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Short communication

Fast restoration of grassland vegetation by a combination of seed mixture sowing and low-diversity hay transfer

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ABSTRACT

Technical reclamation of grasslands is a powerful tool for conserving biodiversity in fragmented landscapes. Plant material transfer and sowing seeds of local provenance are used most frequently to recover grassland vegetation in former croplands. The joint application of these methods is rarely used, although it has the potential to gain a predictable and directed vegetation development with effective early weed suppression. We studied the effectiveness of combining low diversity seed sowing and hay-transfer in weed suppression and recovery of perennial grassland vegetation in Hortobágy Puszta, Central-Europe, by testing the following hypotheses: (i) lower weed cover and biomass is expected in vegetation recovered by the joint method of sowing and hay transfer than by seed sowing only. (ii) With sowing and additional hay transfer a higher rate of establishment of *Festuca* species is expected than with sowing only. Our results supported both hypotheses. We found that the additional application of hay significantly accelerated the development of perennial grassland vegetation and provided a higher weed suppression rate in the first year and onwards in most plots than seed sowing only. A higher establishment rate was detected both in the cover and the biomass of perennial grasses including *Festuca* species in all plots with hay addition than with sowing only. Our results suggest that a combination of hay transfer and low diversity sowing may provide a cost-effective alternative to the more costly high-density sowing and if proper sources for high-diversity hay are available, it may replace high-diversity seed mixtures.

1. Introduction

Recovery and preservation of grasslands in fragmented agricultural landscapes has become one of the cornerstones of biodiversity conservation policy in Europe (Bischoff, 2002; Eggenschwiler et al., 2009). Thus, an increasing number of grassland restoration projects have been started and funded recently by the European Union (Cramer et al., 2008; Lindborg et al., 2008). The major aims of grassland restoration projects are (i) to recover grassland species richness, (ii) create buffer zones around native grassland fragments to eliminate negative impacts from surrounding areas and (iii) to connect fragments by green corridors (Walker et al., 2004). To achieve these aims, the recovery of native perennial grass cover is often given high priority to rapidly provide ecosystem services (erosion control, recovery of traditional landscapes, biomass production) and to reduce the colonisation and further spread of unwanted weeds (Jongepierová et al., 2007; Conrad and Tischew, 2011; Kirmer et al., 2011; Tropek et al., 2010).

Two methods most frequently applied in restoration practice to recover grassland vegetation in former croplands are transfer of plant material and sowing of seeds of local provenance (Kiehl et al., 2010; Rydgren et al., 2010; Török et al., 2011). Application of both methods provides a relatively rapid grassland recovery, although several shortcomings were identified with each (Kiehl et al., 2010). Seed sowing allows a precise set of species composition and amount of seeds sown but often results in a high cover and biomass of weeds in the first few years (Lepš et al., 2007). Hay transfer often provides a higher rate of suppression of light-demanding weeds than seed sowing. The spread hay protects the soil surface from desiccation and may allow the germination of late successional species (Fowler, 1988; Török et al., 2010). However, the species composition of hay can be highly variable and seed content is difficult to assess (Kiehl et al., 2010; Hedberg and Kotowski, 2010). These two effects make the predictions on the development of grassland vegetation highly uncertain.

The joint application of the two methods is rarely applied (but see Donath et al., 2007) although it has the potential to gain a

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predictable and directed vegetation development with effective early weed suppression. In the present study we applied low-diversity seed sowing and the combination of seed sowing and hay transfer (hay from a species-poor loess grassland) in three former crop fields. Based on the early development of vegetation (3 years) and the dynamics of biomass, we tested the effectiveness of combining low-diversity seed sowing and hay transfer in weed suppression and in recovery of perennial grass vegetation. We specifically tested the following hypotheses: (i) lower weed cover and biomass is expected in vegetation recovered by the joint method of sowing and hay transfer than by seed sowing only. (ii) With sowing and additional hay transfer, a higher rate of establishment of *Festuca* species is expected than with sowing only.

