Seeds harvested during mowing from semi-natural grasslands as an ad hoc but effective solution for grassland restoration

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Species-rich grasslands formed by local ecotypes of native species provide numerous ecosystem services both in rural areas as well as urban grasslands. Nonetheless, their area is still too small, making grasslands one of the most frequently restored habitats. Successful restoration requires high-quality seed material, which is expensive and often not easy to acquire. In this study, we tested the potential of seeds accidentally collected during the mowing of a semi-natural grassland for grassland restoration. We tested seed purity, species composition, and germination capability in both laboratory and field conditions. Ninety percent of the collected material consisted of pure seeds of numerous species. Their germination capability was relatively low but still sufficient for successful grassland restoration under a typical seed density/mass per unit area seeding ratio. The germination capacity was the highest in the first two weeks after sowing and increased with overwintering seed storage. The results suggested that the seeds could be successfully used for species-rich grassland restoration. In terms of advantages, the seed mixture had a low cost and contained native species seeds representing local ecotypes. In terms of disadvantages, there was a relatively low amount of seed material and an inability to plan the time of seed harvesting. Thus, the use of the accidentally collected seeds can be considered an effective but rather ad hoc solution.

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Abstract

Species-rich grasslands formed by local ecotypes of native species provide numerous ecosystem services both in rural areas as well as urban grasslands. Nonetheless, their area is still too small, making grasslands one of the most frequently restored habitats. Successful restoration requires high-quality plant material, which is expensive and often not easy to acquire. In this study, we tested the potential of seeds accidentally collected during the mowing of a semi-natural grassland for grassland restoration. We tested seed purity, species composition, and germination capability in both laboratory and field conditions. Ninety percent of the collected material consisted of pure seeds of numerous species. Their germination capability was relatively low but still sufficient for successful grassland restoration under a typical seed density/mass per unit area seeding ratio. The germination capacity was the highest in the first two weeks after sowing and increased with overwintering seed storage. The results suggested that the seeds could be successfully used for species-rich grassland restoration. In terms of advantages, the seed mixture had a low cost and contained native species seeds representing local ecotypes. In terms of disadvantages, there was a relatively low amount of seed material and an inability to plan the time of seed harvesting. Thus, the use of the accidentally collected seeds can be considered an effective but rather ad hoc solution.

Introduction

Seminatural, species-rich grasslands provide numerous ecosystem services (Habel et al., 2013). Unfortunately, their area has diminished due to two contrasting processes: land abandonment in less productive areas, and management intensification on more suitable lands (Stoate et al., 2009; Pe'er et al., 2014). The advantages of species-rich, low-intensity urban grasslands are also valued in cities where grasslands that support higher biodiversity levels should be promoted in place of traditional, intensively used urban lawns composed of few grass species (Klaus, 2013; Bretzel et al., 2016; Ignatieva et al., 2020). As a result, grasslands are among the most frequently restored habitats (Török et al., 2011; Sojneková & Chytrý, 2015; Török et al., 2021), and species-rich, low-intensity urban grasslands have become more common in cities (Bretzel et al., 2016; Ignatieva et al., 2020). Successful restoration requires specific seed mixtures that represent local ecotypes of grassland plant species, which are more resistant to environmental conditions than commonly used commercial products (Hufford and Mazer, 2003; Durka et al., 2017). Moreover, the seed mixtures should be species-rich, since biodiversity correlates positively with the ecosystem services provided by grasslands (Thompson & Kao-Kniffin, 2016; Onandia et al., 2019), and species-rich grasslands are more resistant to environmental stresses such as drought (De Keersmaecker et al., 2016; Cole et al., 2018).

Providing appropriate seed sources for grassland restoration is challenging (Rudolph et al., 2017; Muir et al., 2018; Ignatieva et al., 2020). The commercially available seed mixtures do not always fulfil the abovementioned requirements (Kiehl et al., 2010; Schaub et al., 2021). Some countries such as Germany have a well-developed production of native seed mixtures that respect seed zones, that is, providing seeds of plants adapted to local climate (Durka et al., 2017).

82 However, seeds from high-quality plantations are expensive, especially in the case of species-
83 rich mixtures (Schaub et al., 2021). In other countries, such as Poland, obtaining species-rich
84 seed mixtures of native plants with known geographical origins is a problem. Therefore,
85 alternative methods such as spreading fresh hay or using seeds brushed from semi-natural
86 meadows are applied, but they are also costly (Schaub et al., 2021). Another possible solution is
87 to use seeds that are accidentally collected during mowing, but their potential for restoration is
88 unknown.
89   In this article, we assessed the quality of a seed mixture obtained accidentally from a
90 mower machine working in valuable grasslands patches. We examined the seed composition,
91 rate of seed germination, level of transferability, and the overall potential for grassland
92 restoration. The obtained results were compared with data regarding the characteristics of seeds
93 obtained from other sources.
94
95

