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THE EVALUATION OF SOIL SEED BANK IN TWO *Arrhenatherion* MEADOW HABITATS IN CENTRAL POLAND

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Abstract. Too intensive management by mowing or grazing or cessation of management both lead to the floristic impoverishment of meadow communities. Soil seed bank can play an essential role in the ecological restoration of species-rich semi-natural grasslands. In Poland, little research has been conducted in this area, particularly refers to *Arrhenatherion* meadows. The aim of the studies was to determine the density and species composition of the soil seed bank of *Arrhenatheretum elatioris* meadows as well as the distribution of seeds across four soil levels. The studies were carried out in two habitats: *Arrhenatheretum elatioris* (code 6510-1) and *Poa pratensis – Festuca rubra* (code 6510-2). Soil samples were collected up to a depth of 20 cm, divided into four levels: 0-5 cm, 5-10 cm, 10-15 cm 15-20 cm. The size and species composition of the seed bank was determined by extracting seeds from the soil samples. The number of diaspores (seeds and fruits) in the topsoil (0-20 cm) layer was 56,430 seeds·m^{-2} (*Arrhenatheretum elatioris*) and 118,510 seeds·m^{-2} (*Poa pratensis – Festuca rubra*). The soil seed banks were dominated by diaspores of annual dicotyledonous species (above 80%) which were mainly seeds of arable weeds or ruderal plants. The assessed soil seed banks were dominated by *Chenopodium album* and *Stellaria media.* In both grasslands, the quantity of *Poaceae* and *Fabaceae* diaspores were very low. These results confirmed that most mesic grassland species did not form persistent seed banks and reintroduction of target species seeds is necessary in order to restore the species-rich *Arrhenatherion elatioris* meadows.

Key words: *Arrhenatheretum elatioris*, density of soil seed bank, false oat-grass meadows, habitat code 6510, species composition, vertical distribution

INTRODUCTION

The anthropogenic origin of grasslands in our climate zone causes the flora of meadows and pastures to be among the most vulnerable components of the vegetation.

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The problem of the disappearance of some species and whole plant communities in Europe, mainly in countries with intensive agriculture, has been observed for several decades [Garcia 1992, Nösberger and Rodriguez 1996, Pärtel *et al.* 2005]. Too intensive management by mowing or grazing or cessation of management both lead to the floristic impoverishment of meadow communities. 65 types of grassland habitats in Europe are at risk as a result of the intensification of grassland and pasture management, while 26 types are threatened by its extensification [EEC 1992, EU Habitat Directive]. In Poland, the problem has been mentioned by a number of authors from different regions of the country [Warda and Kozłowski 2012, Kucharski 2015]. Kryszak's studies [2001] demonstrated that between 1950 and 1999, 74 species of plants from 23 botanical families had disappeared from the sward of medium-moist, *Molinio--Arrhenatheretea* class meadows in the Greater Poland region. According to Kucharski [1999], 57 species of *Molinio-Arrhenatheretea* meadows in Central Poland are among the vulnerable ones.

Some meadow communities connected with extensive forms of management are among the most vulnerable ones. Floristically diverse meadows of *Arrhenatherion* are among the rare ones [Kucharski 1999]. The *Arrhenatherion* meadows are classified in the EU Habitat Directive [EEC 1992] as "Lowland hay meadows". They are located beyond the reach of the flooding rivers, in eutrophic and mesotrophic, moderately wet and periodically dry habitats. A wide variety of flowering plant species make them one of the most spectacular and decorative components of the landscape. Especially valuable are the moister parts of these meadows with numerous orchids. It is not only vital to preserve the floristic biodiversity of meadow communities, but also to restore the multi-species meadows. They are very important for nature conservation (protection of native, rare and endemic plant species) and environmental protection. In addition, floristically rich meadows are an important part of our cultural heritage. We must protect and restore them also for aesthetic, scenic and recreational purposes, which improves the quality of life in the region [Kozłowski 2002].

