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ORIGINAL ARTICLE

The effect of 19 years of restoration managements on forage quality and herbage-soil relationships within improved upland grassland

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Abstract

Restoration managements based on extensification strategies are commonly used to improve biodiversity on formerly improved grasslands. In this study the long-term effects of six different restoration management regimes (extensive sheep grazing only, hay cutting only, hay cutting followed by aftermath extensive grazing; each with and without lime application) on forage quality, and soil/herbage/sward characteristics relationships were determined and compared with a conventionally fertilized, limed and extensively grazed control.

Restoration managements incorporating cutting resulted in higher forage quality than forage from grazed-only treatments; the latter featuring only a few forb species and large proportion of ungrazed matured grasses plus dead biomass. Concentrations of crude protein, neutral detergent fibre and K in the herbage were negatively correlated with cover of forbs and total number of plant species, whereas in vitro organic matter digestibility, and concentrations of water-soluble carbohydrates, Ca, Mg, and Na were correlated positively. In contrast, concentrations of Ca, Mg, and Na were negatively correlated with the total cover of graminoids and dry matter standing biomass. Regardless of management treatment the forage was generally suitable only for sheep or beef cattle feeding. A positive relationship between P and K concentration in the soil and in the herbage was recorded. No effect of previous liming on forage quality was found. Overall, this study found introducing long-term restoration managements to support biodiversity by postponing the timing of the first defoliation by cutting to mid growing season did not deteriorate forage quality in comparison with continual extensive sheep grazing in improved upland grassland.

KEYWORDS

cutting, forage quality, liming, rehabilitation, sheep grazing, soil properties

1 | INTRODUCTION

Improvement of grazed grasslands through the application of N, P and K fertilizers and of lime increases plant and livestock productivity, but by changing nutrient availability simultaneously reduces plant species richness (Bakker et al., 2002; Hejcman et al., 2010; Pavlů et al., 2011; Humbert et al., 2016). The majority of European grasslands underwent such improvement in the second half of the 20th century, leading to the predominance of productive, but species-poor, grasslands with high residual nutrient availability in the soil (Pegtel et al., 1996; Isselstein et al., 2005; Pavlů et al., 2011). Restoration management strategies effective at removing soil nutrients (Hansson & Fogelfors, 2000; Van Diggelen & Marrs, 2003) and increasing plant species diversity are long-term hay-making with biomass removal or grazing without fertilization (Pavlů et al., 2021). Through such long-term extensification management practices we can affect soil chemical properties, botanical composition and forage quality (Pavlů et al., 2006; Pavlů et al., 2011). However, while there have been many studies exploring changes in vegetation structure and soil nutrient status in response to different types of extensification management, very little is known about related impacts on forage quality (Hofmann & Isselstein, 2005; French, 2017). To promote such extensive species-rich grasslands as a source of ruminants feeding would not only support sustainable farming but could also simultaneously improve livestock welfare and health (French, 2017). It is hypothesised that increases in protein supply associated with a greater legume and forb proportion within the diet together with the more rapid particle breakdown of these within the rumen (Waghorn et al., 1989; Jamot & Grenet, 1991) would offset the greater maturity and related fibre concentrations of the grass fraction.

The study was conducted using the Brignant long-term plots at the Pwllpeiran Upland Research Centre (UK). In a previous study (Pavlů et al., 2021) it was found that defoliation type was the key driver influencing plant species diversity (hay cutting followed by aftermath grazing > hay cutting > grazing). Conversely, higher concentrations of Ca and Mg in the soil in treatments with former liming had no effect on species richness and plant species composition. In the current article we quantified related forage quality after 19 years of continual exposure to various alternative restoration regimes. We explored sward nutritional composition and its relationship with species richness and soil chemical properties when managed according to one of seven regimes that represent the common and best practices in less favoured areas dominated by temperate European upland grassland. In doing so we addressed the following key questions: (i) what are the effects of long-term restoration managements and previous liming on herbage quality characteristics? (ii) what relationships exist between minerals in the soil and in the herbage? and (iii) what relationships exist between herbage quality and sward characteristics?