96 **Materials & Methods**

97

98 **Seed donor site description and method of seed material harvesting**
99 Seeds were collected at the Experimental Station of Wrocław University of Environmental and
100 Life Sciences in Radomierz (50°54'15.1"N 15°53'58.8"E), Silesia, Poland, Central Europe. The
101 station is located in the sub-mountain area of the Kaczawskie Mountains, with an annual sum of
102 precipitation of 850 mm and a mean annual temperature of 9°C. Dystrict Cambisol is the
103 dominant soil type. The station covers 150 ha of extensively used pastures and 100 ha of
104 meadows and arable lands, where approximately 200 Charolais cattle are bred. The livestock is
105 grazed on the pastures during the entire growing season, and rotation pasturage is used with
106 sporadic mowing. During field observation in June 2020, 95 plant species of grasses, legumes,
107 and herbs were found in the area of mowed meadow where the seeds were collected (*Table S1*).
108 The dominant species were grasses: *Trisetum flavescens* (L.) P. Beauv., *Dactylis glomerata* L.,
109 *Arrhenatherum elatius* (L.) J. Presl & C. Presl, *Agrostis capillaris* L., *Festuca rubra* L., *Poa*
110 *pratensis* L., *Festuca pratensis* Huds.
111   The seeds were collected accidentally as remains on a mowing machine (front-mounted
112 disc mower Kuhn GMD3125F-FF) after mowing an area of ca. 8 ha semi-natural grassland on
113 July 14, 2020 (*Fig. S1*). The seeds and residuals (e.g., chuff, husks, and dirt) were collected from
114 the mower housing using a brush, several times during each technical breaks, and stored in a
115 cloth bag. The weight of the fresh material collected was approximately 5 kg (*Fig. S2*). The
116 material was mixed thoroughly to achieve sample homogeneity. Then, the spoon method (Van
117 der Veen & Fieller, 1982) was used for sampling.

118

119 **Seed purity and seed identification**
120 To determine the purity of the seeds (i.e., fraction of pure seed mass to residuals), 20 samples
121 were taken, each weighing 1 g (*Fig. S3*). Using a stereo microscope, the seeds were manually

122   separated from the residuals and weighed. An additional 10 samples, each weighing 1 g, were
123   taken for species identification based on the morphology of the seeds (i.e., seed identification).
124   The seeds were observed using the stereo microscope, and their taxonomical identification was
125   done using the Seed Identification Guide (www.idseed.org) according to Kozłowski (2012).
126
127   **Germination capacity**
128   The Petri dish method was used to test the germination capacity of the collected seeds. Thirty
129   seed samples each weighing 1 g (sampled in June 2020) were taken for germination trials (*Fig.*
130   *S4*). Germination tests began in three seasons: July 2020 (J20), October 2020 (O20), and March
131   2021 (M21). For the test in summer (J20), seeds without any pretreatment were used. For the test
132   in autumn (O20), the seeds were kept in a refrigerator at 5°C for two weeks and −10°C for one
133   week. Eventually, for the third germination test in Spring 2021 (M21), the seeds were stored
134   during the entire winter in outdoor conditions. The three methods were intended to represent
135   typical situations: seed used immediately after collection, seed with freezing pretreatment, and
136   seed seeded in spring after overwintering in natural conditions. In each period, the tests were
137   performed using 10, 1-g samples in 10 Petri dishes. The percentage of germination was evaluated
138   after 7, 14, 21, 28, 35, and 42 days for both monocotyledonous and dicotyledonous plants. To
139   calculate the seed germination percentage, the average number of seeds in a 1-g sample was
140   used.
141
142   **Pot experiments**
143   Two pot experiments were established to assess the species composition of the emerging
144   seedlings. Ten, 1-g seed samples were sown in individual plastic pots sized 47 ×15 × 15 cm. The
145   pots were filled with commercially available soil substrate (pH = 6.07; N = 8.04 g/kg; P = 42.25
146   g/kg; K = 295.00 g/kg; Mg = 157.21 g/kg; C ≥ 30 %), and the seeds were broadcasted on the
147   soil. They were pressed to the soil, and not covered by an additional soil layer. The seeds were
148   sown in two periods: July and October of 2020 (*Fig. S5*). Both trials were carried out in a
149   common garden, and the pots were kept outside during the winter. Twice a week a manual
150   watering was applied, except for the winter. In the pots with seeds sown in July 2020, the plants
151   were cut to a height of 3–5 cm in October 2020. Identification of species in the pots with seeds
152   sown in July was performed two times, in October 2020 and May 2021, while in the pots with
153   seeds sown in October, the observations were done once, in May 2021.
154
155   **Field experiment**
156   A field experiment was carried out in two city parks in Wrocław to compare the seeds collected
157   from mower with commercially used seed mixtures, and fresh hay application, whether it has
158   the features and potential for city grassland improvement (*Fig. S6, S7*). The vegetation (i.e.,
159   species composition and cover) developed from the examined mower seed mixture (MO) was
160   compared with that emerging after applying four other seed sources: a flower meadow seed
161   mixture (FM), a road margin seed mixture (RM), a thermophilus margin seed mixture (TM), and

