Abandonment of croplands: problem or chance for grassland restoration? Case studies from Hungary

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Abstract. In Central- and Eastern Europe, the collapse of socialist regimes resulted in a transformation of state-owned agricultural cooperatives to privately owned lands from the early 1990s onwards. These socioeconomic processes resulted in landscape-scale changes in biodiversity, ecosystem services and agricultural production. In parallel, large-scale abandonment of croplands, especially on sandy, salty or frequently inundated areas, became common. Abandoned croplands are usually sensitive to species invasions, and are hotspots of noxious weeds, posing threats both to agriculture and nature conservation. Grassland restoration on former croplands can be an effective strategy for suppressing these species. Thus, a common goal of nature conservation and agriculture can be the restoration of grasslands on former croplands to (1) suppress weed and/or invasive species in line with the EU policy "Good Farming Practices", (2) support animal husbandry by creating meadows or pastures, and to (3) recover biodiversity and ecosystem services. In the present paper we report "best practices" of grassland restoration projects from Hungary. Our aim was to compare the effectiveness of spontaneous grassland recovery vs. active grassland restoration by seed sowing in terms of the recovery of biodiversity and ecosystem services, such as weed control and biomass production. Our results showed that grassland restoration on abandoned fields offers a viable solution for restoring biodiversity and ecosystem services. Seed sowing ensures higher weed control and biomass production, but results in lower biodiversity compared to spontaneous recovery. Both restoration methods can be cost-effective, or even profitable even within a relatively short period of a nature conservation project.

Key words: *agri-environmental schemes; agri-environmental subsidy; agrobiodiversity; Central Europe; intensive agriculture; old-field; seed sowing; Special Feature: Ecosystem Management in Transition in Central and Eastern Europe; spontaneous succession.*

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Introduction

In Central- and Eastern Europe, the collapse of socialist regimes resulted in a transformation of state-owned agricultural cooperatives to privately owned lands in the early 1990s (Török et al. 2011*a*). In parallel, large-scale abandonment of croplands, especially on sandy, salty or frequently inundated areas, became common in Central- and Eastern Europe, because of the low fertility of the soil and inadequate financial conditions of the new owners. For example, 600,000 ha (10% of all croplands) was abandoned between 1990 and 2004 in Hungary (Hobbs and Cramer 2007). However, there are no up-to-date surveys available on the temporal dynamics and magnitude of cropland abandonment at the national scale.

These socioeconomic processes resulted in landscape-scale changes in biodiversity, ecosystem functions and agricultural production. Abandoned croplands are usually sensitive to the immigration of many noxious indigenous or invasive species, such as *Ambrosia artemisiifolia*, *Asclepias syriaca*, *Calamagrostis epigeios, Solidago* spp. and *Robinia pseudo-acacia* (Csecserits and Rédei 2001, Prach et al. 2007, Házi et al. 2011, Albert et al. 2014, Bartha et al.

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2014) and can act as hotspots for their further spread in the landscape. These species pose future threats both to agriculture and nature conservation, and their suppression can be very expensive in large areas. Grassland restoration on former croplands can be an effective prevention strategy against these species. Thus, a common goal of nature conservation and agriculture can be the restoration of grasslands on abandoned fields to (1) suppress weedy and invasive species in line with the EU policy "Good Farming Practices," (2) support animal husbandry by creating meadows or pastures, and to (3) recover biodiversity and ecosystem services.

Sustaining biodiversity and ecosystem services in agricultural landscapes became a high priority in environmental policy worldwide (Ryan et al. 1998, Isselstein et al. 2005, Pullin et al. 2009, Smith et al. 2011). Grasslands embedded in agricultural landscapes provide many kinds of ecosystem services, such as provisioning (e.g., provision of food and raw materials), regulating (erosion regulation, carbon sequestration, and pollination), and cultural (recreation, sport and tourism) services (Hönigová et al. 2012, Dengler et al. 2014). Specifically, restoration of grasslands on former croplands can be an effective tool to restore ecosystem services such as weed control, biomass production, besides biodiversity (Tallis et al. 2008). Grassland restoration actions can be considered successful both from the nature conservation and agronomic viewpoint if cover of weeds is low while cover of native perennial grasses and other target species is high in the restored sites (Török et al. 2010). After a successful project, restored grasslands can be utilized as pastures or hay meadows and can support local animal husbandry (Kelemen et al. 2014). In order to solve the problems associated with abandoned fields, to increase the area of grasslands and to support local animal husbandry, the European Union strongly supports agri-environmental subsidies for grassland restoration. Nowadays, approximately 20% of the agriculturally used area is managed under agri-environmental schemes in the European Union (Rounsewell et al. 2005). Many LIFE Nature programs funded by the European Commission are concerned with grassland restoration (more than 290 projects, Török et al. 2011*a*). In the United States, several projects aimed to transform former croplands to grasslands to preserve species diversity and sustain soil and water resources (Deal et al. 2014). Besides this, within the USDA's Conservation Reserve Program millions of hectares of former croplands were converted to grasslands to reduce soil erosion by establishing perennial vegetation (Baer et al. 2002).

