately by the plants under the dung as soon as they were released from the dung. However, other studies have reported direct positive effects of dung-derived nutrients on the nutrient concentrations in the soil (MacDiarmid and Watkin 1972a, Aarons et al. 2009, Yoshitake et al. 2014) or herbage (Scheile et al. 2018). The inconsistencies in results might be attributed to nutrient mobility through the soil sampling depth, or to differences among types of grassland ecosystems, grazing management, soil type, differences in plant species, and environmental factors.

We can conclude that the intensity of grazing management can influence the utilization of nutrients released from dung. The intensive grazing supported

Table 3. Soil chemical properties under different sward height patches: pH_{CaCl_2}, total nitrogen (N_{tot}), organic carbon (C_{org}), plant available (Mehlich 3) concentration of P, K, Ca, Mg and C:N ratio in 0–10 cm layer

Soil chemical properties	Tall sward-height patches			Grazed patches		*F*-ratio	*P*-value
	IG_TF	EG_TF	EG_T0	IG_C	EG_C		
pH_{CaCl_2}	5.49 ± 0.06^{a}	5.62 ± 0.20^{a}	5.27 ± 0.06^{ab}	4.91 ± 0.07^{b}	5.06 ± 0.07^{b}	7.80	< 0.001
N_{tot} (mg/kg)	5066 ± 101	5041 ± 171	4886 ±1 87	4876.80 ± 190	5068.23 ± 255	0.27	0.897
P (mg/kg)	53.72 ± 7.37	41.40 ± 4.31	47.24 ± 6.78	51.36 ± 6.82	52.36 ± 7.15	0.56	0.693
K (mg/kg)	226.42 ± 38.23	192.12 ± 15.97	191.77 ± 14.63	156.47 ± 18.69	173.14 ± 18.96	1.49	0.228
Ca (mg/kg)	1910 ± 123	2016 ± 192	1830 ± 131	1470 ± 111	2036 ± 142	2.52	0.060
Mg (mg/kg)	178.46 ± 16.31	166.23 ± 22.70	152.38 ± 16.23	113.60 ± 12.52	159.93 ± 14.96	2.21	0.089
C_{org} (mg/kg)	49 838 ± 1047	53 800 ± 1528	52 563 ± 1955	48 655 ± 2466	54 892 ± 2736	1.66	0.181
C:N	9.84 ± 0.32^{c}	10.69 ± 0.32^{bc}	10.77 ± 0.32^{bc}	11.34 ± 0.26^{ab}	12.65 ± 0.61^{a}	11.54	< 0.001

Numbers represent average values of patches; ± values represent standard error of the mean. *F*-ratio – *F*-statistics for the test of a particular analysis; *P*-value – corresponding probability value. Significant differences ($P < 0.05$) between patches according to Tukey's post-hoc test are indicated by different letters in the row. Abbreviations for the type of patches see Table 1

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the frequency of defoliation, therefore some nutrients from dung were utilized for regrowth of the sward. In contrast to previous research, the presence of dung did not have any influence on the soil nutrient concentrations in any type of patches. Therefore we suppose that the non-utilized nutrients were either leached or volatilized, and thus soil nutrient enrichment was very low. The higher intensity of grazing can increase the utilization of nutrients from dung and can support higher forage production per area.

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