2. Materials and methods

2.1. Study sites, restoration and sampling

The fields studied are located in the “Egyek-Pusztakócsi mocsarak” protected area (4000 ha, Hortobágy National Park, East Hungary, N47°34, E20°55′). Grassland restoration was carried out on a total of 760 hectares of former croplands (2005–2008; funded by LIFE Nature program – LIFE04NAT/HU/000119). Before the river regulation works in the 19th century, the area was a floodplain of the Tisza river with an altitude of 88 m and 92 m (Molnár and Borhidi, 2003). The mean annual temperature is 9.5 °C, mean annual rainfall is approximately 550 mm, and the maximum annual precipitation falls in June (approximately 80 mm). Large year-to-year fluctuations both in the mean temperature and annual rainfall are typical.

Three fields with different previous crops were selected for study. The last cultivated crop was cereal (*Hordeum vulgare*, Field 1, altitude 91 m), sunflower (*Helianthus annuus*, Field 2, altitude 89 m) and alfalfa (*Medicago sativa*, Field 3, altitude 89 m). The whole area of each field was sown with seeds of *Festuca pseudovina* in a density of 20 kg/ha, following soil preparation (disking and smoothing) in October 2008. In each field, avoiding field margins (distance from margin was greater than 10 m) two randomly chosen plots of 15 m × 15 m were marked. On one of the plots only the above described seed sowing was applied. On the other plot in addition to the sowing, hay was spread to a thickness of 5 cm. Hay was harvested in late June and spread in late October after sowing in 2008. Hay originated from a moderately grazed species-poor native loess grassland characterised by *Festuca rupicola* (up to 40–60% of total cover) and no *F. pseudovina*. Additional species present with a mean cover exceeding 1% were *Achillea collina*, *Carex praecox*, *Convolvulus arvensis*, *Coronilla varia*, *Dactylis glomerata*, *Medicago lupulina*, *Plantago media*, *Poa angustifolia*, *Salvia nemorosa*, and *Vicia grandiflora*. *F. pseudovina* and *F. rupicola* are both tussock-forming short-grasses characteristic of alkali and loess grasslands in the region. The separated transfer of the two different *Festuca* species enabled us to distinguish *Festuca* individuals sown (*F. pseudovina*) from *Festuca* individuals established from hay (*F. rupicola*). Fields were mown once a year, plant material except of spread hay layer was removed No other management was applied.

Within each plot eight, 1 m^2-sized subplots were randomly selected, where we recorded the percentage cover of vascular plants each year after restoration between 2009 and 2011. We also collected 20 aboveground biomass samples (20 cm × 20 cm, clipped at the soil surface) from each plot randomly, but near the subplots before mowing in each year. Samples were dried (65 °C, 24 h), and sorted into species. Dry weights were measured with an accuracy of 0.01 g.

2.2. Data analysis

Weed species were identified based on the social behaviour type system of Borhidi (1995), which is an extension and adaptation of Grime’s C–S–R strategy system for local conditions (Grime, 1979). Weeds are listed in Appendix A. Species were classified for some analyses as graminoids (Poaceae, Cyperaceae, and Juncaceae) and forbs (dicots and non-graminoid monocots). The separation of vegetative individuals of *F. pseudovina* and *F. rupicola* in dried biomass samples was uncertain; thus, we pooled them as *Festuca* sp. in analyses based on biomass scores. Repeated Measures GLM was calculated using SPSS 17.0 using time as repeated measures factor, fields and block design as random factor, and restoration technique (seed sowing + hay or seed sowing only) as fixed effect (Zar, 1999). DCA (detrended correspondence analysis) was calculated on cover values using CANOCO 4.5 (ter Braak and Šmilauer, 2002). Plant nomenclature follows (Simon, 2000).

3. Results

3.1. Vegetation development

During the three years of the study, a rapid development from weed-dominated stages towards perennial grass-dominated vegetation was observed (Fig. 1). Altogether 125 species, including 56 weed species were recorded during the three years of the study.