In grassland restoration, spontaneous grassland recovery became increasingly acknowledged (Török et al. 2011*a*). In many cases, it is the best option, because it is a natural method, it has low costs and if proper propagule sources of target species are present, successful grassland recovery can be expected (Hedberg and Kotowski 2010, Kiehl et al. 2010). Promising examples of spontaneous grassland recovery were reported from many parts of Central- and Eastern Europe, such as the Czech Republic (e.g., Lencová and Prach 2011, Jírová et al. 2012, Prach and Řehounková 2008), Hungary (e.g., Csecserits et al. 2007, 2011, Török et al. 2011*b*, Albert et al. 2014), and Romania (e.g., Ruprecht 2005, 2006). However, if propagule sources are limited, vegetation development may stall at a stage dominated by weeds (Prach and Pyšek 2001, Matus et al. 2003, Foster et al. 2007). In such sites, it may be a solution to sow native seeds to initiate community development toward a desired state. Grassland restoration by seed sowing provides high directionality and predictability of grassland development in the short run, thus, this method is generally preferred in projects which need fast results over large areas (Török et al. 2010, 2011*a*). One drawback is, that in fields restored by seed sowing, the developed dense canopy of sown grasses can lead to microsite limitation and can hamper the immigration of target species, especially in case of high sowing density (Török et al. 2010, Deák et al. 2011).

Our aim was to compare the effectiveness of spontaneous grassland recovery vs. active grassland restoration by seed sowing in terms of the restoration of ecosystem services, that is, weed control, biomass production, and recovery of biodiversity. We compared the effectiveness of these frequently applied restoration methods 5 yrs after restoration. This period corresponds to the average timeframe of restoration projects (e.g., operative programs, LIFE and LIFE+ projects; http://ec.europa.eu/environment/life). We also compared the cost-effectiveness of spontaneous recovery and seed sowing. We tested the following hypotheses: (1) The cover and species number of weeds is lower in fields restored by seed sowing than in spontaneously recovering fields. (2) Graminoid biomass is higher in fields restored by seed sowing compared to fields recovering spontaneously. (3) Shannon diversity and the number of spontaneously immigrated target species are higher in spontaneously recovering fields than in fields restored by seed sowing.

Methods

Study area

Our study sites are situated in the Hungarian Great Plain, in the Hortobágy National Park. The climate of the region is moderately continental, characterized by a mean annual precipitation of 550 mm and a mean temperature of 9.5 °C with high year-to-year fluctuations. Hortobágy National Park harbors one of the largest open landscapes in Europe, characterized by a diverse mosaic of loess and alkali grasslands, meadows, and wetlands (Deák et al. 2014*a*, *b*, *c*, 2015). Alkali soils are generally inadequate for arable farming because of their high salt content and low fertility (Török et al. 2012*a*, Valkó et al. 2014), thus arable farming has been typical on higher elevated loess plateaux (Tóth and Hüse 2014). Because of their good-quality chernosemic soils, most stands of loess grasslands have been converted to arable fields (Török et al. 2013). In the study region, alfalfa (*Medicago sativa*) fields are typically situated on the high plateaux, which were formerly covered by loess grasslands (Török et al. 2011*b*).

Restoration measures

We studied the vegetation of fields restored by two frequently applied grassland restoration measures. (1) "Spontaneously recovering fields" are former alfalfa fields, that had not been re-sown with alfalfa for 5 yrs. Besides regular mowing, no other restoration measures were applied (Török et al. 2011*b*). (2) On "sown fields", former alfalfa fields were ploughed, then restored by sowing low-diversity seed mixtures. In total 760 hectares of grasslands were restored on former croplands, making this one of the largest grassland restoration projects in Europe (LIFE 04 NAT HU 119). Seed mixtures were sown at a density of 20 kg/ha in October 2005 (Török et al. 2010, Deák et al. 2011, Lengyel et al. 2012); the mixture contained seeds of *Festuca rupicola* (40%), *Poa angustifolia* (30%), and *Bromus inermis* (30%) (Török et al. 2010). These species were selected because they are typical species of loess grasslands and potentially strong competitors that can suppress weeds. Seeds of *Festuca pseudovina* and *F. rupicola* were harvested in the vicinity of the study sites. Seeds of *P. angustifolia* and *B. inermis* were purchased from a commercial source (Agricultural Research Station Nonprofit Company, Hungary), but the stock had originated from the Hortobágy area. All restored sites and reference grasslands were managed by mowing once a year in June.

Sampling design

We selected three sites of 5-yr-old spontaneously recovering fields and sown fields, respectively. In each restored site, we designated two 5 × 5-m blocks, and within the blocks four 1 × 1-m sized plots (in total eight plot/site), where we recorded the percentage cover scores of vascular plant species in the fifth year after restoration. Vegetation was sampled in the middle of the growing season (early June 2009 in spontaneously recovering fields, and early June 2010 in sown fields). We sampled aboveground biomass in twenty 20 × 20-cm sized plots in each restored site. Biomass sampling was done in late June 2009 in spontaneously recovering fields, and in late June 2010 in sown fields, at the peak of the biomass production. Biomass samples were dried (65 °C, 24 h), then sorted to the following fractions: graminoid biomass, forb biomass and litter. The dry weights of these fractions were measured with an accuracy of 0.01 g.

As a reference, we selected three sites of loess grasslands (*Salvio nemorosae—F. rupicolae*) in the vicinity of the restoration sites. In the reference sites we sampled aboveground vegetation and biomass using the same sampling design described above.

Data analysis

Weed species were selected based on Grime's ruderal species group (Grime 1979), adapted to Hungarian conditions (Social Behavior Types general classification of Borhidi 1995). The following species groups were considered as weeds: adventive competitors (AC), ruderal competitors (RC) and weeds (W). We classified species characteristic to loess grasslands (Festuco-Brometea class) as target species, based on the classification of Borhidi (1995).