162   seeds delivered by spreading fresh hay (FH). The FM mixture represented a commercial seed
163   mixture of 14 species of unknown geographical origin claimed to deliver food for bees produced
164   by the SAATBAU company. The RM and TM seed mixtures were distributed by specialized
165   company Rieger-Hofmann® GmbH, focusing on the production of seed mixtures of native
166   species with controlled geographical origins. The RM mixture contained seeds of 57 species that
167   are typical of semi-natural grasslands and suitable for creating road-margin vegetation. The TM
168   mixture contained seeds of 57 dicotyledonous species characteristic of the vegetation found in
169   thermophilus margins. Finally, the fresh hay (FH) was collected from the Radomierz station
170   from a grassland patch where 53 plant species were recognized.
171   Experimental plots were arranged according to complete randomization schemes with
172   four replicates for all treatments. The size of an individual plot was 2.5 × 2.5 m. A particular
173   seed source was represented by eight plots (four repetitions of two parks). The entire
174   experimental area was mowed, the resident vegetation was removed in July 2020, and the soil
175   was prepared using a rototiller. The fresh hay was collected on July 31, 2020 and immediately
176   transported to experimental sites for spreading. The ratio of donor to acceptor site area was 1:1,
177   and the fresh hay layer covered the soil at a thickness of ca. 10 cm. The seeds were seeded in
178   September 2020 at a seed rate recommended by the producer: 2 g×m-2 for TM, and 4 g×m-2 for
179   RM, FM, and MO. Afterward, the seeded soil was rolled. In addition to the experimental plots,
180   four additional squares per experiment were placed in the corners of the experimental area. The
181   additional plots served as a control; they were mowed but not rototilled, rolled, nor seeded. The
182   species composition and percentage cover of the plants were assessed visually for areas (2 x 2 m)
183   in the center of each experimental plot in June 2021, giving a buffer with a width of 1 m between
184   neighboring treatments.
185
186   **Statistical analyses**
187   The frequency of species occurrence in the seed identification, pot experiment, and field
188   experiment was expressed as a fraction of the repetitions, where seedlings (or seeds) of a given
189   species were found. The total average frequency was calculated based on the average frequencies
190   for all trials. The significance of differences between periods of observation in the germination
191   capacity trial was verified using the Friedman test, as well as the Wilcoxon pairwise test with a
192   Bonferroni correction as a post hoc test. The total percentage of germination and seedling
193   emergence in the particular seasons (i.e., J20, O20, and M21) was determined using the Kruskal–
194   Wallis test, with Monte-Carlo permutation and Mann–Whitney test with Bonferroni correction as
195   post hoc test. The same tests were applied to evaluate the results of the pot and field experiments.
196   Statistical analyses were performed using Past 4.06b software.
197   The transfer rate was calculated as the percentage of transferred species relative to the
198   total number of species of the donor site (Kiehl et al., 2010; Scotton, Kirmer & Krautzer, 2012).
199   Since, in the field experiment, the presence of seeds from a local seed bank or local species pool
200   could not be excluded, we did not consider all species found in this experiment as emerging from
201   the evaluated seed mixture. However, if the species that occurred in the field were also detected

202 in seed species identification and in the pot trials, we assumed that they came from the seed
203 mixture.
204

Results

Seed purity and seed identification

207 The 1-g samples contained on average 0.9 g (SD = 0.039) of pure seeds and 0.1 g (SD = 0.039)
208 of residuals. The average number of seeds per 1-g sample was 1267 (SD = 151.3). At the species
209 level, the seeds of 19 different species were recognized, the most frequent of which were
210 *Alopecurus pratensis*, *Dactylis glomerata*, *Festuca pratensis* and *F. rubra* (for detailed results,
211 see *Table 1*). The visual assessment showed that the seeds of *Alopecurus pratensis* were the most
212 abundant in the samples.
213

Germination capacity

215 There were significant differences in the number of seeds germinating on Petri dishes between
216 the observation seasons (i.e., J20, O20, and M21) and over the weeks of the experiment: for
217 monocotyledonous species, $\chi2 = 138.87$ and $p < 0.05$; for dicotyledonous species, $\chi2 = 36.629$
218 and $p < 0.05$ (*Fig. 1A-B*). The monocotyledon seeds sowed in Autumn 2020 (O20) and Spring
219 2021 (M21) exhibited the highest germination rate during the first week of the trial, while the
220 seeds sown in Summer 2020 (J20) exhibited the highest germination rate during the second week
221 (*Fig. 1*). However, seedling germination generally decreased over time. We did not observe
222 significant differences between observation weeks for dicotyledonous plant germination, except
223 for the highest germination rate in the first week of the Autumn 2020 (O20) trial.
224   The detailed results of total germination (i.e., the sum over six weeks) are presented in
225 *Fig. 2*. The number of emerged monocotyledon seedlings differed significantly between the
226 seasons ($\chi2=7.646$, $p=0.022$), while that of dicotyledonous seedlings did not ($\chi2=4.638$,
227 $p=0.084$). In the spring trial (M21), after overwintering, the total germination of monocotyledon
228 seeds was better than that of the summer trial (*Fig. 2A*).
229   Similarly, the total germination percentage after six weeks significantly differed between
230 the seasons ($\chi2 = 8.12$; $p = 0.02$, Fig. 3). The percentage of emerged seeds sown in Spring 2021
231 (M21), after overwintering, was higher (44.05%) than that of seeds sown immediately after
232 collecting in Summer 2020 (J20, 39.93%) (*Fig. 3*).
233

