Journal for Nature Conservation xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration?

Péter Török[a,*], Tamás Miglécz[a], Orsolya Valkó[a], András Kelemen[a], Balázs Deák[b], Szabolcs Lengyel[a], Béla Tóthmérész[a]

[a] Department of Ecology, University of Debrecen, P.O. Box 71, H-4010 Debrecen, Hungary
[b] Hortobágy National Park Directorate, Sumen út 2, H-4024 Debrecen, Hungary

ARTICLE INFO

Article history:
Received 15 May 2011
Received in revised form 28 June 2011
Accepted 20 July 2011

Keywords:
Seed sowing
Weed suppression
Plant trait
Succession
Establishment success
Cropland

ABSTRACT

Grassland restoration on former croplands offers good opportunity to mitigate the loss of grassland biodiversity. Weed suppression can be another benefit, which becomes increasingly important because of the high recent rate of abandonment of arable lands in Central and Eastern Europe. Our aim was to evaluate the usefulness of sowing two low-diversity seed mixtures followed by annual mowing, a frequently used restoration technique, in weed suppression. We found that rapidly forming cover of sown grasses effectively suppressed short-lived weeds and their germination except in the first year. The detected dense seed bank of short-lived weeds points out the possibility and threat of later weed infestation. In the short run perennial weeds cannot be suppressed easily by sowing and annual mowing. We found that the effectiveness of seed sowing followed by mowing in weed suppression can be different on sites with different history or seed mixture. Rapidly establishing perennial weeds, such as *Agropyron* species were only detected in former alfalfa fields; *Cirsium arvense* was found in former cereal and sunflower fields but not in former alfalfa fields. We found that the rate of weed suppression and success was influenced by the seed mixtures used. In several alkali restorations the high proportion of perennial weeds was detected in year 3. In loess restorations, much lower scores were typical. This was likely caused by the different seed mixture used. The loess seed mixture contained seeds of a clonally spreading tall-grass, *Bromus inermis*, which could compete more effectively with clonally spreading weeds, than could short grass species with or without tussock forming. Our findings indicate that post-restoration management require carefully designed actions that are fine-tuned addressing specific threats at the site level.

Introduction

Grassland restoration in former arable lands offers a great opportunity to mitigate the overall loss of grassland biodiversity (Ewers & Didham 2005; Plieninger & Gaertner 2011; Römermann et al. 2005). Grassland restoration can be used to establish novel grasslands, increase the area of grassland fragments, and to create connections between, and buffer zones around, grassland fragments (Critchley et al. 2003). Thus, negative influences from surrounding agricultural areas (like infiltration/runoff of chemicals, and human disturbance) can be reduced (Karlík & Poschlod 2009; Török et al. 2010). Weed control can be another benefit of restoration, especially in areas such as abandoned croplands, roadsides, and field margins (Blumenthal et al. 2005). Weed control is becoming increasingly important because of the recent high rate of abandonment of agricultural areas in Central and Eastern Europe, and elsewhere (Cramer et al. 2008; Pullin et al. 2009), which can present substantial management problems. It is often a high priority to control weeds in abandoned areas to avoid weed infestation of natural habitats and agricultural fields and to slow their spread in the landscape (Blumenthal et al. 2003). Given the generally high costs of weed control interventions, the potential weed control benefit of grassland restoration can be a powerful argument to convince decision makers to fund grassland restoration worldwide.

Agricultural weed species as 'ruderal strategists' are generally characterised by high growth rates, short life spans and high reproductive allocation in the form of large amounts of persistent seeds (Bekker et al. 1997; Thompson et al. 1997). Weeds can rapidly establish in abandoned croplands already having vegetative propagule banks (e.g. tillers or rhizomes) and/or seed banks in the soil (Grime 1979; Prach et al. 2007). Weeds are often successful competitors in crop fields where high levels of soil nutrients are available but usually poorly adapted to late successional competitive environments (Blumenthal et al. 2005; Török et al. 2008). This observation raises the possibility that restoration using a direct sowing of late successional competitor species may be useful in

* Corresponding author.
E-mail address: molinia@gmail.com (P. Török).