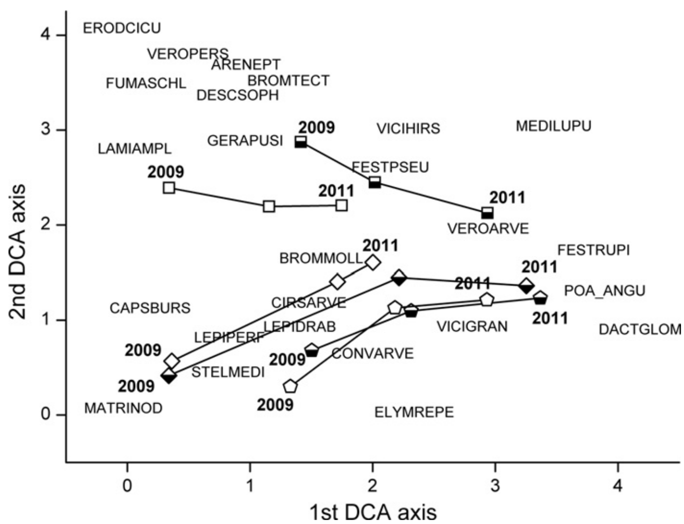

Fig. 1. DCA ordination of vegetation development 2009–2011. Centroids of each field and year are shown. Eigenvalues for the first and second axis are 0.60 and 0.48, and gradient length for that of are 4.12 and 3.45, respectively. Notations: empty symbols = sown only, half-empty symbols = sown plots with additional hay, rectangle = cereal, deltoid = sunflower, and pentagon = alfalfa fields. The 25 species with the highest total cover scores were shown. Species abbreviations were made using four letters of genus and four letters of species names as follows: *Arenaria leptoclados* = ARENLEPT; *Bromus mollis* = BROMMOLL; *Bromus tectorum* = BROMTECT; *Capsella bursa-pastoris* = CAPSBURS; *Cirsium arvense* = CIRSARVE; *Convolvulus arvensis* = CONVARVE; *Dactylis glomerata* = DACTGLOM; *Descurainia sophia* = DESCSOPH; *Elymus repens* = ELYMREPE; *Erodium cicutarium* = ERODCICU; *Festuca pseudovina* = FESTPSEU; *Festuca rupicola* = FESTRUPI; *Fumaria schleicheri* = FUMASCHL; *Geranium pusillum* = GERAPUSI; *Lamium amplexicaule* = LAMIAMPL; *Lepidium perfoliatum* = LEPIPERF; *Lepidium draba* = LEPIDRAB; *Matricaria inodora* = MATRINOD; *Medicago lupulina* = MEDILUPU; *Poa angustifolia* = POA_ANGU; *Stellaria media* = STELMEDI; *Veronica arvensis* = VEROARVE; *Veronica persica* = VEROPERS; *Vicia grandiflora* = VICIGRAN; and *Vicia hirsuta* = VICIHIRS. Weed species were designated using underline.

Table 1
Vegetation characteristics in the three fields in the three years of the study (mean ± SD, n = 8).

	Seed sowing + hay			Seed sowing only		
	2009	2010	2011	2009	2010	2011
Field 1						
Cover						
Total	37.5 ± 12.5	67.8 ± 18.2	76.2 ± 13.4	80.4 ± 18.2	82.6 ± 19.8	65.5 ± 18.9
Weed species	14.1 ± 8.1	4.3 ± 4.4	0.2 ± 0.3	63.7 ± 20.3	31.6 ± 21.9	10.5 ± 4.6
Festuca pseudovina	10.4 ± 10.4	24.6 ± 15.9	23.4 ± 21.9	2.2 ± 2.2	20.6 ± 17.1	22.0 ± 10.4
Festuca rupicola	3.7 ± 4.0	9.4 ± 5.2	31.4 ± 25.5	0.0 ± 0.0	0.3 ± 0.7	0.0 ± 0.0
Species richness						
Total	12.6 ± 2.2	17.0 ± 3.4	8.4 ± 2.2	14.9 ± 2.9	17.5 ± 2.4	14.4 ± 3.3
Weed species	6.8 ± 1.4	6.3 ± 2.3	0.4 ± 0.5	9.6 ± 1.5	8.4 ± 2.3	7.3 ± 3.0
Field 2						
Cover						
Total	80.1 ± 20.5	94.7 ± 8.3	82.9 ± 7.8	61.9 ± 13.5	96.0 ± 3.9	67.2 ± 12.9
Weed species	66.9 ± 14.5	20.8 ± 20.9	15.3 ± 7.4	49.9 ± 15.4	24.1 ± 22.9	25.8 ± 19.7
Festuca pseudovina	2.9 ± 2.5	21.1 ± 11.5	2.5 ± 2.1	2.9 ± 2.5	26.0 ± 14.5	28.8 ± 21.4
Festuca rupicola	0.9 ± 1.1	8.1 ± 8.1	35.8 ± 17.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Species richness						
Total	15.1 ± 5.3	18.9 ± 2.0	12.8 ± 1.7	12.3 ± 1.9	13.9 ± 3.1	11.0 ± 4.0
Weed species	7.3 ± 2.2	6.5 ± 1.9	3.1 ± 0.6	7.0 ± 1.3	5.6 ± 2.4	5.8 ± 3.7
Field 3						
Cover						
Total	60.7 ± 15.9	97.8 ± 4.0	79.1 ± 10.7	75.9 ± 18.7	92.3 ± 8.4	83.4 ± 12.8
Weed species	36.5 ± 16.1	35.8 ± 30.9	16.9 ± 19.1	60.4 ± 17.8	43.2 ± 15.8	21.0 ± 18.7
Festuca pseudovina	4.2 ± 4.1	15.2 ± 12.3	1.3 ± 1.7	3.1 ± 3.2	29.8 ± 17.0	16.5 ± 21.0
Festuca rupicola	3.4 ± 3.6	12.8 ± 12.8	37.9 ± 22.2	0.0 ± 0.0	3.7 ± 8.6	4.5 ± 4.7
Species richness						
Total	14.1 ± 2.6	19.3 ± 2.1	10.7 ± 2.9	11.3 ± 3.1	16.5 ± 1.9	8.4 ± 3.5
Weed species	5.8 ± 1.6	6.3 ± 0.9	2.6 ± 1.5	6.0 ± 2.1	6.3 ± 2.0	2.6 ± 1.2

