INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
18–1632/2019/22–2–347–354
DOI: 10.17957/IJAB/15.1070
http://www.fspublishers.org

Full Length Article

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

Daniel Pruchniewicz[*] and Ludwik Żołnierz
Department of Botany and Plant Ecology, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24a, PL-50-363 Wrocław, Poland
[*]For correspondence: daniel.pruchniewicz@upwr.edu.pl

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 *C. 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 years 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.

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; Vries *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 *C. 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 Gloser, 1999; Rebele and Lehmann, 2001; Gloser *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; Gloser *et al.*, 2004; Kavanová and Gloser, 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).

To cite this paper: Pruchniewicz, D. and L. Żołnierz, 2019. The Effect of different restoration treatments on the vegetation of the mesic meadow degraded by the expansion of *Calamagrostis epigejos*. *Intl. J. Agric. Biol.*, 22: 347–354

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 Żołnierz, 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 (Żołnierz, 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; Żołnierz *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, 1999; Rebele and Lehmann, 2001; Pruchniewicz and Żołnierz, 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 years period. The goal of our survey was to learn how five management methods influence: 1) the abundance of *C. 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 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 17º. The mean annual temperature in the study area is around 5.5°C and the mean yearly precipitation ranges between 700 and 800 mm (W.B.O., 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).

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: $H' = -\Sigma (p_i \ln p_i)$. 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 *C. 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 using 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, mowig also increased 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. Only both mowing treatments caused the significant increase of the eveness index (J') during the course of the experiment.

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

Treatment	Year	Cover of *C. epigejos* [%]	Thickness of *C. epigejos* necromass layer [cm]	Shoot height [cm]
Control	2015	78.75 ± 3.15 a^{x}	6.88 ± 1.76 a^{x}	98.00 ± 8.45 a^{x}
	2018	71.25 ± 3.15 A^{y}	5.25 ± 0.25 C^{x}	82.00 ± 7.67 A^{x}
Mowing once a year	2015	76.25 ± 2.39 a^{x}	5.13 ± 0.97 a^{x}	93.00 ± 3.08 a^{x}
	2018	43.75 ± 1.25 AB^{y}	3.88 ± 0.83 AC^{x}	69.50 ± 6.14 AB^{y}
Mowing twice a year	2015	76.25 ± 2.39 a^{x}	5.13 ± 1.23 a^{x}	92.00 ± 5.51 a^{x}
	2018	18.75 ± 4.27 AB^{y}	0.90 ± 0.41 B^{y}	60.00 ± 5.58 B^{y}
Burning	2015	75.00 ± 2.89 a^{x}	5.00 ± 0.41 a^{x}	94.00 ± 4.00 a^{x}
	2018	68.75 ± 6.25 A^{x}	0.10 ± 0.00 D^{y}	69.00 ± 5.12 AB^{y}
Herbicide	2015	77.50 ± 3.23 a^{x}	6.13 ± 2.00 a^{x}	83.50 ± 5.45 a^{x}
	2018	0.55 ± 0.26 B^{y}	1.13 ± 0.31 AB^{y}	56.00 ± 5.97 B^{x}
Litter removing	2015	75.00 ± 2.04 a^{x}	4.75 ± 1.11 a^{x}	97.25 ± 4.64 a^{x}
	2018	52.50 ± 5.95 AB^{y}	4.25 ± 1.49 AC^{x}	67.50 ± 7.71 AB^{x}
Mulching	2015	71.25 ± 1.25 a^{x}	4.38 ± 0.99 a^{x}	97.50 ± 2.72 a^{x}
	2018	36.25 ± 6.88 AB^{y}	2.03 ± 0.89 AB^{x}	65.00 ± 4.30 AB^{y}

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 2015 and 2018 obtained in Wilcoxon's test