To analyze the relationship between cover of perennial graminoids and cover and species richness of spontaneously established target species, we used Pearson correlation (Zar 1999). To compare the species composition of the restored sites and reference grasslands, a PCA ordination was calculated using CANOCO 4.5 (ter Braak and Šmilauer 2002). Vegetation and biomass characteristics of the spontaneously recovering fields, sown fields and loess grasslands were analyzed using general linear models (GLM) and Tukey tests. In the GLM, grassland type (spontaneously recovered, sown and reference) was included as fixed factor, site was included as covariate (Zuur et al. 2009). The cover of former crop (*M. sativa*) and the cover and species richness of spontaneously established target species were compared between spontaneously recovering fields and sown fields by *t*-tests (Zar 1999). All univariate statistics were calculated using SPSS 20.0 (Chicago, IL, USA).

We calculated the cost-effectiveness of the two restoration methods using the cost calculations (costs for soil preparation, seed harvest/purchase, seed sowing, and follow-up management) described in Török et al. (2011*a*) and Deák et al. (2013). We tested three restoration methods: (1) spontaneous recovery, (2) grassland restoration by sowing low-diversity seed mixtures using locally harvested seeds, or (3) seeds purchased from the market. We calculated the possible income from (1) the value of the produced fodder and (2) the agri-environmental subsidies per hectare. Fodder value was calculated using 23 EUR for the average price of a hay bale (1.25 × 1.25 m; 250 kg). We took into account that the hay from spontaneously recovering fields can be used as fodder even from the first year because it contains a high amount of *M. sativa* which provides good forage quality (Török et al. 2011*b*). However, the hay from sown fields can be used only from the second year onwards: it has a poor quality in the first year due to the high biomass of weeds (Deák et al. 2011). For agri-environmental subsidies, we used the values valid in 2009 (http://tudas.nak.hu/hu/tamogatasok/egyseges-kerelem/240-agrar-kornyezetgazdalkodas).

Results

Cover and species richness of functional groups

We recorded altogether 120 vascular plant species. We recorded 58, 41 and 71 species in the spontaneously recovering fields, the fields restored by seed sowing and in the loess grasslands, respectively. Total species richness per plot and Shannon diversity were lowest in the sown fields (Table 1). Cover and species richness of weeds was the highest in spontaneously recovering fields. Weed cover was significantly lower in sown fields than in spontaneously recovering fields. Total cover of target species was significantly higher in sown fields than in spontaneously recovering fields (Table 1). The cover of *M. sativa* was the highest on spontaneously recovering fields, its mean cover was 22.57% (Table 1).

The cover and species number of spontaneously established target species were significantly higher in spontaneously recovering fields than in sown fields (*t*-tests, $F = 33.967$; $P < 0.001$ for cover and $F = 4.685$; $P = 0.036$ for species number). In spontaneously recovering fields, cover of perennial graminoids was positively correlated with both cover and species number of spontaneously immigrated target species (Pearson correlation, $R = 0.726$, $P < 0.001$ and $R = 0.600$, $P = 0.002$; respectively). In sown fields, we found no relationship between cover of perennial graminoids and cover and species number of spontaneously immigrated target species (Pearson correlation, $R = -0.168$, $P = 0.433$ and $R = -0.082$, $P = 0.705$; respectively).

The PCA ordination shows distinct species composition of spontaneously recovering fields and sown fields (Fig. 1). The species composition of spontaneously recovering fields is more heterogeneous than that of the sown fields. The majority of the target species was associated with the remnant loess grasslands, but the spontaneously established *Scorzonera cana* was associated with spontaneously recovering fields, and sown grasses *F. rupicola* and *B. inermis* were associated with sown fields.

Biomass

We found that graminoid biomass proportion was similar in spontaneously recovering fields and loess grasslands, while sown fields were characterized by significantly higher graminoid biomass (GLM, $F = 4.066$, $P < 0.05$, Table 2). Forb biomass was the highest in spontaneously recovering fields and the lowest in sown fields ($F = 27.932$, $P < 0.001$). The amount of litter ($F = 7.327$, $P < 0.001$) and total biomass ($F = 4.218$, $P < 0.05$) were lowest in spontaneously recovering fields (Table 2).

Costs and gains

Costs and gains of the restoration measures are shown in Fig. 2. We found that in the first year, spontaneous recovery has the lowest costs (53 EUR/ha), followed by seed sowing using locally harvested seeds (206 EUR/ha) and seed sowing using purchased material (459 EUR/ha). If site managers receive agri-environmental subsidies, all methods except for seed sowing using purchased seeds become profitable even in the first year. After 5 yrs, seed sowing using locally harvested seeds can result in a profit of 1150 EUR/

Table 1. Plot-level vegetation characteristics (mean ± SE) in spontaneously recovering fields, sown fields, and loess grasslands compared by general linear models and Tukey tests.

	Fields			Field type		Site	
Characteristic	Spontaneously recovering	Sown	Loess grasslands	F	P	F	P
Cover (%)							
Total	85.71 ± 4.58^{a}	91.08 ± 3.00^{b}	92.72 ± 1.25^{c}	14.210	***	38.684	***
Weeds	31.94 ± 3.50^{a}	4.39 ± 1.62^{b}	5.05 ± 0.77^{b}	25.326	***	4.986	**
Target species	13.03 ± 2.70^{a}	78.68 ± 3.02^{b}	79.83 ± 2.28^{b}	60.828	***	14.707	***
Spontaneously immigrated	13.03 ± 2.70^{b}	0.82 ± 0.36^{b}	79.83 ± 2.28^{a}	213.368	***	17.519	***
Medicago sativa	22.57 ± 3.58^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	10.556	***	3.169	n.s.
Species richness (species/m^2)							
Total	14.79 ± 1.06^{a}	9.63 ± 0.60^{b}	16.71 ± 1.52^{a}	10.345	***	1.601	n.s.
Weeds	7.33 ± 0.59^{a}	3.17 ± 0.41^{b}	2.96 ± 0.24^{b}	14.738	***	3.134	n.s.
Target species	2.33 ± 0.33^{a}	3.67 ± 0.21^{a}	9.75 ± 1.14^{b}	5.917	**	0.145	n.s.
Spontaneously immigrated	2.33 ± 0.32^{b}	0.79 ± 0.19^{b}	9.75 ± 1.37^{a}	20.937	***	0.218	n.s.
Shannon diversity	1.69 ± 0.10^{a}	1.16 ± 0.06^{b}	1.66 ± 0.10^{a}	13.613	***	3.530	n.s.