Soil seed bank can play an essential role in the restoration of semi-natural meadows [Bakker and Berendse 1999, Jacquemyn *et al.* 2011, Stroh *et al.* 2012]. As demonstrated by various authors, the richness of the grassland soil bank varies and depends on a number of factors: species composition of the sward and vegetation found in the vicinity both currently and in the past, biological properties of the species (individual fertility, longevity of seeds, morphology of diaspores), weather conditions and the type and intensity of management [Thompson *et al.* 1997, Lopez-Marino *et al.* 2000, Smith *et al.* 2002, Reiné *et al.* 2004, Stańko-Bródkowa 2008, Peng *et al.* 2010, Rossiter *et al.* 2014]. By examining soil seed banks can assess whether it is possible to restore species--rich meadows by using a given soil seed bank only – or whether it is necessary to introduce seeds obtained from another area. Some studies focusing on soil seed banks have demonstrated a high chance of restoring various types of grasslands [Jensen 1998, Liu *et al.* 2009, Kalamees *et al.* 2012, Stroh *et al.* 2012]. For example diaspores of target species of the dry calcareous grasslands are very abundant (approximately 70%) in the soil bank even 25 and 50 years after cessation of management [Kalamees *et al.* 2012, Metsoja *et al.* 2012, Sammuel *et al.* 2012]. Similarly, Jensen (1998) as well as Hölzel and Otte [2001, 2004] suggest that it may be possible to restore meadow communities of coastal floodplains from the diaspores constituting a persistent seed bank. While Bossuyt and Honnay [2008] indicate that seed banks may be useful for heathland restoration. But Wellstein *et al.* [2007] found that in mesic grasslands only a limited proportion of characteristic grassland species is likely to re-establish from the seed bank after disappearance from above-ground vegetation. Also, other results have shown that the seeds accumulated in meadow soils often do not correspond to the species composition of extant vegetation communities [Lopez-Marino *et al.* 2000, Bossuyt *et al.* 2006, 2008, Klimkowska 2006, Peng *et al.* 2010, Valko *et al.* 2011]. In Poland, little research has been conducted in this area, particularly refers to *Arrhenatherion* meadows, but these meadows along with other habitats were the subject of studies conducted in North West European countries [Thompson and Grime 1979, Grime *et al.* 1981, Thompson *et al.* 1997].

The main hypothesis of the study was the assumption that the seeds of partly degraded *Arrhenatherion* meadows are preserved in the topsoil layer and could be used for ecological restoration of multi-species sward. The aim of the studies was to determine the density and species composition of the deposits of diaspores in the topsoil (0-20 cm) of *Arrhenatheretum elatioris* meadows (habitat code 6510-1) and *Poa pratensis – Festuca rubra* meadows (habitat code 6510-2), as well as the distribution of seeds across four soil levels (0-5; 5-10; 10-15; 15-20 cm).

MATERIAL AND METHODS

Study area

The studies were carried out in central Poland, in two meadow habitats in the valley of the river Pisia Tuczna (37 kms west of Warsaw). In the first one, located at a distance of approximately 180-200 m from the river bed (geographical coordinates: 52°09′ N; 20°53′ E), there is an *Arrhenatheretum elatioris* meadow (habitat code 6510-1), and in the second, located at a distance of 260-280 m from the river bed (52°09′ N; 20°53′ E) a *Poa pratensis – Festuca rubra* meadow (habitat code 6510-2).

In the sward of *Arrhenatheretum elatioris* meadow 39 plant species were found, among them 15 grasses, 8 legumes and 16 species of nonlegume forbs. Cover of grasses in total amounted to 46.4% share of total cover. The dominant species among them were: *Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Presl, *Festuca rubra* L. and *Poa pratensis* L. Worth noting a low proportion of valuable tall grasses (18.3%) in the meadow sward. A large coverage – about 38% formed dicotyledonous species. The highest share among them had *Rumex acetosa* L., *Achillea millefolium* L., *Plantago lanceolata* L. and *Leontodon autumnalis* L. Moreover quite high proportions were legumes (13.6%), especially *Trifolium dubium* Sibth. The share of nine species amounted to 1-5%, and the remaining 22 species – less than 1%. In the sward of the *Poa pratensis – Festuca rubra* meadow less species were found – 26 species, among them 11 grasses, 6 *legumes* and 9 nonlegume forbs. In comparison with the *Arrhenatheretum elatioris* meadow, cover of dicotyledonous species was higher (above 43%) in particular *Rumex acetosa* L. and *Leontodon autumnalis* L.