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

Treatment	Year	S	H'	J'
Control	2015	10.00 ± 0.58 a^{x}	1.27 ± 0.14 a^{x}	0.55 ± 0.06 b^{x}
	2018	8.50 ± 0.96 A^{x}	1.12 ± 0.10 B^{x}	0.53 ± 0.06 B^{x}
Mowing once a year	2015	10.50 ± 0.50 a^{x}	1.31 ± 0.09 a^{x}	0.56 ± 0.04 b^{x}
	2018	10.50 ± 0.87 A^{x}	1.82 ± 0.06 A^{y}	0.78 ± 0.04 AB^{y}
Mowing twice a year	2015	9.75 ± 0.85 a^{x}	1.49 ± 0.14 a^{x}	0.66 ± 0.04 ab^{x}
	2018	10.25 ± 1.60 A^{x}	2.01 ± 0.12 A^{y}	0.88 ± 0.01 A^{y}
Burning	2015	9.00 ± 0.91 a^{x}	1.39 ± 0.15 a^{x}	0.64 ± 0.06 ab^{x}
	2018	7.00 ± 1.47 A^{x}	1.08 ± 0.16 B^{y}	0.59 ± 009 B^{x}
Herbicide	2015	9.25 ± 0.75 a^{x}	1.44 ± 0.03 a^{x}	0.65 ± 0.01 ab^{x}
	2018	9.25 ± 0.75 A^{x}	1.61 ± 0.14 A^{x}	0.73 ± 0.07 AB^{x}
Litter removing	2015	10.00 ± 0.71 a^{x}	1.51 ± 0.15 a^{x}	0.66 ± 0.05 ab^{x}
	2018	10.50 ± 1.66 A^{x}	1.74 ± 0.11 A^{x}	0.75 ± 0.00 AB^{x}
Mulching	2015	10.00 ± 0.71a^{x}	1.58 ± 0.12a^{x}	0.69 ± 0.04 a^{x}
	2018	10.50 ± 1.19A^{x}	1.97 ± 0.06A^{y}	0.85 ± 0.04AB^{x}

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 2015 and 2018 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

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 experiment and species (B).

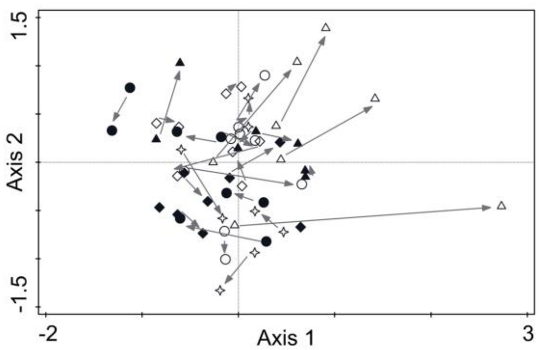

Fig. 1: Non-metric multidimensional scaling (NMDS) ordination diagram for experimental treatments: empty diamonds –control, filled diamonds –mowing once a year, empty circles –mowing twice a year, filled circles –prescribed burning, empty triangles –herbicide, filled triangles –litter removing, asterisks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

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 years 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 successful control of this species may be obtained after eight years of mowing. Hejcman *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 ways 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 Kaligaric, 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