Note: Different superscript letters indicate significant differences.
***$P < 0.001$; **$P < 0.01$.

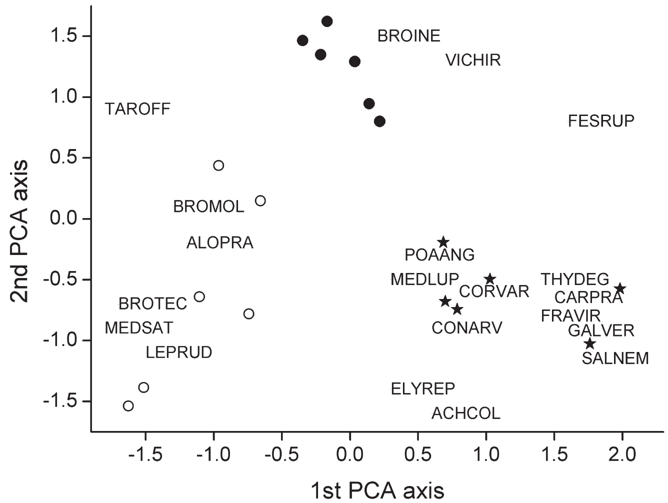

Fig. 1. Species composition of spontaneously recovered fields, sown fields and loess grasslands plotted by a PCA. Notations: ○—spontaneously recovering fields, ●—sown fields and ★—loess grasslands. We plotted the 20 most abundant species using the first three letters of their genus and species names as follows: ACHCOL—*Achillea collina*; ALOPRA—*Alopecurus pratensis*; BROINE—*Bromus inermis*; BROTEC—*Bromus tectorum*; CARPRA—*Carex praecox*; CONARV—*Convolvulus arvensis*; CORVAR—*Coronilla varia*; ELYREP—*Elymus repens*; FESRUP—*Festuca rupicola*; GALVER—*Galium verum*; LEPRUD—*Lepidium ruderale*; MEDLUP—*Medicago lupulina*; MEDSAT—*Medicago sativa*; POAANG—*Poa angustifolia*; SALNEM—*Salvia nemorosa*; TAROFF—*Taraxacum officinale*; THYDEG—*Thymus degenianus*; VICHIR—*Vicia hirsuta*.

Table 2. Biomass fractions (g/0.04 m^2; mean ± SE) in spontaneously recovering fields, sown fields, and loess grasslands compared by general linear models and Tukey tests.

	Fields			Field type		Site	
Biomass fraction	Spontaneously recovering	Sown	Loess grasslands	F	*P*	F	*P*
Graminoid biomass	8.96 ± 0.89^a	18.96 ± 1.67^b	9.13 ± 1.00^a	4.066	*	2.619	n.s.
Forb biomass	10.25 ± 1.22^a	0.65 ± 0.11^b	4.04 ± 0.36^b	27.932	***	0.015	n.s.
Litter	4.12 ± 0.33^a	10.93 ± 0.80^b	13.11 ± 1.51^b	7.327	***	32.529	***
Total biomass	23.33 ± 1.33^a	30.53 ± 1.78^b	26.29 ± 1.81^b	4.218	*	5.612	*

Note: Different superscripted letters indicate significant differences.
***$P < 0.001$; *$P < 0.05$.

ha from subsidies and the additional gains of harvested hay (2852 EUR/ha).

Discussion

We found that in former alfalfa fields, both spontaneous grassland recovery and restoration by seed sowing were effective in restoring ecosystem services within 5 yrs.

Weed control

Several studies reported on dense seed banks of weeds in restored fields even several years after the restoration (Renne and Tracy 2007, Török et al. 2012*b*). For several weed species long-term persistence reaching up to decades was proven (Thompson et al. 1997, Lutman et al. 2001, Davies et al. 2005), thus the re-establishment of weeds from seed banks can be foreseen after soil disturbance. Even though each restoration type was proven to be effective in weed control, weed cover was significantly lower in sown fields than in spontaneously recovering fields 5 yrs after restoration. The likely reason for the effective weed suppression in sown fields is that the developed dense sward of the sown perennial graminoids and the accumulated litter decreased the availability of microsites for the establishment of weeds (see also Deák et al. 2011, Török et al. 2012*b*). However Török et al. (2011*b*) reported that eventually after 10 yrs there was a significant decrease of weed cover in spontaneously recovering alfalfa fields.