A list of weed and target species is presented in Appendix A. Both total species richness (up to a mean of 19.3 species/m^2) and total cover (up to a mean of 97.8%) was the highest in the second year of the study (2010). In the first year in every field, short-lived weed species were recorded at high cover. Increasing cover of perennial grass species and a decreasing cover of weeds was detected during the study regardless of field and restoration technique (Table 1). The rate of weed suppression was significantly influenced by the restoration technique and also significant differences were found between fields (Tables 2 and 3). Typically lower cover scores of weed species were detected in plots with additional hay transfer (Table 1). In year 3 the mean cover scores of weeds was one third of that detected in the first year, and only a few perennial weeds were detected with low cover (the maximum mean cover of perennial weeds was less than 3% in every year and in every field). Out of the common species likely transferred with the applied hay, *F. rupicola*, *D. glomerata*, *P. angustifolia*, *M. lupulina* and *V. grandiflora* established successfully with considerable cover (exceeding 5% at least in one subplot in the third year of the study).

Table 2
Changes in biomass in the three fields in the three years of the study (mean ± SD, n = 20).

	Seed sowing + hay			Seed sowing only		
	2009	2010	2011	2009	2010	2011
FIELD 1						
Biomass						
Total Graminoid	2.8 ± 2.6	7.9 ± 2.8	7.9 ± 3.9	1.6 ± 2.1	6.1 ± 4.0	9.4 ± 3.9
Total Forb	5.4 ± 5.8	1.2 ± 0.7	0.9 ± 1.1	10.5 ± 5.4	5.4 ± 4.1	1.5 ± 1.1
Litter	7.5 ± 6.9	3.5 ± 2.8	7.1 ± 5.7	2.4 ± 2.2	3.2 ± 1.8	9.3 ± 8.7
Weed species	4.3 ± 5.5	0.3 ± 0.2	0.1 ± 0.1	9.8 ± 5.4	3.4 ± 3.9	0.5 ± 0.5
Festuca sp.	1.9 ± 1.5	6.4 ± 3.4	6.8 ± 4.0	0.4 ± 0.6	3.5 ± 3.5	6.6 ± 5.0
FIELD 2						
Biomass						
Total Graminoid	2.9 ± 3.2	13.4 ± 3.5	14.9 ± 6.0	1.3 ± 1.4	11.2 ± 5.8	11.7 ± 5.5
Total Forb	13.7 ± 9.0	2.3 ± 3.1	1.3 ± 1.8	17.5 ± 8.2	4.2 ± 4.8	1.6 ± 1.4
Litter	9.2 ± 10.3	7.5 ± 3.6	16.0 ± 6.3	2.2 ± 2.4	5.0 ± 2.4	15.8 ± 8.6
Weed species	14.1 ± 8.9	4.9 ± 4.6	3.9 ± 2.9	15.1 ± 9.6	2.6 ± 2.9	2.3 ± 3.6
Festuca sp.	0.8 ± 0.8	4.9 ± 4.1	8.0 ± 6.0	0.4 ± 0.5	6.7 ± 6.2	9.1 ± 7.1
FIELD 3						
Biomass						
Total Graminoid	5.5 ± 3.3	16.7 ± 5.7	15.3 ± 6.7	4.5 ± 4.2	13.4 ± 5.1	19.0 ± 10.0
Total Forb	7.2 ± 7.3	1.8 ± 2.8	1.2 ± 1.3	11.6 ± 10.7	1.9 ± 1.8	2.1 ± 3.0