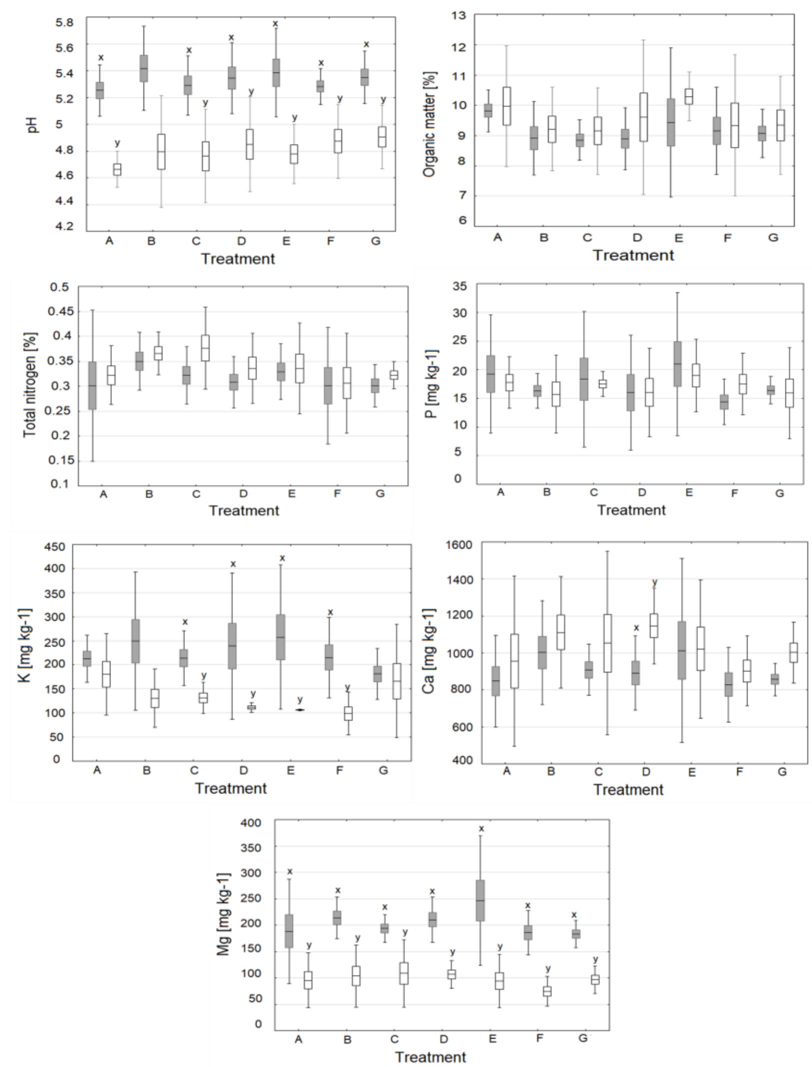

Fig. 2: Physico-chemical properties of soils in the plots representing the experimental treatments: A – Control, B – Mowing once a year, C – Mowing twice a year, D – Burning, E – Herbicyde, F – Litter removing, G – Mulching. Means with standard error values (boxes) and confidence intervals (whiskers) 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

assuming usefulness of mulching of transferred hay in *C. epigejos* control. Its effect was weaker as compared to mowing twice a year but stronger than in the case of single cut.

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 *C. epigejos*, which was reflected in the increase of evenness index. It was supposed that a four years 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 re-colonisation 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; Házi *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. Házi *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 calacareous 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

Both mowing and mulching of transferred hay were 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 is particularly important in mountain regions where big diversity of environmental and biotic factors may significantly influence the results of introduced measures.

Acknowledgements

We are grateful to District Jugów of the State Forests for the permission to carry out our experiment.

References

Aiken, S.G., L.P. Lefkovitch and K.C. Armstrong, 1989. *Calamagrostis epigejos* (Poaceae) in North America, especially Ontario. *Can. J. Bot.*, 67: 3205–3218

Alhamad, M.N., A. Alrababah and M.A. Gharaibeh, 2012. Impact of burning and fertilization on dry Mediterranean grassland productivity and diversity. *Acta Oecol.*, 40: 19–26

Allen, S.E., 1989. *Chemical Analysis of Ecological Materials*, 2nd edition completely revised. Blackwell Scientific Publications. Oxford, London, Edinburgh, UK

Baasch, A., A. Kirmer and S. Tischew, 2012. Nine years of vegetation development in a postmining site: effects of spontaneous and assisted site recovery. *J. Appl. Ecol.*, 49: 251–260

Bakker, J.D., S.D. Wilson, J.M. Christian, X. Li, L.G. Ambrose and J. Waddington, 2003. Contingency of grassland restoration on year, site, and competition from introduced grasses. *Ecol. Appl.*, 13: 137–153

Bobbink, R., H.J. During, J. Schreurs, J. Willems and R. Zielman, 1987. Effects of selective clipping and mowing time on species diversity in chalk grassland. *Fol. Geobot. Phytotaxonom.*, 22: 363–376

Dell Inc., 2016. Dell Statistica (data analysis software system), version 13. software.dell.com

Dolečková, H. and J. Osbornová, 1990. Competition ability and plasticity of *Calamagrostis epigejos*. *Zpr Česk. Bot. Společ. Praha,* 25: 35–38

Doležal, J., Z. Mašková, J. Lepš, D. Steinbachová, F.D. Bello, J. Klimešová, O. Tackenberg, F. Zemek and J. Květ, 2011. Positive long–term effect of mulching on species and functional trait diversity in a nutrient–poor mountain meadow in Central Europe. *Agric. Ecosyst. Environ.*, 145: 10–28