Biomass production

We found that total biomass production extrapolated to hectares was approximately 4.66 t/ha in spontaneously recovering fields and 6.11 t/ha in sown fields. The proportion of biomass fractions was significantly

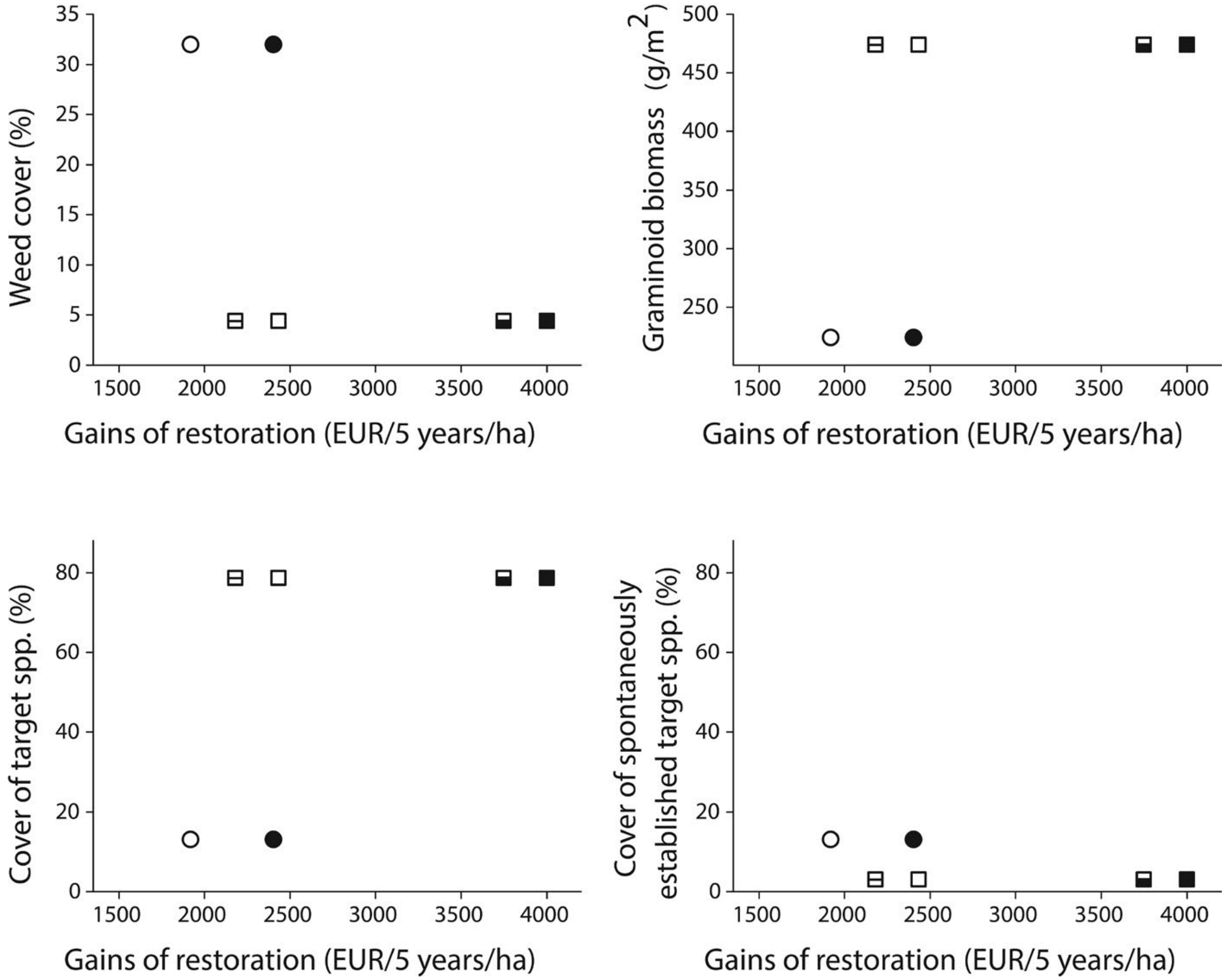

Fig. 2. Cost-effectiveness of the restoration measures in terms of weed cover, graminoid biomass, cover of target species, and cover of spontaneously established target species. We calculated all costs associated with the restoration (after Deák et al. 2013, Török et al. 2011a) and the possible gains from fodder value and agri-environmental subsidies. Lower weed cover, higher graminoid biomass, and higher cover of target and spontaneously established target species corresponds to higher restoration success. Notations: ○—spontaneous recovery, without subsidies; ●—spontaneous recovery, with subsidies; □—seed sowing, using locally harvested seeds, without subsidies; ■—seed sowing, using locally harvested seeds, with subsidies; ⊟—seed sowing, using commercially purchased seeds, without subsidies; ⬓—seed sowing, using commercially purchased seeds, with subsidies.

different between the two types of restored fields. Graminoid biomass was higher in the sown fields, likely because of the high cover of sown grasses (see Table 1).

Litter plays a crucial role in shaping grassland diversity (Bischoff et al. 2005, Lamb 2008, Kelemen et al. 2013). Several studies found a negative correlation between the amount of litter and species richness in restored grasslands, if the amount of litter exceeds 200–300 g/m^2 (Carson and Barrett 1988, Eckstein and Donath 2005, Deák et al. 2011). In our study, litter proportion in sown fields was higher than these thresholds. Decreased species richness was partly due to the weed suppression effect of accumulated litter, which is a favorable point both from the nature conservation and agricultural viewpoint. However, litter acted as a barrier for the establishment of target species as well, which threatens the diversity of restored grasslands in the long run.

Biodiversity

We found that species richness and Shannon diversity were higher in spontaneously recovering fields than in sown fields. Sowing perennial target species is very effective for weed control and ensures the establishment of the target grasses in the restored fields (Török et al. 2010, 2012*b*). However, the dense canopy of perennial graminoids likely suppressed the spontaneous establishment of target species (Kelemen et al. 2013, 2014), although in the sown fields, we found no correlation between cover of perennial graminoids and cover and species richness of spontaneously immigrated target species. The inclusion of *B. inermis* in the seed mixture can further increase microsite limitation in case of improper management. This highly competitive, clonally spreading species can effectively suppress annual and perennial weeds in the early years of grassland recovery (Török et al. 2010, Deák et al. 2011), but later on this species can competitively exclude target species, resulting in species-poor stands, like in huge areas of the North-American prairies (Larson and Anderson 2001, Grant et al. 2009). In spontaneously recovering fields, biotic filtering by perennial graminoids was likely lower, which allowed the spontaneous establishment of more target species than in the sown fields. These results suggest that improvement of biodiversity is necessary on the sown fields. Creating gaps in the dense graminoid sward and sowing seeds of target forb species to these "colonization windows" can be a good practice to improve the diversity of restored fields (Rayburn and Laca 2013, Kirmer et al. 2015).