The soils in the study area are mineral soils, classified as Phaeozems with loamy sand and sand texture, respectively [IUSS Working Group WRB 2006]. The pH of the soil of the *Arrhenatheretum elatioris* meadow is slightly acidic. The soil is characterised by very high levels of phosphorus (above 88 mg $P \cdot kg^{-1}$), high levels of magnesium (51--70 mg $Mg \cdot kg^{-1}$) and low levels of potassium (42-83 mg $K \cdot kg^{-1}$), (Table 1). The pH of the soil of the *Poa pratensis – Festuca rubra* meadow is a little lower than the soil of *Arrhenatheretum elatioris* meadow. These soils are characterized by medium-high levels of phosphorus (45-65.5 mg P·kg^{-1}) and magnesium (31-50 mg Mg·kg^{-1}) and very low levels of potassium (less than 41.5 mg K·kg^{-1}) (Table 1).

Table 1. Soil pH and the contents of organic matter (g·kg^{-1}) and selected macronutrients (mg·kg^{-1} of DM) in soil of the studied habitats

Habitat	$pH_{1\ mol \cdot L^{-1}\ KCl}$	mg·kg^{-1}			g·kg^{-1}
		P	K	Mg	C_{org}
Arrhenatheretum elatioris	5.33	181.30	49.80	53.0	14.44
Poa pratensis – Festuca rubra	4.90	59.00	24.90	43.0	12.01

In both habitats, the groundwater table is very similar, and below 150 cm in the period from the second decade of June to the second decade of August. Usually the differences between those habitats in successive measurements, taken every 10 days between April 1 and September 30, reached only a few (2-5) centimetres. In both habitats grasslands were established on former arable land and most of the crops were root crops and vegetables. The meadows are managed by cutting. In the past they used to be cut three times per year and they were intensively fertilized. At that time, they were also plowed every few years. Nowadays, they are extensive, occasionally fertilized meadows and usually cut twice a year [Rutkowska i Janicka 2001, Janicka 2012].

Soil samples

Soil samples used for the assessment of the soil seed bank were collected in April, before the fresh seed rain. The samples, with their structure intact, were randomly collected using a steel cylinder with a diameter of 11 cm and a height of 10 cm, with six replications for each meadow. The samples were collected up to a depth of 20 cm from two levels, 0-10 cm and 10-20 cm. Then, they were divided into four levels: 0-5 cm, 5-10 cm, 10-15 cm 15-20 cm. This way, 48 soil samples were obtained. The volume of a single sample was 475 cm^3 while the soil surface amounts to 95 cm^2. The total volume of samples of more than 11 L per habitat corresponds to the volume recommended by the literature [Hutchings 1986] for seed bank studies in grassland.

Seed determination

The size and species composition of the reserve of seeds in the soil were determined by extracting seeds from the soil samples. The samples were washed with running water on sieves (mesh width 0.25 mm). In order to separate the minerals from the organic matter, the material was poured over with a potassium iodide solution having a density of 1.60-1.66 g·cm^{-3}. As a result, the mineral parts were deposited at the bottom, and the diaspores and other organic contaminants remained on the surface of the solution. Afterwards, they were transferred onto filters, rinsed with distilled water and dried at a temperature of 60°C. From thus prepared samples live seeds (hard and undamaged ones) were selected under the binocular, other seeds (broken or visibly damaged ones) were rejected. Thus chosen diaspores were assessed in terms of species identification and abundance. The nomenclature of plant species is that used by Mirek *et al.* [2002].

Should be noted that the term plant “diaspores” are usually referred to as seeds, even though many of them are in fact fruits (dry fruits, do not open to disperse the seeds) [Thompson 1992]. So below the term "diaspores" was used in the meaning of seeds and dry indehiscent, single-seeded fruits. By analyzing the soil seed bank four groups of plants were distinguished:

1) grasses – monocotyledonous flowering plants, fruit is a caryopsis, in which the seed coat is fused to the fruit wall,
2) legumes – plants in the family *Fabaceae,*
3) annual forbs – one year a broad-leaved (not grass like) non-woody flowering plant, include all herbaceous dicotyledonous species,
4) perennial nonlegume forbs – many years', a broad-leaved, non-woody flowering plant.

Depending on the persistence forbs were divided into annual and perennial. In many species fruits are dry, indehiscent, and single-seeded (caryopsis, achene, nut, utricle).

The content of nutrients in the soil was determined by the following methods: pH (potentiometrically in 1 n KCl), the P content (colorimetric method), K was measured by flame photometry and Mg (flame atomic absorption spectrometry – AAS method).