2 | MATERIALS AND METHODS

2.1 | Experimental design

The experimental plots used (the Brignant plots) were set up in 1994 at the Pwllpeiran Upland Research Centre on permanent pasture that had been ploughed and reseeded in 1973, and which had received regular inputs of fertilizer and lime. The plots are located 310 m asl (O.S. Ref: SN752757) on free-draining typical brown podzolic soils. The area receives a mean annual rainfall of approximately 1850 mm, with the nearest weather station recording annual minimum and maximum air temperatures of on average −8°C and 28°C, respectively. The plots are arranged in a randomized block design with three blocks and a total of seven grassland management regimes imposed. The treatments are: extensive sheep grazing only, with (GL+) and without (GL-) lime application; hay cutting only, with (HL+) and without (HL-) lime application; and hay cutting followed by aftermath extensive sheep grazing, with (HGL+) and without (HGL-) lime application. Control (CO) plots continuing the previous site management (i.e., limed, fertilized and continually extensively grazed by sheep) are also included within each block. These receive an annual application of 60 kg ha^{-1} N and 30 kg ha^{-1} P with K also applied as required to maintain an index of 2+ (ADAS, 1983). All the lime treatments received a single application of lime in 1998 with the intention of maintaining a soil pH of 6.0. Treatments are imposed on plots 0.08 ha (hay cut only) or 0.15 ha (grazed; hay cutting followed by aftermath extensive sheep grazing) in size. The schematic block design of the experiments and an aerial photo are provided in Figures S1 and S2.

Management of the plots is kept as consistent as possible across years. The grazed treatments are stocked with sheep of an upland breed type with numbers adjusted to maintain a sward surface height

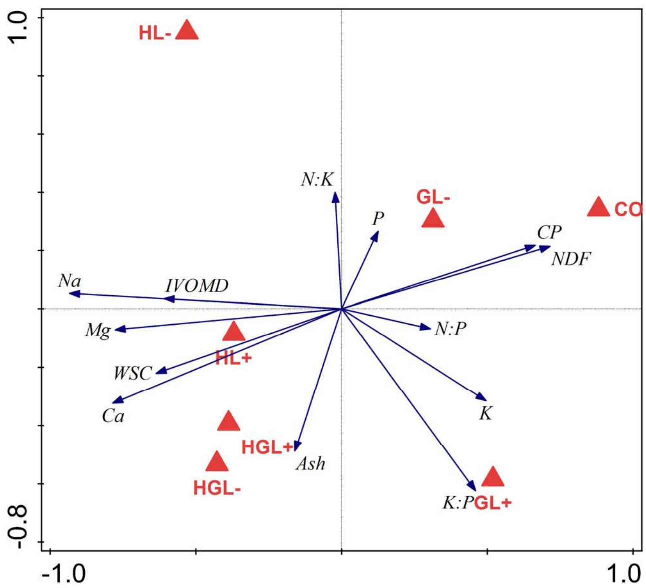

FIGURE 1 Ordination diagram of the results of RDA analysis showing changes in nutrient concentration in the herbage. Treatments are used as predictors, which can see in Table 1 (Analysis 1 for details). Treatment abbreviations are: extensive sheep grazing, with (GL+) and without (GL-) lime application; hay cutting only, with (HL+) and without (HL-) lime application; and hay cutting followed by aftermath extensive sheep grazing, with (HGL+) and without (HGL-) lime application; control (CO) conventionally fertilized, limed and extensively grazed. Herbage characteristics abbreviations are: CP, crude protein; DMSB, dry matter standing biomass; IVOMD, in vitro organic matter digestibility; N:P, N:K, K:P, ratios in the herbage; NDF, neutral detergent fibre; P, K, Ca, Mg, Na, nutrient concentrations in the herbage; WSC, water soluble carbohydrates.

of approximately 4 to 6 cm. Turnout occurs late April/early-May, when there is sufficient biomass to sustain stock. The HL+, HL-, HGL+ and HGL- plots have a single hay harvest taken annually after the 15th of July, when weather conditions allow. Stock is subsequently restocked on the HGL+ and HGL- plots after a short period of sward re-growth. All stocks are removed end of September/early October, depending on seasonal climatic conditions and related biomass growth.