Pot and field experiments

235 In the pot experiment, 31 species were found in all observation periods and sowing seasons
236 (*Table 1*). We did not found significant differences in species richness between sowing periods,
237 observation periods, or sowing x observation interactions. During the observations, a visual
238 assessment determined that *Holcus lanatus* L. was the most abundant species.
239 In the field experiment, the plant species richness of the plots where seed addition was applied
240 differed from the control plots (H=21.77, p<0.001). However, we did not observe significant
241 differences between the plots with seeds from the mower (MO) and the plots where seeds from

242   other sources were added (*Fig. 4A*). We also observed differences in vegetation cover (H=19.74,
243   p<0.001): the plots where the RM mixture was applied had less cover than the control plots (*Fig.*
244   *4B*).
245   Considering the pot and field experiments, altogether, 41 plant species were found (*Table 1*).
246   Typically, monocotyledons showed a high probability of occurrence, which were mostly grasses
247   (Poaceae), while dicotyledons showed a low frequency. In the field experiment, 28 species were
248   observed (*Table 1*). Among these species, grasses such as *Arrhenatherum elatius* (30.7%) and
249   *Lolium perenne* (16.3%) had the highest cover, and *Trifolium repens* L. (4.8%) was the
250   dicotyledonous species with the highest cover.
251
252   **Transfer rate**
253   Among the 42 species found in this evaluation, 11 occurred in all three trial types. Among them,
254   seven species were grasses (*Arrhenatherum elatius*, *Dactylis glomerata*, *Holcus lanatus*, *Lolium*
255   *perenne*, *Phleum pratense*, *Poa pratensis*, and *Trisetum flavescens*), and four were
256   dicotyledonous (*Leucanthemum vulgare*, *Rhinanthus minor*, *Rumex acetosa*, and *Rumex*
257   *obtusifolius*) (*Table 1*). In our donor area, 95 plant species were found (*Table S1*). During all of
258   the three main trials (i.e., seed identification, pot, and field experiments) 40 of these species were
259   also found at the donor site. Calculated in this way, the transfer ratio was 42%. In the field
260   experiment, 28 species that potentially emerged from the seed mixtures were found. However,
261   we cannot exclude the possibility of contamination by propagules within the vicinity of the
262   experiment and/or soil seed bank. However, 21 species that occurred in the field experiment
263   were also confirmed in other trials (i.e., seed identification and/or pot experiments). Therefore, a
264   conservative estimate suggests a transfer rate of 22% (percentage for 21 species), which perhaps
265   reaches 29% by taking the 28 species of unconfirmed origin into account.
266

267   # Discussion
268   Regardless of the seed-harvesting method, the seed material is always contaminated by residuals
269   of stems, leaves, and flowers (Scotton, Kirmer & Krautzer, 2012). Our results revealed that the
270   processes that led to seeds remaining on the mower surface also led to separating the seeds from
271   the residuals. As a result, our samples had a much higher percentage of pure seeds (90%)
272   compared to materials collected by threshing (25–65%), seed-stripping (30–45%), green and dry
273   hay harvesting (0.2–2%), as well as topsoil stripping and turfing (< 0.1%) (Scotton, Kirmer &
274   Krautzer, 2012).
275   Unfortunately, the germination capacity observed here (the overall average was
276   42±2.7%) was considered rather low. Seed materials harvested via on-site threshing and seed-
277   stripping have yielded germination capacities of 60% and 70–80%, respectively (Scotton, Kirmer
278   & Krautzer, 2012). According to Haslgrübler et al. (2015), after storing at room temperature for
279   one year, the germination capacity reached an average value of 54% for on-site threshing and
280   78% for seed-stripping. Scotton, Kirmer & Krautzer (2012) observed a 50–60% germination rate
281   after storage at room temperature.