1617-1381/$ – see front matter © 2011 Elsevier GmbH. All rights reserved.
doi:10.1016/j.jnc.2011.07.006

weed control. Although grassland restoration by seed sowing is often recommended, especially in sites where weed domination is foreseen (Hedberg & Kotowski 2010; Prach & Hobbs 2008), the effectiveness of sowing in weed suppression was analysed only in a few studies (e.g. Lepš et al. 2007; Van der Putten et al. 2000).

We studied the short-term vegetation dynamics and soil seed banks of grasslands restored by sowing low-diversity seed mixtures on former croplands. Our aim was to evaluate the usefulness of a frequently used restoration technique, i.e., sowing low-diversity seed mixtures followed by yearly mowing, in the recovery of grass biodiversity and weed control. We particularly asked the following questions: (i) Which weed species groups are likely to be suppressed by this way of restoration? (ii) How is weed suppression influenced by previous site history and the different seed mixtures? (iii) Can the success of weed suppression be compromised by the re-establishment of weed vegetation from soil seed banks?

Methods

Study sites

The study site is located in the Hortobágyi National Park (Egyek-Pusztakócsi mocsarak, east Hungary, N 47° 34′, E 20° 55′). The climate of the study site is continental with a mean annual precipitation of 550 mm (high yearly fluctuations occur frequently), and a mean temperature of 9.5 °C. A landscape-level grassland restoration project was started in the study region in 2005 (http://life2004.hnp.hu). Two low-diversity seed mixtures of native grasses were sown on 17 former crop fields (10 alfalfa, four sunflower and three cereal fields, 200 ha total) after seed bed preparation (deep ploughing and smoothing) in October 2005 (11 fields) and 2006 (six fields). The 'alkali' seed mixture containing seeds of *Festuca pseudovina* (67%) and *Poa angustifolia* (33%) were sown in nine fields, whereas the 'loess' mixture with the seeds of *Festuca rupicola* (40%), *Bromus inermis* (30%) and *Poa angustifolia* (30%) were sown in eight fields. The seed mixtures were sown at 25 kg per hectare in accordance with former restorations where similar amounts of seeds were sown (please see Kiehl et al. 2010; Török et al. 2011a). After sowing, the fields were regularly mown once in early June each year, before the seed ripening peak of most weed species, and the mown hay was removed from the area. No other management tool was used.

The soil of the studied fields were moderately compact (loam or clay-loam), with a pH (H_2O) of 6.0–7.6, and characterised by low salt (<0.02%) and $CaCO_3$ (<2%) contents. In all fields high phosphorous (typically 500–700 mg/kg) and potassium (typically 400–600 mg/kg) contents were measured, which frequently occurs after long-term crop production.

Study design and sampling

One sampling site (5 m × 5 m) per restored field was designated randomly but avoiding the field margins. In every sampling site, four 1 m × 1 m plots were permanently marked. In the plots, the cover of vascular plant species was recorded in early June before mowing in the three years after the sowing. For vegetation reference we selected typical stands of native alkali (*Achilleo setaceae-Festucetum pseudovinae*, three stands) and loess grasslands (*Salvio nemorosae-Festucetum rupicolae*, three stands) within a 20 km radius of the sown fields. We used the same sampling design for vegetation recording as described above.

Seed bank of sown grasslands was sampled in the third year after the sowing when the perennial cover was closed. Samples were collected after natural winter stratification and snowmelt in the plots for vegetation recording, in late March of 2008 (11 fields) and 2009 (six fields). We bored three soil cores per plot (4 cm in diameter, 10 cm in depth, 126 cm^3/core, and altogether 12 cores per sampling site); 204 soil cores in total. Cores from the same plot were pooled to reduce sample heterogeneity. Sample volume was reduced by 60–80% by the sample concentration method of ter Heerdt et al. (1996). Vegetative organs were separated by washing over a coarse sieve (3 mm mesh size), while seed-free fine soil components were removed using a 0.2-mm-fine mesh. Concentrated samples were spread in a thin layer (maximum thickness about 3–4 mm) on trays, previously filled with steam-sterilised potting soil. Trays were placed under natural light in a greenhouse shaded from early May to August. Seedlings were regularly counted, identified then removed. Unidentified plant specimens were transplanted and grown until they could be identified. In early July, when no seedlings emerged, regular watering was stopped, and the dried sample layers were crumbled and turned. In early September, watering was re-started and continued until early November. Occasional seed contamination (e.g. dispersal by wind) was monitored in sample-free control trays filled with steam-sterilised potting soil.