Statistical analysis

The obtained results of seed distribution of all species together in four layers of the soil in both meadow communities were analysed statistically. However the distribution of seed numbers of particular species was not normal and normality cannot be achieved even by data transformation (log) and therefore not statistically analysed. One factor analyses of variance were conducted (ANOVA). The significance of differences between means was verified on the basis of Tukey's test and significance levels $p < 0.05$. Mean values for the items included in one homogenous group were marked with the same letters in the table. The calculations were performed using the Statgraphics Plus software, version 4.1. The similarity of seed bank and actual vegetation was analysed using Sørensen index. Sørenson similarity = 2w/(A+B), where A-number of species aboveground, B-number of species belowground and w-number of species found both above and belowground.

RESULTS

1. Density and species composition of the seed bank

In the 0-20 cm layer of the *Arrhenatheretum elatioris* meadow soil we found 56,430 seeds·m^{-2}, whereas in the *Poa pratensis – Festuca rubra* meadow the number of seeds were twice as high (118,510 seeds·m^{-2}). Species diversity of the soil seed banks of both communities was similar; in each of them diaspores belonging to 18 species of plants were identified. They included 4-6 species of grasses, 2-3 species of legumes (*Fabaceae*), and 9-12 species of nonlegume forbs (Table 2).

***Arrhenatheretum elatioris* meadow.** The seed bank was the most abundant in annual dicotyledons associated with arable land (Table 2). Three species of this group represented over 83% of the stock. The most numerous diaspores included C*henopodium album* (37,374 seeds·m^{-2}), followed by *Stellaria media* (6,703 seeds·m^{-2}), and *Senecio vulgaris* (2,772 seeds·m^{-2}). Among the seeds of perennial dicotyledonous species the most numerous diaspores included *Taraxacum officinale* (2,948 seeds·m^{-2}), which accounted for almost half of the seed bank of this group of plants. The second most abundant species was *Hypochoeris radicata* (1,228 seeds·m^{-2}). The number of *Rumex obtusifolius* (842 seeds·m^{-2}) and *Ranunculus acris* (667 seeds·m^{-2}) diaspores was relatively high as well. The proportion of grass and legume seeds was rather low, 5.8% altogether. Regarding grasses, the most abundant species included *Alopecurus pratensis*, *Arrhenatherum elatius* and *Bromus inermis*. The number of caryopses of each of these species was about 380-420 seeds·m^{-2}. Another species was *Holcus lanatus* (281 seeds·m^{-2}). With regard to *Fabaceae*, over half of the seed bank in the community was composed of *Vicia hirsuta* seeds (912 seeds·m^{-2}). Less numerous were the seeds of *Trifolium repens* (526 seeds·m^{-2}), and,the smallest in amount – *Trifolium dubium* (246 seeds·m^{-2}).

***Poa pratensis* – *Festuca rubra* meadow**. As in the soil of the *Arrhenatheretum elatioris* meadow, the seed bank was dominated by *Ch. album* (112,614.3 seeds·m^{-2}). Diaspores of this species constituted as much as 95% of the whole seed bank in this community, whereas diaspores of other annual dicotyledons constituted slightly more than 2% altogether (Table 2). Only 5 species of perennial dicotyledonous herbs and weeds were identified. The most abundant one was *R. obtusifolius* (1,930.1 seeds·m^{-2}; 76% of perennial dicotyledonous diaspores). Other species from this group were much less numerously represented, among them the most abundant one was *T. officinale* (210.6 seeds·m^{-2}). The proportion of grass and legume (*Fabaceae*) diaspores was very low, only 0.8% of the seed bank altogether. With regard to grasses, *Poa pratensis* caryopses were the most numerous (281 seeds·m^{-2}). With regard to legumes the seed bank was dominated by the seeds of *T. repens* (421.1 seeds·m^{-2}).