282   The successful germination of our seeds was promoted by cold stratification. During dry storage,
283   seeds of many species have a chance to after-ripen and become capable of germination (Wagner
284   et al., 2021). The seed dormancy strategy is species-specific, and the cold stratification is
285   required to enhance seed germination (Schröder, Glandorf & Kiehl, 2018). Thus, it is suggested
286   that seeds harvested from semi-natural grasslands should be stored under cool conditions (2–5°C
287   with 40–50% humidity) and used within two years (Haslgrübler et al., 2015). Apart from the
288   abovementioned conditions, seed germinability is strongly affected by seed collection date
289   (Scotton et al., 2009). Unfortunately, in the case of seeds collected accidentally, this collection
290   date cannot be changed and depends on mowing terms.
291   Information regarding the thousand seed weight, purity, and germination capacity of the seed
292   material is necessary to decide the suitable seed rate and application method (Krautzer et al.,
293   2013). According to a review by Kiehl et al. (2010), when using site-specific seed mixtures,
294   approximately 1–5 g of seeds per square meter is sufficient for grassland restoration, which
295   responds to a seed density in the range of 1300 to 4600 seeds per square meter (Schröder,
296   Glandorf & Kiehl, 2018; Schröder & Kiehl, 2020). In our study, we used a seed rate of 4 g/m2,
297   which consisted of approximately 5068 seeds per square meter (1267 seeds per gram), and we
298   obtained an average total coverage of 94.6% in the restored grasslands. Therefore, in spite of the
299   relatively low germination rate of the tested seeds, the typical seed number/mass per square
300   meter used for restoration was sufficient for successful grassland establishment. The results of
301   the field experiment proved that the seeds germinated well in the field conditions, considering
302   that both the cover and species richness of the vegetation was similar to those obtained by
303   applying professional seed mixtures. These results can change over time, but since the seeds
304   from the mower were well adapted to the local climate, it can be expected that the plants would
305   survive and perform well in urban conditions.
306   The species composition of a collected seed material depends on the character of the seed donor
307   site (e.g., altitude and soil nutrients), time of day during harvesting, vegetation season of the
308   harvest, weather conditions, and potential seed production. Late harvest increases the number of
309   legumes and other forb seeds (Scotton et al., 2009; Scotton, Kirmer & Krautzer, 2012). In our
310   case, the low frequency of herbs could be the result of harvesting too early, and perhaps if the
311   mowing was performed at the end of August or in September, the richness of dicotyledon species
312   would be higher (Hitchmough, Paraskevopoulou & Dunnett, 2008).
313   The transfer rate depends on numerous factors: site condition, seed-material quality, soil
314   preparation, weather, soil seed bank, vegetation type, harvesting method, and restoration method
315   (Scotton, Kirmer & Krautzer, 2012). The typical transfer rate for grasslands is 30–50% in the
316   first year after application (Hellström et al., 2009, Scotton, Kirmer & Krautzer, 2012). Therefore,
317   our results (average transfer rate 22–29%) suggested that the transfer rate of the seeds collected
318   accidentally from a mower was rather low. Nonetheless, the results of the field experiment
319   proved that the species richness of the tested seed mixture did not differ significantly from that of
320   other seed mixtures. Thus, the overall effect in terms of biodiversity was comparable.

321 In Europe, commercial seed mixtures are typically used for grassland restoration. However, they
322 have many disadvantages, such as containing seeds of different provenances representing non-
323 native ecotypes, and being produced from genetically uniform lines that are optimized for seeds
324 production for agriculture or gardening purposes (Kiehl et al., 2010; Schaub et al., 2021).
325 Typical commercial seed mixtures contain 1–10 species, which is not sufficient to support
326 biodiversity (Schaub et al., 2021), while seed mixtures containing more than 30 species,
327 representing native ecotypes, are usually required for conservation purposes (Schaub et al.,
328 2021). Furthermore, non-legume herbs are absent from many seed mixtures because much of the
329 production of grassland seeds focuses on intensively managed grasslands (Schaub et al., 2021).
330 In contrast to commercial seed mixtures, our samples consisted of more than 30 native species.
331 Among them, 21 species, including rare ones, were able to germinate in field conditions. As an
332 example, interestingly, we observed the germination of the semi-parasitic plant species
333 *Rhinanthus minor* L., which is not commercially available. The most frequent species (i.e.,
334 *Arrhenatherum elatius*, *Dactylis glomerata*, *Phleum pratense*, *Poa pratensis*, *Trisetum*
335 *flavescens*, and *Leucanthemum vulgare*) are considered plants typical of semi-natural grasslands
336 in Central Europe (Leuschner & Ellenberg, 2017). Thus, the observed species composition can
337 be described as desirable in terms of nature-conservation potential. In conclusion, in spite of a
338 rather low germination percentage and transfer rate, the examined seed mixture can still be used
339 successfully to establish a species-rich grassland.
340 If native rare species are produced for commercial seed mixtures, they are difficult to cultivate, it
341 takes several years to propagate seeds, and the cost of production is high (Kiehl et al., 2010).
342 Highly diverse seed mixtures (10–49 species) containing native ecotypes are even more
343 expensive than standard mixtures (1–8 species) by approximately 75% per hectare (Schaub et al.,
344 2020, Schaub et al., 2021). Because of these high costs, Török et al. (2011) recommended the
345 application of high-diversity mixtures in small plots and low-diversity mixtures in large areas. It
346 should also be mentioned that fresh hay applications are also costly, since they require a lot of
347 space for transportation and labor (Shaw et al., 2020; Schaub et al., 2020).
348
349

Conclusions
351 A seed mixture collected accidentally from a mower after mowing semi-natural, species-rich
352 grasslands contained high-purity seeds of numerous species. Their germination capability was
353 relatively low but still sufficient for successful grassland restoration with a typical seed
354 density/mass per unit area seeding ratio. The germination capacity was the highest in the first
355 two weeks after sowing and increased with overwintering seed storage. The results suggested
356 that the seeds could be successfully used for species-rich grassland restoration. In terms of
357 advantages, the seed mixture was low-cost and contained the seeds of native species representing
358 local ecotypes. In terms of disadvantages, there was a relatively low amount of seed material, as
359 well as an inability to plan the time of seed harvesting. Thus, the use of the accidentally collected
360 seeds can be considered an effective but rather ad hoc solution.

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Figure 1

Weekly average seedling emergence of monocotyledonous (A) and dicotyledonous (B) plants.

J20, seeds sown in Summer 2020; O20, seeds sown in Autumn 2020, and M21, seeds sown in Spring 2021. Values followed by the same letter are not significantly different. In the case of dicotyledonous species (panel B), the number of seedlings in the first week differed significantly exclusively in the O20 treatment compared to the other treatments.

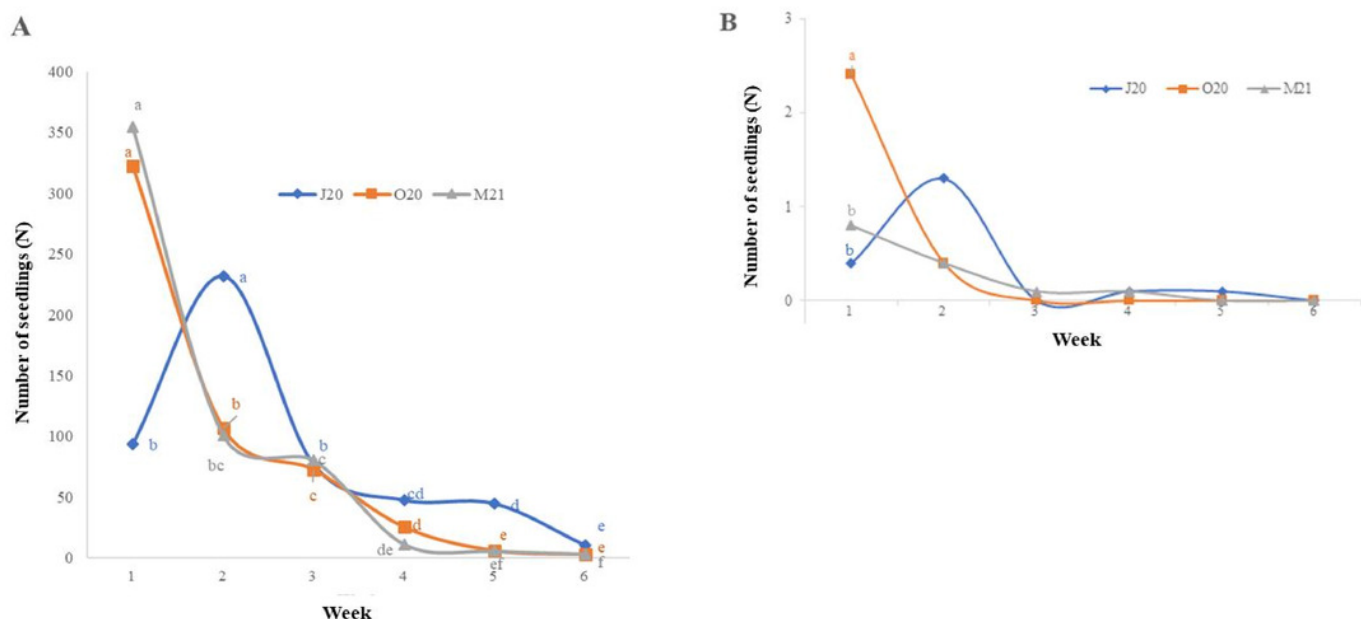



Figure 2

Number of seedlings emerged in different sowing seasons (total germination): (A) monocotyledons and (B) dicotyledons.

J20, seeds sown in Summer 2020; O20, seeds sown in Autumn 2020, and M21, seeds sown in Spring 2021. The different lowercase letters indicated significant differences among seasons. The median value (thick line), upper and lower quartiles (box), minimum and maximum (whiskers), and kernel density estimation (filed area) are shown.

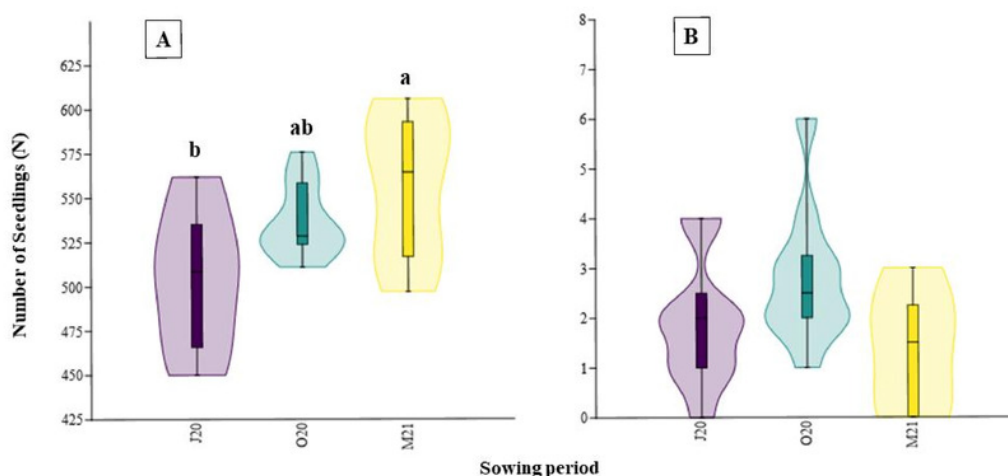



Figure 3

Total percentage of germination of seeds collected in different sowing periods.

J20, seeds sown in Summer 2020; O20, seeds sown in Autumn 2020, and M21, seeds sown in Spring 2021. The different lowercase letters indicated significant differences among seasons. The median value (thick line), upper and lower quartiles (box), minimum and maximum (whiskers), and kernel density estimation (filed area) are shown.

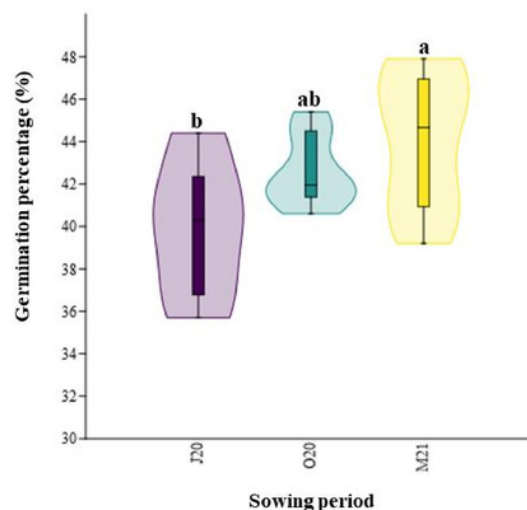
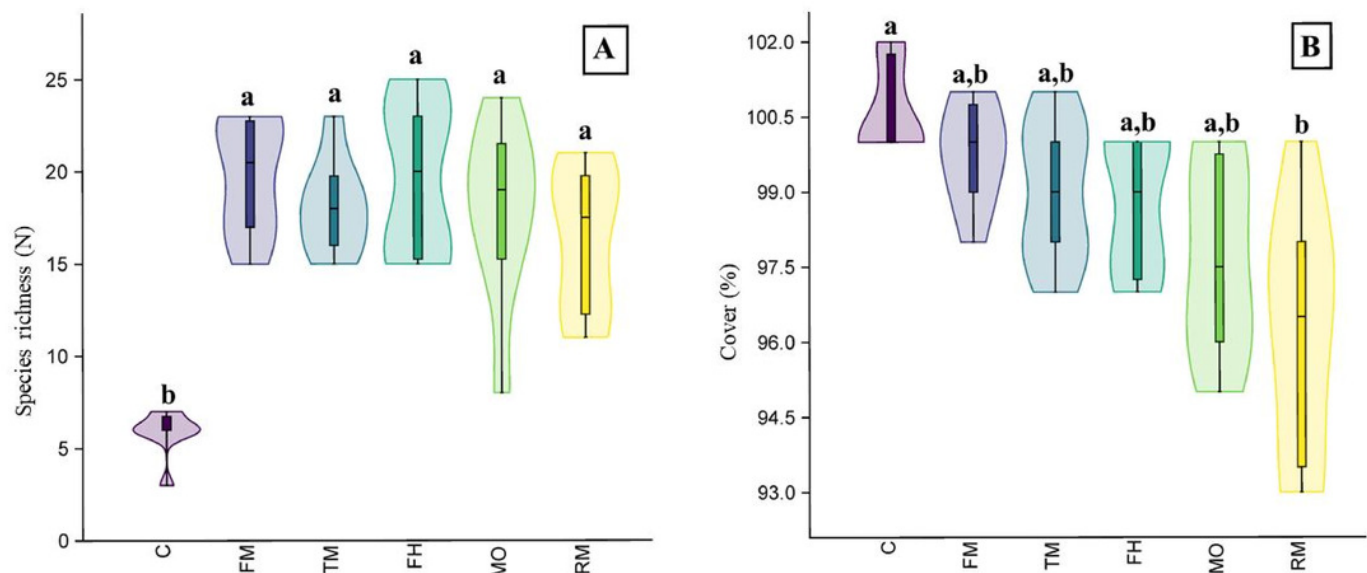



Figure 4

The species richness (A) and cover (B) results of the field experiment.

On the graph, the results of the post-hoc comparisons are presented: values followed by the same letter are not significantly different. The median value (thick line), upper and lower quartiles (box), minimum and maximum (whiskers), and kernel density estimation (filed area) are shown. Abbreviations: MO – seeds from mower, RM – road margin seed mixture, TM – thermophilus, FM – floral meadow, C – control.

Frequencies (freq) and cover of plant species in the experiments.

Frequency (freq) and cover of plant species based on the following: the morphology of the seeds (Seed identification), the pot experiment (Pot), and the plots of the field experiment where seeds collected by the mower (Field experiment) were sown. The last column shows the average frequency for all trials (Average frequency).

Species	Seed identification (freq)	Pot			Field experiment		Average frequency
		Sowed July 2020		Sowed October 2020			
		October 2020 (freq)	May 2021 (freq)	May 2021 (freq)	(freq)	Cover (%)	
Agrostis capillaris L.	-	1.00	0.90	1.00	-	-	0.48
Alopecurus pratensis L.	1.00	0.30	0.10	0.20	-	-	0.27
Anthoxanthum odoratum L.	0.90	0.40	-	-	-	-	0.22
Anthriscus sylvestris (L.) Hoffm.	0.10	-	-	-	-	-	0.02
Arrhenatherum elatius (L.) J.Presl & C.Presl	0.90	0.70	0.90	1.00	0.8	30.7	0.83
Artemisia vulgaris L.	-	0.40	0.20	0.20	0.3	0.5	0.22
Bromus hordeaceus L.	0.30	-	-	-	0.5	2.8	0.22
Campanula patula L.	-	-	-	0.30	-	-	0.05
Cerastium fontanum Baumg.	-	0.10	0.50	0.70	0.5	5.1	0.22
Cirsium arvense (L.) Scop.	-	-	-	0.20	0.5	1.0	0.20
Convolvulus arvensis L.	-	-	-	-	0.1	0.5	0.04
Dactylis glomerata L.	1.00	1.00	1.00	1.00	0.4	1.8	0.79
Deschampsia caespitosa (L.) P. Beauv.	-	0.20	-	-	-	-	0.03
Dianthus deltoides L.	-	-	-	-	0.4	0.5	0.13
Elymus repens (L.) Gould	-	0.90	0.80	0.70	0.4	1.5	0.53
Festuca pratensis Huds.	1.00	0.20	-	0.10	-	-	0.22
Festuca rubra L.	1.00	0.70	0.50	0.70	-	-	0.48
Galium mollugo L.	0.60	-	-	-	0.1	1.0	0.14
Holcus lanatus L.	0.90	0.90	1.00	1.00	0.8	1.2	0.88
Hypochaeris radicata L.	-	-	-	-	0.1	1.0	0.04
Leucanthemum vulgare Lam.	0.20	0.50	0.50	0.10	0.3	1.5	0.30
Lolium perenne L.	0.30	1.00	0.50	0.30	0.5	16.3	0.52
Phleum pratense L.	0.60	0.10	-	-	0.3	2.0	0.20
Plantago lanceolata L.	-	0.10	-	-	0.4	1.5	0.14
Poa pratensis L.	0.90	0.90	1.00	1.00	0.8	2.9	0.88
Polygonum persicaria L.	-	0.10	0.20	0.20	-	-	0.08
Ranunculus acris L.	-	-	0.10	-	-	-	0.02
Ranunculus repens L.	0.10	-	-	0.20	-	-	0.05
Rhinanthus minor L.	0.10	-	0.10	-	0.3	1.3	0.12
Rumex acetosa L.	0.90	0.40	0.60	0.70	0.1	2.0	0.48
Rumex obtusifolius L.	0.10	0.10	-	-	0.1	0.5	0.08
Stellaria holostea L.	-	0.10	-	-	-	-	0.02
Stellaria media (L.) Cirillo	-	0.30	0.50	0.40	0.1	1.0	0.24
Tanacetum vulgare L.	-	-	-	-	0.1	0.5	0.04
Taraxacum officinale (L.) F.H.Wigg	-	0.10	0.10	0.10	1.0	3.8	0.38
Trifolium pratense L.	-	-	-	-	0.4	2.0	0.13
Trifolium repens L.	-	-	-	0.10	0.5	4.8	0.18
Trisetum flavescens (L.) P.Beauv.	0.80	0.10	-	-	0.5	2.2	0.32
Urtica dioica L. **	-	0.20	0.10	0.10	-	-	0.07
Veronica chamaedrys L.	-	-	-	-	0.8	1.7	0.25

Vicia hirsuta (L.) Gray	-	-	-	-	0.4	3.0	0.13
Unrecognized species from Poaceace	-	-	0.10	-	-	-	0.02
number of species	19	25	20	22	28	28	42

** - species occurred in experiments, but not in the donor site

1   **Table 1.** Frequency (freq) and cover of plant species based on the following: the morphology of
2   the seeds (Seed identification), the pot experiment (Pot), and the plots of the field experiment
3   where seeds collected by the mower (Field experiment) were sown. The last column shows the
4   average frequency for all trials (Average frequency).