2.2 | Measurements

Sward biomass was sampled in July 2012 by cutting the herbage within a 14 × 100 cm quadrat to ground level using electric shears (Makita DUM168Z; Makita Ltd., Milton Keynes, UK) at three random sites across each plot. The fresh herbage biomass samples were weighed, oven dried (48 h at 60°C) and then re-weighed to determine dry matter standing biomass (DMSB), which was expressed on a per hectare basis. The samples were then milled to pass through a 1 mm sieve prior to chemical analysis.

Total N was determined using a Leco FP 428 nitrogen analyser (Leco Corp., St. Joseph, MI) and then multiplied by 6.25 to obtain crude protein (CP) concentrations. Concentrations of Ca, K, Mg, Na and P were determined by inductively coupled plasma optical emission spectrometry. In vitro organic matter digestibility (IVOMD) was determined according to the two-stage method of Tilley and Terry (1963), adapted for the ANKOM DAISY^{II} 220 incubator system (ANKOM Technology Corp., Fairport, NY). Water soluble carbohydrate (WSC) concentrations were determined using an Automated Anthrone method (Thomas, 1977) for extracting sugars using a sulphuric acid reagent. Neutral detergent fibre (NDF) was analysed using the Gerhardt FibreCap system (Kitcherside, Glen & Webster, 2000). Reagents were as described by Van Soest et al. (1991), with the following exceptions; sodium sulphite was omitted and Termamyl (NCBE Enzymes, Reading, UK) replaced α-amylase. Ash was defined as the remainder after ignition at 550°C, so that all C is removed, ash was assumed to contain all the inorganic residue of the dry matter. All analyses were conducted in an accredited laboratory at Aberystwyth University.

2.3 | Data analysis

As explanatory variables we used: (i) all study treatments: CO, GL+, GL-, HL+, HL-, HGL+, HGL-; (ii) type of defoliation management regardless of liming: Grazed (CO, GL+, GL-), Hay (HL+, HL-), Hay and Grazed (HGL+, HGL-); (iii) liming regardless of defoliation management: Limed (CO, GL+, HL+, HGL+), No limed (GL-, HL-, HGL-).

A linear mixed-effects model (LMM) with fixed effects of explanatory variables (treatment, defoliation management and liming) and random effect of experimental block was used to analyse the effects of explanatory variables on herbage quality characteristics. If necessary, data were log-transformed to meet LMM assumptions. To control for false-discovery rate (FDR), we applied Benjamini-Hochberg's correction. To identify significant differences between individual treatments a post-hoc comparison using Tukey's HSD test was applied. Relationships between minerals in the soil and in the herbage and between herbage quality and sward characteristics were analysed by linear regression analysis. Soil chemical properties and vegetation (total number of plant species, cover of forbs and graminoids) data were as reported previously (Pavlů et al., 2021). All LMM and regression analyses were performed in Statistica 13.1 (Dell Inc., 2016).

Redundancy analysis (RDA) in the CANOCO 5 program (ter Braak & Šmilauer, 2012) was used to evaluate multivariate herbage chemical properties data. All data in RDA were logarithmically transformed [y = log (y + 1)]. For all analyses 999 permutations were performed, with blocks used as covariables to restrict permutations into blocks. To visualize the results of the RDA analysis a standard biplot ordination diagram was used.

3 | RESULTS

3.1 | Herbage quality

The RDA analysis showed strict discrimination on the first ordination axis according to management regime (Figure 1; Table 1, Analysis 1). In particular, the CP, NDF, P and K concentrations and N:P, K:P ratios in the herbage were positively correlated with grazed only treatments (GL+, GL-, CO), whereas IVOMD, WSC, ash, Na, Mg and Ca concentrations were positively correlated with all treatments where cutting was introduced (HL+, HL-, HGL+, HGL-). The defoliation management was the

TABLE 1 Results of the redundancy analyses for three different H0 analyses (A1-A3)

Analysis	Expl. Var.	Covariables	% expl.	*F*-ratio	*p*-value
A1 Different grassland management regimes have no effect on herbage quality characteristics	CO, GL+, GL-, HL+, HL-, HGL+, HGL-	blocks	49.3 (61.6)	2.1 (3.5)	**0.001 (0.001)**
A2 Different defoliation management regimes have no effect on herbage quality characteristics	Grazing, Hay, Grazing +Hay	blocks	44.8 (48.6)	6.9 (8.1)	**0.001 (0.001)**
A3 Liming have no effect on herbage quality characteristics	Limed+, Limed-	blocks	8.8	1.6	0.167

Note: % expl. = explained variation by axis 1 (adjusted explained variation by all ordination axes), a measure of the explanatory power of the explanatory variables; *F*-ratio = *F*-statistics for the test of a particular analysis; *p*-value = corresponding probability value obtained by the Monte Carlo permutation test. Significant differences are in bold. Treatment abbreviations are: extensive sheep grazing, with (GL+) and without (GL-) lime application; hay cutting only, with (HL+) and without (HL-) lime application; and hay cutting followed by aftermath extensive sheep grazing, with (HGL+) and without (HGL-) lime application; control (CO) conventionally fertilized, limed and extensively grazed.

TABLE 2 Herbage production and quality characteristics per plot under the different treatments in 2012

Herbage production and quality characteristics	*F*-ratio	*p*-value	Treatment						
			CO	GL+	GL-	Hl+	HL-	HGL+	HGL-
DMSB (g m^{-2})	5.62	**0.006**	304 ± 31.3^{ab}	320 ± 46.3^{ab}	405 ± 70.9^{a}	218 ± 9.59^{b}	253 ± 10.1^{b}	263 ± 23.1^{ab}	223 ± 24.4^{b}
IVOMD (%)	5.87	**0.005**	50.3 ± 0.42^{ab}	49.2 ± 0.23^{ab}	48.0 ± 0.92^{b}	53.1 ± 0.61^{a}	52.9 ± 0.21^{a}	51.0 ± 1.74^{ab}	53.2 ± 1.14^{a}
CP (g kg^{-1})	2.70	0.070	144 ± 17.3	118 ± 4.88	111 ± 4.21	108 ± 8.87	107 ± 3.48	96.9 ± 8.16	101 ± 5.00
NDF (g kg^{-1})	10.31	**<0.001**	636 ± 7.7^{ab}	631 ± 12.5^{abc}	653 ± 2.4^{a}	595 ± 4.9^{cd}	605 ± 10.5^{bcd}	606 ± 4.5^{bcd}	588 ± 13.4^{d}
WSC (g kg^{-1})	5.00	**0.009**	56.4 ± 2.66^{b}	88.8 ± 10.7^{a}	75.1 ± 5.57^{ab}	92.9 ± 7.34^{a}	88.9 ± 1.89^{a}	85.0 ± 4.36^{a}	83.6 ± 5.49^{ab}
Ash (g kg^{-1})	2.24	0.110	60.7 ± 2.44	62.0 ± 4.99	52.2 ± 4.31	58.9 ± 1.56	56.7 ± 4.99	65.9 ± 4.30	68.4 ± 1.04
P (g kg^{-1})	0.84	0.562	2.20 ± 0.56	2.03 ± 0.17	1.93 ± 0.12	1.83 ± 0.18	2.27 ± 0.30	1.63 ± 0.17	1.93 ± 0.09
K (g kg^{-1})	1.44	0.278	11.70 ± 3.18	11.80 ± 0.21	9.13 ± 0.58	8.33 ± 0.44	7.27 ± 0.69	8.27 ± 0.50	9.53 ± 0.85
Ca (g kg^{-1})	7.72	**0.001**	2.63 ± 0.62^{c}	3.20 ± 0.10^{bc}	3.20 ± 0.10^{bc}	4.97 ± 0.18^{ab}	4.07 ± 0.35^{abc}	5.07 ± 0.47^{ab}	5.57 ± 0.55^{a}
Mg (g kg^{-1})	6.77	**0.003**	1.10 ± 0.31^{c}	1.37 ± 0.09^{abc}	1.27 ± 0.15^{bc}	2.03 ± 0.15^{a}	1.97 ± 0.12^{ab}	1.83 ± 0.15^{ab}	1.90 ± 0.15^{ab}
Na (g kg^{-1})	13.34	**<0.001**	0.47 ± 0.09^{c}	0.73 ± 0.12^{c}	1.17 ± 0.23^{bc}	2.50 ± 0.30^{ab}	3.30 ± 0.69^{a}	2.70 ± 0.35^{ab}	2.80 ± 0.42^{a}
N:P	0.47	0.819	13.29 ± 5.58	9.43 ± 0.94	9.34 ± 0.97	9.49 ± 0.33	7.78 ± 0.93	9.67 ± 1.14	8.36 ± 0.53
N:K	0.54	0.771	2.59 ± 1.18	1.60 ± 0.09	1.98 ± 0.19	2.07 ± 0.08	2.39 ± 0.20	1.90 ± 0.25	1.72 ± 0.17
K:P	4.31	**0.015**	5.26 ± 0.37^{ab}	5.88 ± 0.45^{a}	4.73 ± 0.19^{ab}	4.59 ± 0.21^{ab}	3.24 ± 0.14^{b}	5.25 ± 0.92^{ab}	4.99 ± 0.65^{ab}

Note: Numbers represent average of three replicates ± standard error of the mean (*SE*); *F*-ratio = *F*-statistics for the test of a particular analysis; *p*-value = corresponding probability value. In cases of significant differences obtained by LMM after table-wise Benjamini-Hochberg's FDR correction (highlighted in bold), the post hoc comparison using the Tukey's HSD test was applied to identify significant differences between treatments. Differences are indicated by different small letters. Treatment abbreviations are: extensive sheep grazing, with (GL+) and without (GL-) lime application; hay cutting only, with (HL+) and without (HL-) lime application; and hay cutting followed by aftermath extensive sheep grazing, with (HGL+) and without (HGL-) lime application; control (CO) conventionally fertilized, limed and extensively grazed. Herbage characteristics abbreviations are: CP, crude protein; DMSB, dry matter standing biomass; IVOMD, in vitro organic matter digestibility; N:P, N:K, K:P, ratios in the herbage; NDF, neutral detergent fibre; P, K, Ca, Mg, Na, nutrient concentrations in the herbage; WSC, water soluble carbohydrates.

second-best explanatory variable, whereas liming had no effect on herbage chemical properties (Table 1, Analyses 2 and 3).

Based on LMM results, there were significant effects of treatment (Table 2) and the type of defoliation (Table 3) on the majority of nutrient characteristics of the herbage, however liming did not have any effect (Table 4).

Organic components DMSB, NDF and IVOMD were significantly influenced by treatment and by the type of defoliation. The DMSB ranged from 218 ± 9.59 (HL+) to 405 ± 70.9 g m^{-2} (GL-), NDF ranged from 588 ± 13.4 (HGL-) to 653 ± 2.4 g kg^{-1} (GL-) and IVOMD ranged from 48.0 ± 0.92 (GL-) to 53.2 ± 1.14% (HGL-) (Table 2). Both DMSB and NDF were significantly supported by grazing only defoliation, whereas IVOMD was supported by defoliation that incorporated cutting (hay and hay/grazed defoliation) (Table 3). Concentrations of CP were not influenced by treatment or type of defoliation (Tables 2 and 3) and ranged from 96.9 ± 8.16 (HGL+) to 144 ± 17.3 g kg^{-1} (CO). WSC was significantly influenced only by treatment, and ranged from 56.4 ± 2.66 (CO) to 92.9 ± 7.34 g kg^{-1} (HL+) (Table 2).

Minerals Ca, Mg and Na were significantly lower under grazed only defoliation than under treatments that incorporated cutting (Tables 2 and 3), whereas liming had no effect on mineral concentrations (Table 4). Concentrations of Ca ranged from 2.63 ± 0.62 (CO) to 5.57 ± 0.55 g kg^{-1} (HGL-), concentrations of Mg from 1.10 ± 0.31 (CO) to 2.03 ± 0.15 g kg^{-1} (HL+), and concentrations of Na from 0.47 ± 0.09 (CO) to 3.30 ± 0.69 g kg^{-1} (HL-) (Table 2).

The concentrations of ash, P and K in the herbage were not influenced by the treatment or the type of defoliation (Tables 2 and 3). Ash concentration ranged from 52.2 ± 4.31 (GL-) to 68.4 ± 1.04 g kg^{-1} (HGL-), P concentration from 1.63 ± 0.17 (HGL+) to 2.27 ± 0.30 g kg^{-1} (HL-), and K concentration from 7.27 ± 0.69 (HL-) to 11.80 ± 0.21 g kg^{-1} (GL+) (Table 2). However, significant differences in the K:P ratio were recorded between treatments (Table 2) and between types of defoliation (Table 3). The lowest K:P ratio was 3.24 ± 0.14 (HL-) and the highest ratio was 5.88 ± 0.45 (GL+) (Table 2). In contrast, there was no effect of the treatment or the type of defoliation on the N:P and N:K ratios in the herbage (Tables 2 and 3), which ranged from 7.78 ± 0.93 (HL-) to 13.29 ± 5.58 (CO) and from 1.60 ± 0.09 (GL+) to 2.59 ± 1.18 (CO), respectively (Table 2).

3.2 | Relationships between minerals in the soil and in the herbage and between herbage quality and sward characteristics

Positive relationships between P and K concentrations in the soil and in the herbage were revealed (p = 0.003, r = 0.62; p = 0.031, r = 0.47), respectively. In contrast, there were no relationships between bivalent cation (Ca and Mg) concentrations in the herbage and in the soil.

IVOMD and concentrations of WSC, Ca, Mg and Na in the herbage were significantly and positively correlated with total number of plant species and total cover of forbs, whereas CP and NDF were correlated negatively. No correlation with total number of plant species was found for any of the other herbage characteristics (P, K and ash) (Table 5). Concentrations of CP, NDF and K in the herbage were significantly and positively correlated with total cover of graminoids,

TABLE 3 Herbage production and quality characteristics per plot under the different type of defoliation in 2012

Herbage production and quality characteristics	*F*-ratio	*p*-value	Type of defoliation: Grazed	Hay	Hay and grazed
DMSB (g m^{-2})	9.88	**0.002**	343 ± 30.4^{a}	235 ± 10.0^{b}	243 ± 17.4^{b}
IVOMD (%)	11.56	**0.001**	49.2 ± 0.45^{b}	53.0 ± 0.30^{a}	52.1 ± 1.06^{a}
CP (g kg^{-1})	4.24	0.033	124.5 ± 7.28	108 ± 4.27	98.8 ± 4.36
NDF (g kg^{-1})	20.70	**<0.001**	640 ± 5.37^{a}	600 ± 5.64^{b}	597 ± 7.59^{b}
WSC (g kg^{-1})	3.84	0.043	73.4 ± 5.89	90.9 ± 3.51	84.3 ± 3.15
Ash g kg^{-1}	4.23	0.034	58.3 ± 2.55	57.8 ± 2.39	67.2 ± 2.06
P (g kg^{-1})	0.99	0.392	2.06 ± 0.18	2.05 ± 0.18	1.78 ± 0.11
K (g kg^{-1})	3.79	0.045	10.9 ± 1.03	7.80 ± 0.44	8.90 ± 0.52
Ca (g kg^{-1})	20.23	**<0.001**	3.01 ± 0.21^{b}	4.52 ± 0.27^{a}	5.32 ± 0.34^{a}
Mg (g kg^{-1})	22.30	**<0.001**	1.24 ± 0.11^{b}	2.00 ± 0.09^{a}	1.87 ± 0.10^{a}
Na (g kg^{-1})	32.98	**<0.001**	0.79 ± 0.13^{b}	2.90 ± 0.38^{a}	2.75 ± 0.24^{a}
N:P	0.57	0.578	10.7 ± 1.78	8.64 ± 0.58	9.01 ± 0.63
N:K	0.89	0.430	2.06 ± 0.37	2.23 ± 0.12	1.81 ± 0.14
K:P	5.50	**0.015**	5.29 ± 0.24^{a}	3.91 ± 0.32^{b}	5.12 ± 0.51^{ab}

Note: Numbers represent average of three replicates ± standard error of the mean (*SE*); *F*-ratio = *F*-statistics for the test of a particular analysis; *p*-value = corresponding probability value. In cases of significant differences obtained by LMM after table-wise Benjamini-Hochberg's FDR correction (highlighted in bold), the post hoc comparison using the Tukey's HSD test was applied to identify significant differences between the types of defoliation. Differences are indicated by different small letters. Herbage characteristics abbreviations are: CP, crude protein; DMSB, dry matter standing biomass; IVOMD, in vitro organic matter digestibility; N:P, N:K, K:P, ratios in the herbage; NDF, neutral detergent fibre; P, K, Ca, Mg, Na, nutrient concentrations in the herbage; WSC, water soluble carbohydrates.

TABLE 4 Herbage production and quality characteristics per plot under the limed or no limed conditions in 2012

Herbage production and quality characteristics	F-ratio	p-value	Limed	No limed
DMSB (g m^{-2})	0.10	0.762	276 ± 17.7	293 ± 35.6
IVOMD (%)	0.16	0.698	50.9 ± 0.59	51.3 ± 0.95
CP (g kg^{-1})	1.40	0.252	117 ± 6.98	106 ± 2.65
NDF (g kg^{-1})	0.03	0.854	617 ± 6.17	615 ± 10.9
WSC (g kg^{-1})	0.07	0.795	80.8 ± 5.25	82.5 ± 3.07
Ash (g kg^{-1})	0.68	0.421	61.9 ± 1.72	59.1 ± 3.09
P (g kg^{-1})	0.45	0.510	1.93 ± 0.15	2.04 ± 0.11
K (g kg^{-1})	1.61	0.222	10.0 ± 0.87	8.64 ± 0.50
Ca (g kg^{-1})	0.30	0.591	3.97 ± 0.37	4.28 ± 0.39
Mg (g kg^{-1})	0.43	0.520	1.58 ± 0.14	1.71 ± 0.13
Na (g kg^{-1})	2.56	0.128	1.60 ± 0.32	2.42 ± 0.40
N:P	1.91	0.185	10.4 ± 1.33	8.49 ± 0.48
N:K	0.10	0.755	2.04 ± 0.28	2.03 ± 0.14
K:P	4.56	0.047	5.24 ± 0.27	4.32 ± 0.34

Note: Numbers represent average of three replicates ± standard error of the mean (*SE*); *F*-ratio = *F*-statistics for the test of a particular analysis; *p*-value = corresponding probability value obtained by LMM. Herbage characteristics abbreviations are: CP, crude protein; DMSB, dry matter standing biomass; IVOMD, in vitro organic matter digestibility; N:P, N:K, K:P, ratios in the herbage; NDF, neutral detergent fibre; P, K, Ca, Mg, Na, nutrient concentrations in the herbage; WSC, water soluble carbohydrates.

TABLE 5 Correlation (*r*) between herbage quality characteristics and sward characteristics

Sward characteristics and herbage production	Herbage quality characteristics									
	IVOMD	CP	NDF	WSC	Ash	P	K	Ca	Mg	Na
Total number of plant species	0.65**	−0.58**	−0.74***	0.55**	0.43	−0.09	−0.36	0.84***	0.79***	0.79***
Total cover of graminoids	−0.74***	0.56**	0.80***	−0.47*	−0.34	0.11	0.47*	−0.86***	−0.81***	−0.83***
Total cover of forbs	0.75***	−0.54*	−0.78***	0.49*	0.30	−0.13	−0.49*	0.81***	0.81***	0.85***
DMSB	−0.72***	0.26	0.79***	−0.44*	−0.28	0.11	0.31	−0.50*	−0.52*	−0.51*

Note: Data of sward characteristics are from previous study (Pavlů et al., 2021). Herbage characteristics abbreviations are: CP, crude protein; DMSB, dry matter standing biomass; IVOMD, in vitro organic matter digestibility; NDF, neutral detergent fibre; P, K, Ca, Mg, Na, nutrient concentrations in the herbage; WSC, water soluble carbohydrates. Asterisks indicate significant differences (*p < 0.05; **p < 0.01; ***p < 0.001). *p*-value = corresponding probability value.

whereas IVOMD, WSC and concentrations of Ca, Mg and Na were correlated negatively. Relationships between herbage quality properties and total cover of forbs and the total number of plant species were opposite to those revealed for the total cover of graminoids and DMSB. IVOMD and concentrations of WSC, Ca, Mg and Na in the herbage were significantly and negatively correlated with DMSB. Conversely, NDF was correlated positively and no correlation with DMSB was found for CP, ash, P or K (Table 5).

4 | DISCUSSION

Compared to cattle, sheep are more selective grazers (Dumont et al., 2011), and choose the best quality components (especially forbs) during grazing (Garcia et al., 2003), regardless of grazing intensity. As species richness in temperate grasslands is usually associated with higher proportions of forbs in the sward (e.g. Hansson & Fogelfors, 2000; Heinsoo et al., 2020), species-poor pastures are formed as a result of this selectivity (Marriott et al., 2009; Pavlů et al., 2021).

The sheep grazing not only reduced the cover of forbs in our experiment (Pavlů et al., 2021) but the extensivity of grazing led to large proportion of ungrazed matured grasses with dead biomass remaining on the pasture (unpublished observation). It resulted together with nutrient enrichment by faeces (dung and urine) in higher DMSB in grazed treatment only although there was continuous defoliation from late April or early May in comparison with cut treatments where the first defoliation was done in July. Moreover, the forage quality was negatively affected by the sampling method, as biomass was cut at the ground level with a stubble height of less than 1 cm. This type of sampling includes low quality dead biomass, which may account for 25% to over

60% of the sward under intensive and extensive grazing respectively (Kassahun et al., 2021). The rejected vegetation resulted in the estimated forage quality based on IVOMD and NDF being lower (Table 3) for vegetation within grazed only treatments compared to treatments which included cutting (hay and hay/grazed treatments), where almost all biomass was removed annually, rejuvenating the sward.

The NDF and CP concentrations recorded in our experiment were typical for UK species rich grasslands (Hayes et al., 2016; French, 2017), and due to the low IVOMD values none of forages met the requirements of high productive dairy animals; only those of sheep or beef cattle (NRC, 1985; NRC, 2000).

The highest concentrations of Ca, Mg and Na were found under treatments which comprised cutting (hay and hay/grazed defoliation) regardless of liming. It was likely due to the higher proportion of forbs in these treatments (Pavlů et al., 2021), as generally forbs contain higher mineral concentrations than grasses (Whitehead, 2000; Pirhofer-Walzl et al., 2011; Liebisch et al., 2013). Although previous liming positively affected Ca and Mg concentrations in the soil (Pavlů et al., 2021), it had no effect on these elements in the forage. It seems that forage quality was considerably affected by botanical composition which reflected applied management. In our experiment, mineral concentrations in the herbage were in the range observed for species rich grasslands in UK (French, 2017) and more suitable for sheep and beef feeding (NRC, 1985; Whitehead, 2000), although some mineral imbalances in the forage can be easily solved by supplying livestock with free-choice mineral supplements (Suttle, 2010).

In our experiment the forage quality was positively affected by the higher total number of plant species, which was almost exclusively increased via the forb species. Species rich grasslands with high proportions of forbs can have higher concentrations of protein and minerals (French, 2017), and higher Ca and Mg concentrations in particular have been linked to higher digestibility (Mládková et al., 2018). Therefore, this type of grassland can have a higher forage quality than unimproved ones with dominance of grasses. While the positive relationships between P and K concentration in the soil and in the herbage recorded have also been reported in earlier studies (Schaffers et al., 1998; Pavlů et al., 2013, 2016), only a few authors have found a similar relationship in the case of P (Pavlů et al., 2016).

5 | CONCLUSION

Restoration managements for supporting biodiversity that postponed the timing of the first defoliation, via hay cutting, to mid growing season (mid-July) did not lead to deterioration in forage quality relative to extensively and continuously grazed treatments. No effect of previous liming on forage quality was found. Lower forage quality in all grazed only treatments was due to a combination of low IVOMD, high NDF, low divalent cations (Ca, Mg) and low Na, and was exclusively connected with a reduction in forbs cover and a higher proportion of mature ungrazed grass dominating the sward, presumably due to selective sheep grazing. However, forage quality in all treatments was suitable only for sheep or beef cattle feeding.

AUTHOR CONTRIBUTIONS

V.P., L.P. and M.D.F. conceived the study; V.P. and L.P. collected the data; K.K., V.P., L.P. and T.K. analysed and interpreted the data; K.K., V.P., and M.D.F. wrote and edited the manuscript. All authors discussed the results and commented on the manuscript.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

Data are accessible on request.

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