Table 2. Number of species and seeds of selected plant group in the topsoil 0-20 cm and percentage of seeds in the total number of diasporas depending on the plant community, seeds·m^{-2}

Plant group	*Arrhenatheretum elatioris*				*Poa pratensis – Festuca rubra* Ass.			
	species	seeds			species	seeds		
		number	%	±SD*		number	%	±SD
Poaceae	6	1,579.2	2.8	1,223.9	4	456.3	0.4	51.4
Fabaceae	3	1,684.5	3.0	73.1	2	491.3	0.4	19.1
Annual dicotyledons	3	46,849.5	83.0	2,925.4	7	115,035.7	97.1	6,922.9
Perennial dicotyledons (without *Fabaceae*)	6	6,316.8	11.2	1,634.0	5	2,526.7	2.1	166.5
Sum	18	56,430.0	100.0		18	118,510.0	100.0	

* SD – standard deviation

2. Distribution of seeds in four 5-centimetre deep layers of the soil

***Arrhenatheretum elatioris* meadow.** The largest number of diaspores (65% of the whole seed bank) was located more than 10 cm below the soil surface (Table 3). Only 17.7% of seeds were found in the shallowest layer of the soil (0-5 cm). In the next layer (5-10 cm), the number of seeds was similar, constituting 16.8% of the seed bank. The number of diaspores in individual layers became more varied with increasing depth. 24.6% of the seed bank was found at the depth of 10-15 cm and in the deepest layer (15--20 cm) as much as 40.9% was identified. The differences between the numbers of diaspores in the other two layers were not statistically proven (Table 3).

Table 3. Seed density in four 5-centimetre deep layers of the soil depending on the plant communities, seeds·m^{-2}

Soil layer, cm	*Arrhenatheretum elatioris*	*Poa pratensis – Festuca rubra*
0-5	9,966.5 *a**	9,650.6 *a*
5-10	9,475.2 *a*	30,004.7 *b*
10-15	13,896.9 *a*	36,146.1 *b*
15-20	23,091.4 *b*	42,708.5 *b*
$LSD_{0,05}$**	8,889.1	18,770.6

* different letters in the same column present significant differences at $P < 0.05$
**$LSD_{0.05}$ – Least Significant Difference, means are significantly different at the 95% level of confidence

***Poa pratensis – Festuca rubra* meadow**. As in the soil of the *Arrhenatheretum elatioris* meadow, the largest part of the seed bank was situated in the deeper topsoil layers of the soil. The most visible differences between the numbers of seeds were observed at a smaller depth. In the outermost layer (0-5 cm), only 8.1% of the seed bank was found, whereas in the next one (5-10 cm) the diaspores were three times as numerous and accounted for 25.3% of the seed bank (Table 3). The number of seeds increased with depth, but the differences between the two remaining layers in terms of seed numbers were not very important – approximately 5%. Seeds were the most abundant at a depth of 15-20 cm, where approximately 36% of the whole seed bank was found. From a statistical viewpoint, only the outermost layer (0-5 cm), where the smallest number of seeds was identified, differed significantly (Table 3).

3. Seed distribution in the soil layers per plant group

Seed distribution in the soil varied depending on the plant group. Irrespective of meadow community around 90% of grass caryopses, legume and perennial dicotyledons diaspores were identified in the outermost layers, up to a depth of 10 cm. Seeds of dicotyledonous annual weeds were mainly present in the deeper layers, i.e. more than 10 cm below the surface (65%), whereas they constituted only about 10% of the seed bank in the 0-5 cm layer (Fig. 1).

Such distribution resulted from the shape and mass of dominant species diaspores. Around 78% of relatively large, elongated *T. officinale* achenes (3-4.5 mm long) and 79-90% of grass caryopses were found in the outermost layers of the soil, whereas the small, round diaspores of *Ch. album* and *S. media* (0.9-1.5 mm in diameter), more easily penetrating soil cracks, were mainly present in the two lower layers (Table 4).

4. Similarity between actual vegetation and soil seed bank

It was found that the species composition of the soil seed bank in studied sites corresponded to approximately 30-40% of the botanical composition of meadow swards. Calculations made for the different levels of soil showed greater similarity in the upper levels than in the bottom which had more seeds of arable weed species. In the outermost layer (0-5 cm) the similarity was the greatest and decreased with soil depth from more than 60% to less than 20%. These relations were similar for both meadows. When considering similarity of particular groups of plants it was found the highest similarity with regard to legumes and grasses – respectively 62% and 58%, slightly lower in perennial herb and weeds (56%), while a very low for the annual dicotyledonous (15%) which are non-essential for the structure of meadow communities.