Donath, T.W., S. Bissels, N. Hölzel and A. Otte, 2007. Large scale application of diaspore transfers with plant material in restoration practice - impact of seed and microsite limitation. *Biol. Conserv.*, 138: 224–234

Ellenberg, H., 1996. *Vegetation Mitteleuropas mit den Alpen*, 5th edition. Ulmer, Stuttgart, Germany

Gaisler, J., V. Pavlů, L. Pavlů and M. Hejcman, 2013. Long–term effects of different mulching and cutting regimes on plant species composition of *Festuca rubra* grassland. *Agric. Ecosyst. Environ.*, 178: 10–17

Galvánek, D. and J. Lepš, 2012. The effect of management on productivity, litter accumulation and seedling recruitment in a Carpathian mountain grassland. *Plant Ecol.*, 213: 523–533

Gloser, V., 2002. Seasonal changes of nitrogen storage compounds in a rhizomatous grass *Calamagrostis epigejos*. *Biol. Plant.*, 45: 563–568

Gloser, V. and J. Gloser, 1999. Production processes in a grass *Calamagrostis epigejos* grown at different soil nitrogen supply. *In: Grassland Ecology V. Proceedings of the 5th Ecological Conference*, pp: 69–76. 23–25 November, 1999. Grassland and Mountain Agriculture Research Institute

Gloser, V. and J. Gloser, 1996. Acclimation capability of *Calamagrostis epigejos* and *C. arundinacea* to changes in radiation environment. *Photosynthetica*, 32: 203–212

Gloser, V., M. Košvancová and J. Gloser, 2004. Changes in growth parameters and content of N–storage compounds in roots and rhizomes of *Calamagrostis epigejos* after repeated defoliation. *Biol. Bratisl.*, 59: 179–184

Házi, J., S. Bartha, S. Szentes, B. Wichmann and K. Penksza, 2011. Seminatural grassland management by mowing of *Calamagrostis epigejos* in Hungary. *Plant Biosyst.*, 145: 699–707

Hejcman, M., M. Češková and V. Pavlů, 2010. Control of *Molinia caerulea* by cutting management on sub–alpine grassland. *Flora*, 205: 577–582

Hensgen, F., L. Bühle and M. Wachendorf, 2016. The effect of harvest, mulching and low–dose fertilization of liquid digestate on above ground biomass yield and diversity of lower mountain semi–natural grasslands. *Agric. Ecosyst. Environ.*, 216: 283–292

Ilmarinen, K. and J. Mikola, 2009. Soil feedback does not explain mowing effects on vegetation structure in a semi–natural grassland. *Acta Oecol.*, 35: 838–848

Jeschke, M., K. Kiehl, J. Pfadenhauer and A. Gigon, 2008. Langfristige Auswirkungen ehemaliger Bewirtschaftungsvarianten auf die Diversität von Blütenpflanzen, Moosen und Flechten eines Kalkmagerrasens. *Bot. Helv.*, 118: 95–109

Kavanová, M. and V. Gloser, 2005. The use of internal nitrogen stores in the rhizomatous grass *Calamagrostis epigejos* during regrowth after defoliation. *Ann. Bot.*, 95: 457–463

Kiehl, K., A. Kirmer, T.W. Donath, L. Rasran and N. Hölzel, 2010. Species introduction in restoration projects – Evaluation of different techniques for the establishment of semi–natural grasslands in Central and NW Europe. *Basic Appl. Ecol.*, 11: 285–299

Klimeš, L. and J. Klimešová, 2002. The effects of mowing and fertilisation on carbohydrate reserves and regrowth of grasses: Do they promote plant coexistence in species-rich meadows. *Evol. Ecol.*, 15: 363–382

Knut, R., N. Jøm-Frode, A. Ingvild, A. Inger and H. Einar, 2010. Recreating semi-natural grasslands: A comparison of four methods. *Ecol. Eng.*, 36: 1672–1679

Kovach Computing Services, 2004. MVSP v3.131

Kramberger, B. and M. Kaligaric, 2008. Semi-natural grasslands: The effect of cutting frequency on long-term changes of floristic composition. *Pol. J. Ecol.*, 56: 33–43

Lanta, V., J. Doležal, P. Lantová, J. Kelíšek and O. Mudrák, 2009. Effects of pasture management and fertilizer regimes on botanical changes in species-rich mountain calcareous grassland in Central Europe. *Grass For. Sci.*, 64: 443–453

Lehmann, C. and F. Rebele, 2002. Successful management of *Calamagrostis epigejos* (L.) ROTH on a sandy landfill site. *J. Appl. Bot.*, 76: 77–81

Mašková, Z., J. Doležal, J. Květ and F. Zemek, 2009. Long-term functioning of a species–rich mountain meadow under different management regimes. *Agric. Ecosyst. Environ.*, 132: 192–202

Moog, D., P. Poschlod, S. Kahmen and K.F. Schreiber, 2002. Comparison of species composition between different grassland management treatments after 25 years. *Appl. Veg. Sci.*, 5: 99–106

Milberg, P., B. Akoto, K.O. Bergman, H. Fogelfors, H. Paltto and M. Tälle, 2014. Is spring burning a viable management tool for semi-natural grasslands? *Appl. Veg. Sci.*, 17: 429–441

Nagata, Y.K. and A. Ushimaru, 2016. Traditional burning and mowing practices support high grassland plant diversity by providing intermediate levels of vegetation height and soil pH. *Appl. Veg. Sci*., 19: 567–577

Oelmann, Y., H.J. Brauckmann, K.F. Schreiber and G. Broll, 2017. 40 years of succession or mulching of abandoned grassland affect phosphorus fractions in soil. *Agric. Ecosyst. Environ*., 237: 66–74

Partzsch, M., 2011. Does land use change affect the interactions between two dry grassland species? *Flora*, 206: 550–558

Poschlod, P., J.P. Bakker and S. Kahmen, 2005. Changing land use and its impact on biodiversity. *Basic Appl. Ecol*., 6: 93–98

Pourová, K., 2009. Přehled managementových studií lučních porostů na území Krkonošského národního parku. *Opera Corcon*., 46: 105–132

Pruchniewicz, D., 2017. Abandonment of traditionally managed mesic mountain meadows affects plant species composition and diversity. *Basic Appl. Ecol*., 20: 10–18

Pruchniewicz, D. and L. Żołnierz, 2017a. The influence of *Calamagrostis epigejos* expansion on the species composition and soil properties of mountain mesic meadows. *Acta Soc. Bot. Pol*., 86: 1–11

Pruchniewicz, D. and L. Żołnierz, 2017b. Relationship between litter produced *by Calamagrostis epigejos* and seedling recruitment of mesic meadow species in mountain conditions. *Commun. Ecol*., 18: 149–156

Pruchniewicz, D. and L. Żołnierz, 2014. The influence of environmental factors and management methods on the vegetation of mesic grasslands in a central European mountain range. *Flora*, 209: 687–692

Pruchniewicz, D., L. Żołnierz and V. Andonovski, 2017. Habitat factors influencing competitive ability of *Calamagrostis epigejos* (L.) Roth in mountain plant communities. *Turk. J. Bot*., 41: 579–587

Pruchniewicz, D., T.W. Donath, A. Otte, L. Żołnierz and R.L. Eckstein, 2016. Effect of expansive species on seed rain and soil seed bank of mountain mesic meadows. *Tuexenia*, 36: 81–96

Radojević, M. and V.N. Bashkin, 2006. *Practical Environmental Analysis*. The Royal Society of Chemistry, Cambridge

Rebele, F. and C. Lehmann, 2002. Restoration of a landfill site in Berlin, Germany by spontaneous and directed succession. *Restor. Ecol*., 10: 340–347

Rebele, F. and C. Lehmann, 2001. Biological flora of Central Europe: *Calamagrostis epigejos* (L.) Roth. *Flora*, 196: 325–344

Rodriguez, A.M. and E.J. Jacobo, 2013. Glyphosate effects on seed bank and vegetation composition of temperate grasslands. *Appl. Veg. Sci*., 16: 51–62