Data processing

Vegetative individuals of *Agropyron repens* and *A. intermedium* were difficult to distinguish, so their scores were pooled as *Agropyron* sp. during the data analyses. Similarly, seedlings of *Typha angustifolia* and *T. latifolia* were pooled as *Typha* sp. in all analyses.

Weed species were selected based on Grime's ruderal species group (1979), as adapted to local conditions in the Social Behaviour Types general classification of Borhidi (1995) and fine tuned by the personal expertise of the authors in alkali and loess vegetation. The species groups AC (adventive competitors, e.g. *Conyza canadensis*, *Ambrosia artemisiifolia*), RC (ruderal competitors, e.g. *Cirsium arvense*, *Agropyron repens*) and W (mostly annual and biannual weedy grasses and forbs of low competitiveness) were considered as weeds. We classified all detected species into functional groups based on simplified life-form categories (*short-lived*: Th, TH and *perennial*: H, G, Ch) and morphological features (*graminoids* = Juncaceae, Cyperaceae and Poaceae, and *forbs*). Differences in vegetation mean cover and species richness scores between years were analysed using ANOVA with repeated measures (RM) followed by Tukey tests for mean comparison (Zar 1999). DCA ordination was based on the percentage cover of the species using CANOCO 4.5 (ter Braak & Šmilauer 2002). Nomenclature follows Simon (2000) for taxa and Borhidi (2003) for syntaxa.

Results

Vegetation changes

Temporal vegetation development is represented by the first axis in Fig. 1. The first year vegetation characterised by short-lived species was gradually replaced by a perennial vegetation dominated by sown grasses in most sites. By the third year, vegetation records of the alkali and loess restorations are clearly separated. There was also a separation between the point cloud representing the third year vegetation of alkali restorations of former alfalfa fields and that representing the third year vegetation of former cereal and sunflower fields. The third year vegetation records of several sown fields are close to the reference grasslands.

We detected a total of 113 species (incl. 47 weeds) in the vegetation of sown fields during the three years of study. Only 34 of these species had more than 5% cover in at least one field and year (Appendix A). The mean total species richness and the species richness of short-lived weeds was highest in the first year and thereafter a tendency to decrease was typical both in alkali (Table 1, RM

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006

Table 1
Species richness and cover scores of short lived-weeds and cover (mean ± SE, %) of sown grasses in fields sown with alkali and loess seed mixtures. Different superscripted letters indicate significant differences between years (RM ANOVA and Tukey test, $P < 0.001$, $N = 9$ for alkali, and $N = 8$ for loess fields, respectively).

	Year 1	Year 2	Year 3
Alkali restorations			
Total species richness	15.3 ± 1.1[a]	9.7 ± 1.4[b]	6.8 ± 0.9[b]
Species richness of short lived weeds	8.1 ± 0.7[a]	3.3 ± 0.8[b]	1.3 ± 0.5[b]
Cover proportion of sown grasses	22.6 ± 7.6[a]	54.7 ± 11.3[b]	67.6 ± 5.8[b]
Cover proportion of short-lived weeds	64.2 ± 9.9[a]	18.5 ± 6.8[b]	1.7 ± 0.6[b]
Loess restorations			
Total species richness	15.4 ± 0.5[a]	9.0 ± 1.0[b]	8.1 ± 0.6[b]
Species richness of short lived weeds	7.8 ± 0.6[a]	2.0 ± 0.4[b]	1.0 ± 0.3[b]
Cover proportion of sown grasses	16.0 ± 5.0[a]	76.5 ± 6.8[b]	86.7 ± 3.2[b]
Cover proportion of short-lived weeds	69.6 ± 8.5[a]	4.3 ± 1.2[b]	1.8 ± 0.6[b]