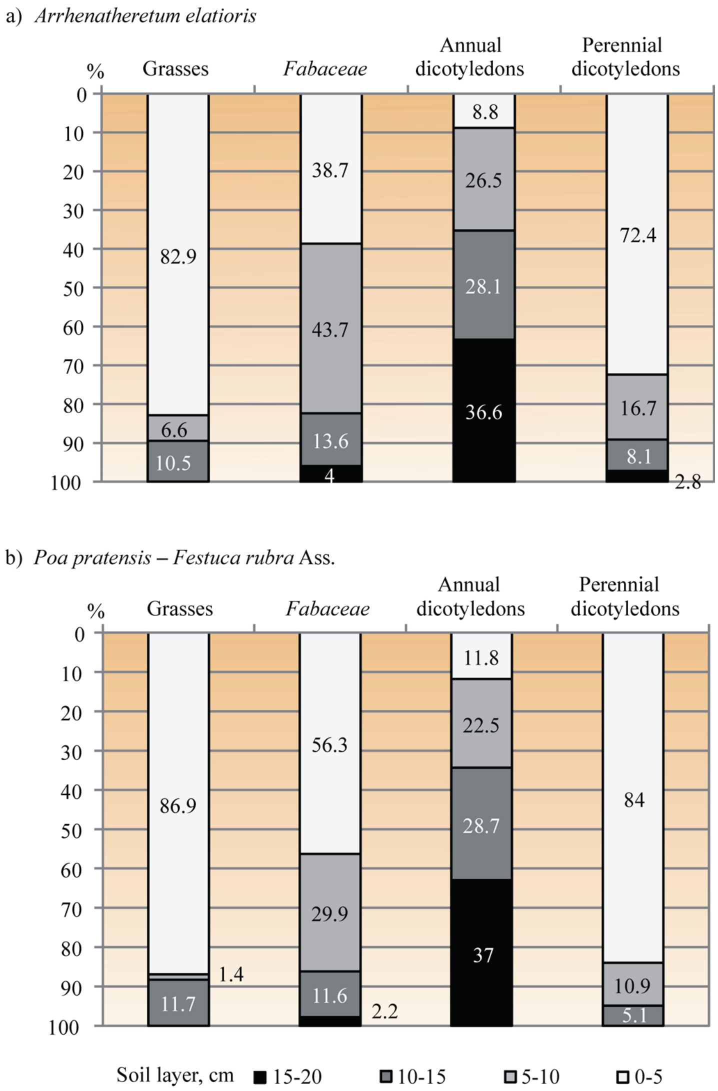

Fig. 1. Share of diaspores of selected plant group in the soil layers in both meadow communities, %

Table 4. Diaspore distribution of the dominant species in the soil layers in both meadow communities, %

a) *Arrhenatheretum elatioris*

Species	Soil layer, cm			
	0-5	5-10	10-15	15-20
Alopecurus pratensis	79.2	6.6	14.2	0.0
Poa pratensis	88.9	0.0	11.1	0.0
Trifolium repens	45.1	35.4	13.3	6.2
Chenopodium album	3.6	25.9	28.6	41.9
Stellaria media	7.0	15.5	57.7	19.8
Senecio vulgaris	96.8	0.0	1.6	1.6
Taraxacum officinale	77.6	17.4	4.2	0.8
Rumex obtusifolius	89.9	5.5	4.6	0.0

b) *Poa pratensis – Festuca rubra* Ass.

Species	Soil layer, cm			
	0-5	5-10	10-15	15-20
Festuca rubra	90.5	3.5	6.0	0.0
Poa pratensis	84.9	4.0	11.1	0.0
Trifolium repens	47.5	36.8	12.6	3.1
Chenopodium album	10.3	24.5	28.4	36.8
Stellaria media	6.8	16.7	54.8	21.7
Senecio vulgaris	92.7	4.9	2.4	0.0
Taraxacum officinale	78.2	13.8	6.6	1.4
Plantago lanceolata	71.7	17.4	6.5	4.4

DISCUSSION

In Poland yet there are few studies about the soil seed bank of *Arrhenatherion* meadows, but they were the subject of studies conducted in North West European countries [Thompson *et al.* 1997, Schmiede *et al*. 2009]. The soil seed banks of peatland, wetland and fen meadows located on organic soils [Klimkowska 2006] and xerothermic, dry calcareous grasslands [Czarnecka 2004] have been studied. Unfortunately these studies are not comparable to mesic grasslands because most mesic grassland species did not form a persistent seed bank [Bekker *et al.* 2000, Wellstein *et al.* 2007]. More often the soil seed banks have been studied in areas of fallow land [Falińska 1999, 2000]. The results of our studies describe some features of soil seed bank characteristics for extensive, occasionally fertilized *Arrhenatherion* meadows of central Poland, usually cut twice a year. The species richness and abundance of seeds and their distribution according to soil depth were evaluated. These informations are important for restoration working to improve floristic diversity of grasslands.

The seed bank in the dry-ground habitats of *Arrhenatheretum elatioris* meadows assessed in our studies proved to be more abundant than the seed bank in the soils of permanent mesic grasslands studied by other authors [Wellstein *et al.* 2007], which particularly refers to the soil of *Poa pratensis – Festuca rubra* meadow. According to Reiné *et al.* [2004], the density of seed banks in grassland soils is highly diversified. The authors identified from 6,000 to 54,500 live seeds per 1 m^2 in the topsoil (up to a depth of 20 cm), depending on the type and intensity of grassland management, fertilization and irrigation. Greater abundance of the seed bank assessed in our study results from the fact that this area was used as arable land in the past.

The most numerous in the soil seed bank are seeds of annual dicotyledonous species, which accounted for 83% (*Arrhenatheretum elatioris* meadow) and 97% (*Poa pratensis – Festuca rubra* meadow) in the 0-20 cm layer. These were mainly seeds of arable weeds or ruderal plants with a long flowering period characterized by high adaptability to different habitat conditions. This is consistent with the results obtained by others, e.g. Lopez-Marino *et al.* [2000] and indicates that studied area underwent past changes in land-use from arable to grassland. Therefore in meadow soils over half of the seed bank is often composed of arable weeds creating long term persistent seed banks that are non--significant for the structure of meadow communities. Similar phenomena have been reported by other authors from European grasslands (e.g. Grime *et al.* 1981, 1988, Bekker *et al.* 1997, López-Mariño *et al.* 2000, Hölzel et al. 2001).

The density of soil seed bank assessed in our studies was mainly composed by *Ch. album* seeds. That species is characterized by enormous individual fertility and seed longevity [Kwiecińska 2004, Dostatny and Małuszyńska 2008]. It germinates very quickly, which enables it to produce more than one generation per year. Moreover, *Ch. album* creates very persistent seed bank, the seeds for several decades retain their ability to germinate [Kwiecińska 2004, Dostatny and Małuszyńska 2008].

A large number of small, round diaspores of *Ch. album* and *S. media* was found in deeper layers (10-15 and 15-20 cm). This is in agreement with Thompson *et al*. [1998], confirming that mass and shape are two main indicators of vertical seed distribution in the soil [see also Bekker *et al.* 1998]. The presence of 85% caryopses of grasses and 78% *T. officinale* diaspores in the upper soil layer (0-5 cm), suggest that seeds of these species are characterized the slight movement in the soil. Large seeds, with a large surface to volume ratio, and those equipped with awns or plumose bristles, are more difficult to slide down the soil cracks and transported by earthworms or other soil animals. Moreover, as pointed out by many authors, seed distribution is highly dependent on grassland management and agricultural practice [Smith *et al.* 2002, Reiné *et al.* 2004]. As a result of soil inversion, diaspores accumulate in the deeper soil layers. Large accumulations of seeds (forming a persistent seed bank) found by us in deeper soil layers indicate that the area had previously been ploughed [Lopez-Marino *et al.* 2000, Wagner *et al.* 2003, Rossiter *et al.* 2014].

The similarity between actual vegetation and soil seed bank is in agreement with other studies indicated that the seeds accumulated in meadow soils often do not correspond to the species composition of meadow communities [Lopez-Marino *et al.* 2000, Bossuyt *et al.* 2006, Klimkowska 2006, Valko *et al.* 2011]. Bossuyt *et al.* [2006] failed to find the seeds of as many as 71 species normally occurring in the sward of grasslands located on poor limestone soils. Similarly, grass species characteristic for wetland meadows were virtually absent in the soil seed bank of the degraded meadow at Całowanie Fen [Klimkowska 2006]. One of the reasons of this phenomenon is the low dispersal and accumulation ability of the diaspores. Seed maturation is often interrupted by haying. Moreover, the seeds of most target species from mesic grassland, especially grass seeds, tend to remain in the soil for a short time (form only a transient seed bank). This is mainly due to their limited viability, usually from 3 to 5 years [Grime *et al.* 1988, Falińska *et al.* 1994, Thompson *et al.* 1998, Smith *et al.* 2002].

Thus, in order to restore the considerable floristic diversity of semi-natural meadows, including *Arrhenatheretum elatioris* meadows, especially after a long period of time, it is often necessary to introduce seeds. Seed mixtures can be directly harvested from the sward of existing high conservation value meadows which are ecologically and geographically close to the site to be restored or they can be composed of the seeds of individual species obtained from agricultural propagation of wild local ecotypes in Poland. Use regional provenances allow to avoid hybridisation and loss of local ecotypes [Scotton *et al.* 2012]. Whereas Godefroid *et al.* [2011] suggested using a higher number of transplants (preferring seedlings rather than seeds).

Therefore, studies have been conducted recently to investigate different techniques for harvesting seeds and transfer [Scotton *et al.* 2012]. The choice of seed harvest and transfer method depends on the species, the size of restoration area and financial resources. Moreover, it is very important to limit the competitiveness of the original sward. Transfer of seed-containing hay is easy and effective in the restoration of meadow communities [Kiehl *et al.* 2006, 2010]. This method is often successful, especially when has been applied with topsoil removal [Klimkowska *et al.* 2010].

SUMMARY AND CONCLUSIONS

The tested soil seed banks were dominated by diaspores of annual dicotyledonous species which were mainly seeds of arable land weeds or ruderal plants. The position of these species results from its enormous individual fertility and seed longevity and also from location of studied area and its former utilization. In order to restore the species-rich *Arrhenatherion* meadows located on former arable land, it is necessary to introduce seeds of target species because the dominant species of such meadows do not create permanent seed banks.

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OCENA GLEBOWEGO BANKU NASION W DWÓCH SIEDLISKACH ŁĄK RAJGRASOWYCH W POLSCE CENTRALNEJ

Streszczenie. Zarówno zbyt intensywne użytkowanie kośne lub pastwiskowe, jak i zaniechanie użytkowania prowadzą do ubożenia florystycznego zbiorowisk łąkowych. Ważną rolę w odtwarzaniu półnaturalnych łąk może spełniać glebowy bank diaspor. W Polsce badań z tego zakresu jest jednak niewiele, zwłaszcza w odniesieniu do łąk rajgrasowych. Celem badań była ocena wielkości i składu gatunkowego zapasu diaspor w wierzchniej warstwie gleby łąki rajgrasowej (*Arrhenatheretum elatioris*) oraz rozmieszczenia diaspor w czterech poziomach. Badania prowadzono w dwóch naturalnych siedliskach łąkowych: *Arrhenatheretum elatioris* (6510-1) i *Poa pratensis – Festuca rubra* (6510-2). Próby glebowe pobierano do głębokości 20 cm, a następnie podzielono na 4 poziomy: 0-5 cm, 5-10 cm, 10-15 cm i 15-20 cm. Wielkość i skład gatunkowy banku nasion w glebie określono metodą ekstrakcji nasion z prób glebowych. Liczba diaspor (nasion i owoców) w wierzchniej (0-20 cm) warstwie gleby wynosiła 56430 szt.$\cdot$m^{-2} (*Arrhenatheretum elatioris*) i 118,510 seeds$\cdot$m^{-2} (*Poa pratensis – Festuca rubra*). W glebowym banku diaspor dominowały owoce i nasiona jednorocznych gatunków dwuliściennych (ponad 80%), były to głównie nasiona chwastów pól uprawnych lub roślin ruderalnych. O wielkości ocenianych glebowych zapasów diaspor decydowały przede wszystkim diaspory *Chenopodium album*. Diaspory tego gatunku oraz *Stellaria media* (L.) Vill. znajdowały się głównie w dwóch dolnych warstwach gleby (poniżej 10 cm). Niezależnie od siedliska, w glebowym zapasie diaspor bardzo mały udział stanowiły *Poaceae* i *Fabaceae*. Na podstawie uzyskanych wyników można stwierdzić, że przywrócenie znacznej różnorodności florystycznej łąk rajgrasowych (*Arrhenatherion elatioris* All.) wymaga wprowadzenia diaspor.

Słowa kluczowe: *Arrhenatheretum elatioris*, łąki rajgrasowe, pionowe rozmieszczenie nasion w glebie, siedlisko priorytetowe 6510, skład gatunkowy, wielkość glebowego banku nasion

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