Cost-effectiveness

We found that both spontaneous grassland recovery and restoration by seed sowing can be a cost-effective, or even profitable method to restore ecosystem services. Agri-environmental subsidies can highly contribute to the profitability of the restoration methods. This is especially true in the first year after seed sowing, when the quality of hay is too low to be used as fodder, because of the high biomass of weeds (Török et al. 2010). Contrary, in case of spontaneous recovery, the hay can be used as fodder from the first year after restoration, because of the high biomass of *M. sativa* which provided high-quality forage. For both restoration methods, besides subsidies, additional gains can be foreseen and restored fields can also support local animal husbandry. One can save costs if seeds of locally harvested target species are available for the seed mixtures. In that case, with agri-environmental subsidies, grassland restoration can be profitable even in the first year. Purchasing seeds from the market increases the costs of restoration, but with agri-environmental subsidies, this way of restoration also becomes profitable from the second year onwards. However, sowing with seeds purchased from the market is not as desirable from a nature conservation viewpoint as the seed sowing with locally harvested seeds (Mijnsbrugge et al. 2010), because these ecotypes are better adapted to local environmental conditions.

There are trade-offs between the rate of initial investment and the potential risks and gains, which should be considered when choosing the restoration method. The profitability of the two methods is influenced by socioeconomic factors, such as the price of the hay or the availability of subsidies. The type of last cultivated crop is also important, because spontaneous grassland recovery is faster and more successful in alfalfa fields compared to annual cropfields (Török et al. 2011*b*) where spontaneous recovery might be a less feasible method. Even though spontaneous recovery is cheap, it may incur loss of income through higher weed content, resulting in lower hay quality. Seed sowing requires higher initial investments, but the results are more predictable compared to spontaneous recovery, because the sown grasses provide high-quality hay and suppress weeds effectively.

Conclusions

Our results showed that grassland restoration on abandoned fields offer a viable solution for restoring ecosystem services. We found that seed sowing ensures higher weed control and biomass production, but lower biodiversity compared to spontaneous recovery. Grassland restoration projects support several further ecosystem services, such as purification of water, soil protection, pollination, and recreation (Mace et al. 2012, Dengler et al. 2014). Restored grasslands can act as buffer zones around natural grasslands, and provide habitats for grassland specialist plant and animal species (Ryan et al. 1998, Lengyel et al. 2012). We found that both spontaneous grassland recovery and restoration by seed sowing can be a cost-effective or even profitable method, and can be successful even in a relatively short period of a nature conservation project. The selection of the proper restoration method depends on many factors, such as ecological site characteristics (former crop, area of the field, availability of propagule sources, soil type, and climate) and economical constraints (available machinery, manpower, financial background, and the support of grants and other form of subsidies).

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Literature Cited

Albert, Á.-J., A. Kelemen, O. Valkó, T. Miglécz, A. Csecserits, T. Rédei, B. Deák, B. Tóthmérész, and P. Török. 2014. Trait-based analysis of spontaneous grassland recovery in sandy old-fields. Applied Vegetation Science 17:214–224.

Baer, S. G., D. J. Kitchen, J. M. Blair, and C. W. Rice. 2002. Changes in ecosystem function along a chronosequence of restored grasslands. Ecological Applications 12:1688–1701.

Bartha, S., et al. 2014. Impact of mid-successional dominant species on the diversity and progress of succession in regenerating temperate grasslands. Applied Vegetation Science 17:201–213.

Bischoff, A., H. Auge, and E.-G. Mahn. 2005. Seasonal changes in the relationship between plant species richness and community biomass in early succession. Basic and Applied Ecology 6:385–394.

Borhidi, A. 1995. Social behaviour types, the naturalness and relative indicator values of the higher plants in the Hungarian Flora. Acta Botanica Hungarica 39:97–181.

ter Braak, C. J. F., and P. Šmilauer. 2002. CANOCO Reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca, New York, USA.

Carson, W. P., and G. W. Barrett. 1988. Succession in old-field plant communities: effects of contrasting types of nutrient enrichment. Ecology 69:984–994.

Csecserits, A., and T. Rédei. 2001. Secondary succession on sandy old-fields in Hungary. Applied Vegetation Science 4:63–74.

Csecserits, A., R. Szabó, M. Halassy, and T. Rédei. 2007. Testing the validity of successional predictions on an old-field chronosequence in Hungary. Community Ecology 8:195–207.

Csecserits, A., M. Halassy, G. Kröel-Dulay, T. Rédei, K. Szitár, and R. Szabó. 2011. Different regeneration success of sandy old-fields in the forest-steppe region of Hungary. Plant Biosystems 145:715–729.

Davies, A. S., J. Cardina, F. Forcella, G. A. Johnson, G. Kegode, J. L. Lindquist, E. C. Luschei, K. A. Renner, C. L. Sprague, and M. M. Williams. 2005. Environmental factors affecting seed persistence of annual weeds across the US corn belt. Weed Science 53:860–868.

Deák, B., O. Valkó, A. Kelemen, P. Török, T. Miglécz, T. Ölvedi, S. Lengyel, and B. Tóthmérész. 2011. Litter and graminoid biomass accumulation suppresses weedy forbs in grassland restoration. Plant Biosystems 145:730–737.