Römermann, C., M. Bernhardt-Römermann, M. Kleyer and P. Poschlod, 2009. Substitutes for grazing in semi-natural grasslands - do mowing or mulching represent valuable alternatives to maintain vegetation structure. *J. Veg. Sci*., 20: 1086–1098

Rudmann-Maurer, K., A. Weyand, M. Fischer and J. Stöcklin, 2008. The role of land use and natural determinants for grassland vegetation composition in the Swiss Alps. *Basic Appl. Ecol*., 9: 494–503

Ruprecht, E., M.Z. Enyedi, R.L. Eckstein and T.W. Donath, 2010. Restorative removal of plant litter and vegetation 40 years after abandonment enhances re-emergence of steppe grassland vegetation. *Biol. Conserv*., 143: 449–456

Ryser, P., R. Langenauer and A. Gigon, 1995. Species richness and vegetation structure in a limestone grassland after 15 years management with six biomass removal regimes. *Folia Geobot*., 30: 157–167

Schmiede, R., A. Otte and T.W. Donath, 2012. Enhancing plant biodiversity in species-poor grassland through plant material transfer - the impact of sward disturbance. *Appl. Veg. Sci*., 15: 290–298

Sengl, P., M. Magnes, K. Weitenthaler, V. Wagner, L. Erdös and C. Berg, 2017. Restoration of lowland meadows in Austria: A comparison of five techniques. *Basic Appl. Ecol*., 24: 19–29

Somodi, I., K. Virágh and J. Podani, 2008. The effect of the expansion of the clonal grass *Calamagrostis epigejos* on the species turnover of a semi-arid grassland. *Appl. Veg. Sci*., 11: 187–192

Tenharkel, M.J. and F. Vandermeulen, 1996. Impact of grazing and atmospheric nitrogen deposition on vegetation of dry coastal dune grasslands. *J. Veg. Sci*., 7: 445–452

ter Braak, C.J.F. and P. Šmilauer, 2012. *Canoco Reference Manual and user's Guide: Software for Ordination, Version 5.0*. – Microcomputer Power, Ithaca, New York, USA

Török, P., E. Vida, B. Deák and S. Lengyel, 2011. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. *Biodivers. Conserv*., 20: 2311–2332

Valkó, O., A. Kelemen, T. Miglécz, P. Török, B. Deák, K. Toth, J.P. Tóth and B. Tóthmérész, 2017. Litter removal does not compensate detrimental fire effects on biodiversity in regularly burned semi-natural grasslands. *Sci. Total Environ*., 622–623: 783–789

Valkó, O., P. Török, B. Deák and B. Tóthmérész, 2014. Review: Prospects and limitations of prescribed burning as a management tool in European grasslands. *Basic Appl. Ecol*., 15: 26–33

Valkó, O., P. Török, G. Matus and B. Tóthmérész, 2012. Is regular mowing the most appropriate and cost-effective management maintaining diversity and biomass of target forbs in mountain hay meadows? *Flora*, 207: 303–309

Vries, M.F.W.D., P. Poschlod and J.H. Willems, 2002. Challenges for the conservation of calcareous grasslands in northwestern Europe: Integrating the requirements of flora and fauna. *Biol. Conserv*., 104: 265–273

W.B.O. (Wojewódzkie Biuro Urbanistyczne we Wrocławiu), 2005. Ecophysiographic study for the Lower Silesian Voivodeship. Available at: *http://eko.wbu.wroc.pl/eko/* (Accessed: 1 Sep. 2018)

Wilson, S.D. and D. Tilman, 2002. Quadratic variation in old-field species richness along experimental gradients of disturbance and nitrogen. *Ecology*, 83: 492–504

Żołnierz, L., 2007. *Zbiorowiska Trawiaste Występujące na Dolnośląskich Serpentynitach – Wybrane Aspekty Ekologii. Grasslands on Serpentines in Lower Silesia (SW Poland) – Some Aspects of their Ecology*. Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu, Poland

Żołnierz, L., J. Weber, M. Gilewska, S. Strączyńska and D. Pruchniewicz, 2016. The spontaneous development of understory vegetation on reclaimed and afforested post-mine excavation filled with fly ash. *Catena*, 136: 84–90

[Received 12 Nov 2018; Accepted 11 Feb 2019; Published (online) 21 Jun 2019]