Litter	12.9 ± 15.4	5.3 ± 3.5	12.3 ± 8.7	5.8 ± 4.6	4.3 ± 2.9	8.2 ± 4.0
Weed species	6.7 ± 5.3	2.6 ± 3.7	4.7 ± 2.5	13.4 ± 10.6	6.9 ± 3.9	6.6 ± 4.2
Festuca sp.	1.5 ± 1.3	7.5 ± 5.4	8.1 ± 7.5	0.7 ± 0.8	5.3 ± 4.6	11.6 ± 10.9

Table 3
Effect of time, field and restoration technique on vegetation characteristics. Statistics were calculated using repeated measures GLMs that included time (repeated measures factor), field and block design (random factor), and restoration technique (seed sowing + hay and seed sowing only, fixed effect). Significant differences were indicated with boldface.

	Time		Field		Resttech		Time × Field		Time × Resttech		Field × Resttech		Time × Field × Resttech	
	F	p	F	p	F	p	F	p	F	p	F	p	F	p
Cover														
Total	**7.6**	**0.002**	**12.4**	**<0.001**	1.6	0.200	2.2	0.081	**7.4**	**0.002**	**10.2**	**<0.001**	**6.7**	**<0.001**
Weed species	**29.6**	**<0.001**	**6.9**	**0.003**	**13.7**	**0.001**	**3.0**	**0.023**	2.4	0.106	**5.9**	**0.005**	**8.2**	**<0.001**
Target species	**21.1**	**<0.001**	0.408	0.668	**26.2**	**<0.001**	1.9	0.126	**8.0**	**0.001**	1.4	0.257	0.9	0.474
Festuca pseudovina	**12.7**	**<0.001**	1.8	0.177	**4.6**	**0.037**	1.4	0.233	**7.5**	**0.002**	**4.1**	**0.023**	1.2	0.314
Festuca rupicola	**9.2**	**0.001**	1.0	0.361	**62.2**	**<0.001**	0.8	0.501	**24.1**	**<0.001**	0.9	0.993	0.1	0.975
Species richness														
Total	**12.8**	**<0.001**	0.9	0.424	3.7	0.061	**2.7**	**0.039**	**4.6**	**0.016**	**14.9**	**<0.001**	1.0	0.388
Weed species	**6.6**	**0.003**	**5.5**	**0.008**	**15.9**	**<0.001**	2.2	0.075	**6.9**	**0.003**	**10.4**	**<0.001**	1.8	0.129
Target species	**5.7**	**0.007**	1.8	0.175	**58.7**	**<0.001**	**2.8**	**0.033**	0.4	0.687	**5.0**	**0.012**	1.8	0.133

Significantly higher cover scores for *Festuca* species were detected in plots with additional hay-transfer. The sown *F. pseudovina* performed slightly better in plots with additional hay transfer in the first year (Table 1). From the first year to the second year the cover of *F. pseudovina* increased to a mean of 15.2–24.6%, but later, in two fields this declined to 1.3–2.5%. *F. rupicola* was established mostly in plots with additional hay transfer, but it was also recorded with low cover scores in some plots sown only with *F. pseudovina* seeds. In plots with additional hay transfer the *F. rupicola* cover increased continuously to 31.4–37.9% in year 3.

3.2. Biomass changes

The biomass of weeds significantly decreased during the study, but the rate of suppression was significantly affected by the field and restoration technique (Table 2). The decrease of weed biomass was greater in plots with additional hay transfer between year 1 and year 2 than in plots with seed sowing only (Table 2). The biomass of *Festuca* sp. significantly increased during the three years of the study regardless of the field and restoration technique. The greatest increase in the biomass of *Festuca* sp. was recorded between year 1 and year 2 in most plots regardless of field and restoration technique. The amount of litter decreased from year 1 to year 2 in all plots restored with additional hay transfer. Conversely, in most plots restored by seed sowing only a slight increase of litter was recorded between year 1 and year 2. We recorded in year 3 a two- to three-times higher amount of litter than in year 2 regardless to field and restoration technique.

4. Discussion

4.1. Weed suppression by hay

We found that the additional application of hay significantly accelerated the development of perennial grassland vegetation and provided a higher weed suppression rate already in the first year in most fields, than seed sowing only. These findings supported our first hypothesis. The improved weed suppression caused by additional application of hay was seen not only in the decrease in weed cover, but also in the decrease in weed species richness, and in most fields, the decrease in weed biomass. These results support the expectations of Klimkowska et al. (2010), where the improved weed suppression effect of hay spreading was assumed. The likely reasons for the improved weed suppression are that the hay layer (i) decreases the magnitude of the light irradiance of the soil surface and (ii) buffers the fluctuations in temperature and water availability which both are common germination signals for several gap strategist weeds (Foster and Gross, 1998), and the spread hay (iii) forms a physical barrier for weed immigration and establishment (Wedin and Tilman, 1993), and (iv) exerts an allelopathic effect (Ruprecht et al., 2010a). Furthermore, the improved suppression of weedy species was accentuated also by the higher cover of *Festuca* species established in most plots with additional hay transfer (Table 1). This corresponds with the findings of another study by the authors, where a negative relationship was detected between the cover of weeds and sown perennial grasses (Deák et al., 2011).

A dense litter layer can be beneficial for weed suppression during grassland restoration, but on the other hand, after the development of perennial grass dominated vegetation, accumulated litter can have negative effects on the establishment of target species (Ruprecht et al., 2010b). In grassland restoration experiments a high rate of litter accumulation is a typical problem which can hamper the germination or establishment of target species by reducing the availability of suitable microsites (Deák et al., 2011). In our study, the joint application of hay transfer and seed sowing resulted in three–four times higher litter scores in the first year after restoration than seed sowing only, which was beneficial for weed suppression. The amount of litter in plots with additional hay transfer decreased by year 3 to the same levels detected in fields restored by seed sowing only. These results suggest that no increased rate of microsite limitation for target species appeared to be similar in fields restored by joint application of sowing and hay transfer compared to seed sowing only three years after restoration, which is favourable from a restoration point of view.

4.2. Establishment of Festuca species

The development of perennial grass cover was facilitated by additional application of hay (Table 1). This corresponds with findings of Kirmer et al. (2011), where diaspore-poor hay such a mulch layer was used in plots sown with low and high-diversity seed mixtures. A higher cover and biomass of perennial grasses was found in all plots with additional application of hay than in plots with sowing only. These results support our second hypothesis. In all fields in plots with additional hay transfer an increasing cover of *F. rupicola* was recorded. In the present study also the facilitated establishment of the sown perennial grass *F. pseudovina* was detected in plots restored by the joint method of seed sowing and hay transfer. Higher cover of the sown *F. pseudovina* was detected in the first year in all plots treated by additional hay. Similar results were obtained by Kirmer et al. (2011) sowing *Festuca ovina* and *F. rubra* cultivars with an additional mulching. The most likely reason for this is that additional application of hay provided more favourable water regime for the establishment of late successional species like *F. pseudovina* and *F. rupicola* by protecting the soil surface from rapid desiccation. Similar results were found by Kiehl and Pfadenhauer (2007) who detected that the transferred hay provided suitable safe sites for the germination of target species in restored calcareous grasslands. We also found that a lower sowing density (20 kg/ha) facilitated the establishment of perennial grass cover in both restoration measures, and no negative effect was detected on the establishment of hay-transferred species on the short run (was especially feasible considering the establishment of *F. rupicola*). The most likely explanation is that the tussock forming *F. rupicola* in a relatively low sowing density enabled also the establishment of hay transferred species. This corresponds with the findings of Donath et al. (2007) where even at a much higher load of seeds (50 kg/ha), no negative effects of sown grasses on hay species establishment and richness were detected.

In two fields in year 3 a sharp decline of *F. pseudovina* was detected in plots with additional hay transfer. Extremely high precipitation in year 2 may have been responsible for this phenomenon. High precipitation might have altered the competitive environment favouring the establishment of some hay-transferred species showing higher performance in mesic conditions like *D. glomerata* and *P. angustifolia*, especially in lower laying Field 2 and Field 3. In upper lying Field 1 where these species were missing in most subplots or present only in very low cover, *F. pseudovina* performed much better in year 3.

4.3. Implications and perspectives for practice

Our results clearly indicated the benefits of the joint application of seed sowing and hay-transfer. With sowing only, a rapid weed suppression is feasible at higher sowing rate (typically greater than 30 kg/ha; Török et al., 2011). With additional hay transfer a rapid suppression of weeds is possible even at low density sowing (up to 20 kg/ha). Low density sowing of seeds helps in the rapid development of perennial grass cover and provides a higher directionality of vegetation changes than hay transfer only. Furthermore, the combination of hay transfer and low-diversity sowing may provide a cost-effective solution replacing the more costly high-diversity or high-density sowing if proper sources for high-diversity hay are available (Donath et al., 2007; Kiehl et al., 2010). An indirect benefit of the application of additional hay transfer is that the necessary management by mowing in several types of donor grasslands is executed during the harvest of hay.

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Appendix A. Weed and target species detected in the vegetation of the fields (2009–2011). Perennials are indicated with boldface.

Weed species		Target species
Ambrosia artemisiifolia	*Oxalis stricta*	***Achillea collina***
Anagallis arvensis	*Papaver confine*	***Alopecurus geniculatus***
Anthemis arvensis	*Papaver rhoeas*	***Alopecurus pratensis***
Apera spica-venti	*Picris hieracioides*	***Bromus inermis***
Arabidopsis thaliana	*Polygonum aviculare*	*Cerastium dubium*
Arctium lappa	*Rumex acetosella*	*Cruciata pedemontana*
Artemisia vulgaris	***Rumex crispus***	***Festuca pseudovina***
Bilderdykia convolvulus	*Setaria glauca*	***Festuca rupicola***
Bromus arvensis	*Sinapis arvense*	*Gypsophila muralis*
Bromus sterilis	*Sonchus oleraceus*	*Hordeum hystrix*
Camelina microcarpa	***Taraxacum officinale***	***Inula britannica***
Capsella bursa-pastoris	*Thlaspi arvense*	***Koeleria cristata***
Carduus acanthoides	*Veronica hederifolia*	*Lactuca saligna*
Chenopodium album	*Veronica persica*	***Lathyrus tuberosus***
Chenopodium ficifolius	*Veronica polita*	*Matricaria chamomilla*
Cirsium arvense	*Vicia villosa*	*Medicago lupulina*
Consolida regalis	*Viola arvensis*	*Myosurus minimus*
Convolvulus arvensis		***Nonnea pulla***
Conyza canadensis		***Plantago lanceolata***
Crepis biennis		***Poa angustifolia***
Crepis setosa		***Podospermum canum***
Crepis tectorum		***Potentilla argentea***
Descurainia sophia		***Salvia austriaca***
Draba nemorosa		***Stellaria graminea***
Elymus repens		***Thymus pulegioides***
Erodium cicutarium		*Trifolium angulatum*
Erophila verna		*Trifolium campestre*
Erysimum repandum		***Trifolium repens***
Fumaria schleicherii		*Trifolium retusum*
Galium spurium		*Trifolium strictum*
Geranium molle		*Trifolium striatum*
Holosteum umbellatum		*Vicia angustifolia*
Lactuca serriola		*Vicia grandiflora*
Lamium amplexicaule		*Vicia hirsuta*
Lamium purpureum		*Vicia lathyroides*
Lepidium campestre		*Vicia pannonica*
Matricaria inodora		*Vicia tetrasperma*
Melandrium album		
Myosotis stricta		

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