Deák, B., O. Valkó, and I. Kapocsi. 2013. Általános és alternatív természetvédelmi célú gyeptelepítési módszerek technológiai kivitelezése és költségei. Pages 77–82 *in* P. Török, editor. Gyeptelepítés elmélete és gyakorlata az ökológiai szemléletu gazdálkodásban. Ökológiai Mezogazdasági Kutatóintézet, Budapest, Hungary.

Deák, B., O. Valkó, P. Török, and B. Tóthmérész. 2014a. Solonetz meadow vegetation (*Beckmannion eruciformis*) in East-Hungary—an alliance driven by moisture and salinity. Tuexenia 34:187–203.

Deák, B., O. Valkó, B. Tóthmérész, and P. Török. 2014b. Alkali marshes of Central-Europe ecology, management and nature conservation. Pages 1–11 *in* H.-B. Shao, editor. Salt marshes: ecosystem, vegetation and restoration strategies. Nova Science Publishers, Hauppauge, New York, USA.

Deák, B., O. Valkó, C. Alexander, W. Mücke, A. Kania, J. Tamás, and H. Heilmeier. 2014c. Fine-scale vertical position as an indicator of vegetation in alkali grasslands—case study based on remotely sensed data. Flora 209:693–697.

Deák, B., O. Valkó, P. Török, A. Kelemen, K. Tóth, T. Miglécz, and B. Tóthmérész. 2015. Reed cut, habitat diversity and productivity in wetlands. Ecological Complexity 22:121–125.

Deal, M. W., J. Xu, R. John, T. Zenone, J. Chen, H. Chu, P. Jasrotia, K. Kahmark, J. Bossenbroek, and C. Mayer. 2014. Net primary production in three bioenergy crop systems following land conversion. Journal of Plant Ecology. 7:451–460.

Dengler, J., M. Janišová, P. Török, and C. Wellstein. 2014. Biodiversity of Palaearctic grasslands: a synthesis. Agriculture, Ecosystems & Environment 182:1–14.

Eckstein, R. L., and T. W. Donath. 2005. Interactions between litter and water availability affect seedling emergence in four familiar pairs of floodplain species. Journal of Ecology 93:807–816.

Foster, B. L., C. A. Murphy, K. R. Keller, T. A. Aschenbach, E. J. Questad, and K. Kindscher. 2007. Restoration of prairie community structure and ecosystem function in an abandoned hayfield: a sowing experiment. Restoration Ecology 15:652–661.

Grant, T. A., B. Flanders-Wanner, T. L. Shaffer, R. K. Murphy, and G. A. Knutsen. 2009. An emerging crisis across northern prairie refuges: prevalence of invasive plants and a plan for adaptive management. Ecological Restoration 27:58–65.

Grime, J. P. 1979. Plant strategies and vegetation processes. J Wiley & Sons, Chichester, UK.

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

Hedberg, P., and W. Kotowski. 2010. New nature by sowing? The current state of species introduction in grassland restoration, and the road ahead. Journal of Nature Conservation 18:304–308.

Hobbs, R. J., and V. A. Cramer. 2007. Why old fields? Socioeconomic and ecological causes and consequences of land abandonment. Pages 1–15 *in* V. A. Cramer, and R. J. Hobbs, editors. Old fields: dynamics and restoration of abandoned farmland. Island Press, Washington, D.C., USA.

Hönigová, I., D. Vackár, El. Lorencová, J. Melichar, M. Götzl, G. Sonderegger, V. Oušková, M. Hošek, and K. Chobot. 2012. Survey on grassland ecosystem services. Report to the EEA—European Topic Centre on Biological Diversity. Nature Conservation Agency of the Czech Republic, Prague, Czech Republic.

Isselstein, J., B. Jeangros, and V. Pavlů. 2005. Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe—a review. Agronomy Research 3:139–151.

Jírová, A., A. Klaudisová, and K. Prach. 2012. Spontaneous restoration of target vegetation in old-fields in a central European landscape: a repeated analysis after three decades. Applied Vegetation Science 15:245–252.

Kelemen, A., P. Török, O. Valkó, T. Miglécz, and B. Tóthmérész. 2013. Mechanisms shaping plant biomass and species richness: plant strategies and litter effect in alkali and loess grasslands. Journal of Vegetation Science 24:1195–1203.

Kelemen, A., P. Török, O. Valkó, B. Deák, T. Miglécz, K. Tóth, T. Ölvedi, and B. Tóthmérész. 2014. Sustaining recovered grasslands is not likely without proper management: vegetation changes and large-scale evidences after cessation of mowing. Biodiversity and Conservation 23:741–751.

Kiehl, K., A. Kirmer, T. W. Donath, L. Rasran, and N. Hölzel. 2010. Species introduction in restoration projects—evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. Basic and Applied Ecology 11:285–299.

Kirmer, A., et al. 2015. Large-scale grassland restoration: high diversity seeding and knowledge transfer of regional seed propagation to Hungary. Debrecen University Press, Debrecen, Hungary.

Lamb, E. G. 2008. Direct and indirect control of grassland community structure by litter, resources, and biomass. Ecology 89:216–225.

Larson, D. L., and P. J. Anderson. 2001. Alien plant invasion in mixed-grass prairie: effects of vegetation type and anthropogenic disturbance. Ecological Applications 11:128–141.

Lencová, K., and K. Prach. 2011. Restoration of hay meadows on ex-arable land: commercial seed mixtures vs. spontaneous succession. Grass and Forage Science 66:265–271.

Lengyel, S., K. Varga, B. Kosztyi, L. Lontay, E. Déri, P. Török, and B. Tóthmérész. 2012. Grassland restoration to conserve landscape-level biodiversity: a synthesis of early results from a large-scale project. Applied Vegetation Science 15:264–276.
Lutman, P. J. W., G. W. Cussans, K. J. Wright, B. J. Wilson, N. G. Mc Wright, and H. M. Lawson. 2001. The persistence of seeds of 16 weed species over six years in two arable fields. Weed Research 42:231–241.
Mace, G. M., K. Norris, and A. H. Fitter. 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology and Evolution 27:19–26.
Matus, G., B. Tóthmérész, and M. Papp. 2003. Restoration prospects of abandoned species-rich sandy grassland in Hungary. Applied Vegetation Science 6:169–178.
Mijnsbrugge, K. V., A. Bischoff, and B. Smith. 2010. A question of origin: where and how to collect seed for ecological restoration. Basic and Applied Ecology 11:300–311.
Prach, K., and P. Pyšek. 2001. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. Ecological Engineering 17:55–62.
Prach, K., and K. Řehounková. 2008. Spontaneous vegetation succession in gravel–sand pits: a potential for restoration. Restoration Ecology 16:305–312.
Prach, K., J. Lepš, and M. Rejmánek. 2007. Old field succession in Central Europe: local and regional patterns. Pages 180–201 *in* V. A. Cramer, and R. J. Hobbs, editors. Old fields: dynamics and restoration of abandoned farmland. Island Press, Washington, D.C., USA.
Pullin, A. S., et al. 2009. Conservation focus on Europe: major conservation policy issues that need to be informed by conservation science. Conservation Biology 23:818–824.
Rayburn, A. P., and E. A. Laca. 2013. Strip-seeding for grassland restoration: past successes and future potential. Ecological Restoration 31:147–153.
Renne, I. J., and B. F. Tracy. 2007. Disturbance persistence in managed grasslands: shifts in aboveground community structure and the weed seed bank. Plant Ecology 190:71–80.
Rounsewell, M. D. A., F. Ewert, I. Reginster, R. Leemans, and T. R. Carter. 2005. Future scenarios of European agricultural land use—II. Projecting changes in cropland and grassland. Agriculture, Ecosystems and Environment 107:117–135.
Ruprecht, E. 2005. Secondary succession in old-fields in the Transylvanian Lowland (Romania). Preslia 77:145–157.
Ruprecht, E. 2006. Successfully recovered grassland: a promising example from Romanian old-fields. Restoration Ecology 14:473–480.
Ryan, M. R., L. W. Burger, and E. W. Kurzejeski. 1998. The impact of CRP on avian wildlife: a review. Journal of Production Agriculture 11:61–66.
Smith, L. M., D. A. Haukos, S. T. McMurry, T. LaGrange, and D. Willis. 2011. Ecosystem services provided by playas in the High Plains: potential influences of USDA conservation programs. Ecological Applications. 21:S82–S92.
Tallis, H., P. Kareiva, M. Marvier, and A. Chang. 2008. An ecosystem services framework to support both practical conservation and economic development. Proceedings of the National Academy of Sciences USA 105:9457–9464.
Thompson, K., J. P. Bakker, and R. M. Bekker. 1997. Soil seed banks of North West Europe: methodology, density and longevity. Cambridge University Press, Cambridge, UK.
Török, P., B. Deák, E. Vida, O. Valkó, S. Lengyel, and B. Tóthmérész. 2010. Restoring grassland biodiversity: sowing low diversity seed mixtures can lead to rapid favourable changes. Biological Conservation 148:806–812.
Török, P., E. Vida, B. Deák, S. Lengyel, and B. Tóthmérész. 2011a. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. Biodiversity and Conservation 20:2311–2332.
Török, P., A. Kelemen, O. Valkó, B. Deák, B. Lukács, and B. Tóthmérész. 2011b. Lucerne-dominated fields recover native grass diversity without intensive management actions. Journal of Applied Ecology 48:257–264.
Török, P., I. Kapocsi, and B. Deák. 2012a. Conservation and management of alkali grassland biodiversity in Central-Europe. Pages 109–118 *in* W. J. Zhang, editor. Grasslands: types, biodiversity and impacts. Nova Science Publishers Inc., New York, New York, USA.
Török, P., T. Miglécz, O. Valkó, A. Kelemen, B. Deák, S. Lengyel, and B. Tóthmérész. 2012b. Recovery of native grass biodiversity by sowing on former croplands: is weed suppression a feasible goal for grassland restoration? Journal for Nature Conservation 20:41–48.
Török, P., B. Deák, O. Valkó, A. Kelemen, I. Kapocsi, T. Miglécz, and B. Tóthmérész. 2013. Recovery of alkali grasslands using native seed mixtures in Hungary. Pages 18–198 *in* K. Kiehl, A. Kirmer, N. Shaw, and S. Tischew, editors. Guidelines for native seed production and grassland restoration. Cambridge University Press, Newcastle upon Tyne, UK.
Tóth, K., and B. Hüse. 2014. Soil seed banks in loess grasslands and their role in grassland recovery. Applied Ecology and Environmental Research 12:37–547.
Valkó, O., B. Tóthmérész, A. Kelemen, E. Simon, T. Miglécz, B. Lukács, and P. Török. 2014. Environmental factors driving vegetation and seed bank diversity in alkali grasslands. Agriculture, Ecosystems & Environment 182:80–87.
Zar, J. H. 1999. Biostatistical analysis. Prentice & Hall, Upper Saddle River, New Jersey, USA.
Zuur, A. F., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, New York, USA.