ANOVA, $N = 9$, $F = 20.9$ and 39.3 for total and weed species richness, respectively, $P < 0.001$) and loess restorations (RM ANOVA, $N = 8$, $F = 32.8$ and 101.3, respectively, $P < 0.001$). A high cover of short-lived weeds was detected in almost every field in the first year (for frequent species see Fig. 1, and for more detailed changes see Appendix A). After the first year, a sharp decline in the cover of short-lived weeds was typical, in parallel with an increase of sown grass cover, which was detected in every field (RM ANOVA, for alkali restorations: $N = 9$, $F = 37.6$ and 25.5 for weed and sown grass cover, respectively, $P < 0.001$; and for loess restorations: $N = 8$, $F = 60.6$ and 67.5, respectively, $P < 0.001$; Appendix A). By the third year, perennial species became dominant (mostly perennial sown grasses) in every field.

In several fields a considerable cover of a few species of perennial weeds was detected which were not found as considerable cover in native target grasslands (Appendix B). In most alkali restorations on alfalfa fields, a high or increasing cover of perennial weedy *Agropyron* species was typical (Appendix A). In fields alfalfa-alkali-1 and alfalfa-alkali-2 the cover of *Agropyron* species was increased during the three years (RM ANOVA, $N = 4$, the detected increase was significant for alfalfa-alkali-1: $P < 0.001$, $F = 25.83$). In most of the former cereal and sunflower fields sown with alkali seed mixture a high cover of *Cirsium arvense* was detected. *Cirsium arvense* cover increased continuously in fields cereal-alkali-2, sunflower-alkali-1 to 3 from year 1 to year 3 (significantly in cereal-alkali-2: RM ANOVA, $N = 4$, $F = 7.59$, $P = 0.023$, and marginally significantly in sunflower-alkali-1: $F = 4.12$, $P = 0.079$). Conversely, in most loess restorations either a low cover (typically lower than 5%) or a decreasing cover of perennial weeds was detected after the first year regardless of site history (e.g. cereal-loess-1 first year cover of 35.1 ± 1.8% decreased to 15.8 ± 3.6% to year 3; mean ± SE). However, in field cereal-loess-1, the cover of *Cirsium arvense* increased with high fluctuations from 7.1 ± 3.4% in 1 year to 14.8 ± 3.3% to year 3.

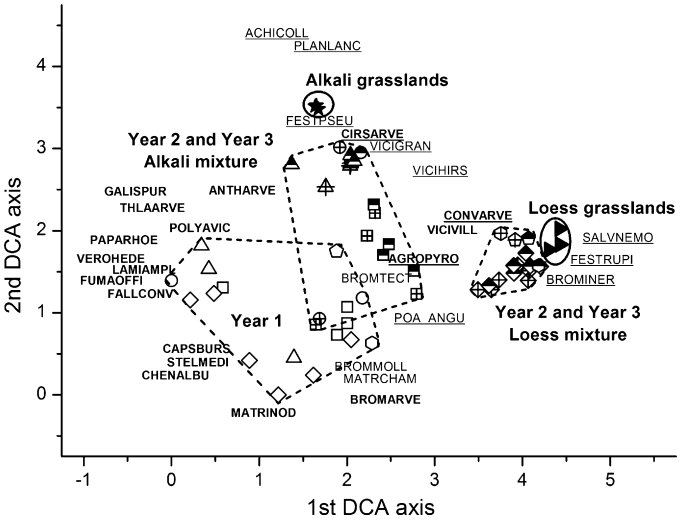

Fig. 1. Vegetation development in former alfalfa, cereal and sunflower fields sown with low-diversity seed mixtures towards reference grasslands as shown by a DCA ordination (eigenvalues for 1st and 2nd axis are 0.71 and 0.46, while gradient lengths are 4.42 and 3.53, respectively. Cumulative species variances for 1st and 2nd axis are 12.5 and 20.5, respectively). *Notations*: Alfalfa fields with alkali mixture = Year 1: □, Year 2: ⊞, Year 3: ⬒. