



**Full Length Article**

## The Effect of Different Restoration Treatments on the Vegetation of the Mesic Meadow Degraded by the Expansion of *Calamagrostis epigejos*

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### Abstract

Rhizomatous grass *Calamagrostis epigejos* belongs to the most expansive species degrading Central European meadow communities. The present study evaluated the usefulness of some measures during the restoration of mountain meadows degraded by the strong expansion of *Calamagrostis epigejos*. The experiment was carried out in the Central Sudetes (SW Poland) on a meadow representing the *Arrhenatheretalia* order. In the random block experimental design, the following treatments were tested: control, mowing once a year, mowing twice a year, prescribed burning, use of a selective herbicide, removing of the necromass and mulching of transferred hay. Herbicide application and mowing twice a year restricted the expansion of *C. epigejos* compared to mowing once a year, mulching and removing of the necromass relatively less effective. None of the treatments influenced the number of meadow species. However, some of tested treatments affected species diversity. Both mowing and mulching treatments positively affected values of the Shannon-Wiener index of species diversity and mowing twice a year also increased the evenness index. The results indicate that treatments used within a four-year long experiment could affect the proportions between species, but still not their richness. The results of the survey showed that both mowing and mulching of transferred hay may be worth recommending as ecologically friendly and economically advantageous measures of management in mountain meadows degraded by *C. epigejos* expansion. © 2019 Friends Science Publishers

**Keywords:** *Arrhenatheretalia* meadows; Wood small-reed; Degradation of vegetation; Restoration; Species diversity

### Introduction

Mesic mountain meadows of the *Arrhenatheretalia* order belong to the plant communities characterized by the high species diversity of vegetation. Their species composition was developed as the result of centuries-long traditional management, which led to the creation of specific features of European mountain landscape (Ellenberg, 1996; WallisDeVries *et al.*, 2002; Poschlod *et al.*, 2005). However, within the last years a decrease of mountain meadows biodiversity was observed in many regions of Europe, which is a result of ceasing traditional management or even their permanent fallowing caused by economic reasons (Lanta *et al.*, 2009; Partzsch, 2011; Pruchniewicz and Żołnierz, 2014). Some fast going processes are observed in fallowed meadows. On the one hand, succession directed to re-establish potential forest vegetation begins, and on the other, a quick development of patches dominated by some herbaceous species occurs. One of the examples of last process is the expansion of *Calamagrostis epigejos* and that process is common for various regions of Europe, both in lowlands and lower mountain ranges (Rebele and Lehmann, 2001).

Wood small-reed *Calamagrostis epigejos* is a perennial grass which occurs in Europe in a broad spectrum of plant communities, from forest ones through various grassland types up to ruderal sites of different origin. In all those habitats, *C. epigejos* shows a set of features characteristic of the expansive species, such as: fast rate of growth, huge biomass production, high morphological and physiological plasticity, strong development of underground shoots etc. (Gloser and Glöser, 1999; Rebele and Lehmann, 2001; Glöser *et al.*, 2004). Among the reasons of the competitive strength of *C. epigejos* and its ability to dominate various plant communities, there are efficient uptake of nitrogen from the soil, its storage in the roots and underground shoots, as well as translocation from the aerial parts before the end of the growing season (Gloser, 2002; Glöser *et al.*, 2004; Kavanová and Glöser, 2005). Furthermore, the mechanism of the *C. epigejos* expansion in plant communities is based on the high production of underground shoots (Pruchniewicz and Żołnierz, 2017a), guerilla-type growth (Dolečková and Osbornová, 1990) and the production of big amount of aerial biomass followed by the deposition of thick slowly decomposed litter layer preventing the seedling recruiting of other species (Somodi *et al.*, 2008; Pruchniewicz and Żołnierz, 2017b).

The expansion of *C. epigejos* into various plant communities is reported from different regions of Middle Europe (Rebele and Lehmann, 2001; Somodi *et al.*, 2008; Pruchniewicz and Żolnierz, 2014), Eastern Europe (Tenharkel and Vandermeulen, 1996) and even outside of that species' natural range in North America (Aiken *et al.*, 1989). The expansion of *C. epigejos* leads to degradation of various natural and semi-natural plant communities, including mesic and dry grasslands (Żolnierz, 2007; Somodi *et al.*, 2008; Pruchniewicz, 2017) as well as serious problems in the reclamation of post-industrial sites (Rebele and Lehmann, 2002; Baasch *et al.*, 2012; Żolnierz *et al.*, 2016).

While the mechanisms for the adaptation of *C. epigejos* to the specific conditions of various habitats seem to be already well described (*e.g.*, Gloser and Gloser, 1996; Gloser and Gloser, 1999; Rebele and Lehmann, 2001; Pruchniewicz and Żolnierz, 2017a, b; Pruchniewicz *et al.*, 2017), one may still feel a deficiency of knowledge on the measures of the prevention of *C. epigejos* expansion and the restoration of previous species diversity of plant communities.

The decline of biodiversity is a common phenomenon concerning mountain meadows which are not traditionally managed anymore in various countries (Poschlod *et al.*, 2005). That is why, there is an urgent need to introduce broad programs aimed at the restoration of their previous richness and diversity of vegetation. The achievement of that goal is impossible without the use of active measures. The usefulness of those methods should be tested in various locations in order to learn some universal mechanisms, but also regionally-specific factors influencing the treatment efficiency.

Trying to evaluate the effectiveness of different methods of restoring meadow vegetation degraded by the expansion of *C. epigejos*, a field experiment was established with treatments repeated within a four-year period. The goal of our survey was to learn how five management methods influence: 1) the abundance of *Calamagrostis epigejos*, 2) species richness, diversity and evenness, 3) species composition and 4) soil properties. Our intention was to test the hypothesis that all treatments used in the experiment are equally effective in restoring degraded mountain meadows.

## Materials and Methods

### Field Survey

The experiment was carried out in the Central Sudetes Mts. (SW Poland). An unmanaged *Arrhenatheretalia* – type meadow was selected for the study. The surveyed meadow is located in a forest glade degraded by the *C. epigejos* expansion (mean coverage ca 80% in degraded patches) at the altitude of 730 m a.s.l. The meadow covers the SSE exposed slope with the inclination of 17°. The mean annual temperature in the study area is around 5.5°C and the mean yearly precipitation ranges between 700 and 800 mm (WBO, 2005).

The efficiency of chosen management methods was tested in a random block experiment lasting four years. Each of four blocks contained 7 plots. Seven treatments were tested in the experiment: control, mowing once a year (mid June), mowing twice a year (mid June and mid August), prescribed burning (last decade of March), selective herbicide Quizalofop-P-ethyl (QPE, commercial name: Leopard Extra ® 05 EC, used at the end of June), removing of necromass (by hand in June) and mulching of transferred hay (in the middle of July). At the start of the experiment and in the fourth year were collected soil samples and relevés from all plots as well as data concerning biometric features of *C. epigejos* and depth of litter layer.

The transferred hay was collected every year in the middle of July from the same place within a species-rich mesic meadow located a few kilometers apart from the study site. Its species composition was dominated by grasses (*Holcus lanatus*, *Trisetum flavescens*, *Anthoxanthum odoratum* – 15-30% of coverage). Among forbs to the most abundant species belonged: *Stellaria graminea*, *Plantago lanceolata*, *Veronica chamaedrys* (10-22%). Generally, the list of species in the meadow patch from which the hay was collected contained 13 species (4 grasses, 9 forbs). The collected hay was cut into 3 cm long pieces and carefully mixed. Homogeneous portions of about 8 l volume were mixed with mulched sward on relevant plots.

### Soil Chemical Analyses

The soil samples were collected randomly within the studied meadows with the use of a 15 cm high metal cylinder of 8 cm diameter. The samples were later dried at room temperature, after constant mass was obtained and sifted through a sieve with 2 mm mesh. Afterwards, the following characteristics of the samples were measured: pH (potentiometrically in water), organic matter contents (loss-on-ignition in 600°C, 6 h, cooling overnight), total nitrogen contents (Kjeldahl procedure). Soluble forms of potassium, calcium and magnesium were extracted with 1 M ammonium acetate, pH 7. Varian Spectraa 200 spectrometer was used to determine Mg concentrations working in atomic absorption. K and Ca were determined with the same apparatus in the emission measurement mode. Exchangeable forms of phosphorus were extracted with 0.5 M sodium bicarbonate at pH 8.5 and determined colorimetrically (Allen, 1989; Radojević and Bashkin, 2006).

### Statistical Analysis

The compatibility of data with normal distribution was tested with W Shapiro-Wilk test. The variables for which normal distribution obtained were studied with parametric methods: Student's t-test and analysis of variance with Fisher test. Levene's test was used to check for homogeneity of variances. The data for which normal distribution was not found and/or the assumption of variance homogeneity was not met were tested using non-parametric methods:

Wilcoxon signed rank test for paired data or Kruskal-Wallis test. Statistica package ver. 13 (Dell Inc., 2016) was used for above mentioned analyses.

In order to compare the species composition changes during the course of the experiment a Non-metric multidimensional scaling (NMDS) with Bray-Curtis distance with a 3-dimensional solution measure was used. Detrended correspondence analysis (DCA) and redundancy analysis (RDA) were used to assess the effect of studied treatments on the species composition. All ordination analyses were performed using the CANOCO v. 5.03 software (ter Braak and Šmilauer, 2012).

Species diversity was assessed by the number of species and diversity indices. The Shannon–Wiener diversity index was calculated according to the formula:  $H' = -\sum (p_i \ln p_i)$ . Shannon–Wiener evenness index was calculated as follows:  $J' = H' / \ln S$ , where  $p_i = n_i / N$ ,  $n_i$  = the abundance of the species is expressed as its cover,  $N$  = the sum of abundances of all species, and  $S$  = the total number of species. The MVSP v. 3.131 package (Kovach Computing Services, 2004) was used for calculations of all diversity indices.

## Results

### Effect on Coverage, Necromass Deposition and Shoot Height of *C. epigejos*

At the end of the experiment, the highest coverage of *C. epigejos* was observed in plots representing treatments control and prescribed burning, while the lowest one after the use of herbicide. All treatments except prescribed burning significantly reduced the cover of *Calamagrostis epigejos* during the course of the experiment.

There was a significant effect on the amount of deposited *C. epigejos* necromass with strongest reduction of the necromass amount prescribed burning, then by mowing twice a year and followed by the use of herbicide (Table 1).

Treatments mowing once a year, mowing twice a year, burning and mulching significantly affected the shoot height of *C. epigejos* and shortest shoots observed for herbicide, mowing twice a year and mulching of transferred hay.

### Effect on the Species Richness and Diversity

Both mowing and mulching treatments of transferred hay significantly and positively affected values of the Shannon-Wiener index of species diversity, mowing also increased the evenness index (Table 2). On the other hand, no effect on the number of species was observed. It indicates that used treatments could affect the proportions between species, but not their richness. With regard to the changes within the duration of the experiment, it is noticeable that the biggest increase of diversity index was observed in treatments mowing twice a year, mulching, mowing once a year, herbicide and litter removing, while its lowest values occurred as a result of prescribed burning and in control.

**Table 1:** Mean values ( $\pm 1$ SE) of *C. epigejos* cover, shoot height and its necromass layer thickness in experimental treatments

Treatment	Year	Cover of <i>C. epigejos</i> [%]	Thickness of <i>C. epigejos</i> necromass layer [cm]	Shoot height [cm]
Control	2014	78.75 $\pm$ 3.15 a <sup>x</sup>	6.88 $\pm$ 1.76 a <sup>x</sup>	98 $\pm$ 8.45 a <sup>x</sup>
	2017	71.25 $\pm$ 3.15 A <sup>y</sup>	5.25 $\pm$ 0.25 C <sup>x</sup>	82 $\pm$ 7.67 A <sup>x</sup>
Mowing once a year	2014	76.25 $\pm$ 2.39 a <sup>x</sup>	5.13 $\pm$ 0.97 a <sup>x</sup>	93 $\pm$ 3.08 a <sup>x</sup>
	2017	43.75 $\pm$ 1.25 AB <sup>y</sup>	3.88 $\pm$ 0.83 AC <sup>x</sup>	69.50 $\pm$ 6.14 AB <sup>y</sup>
Mowing twice a year	2014	76.25 $\pm$ 2.39 a <sup>x</sup>	5.13 $\pm$ 1.23 a <sup>x</sup>	92 $\pm$ 5.51 a <sup>x</sup>
	2017	18.75 $\pm$ 4.27 AB <sup>y</sup>	0.90 $\pm$ 0.41 B <sup>y</sup>	60 $\pm$ 5.58 B <sup>y</sup>
Burning	2014	75 $\pm$ 2.89 a <sup>x</sup>	5.00 $\pm$ 0.41 a <sup>x</sup>	94 $\pm$ 4.00 a <sup>x</sup>
	2017	68.75 $\pm$ 6.25 A <sup>x</sup>	0.10 $\pm$ 0.00 D <sup>y</sup>	69 $\pm$ 5.12 AB <sup>y</sup>
Herbicide	2014	77.5 $\pm$ 3.23 a <sup>x</sup>	6.13 $\pm$ 2.00 a <sup>x</sup>	83.5 $\pm$ 5.45 a <sup>x</sup>
	2017	0.55 $\pm$ 0.26 B <sup>y</sup>	1.13 $\pm$ 0.31 AB <sup>y</sup>	56 $\pm$ 5.97 B <sup>y</sup>
Litter removing	2014	75 $\pm$ 2.04 a <sup>x</sup>	4.75 $\pm$ 1.11 a <sup>x</sup>	97.25 $\pm$ 4.64 a <sup>x</sup>
	2017	52.5 $\pm$ 5.95 AB <sup>y</sup>	4.25 $\pm$ 1.49 AC <sup>x</sup>	67.50 $\pm$ 7.71 AB <sup>y</sup>
Mulching	2014	71.25 $\pm$ 1.25 a <sup>x</sup>	4.38 $\pm$ 0.99 a <sup>x</sup>	97.50 $\pm$ 2.72 a <sup>x</sup>
	2017	36.25 $\pm$ 6.88 AB <sup>y</sup>	2.03 $\pm$ 0.89 AB <sup>x</sup>	65 $\pm$ 4.30 AB <sup>y</sup>

Letters (a-c for year 2015 and A-C for year 2018) were used to mark homogeneous groups obtained in LSD Fisher and Kruskal-Wallis tests at  $p \leq 0.05$ ; superscript letters (x, y) mark the differences between 2014 and 2017 obtained in Wilcoxon's test

**Table 2:** Mean values ( $\pm 1$ SE) of species number (S), diversity index (H'), evenness (J') in experimental treatments

Treatment	Year	S	H'	J'
Control	2015	10 $\pm$ 0.58 a <sup>x</sup>	1.27 $\pm$ 0.14 a <sup>x</sup>	0.55 $\pm$ 0.06 b <sup>x</sup>
	2018	8.50 $\pm$ 0.96 A <sup>x</sup>	1.12 $\pm$ 0.10 B <sup>x</sup>	0.53 $\pm$ 0.06 B <sup>x</sup>
Mowing once a year	2015	10.50 $\pm$ 0.50 a <sup>x</sup>	1.31 $\pm$ 0.09 a <sup>x</sup>	0.56 $\pm$ 0.04 b <sup>x</sup>
	2018	10.50 $\pm$ 0.87 A <sup>x</sup>	1.82 $\pm$ 0.06 A <sup>y</sup>	0.78 $\pm$ 0.04 AB <sup>y</sup>
Mowing twice a year	2015	9.75 $\pm$ 0.85 a <sup>x</sup>	1.49 $\pm$ 0.14 a <sup>x</sup>	0.66 $\pm$ 0.04 ab <sup>x</sup>
	2018	10.25 $\pm$ 1.60 A <sup>x</sup>	2.01 $\pm$ 0.12 A <sup>y</sup>	0.88 $\pm$ 0.01 A <sup>y</sup>
Burning	2015	9 $\pm$ 0.91 a <sup>x</sup>	1.39 $\pm$ 0.15 a <sup>x</sup>	0.64 $\pm$ 0.06 ab <sup>x</sup>
	2018	7 $\pm$ 1.47 A <sup>x</sup>	1.08 $\pm$ 0.16 B <sup>y</sup>	0.59 $\pm$ 0.09 B <sup>x</sup>
Herbicide	2015	9.25 $\pm$ 0.75 a <sup>x</sup>	1.44 $\pm$ 0.03 a <sup>x</sup>	0.65 $\pm$ 0.01 ab <sup>x</sup>
	2018	9.25 $\pm$ 0.75 A <sup>x</sup>	1.61 $\pm$ 0.14 A <sup>x</sup>	0.73 $\pm$ 0.07 AB <sup>x</sup>
Litter removing	2015	10 $\pm$ 0.71 a <sup>x</sup>	1.51 $\pm$ 0.15 a <sup>x</sup>	0.66 $\pm$ 0.05 ab <sup>x</sup>
	2018	10.50 $\pm$ 1.66 A <sup>x</sup>	1.74 $\pm$ 0.11 A <sup>x</sup>	0.75 $\pm$ 0.00 AB <sup>x</sup>
Mulching	2015	10 $\pm$ 0.71 a <sup>x</sup>	1.58 $\pm$ 0.12 a <sup>x</sup>	0.69 $\pm$ 0.04 a <sup>x</sup>
	2018	10.50 $\pm$ 1.19 A <sup>x</sup>	1.97 $\pm$ 0.06 A <sup>y</sup>	0.85 $\pm$ 0.04 AB <sup>x</sup>

Letters (a-c for year 2015 and A-C for year 2018) were used to mark homogeneous groups obtained in LSD Fisher and Kruskal-Wallis tests at  $p \leq 0.05$ ; superscript letters (x, y) mark the differences between 2014 and 2017 obtained in Wilcoxon's test

**Table 3:** Summary of the forward variable selection in the RDA analysis

Treatment	Explained variance %	Contribution %	pseudo-F	P
Herbicide	4.7	27.5	2.7	0.002
Control	3.3	19.5	2.0	0.014
Burning	2.9	16.9	1.7	0.006
Litter removing	2.9	16.8	1.7	0.040

Only both mowing treatments caused the significant increase of the evenness index (J') during the course of the experiment.

### Effect on the Species Composition

In the non-metric multidimensional scaling (NMDS), the cumulative values of the explained variance of species data for the first two axes were 41.00 and 73.25 respectively. The stress level was 17.6%. Fig. 1 shows the results of NMDS ordination for plots (A) with indication of ongoing changes during the course of the experiment and species (B).

The redundancy analysis (RDA) was chosen to study the effect of used treatments on the species composition after obtaining the length of gradient 2.8 SD in detrended correspondence analysis (DCA). The analysis was carried out only for data sampled at the end of the experiment in 2018. Explanatory variables account for 17.1% of variation and adjusted explained variation is on the level of 7.0%. Monte Carlo permutation test with stepwise variable selection revealed a significant effect on species composition of four experimental treatments (Table 3) – in descending strength order: use of herbicide, control A, prescribed burning and necromass removing.

### Effect on the Site Properties

No significant differences were found between treatments on investigated soil properties at the beginning of the experiment. The comparison of soil features between the beginning and end of the experiment showed significant increase of soil acidity in all treatments except mowing once a year, a decrease of exchangeable concentrations of potassium as the effect of treatments mowing twice a year, burning, herbicide and litter removing, an increase of exchangeable calcium concentration resulting from prescribed burning and finally a decrease of exchangeable concentrations of magnesium caused by the all treatments (Fig. 2).

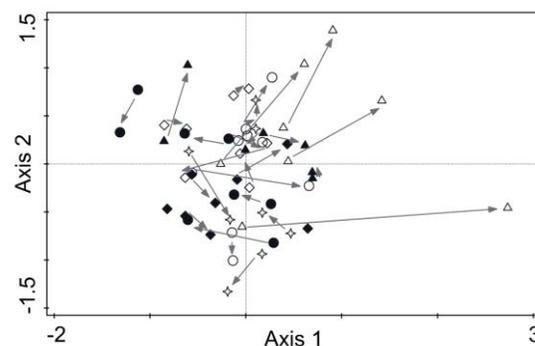
### Discussion

Although the problem of *C. epigejos* expansion in various grassland communities focuses the attention of researchers in many countries (e.g.: Aiken *et al.*, 1989; Rebele and Lehmann, 2001; Pruchniewicz, 2017), there are still few reports on the methods of suppressing it and reversing its consequences. In our four year long experiment, the effect of various treatments on the abundance of *C. epigejos* and litter production, species richness and diversity of vegetation and soil features was investigated.

### Effect on the Abundance of *C. epigejos* and Litter Accumulation

Bakker *et al.* (2003) have reported effective reduction of alien species as a result of the herbicide use, but on the other hand Wilson and Tilman (2002) indicated that it stimulates the launch of the soil seed bank. Our results did not confirm such these results. The present study observed no enhanced re-sprouting of *C. epigejos* from the seed bank. It could result from the low ability of seeds to germinate, as it was observed in the earlier studies (Rebele and Lehmann, 2001; Pruchniewicz *et al.*, 2016).

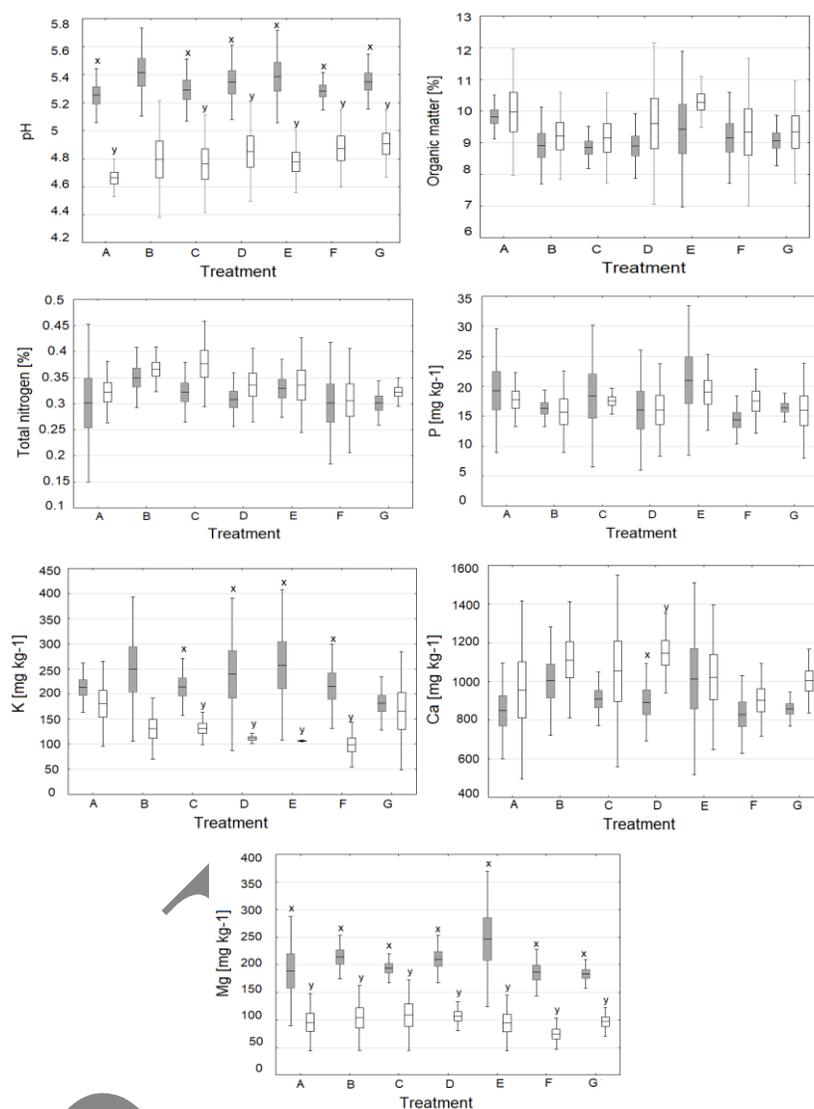
Mowing was found to be an effective measure of decreasing the *C. epigejos* abundance in experiments carried out by Lehmann and Rebele (2002) on a sandy landfill site, as well as by Klimeš and Klimešová (2002) on meadows. Házi *et al.* (2011) studied the possibilities of suppressing the *C. epigejos* spread in Hungarian meadows and stated that



**Fig. 1:** Non-metric multidimensional scaling (NMDS) ordination diagram for experimental treatments: empty diamonds –control, filled diamonds –mowing once a year, empty circles –mowing twice a year, filled circles –prescribed burning, empty triangles –herbicide, filled triangles –litter removing, asterisks –mulching of transferred hay. Arrows indicate changes in species composition within the course of the experiment

successful control of this species may be obtained after eight years of mowing. Hejman *et al.* (2010) observed the abundance reduction of another expansive tall grass *Molinia caerulea* in mountain *Nardus stricta* grassland as a result of one cut per year in late July. Mowing twice a year was also recommended by Lehmann and Rebele (2002) as a measure suitable to control the *C. epigejos* abundance. In the survey of Házi *et al.* (2011), the reduction of *C. epigejos* abundance was observed in the third year of the experiment, as for present study. Slow decline of that grass may be the result of the nitrogen storage in the roots and shoot bases as well as translocation from dying organs (Gloser, 2002). Additionally, Pourová (2009) studied mountain degraded meadows in another range of the Sudetes, reported that *C. epigejos* coverage may be reduced by 1/3 after mowing and manure application. Mowing of the mountain meadows is one of the most economically effective management way according to Török *et al.* (2011). It may be used to successfully control *Brachypodium pinnatum* in chalk grasslands (Bobbink *et al.*, 1987) as well as other clonal grasses and tall forbs in semi-natural grasslands (Kramberger and Kaligarić, 2008).

Mulching may be seen as an economically advantageous alternative of mowing according to Mašková *et al.* (2009) and Doležal *et al.* (2011) as they observed in experiments oriented to suppress the domination of some tall grass species in the Bohemian Forest Mts. Furthermore, Gaisler *et al.* (2013) claimed that mulching performed at least twice a year may in a cost effective way replace mowing in low productive mountain grassland. However, they pointed out the importance of proper frequency and timing of that management measure. Our results positively verified the hypothesis assuming usefulness of mulching of transferred hay in *Calamagrostis epigejos* control. Its effect was weaker as compared to mowing twice a year but stronger than in the case of single cut.



**Fig. 2:** Physico-chemical properties of soils in the plots representing the experimental treatments: A – Control, B – Mowing once a year, C – Mowing twice a year, D – Burning, E – Herbicide, F – Litter removing, G – Mulching. Means with standard error values (boxes) and confidence intervals (whiskers) for plots are given. Different letters indicate significant differences obtained in the Kruskal–Wallis test ( $p \leq 0.05$ ) between beginning (gray boxes) and end of the experiment (empty boxes). No significant differences were found between treatments for all studied features

In present study prescribed burning was the most effective way of preventing the litter accumulation, of course, except its mechanical removing, whereas mulching had no significant effect. That last mentioned treatment, even though it leaves the fine cut plant aerial biomass on the soil surface, resulted in a decrease of litter accumulation in surveys carried out in mountain meadows by Mašková *et al.* (2009) and Doležal *et al.* (2011). The positive effect of burning on litter removing was observed in studies performed in dry grassland by Alhamad *et al.* (2012). Ruprecht *et al.* (2010) indicated stimulation of germination of some rare dry grassland species after litter removal alone or combined with mowing of vegetation.

### Effect on the Species Richness, Diversity and Composition

None of the applied treatments led to an increase of species number in experiment. However, mowing and mulching of transferred hay caused the increase of species diversity expressed by the Shannon-Wiener index. Mowing twice a year appeared as the most effective measure. This treatment also decreased the dominance of *Calamagrostis epigejos*, which was reflected in the increase of evenness index. It was supposed that a four year period is long enough to achieve some change in the proportions between species, including a spectacular decrease of the *C. epigejos* share.

Nevertheless, it seems to be still too short a time to launch the recolonisation of degraded patches by the meadow species. It should be emphasized that there is a negative effect of prescribed burning and lack of any influence of herbicide on species diversity.

An advantageous effect of mowing on the species diversity was observed by many researchers both in meadows influenced by the expansion of *C. epigejos* (Lehmann and Rebele, 2002; Rudmann-Maurer *et al.*, 2008; Hází *et al.*, 2011; Valkó *et al.*, 2012; Pruchniewicz, 2017), as well as in the case of grasslands degraded after an increase in the share of other species *e. g.*: *Molinia* (Hejcman *et al.*, 2010). However, Mašková *et al.* (2009) observed slightly lowered diversity and evenness indices after mowing mountain meadow in the experiment carried out in the Bohemian Forest. Hází *et al.* (2011) noticed some shift in time of mowing effects in meadow affected by *C. epigejos*: species richness increased after four years and diversity after eight years, *i. e.* effects opposite to our results. The positive effect of mowing on species richness may consist also in stimulating seedling recruitment as a result of removing the accumulating litter (Galvánek and Lepš, 2012).

Various researchers evaluated the effect of mulching on the species diversity of meadows and reported it as a technically simple and economically rational substitute of mowing (Mašková *et al.*, 2009; Doležal *et al.*, 2011; Gaisler *et al.*, 2013; Oelmann *et al.*, 2017), as well as grazing (Römermann *et al.*, 2009) in the grassland management. Mulching stimulated species richness and diversity in the study carried out by Mašková *et al.* (2009) as well as species and functional diversity in the survey of Doležal *et al.* (2011). On the other hand, that type of management caused a decrease of species number in the experiment carried out by Hensgen *et al.* (2016). Doležal *et al.* (2011) pointed out that decomposition of mulch creates a patchy pattern of variable microsites, which is advantageous for dynamic guerilla-type species, while a homogenous layer of litter is favorable for phalanx-type species. Those differences may be of principle significance for species richness and diversity.

In present experiment, it was decided to combine mulching with hay transfer, which is also a grassland restoration measure evaluated in many studies. It was used in a study carried out by Kiehl *et al.* (2010), who stated 13-15 years after hay transfer that 102 species successfully stabilized in a calcareous grassland in Bavaria. This measure was able to reestablish 101 species in alluvial meadows already after three years in the study of Schmiede *et al.* (2012) as well. Hay transfer gave promising effects in the study carried out by Sengl *et al.* (2017) in lowland meadows in Austria. They found it an effective and cheaper alternative for the sod transplantation. Donath *et al.* (2007) and Knut *et al.* (2010) pointed out that the use of local plant material in hay transfer ensures the genetic integrity of local populations. That is why in present study, hay was collected in a close vicinity of the study area.

The prescribed burning was found to be a worthless measure of mountain grassland management with regard to maintaining species richness and diversity. This statement is in line with observations of some other authors. Moog *et al.* (2002) found that treatment as unsuitable for conservation purposes in management of grasslands in low-intensity farming. Controlled burning reduced species diversity in studies carried out in calcareous grasslands (Ryser *et al.*, 1995; Jeschke *et al.*, 2008). Milberg *et al.* (2014) found spring burning as not an appropriate conservation method in Swedish species-rich grasslands. Also Valkó *et al.* (2014) reported that burning was not recommended in the majority of European studies.

Additionally, the use of herbicide brought no positive effect on species richness, though this measure effectively reduced *C. epigejos* abundance in present experiment. Reports from literature are scarce. In seed bank of Argentinian temperate grasslands, Rodriguez and Jacobo (2013) observed a dramatic shift in species composition and a decrease of species richness and diversity after use of herbicide.

#### Effect on the Habitat Properties

There is still only a limited amount of data regarding the influence of various management measures on the habitat properties. On the other hand, reports of various authors show no equivocal results of used treatments. For instance, burning positively influenced soil pH in traditionally managed meadows in Japan (Nagata and Ushimaru, 2016), but had no such effect in the study of Valkó *et al.* (2017) carried out in the Carpathian Basin, neither did it affect the contents of potassium, phosphorus and organic matter. Doležal *et al.* (2011) carried out a 13-year experiment, thus much longer than present study. They observed gradual nutrient loss in soils caused by mowing and its enhancement after mulching at the same time. What is interesting is that there were no differences noticed between treatments during the first three years, but after 9 years authors observed in the mulched plots a significant increase of soil pH, as well as higher contents of organic matter, total nitrogen, plant available potassium, phosphorus and calcium. Oelmann *et al.* (2017) recommend mulching as a suitable measure for maintaining phosphorus bioavailable fractions in restored grassland. Hejcman *et al.* (2010) revealed a decrease of soil potassium availability following the cutting of *Molinia caerulea* in mountain *Nardus stricta* grassland. In a three year long experiment Ilmarinen and Mikola (2009) negatively verified the assumption that mowing can suppress the decomposer's activity in grassland soil, by reducing plant nutrient availability and thus influencing plant growth.

Bearing in mind the general scarcity and discrepancies of the results obtained by the various authors, it is reported that in-depth studies of the effect of grassland regeneration treatments on habitat features are necessary.

## Conclusion

Mowing and mulching of transferred hay brought promising results both in restricting the *C. epigejos* dominance and as measures of restoration aimed at increasing species diversity. Herbicide use was an effective way to decrease the abundance of *Calamagrostis epigejos* but without a positive influence on species diversity.

Four years appeared to be a period long enough to start changing properties between species, suppressing *C. epigejos* dominance and increasing diversity, but still no effect on the species richness was observed. Species composition was significantly affected by the following treatments: use of herbicide, control, prescribed burning and necromass removing.

All treatments led to an increase of soil acidity and a decrease of magnesium content within the ongoing experiment. Other observed effects were as follows: lowering of soil potassium content after mowing twice a year, burning, herbicide use and mulching, as well as increase of calcium content after burning.

The present study results showed that both mowing and mulching of transferred hay seem to be worth recommending as ecologically friendly and economically advantageous measures of mountain grassland management. However, results of different management measures may be regionally specific and therefore their usefulness should be carefully studied each time before starting a restoration program. This remark seems to be particularly important in mountain regions where big diversity of environmental and biotic factors may significantly influence the results of introduced measures.

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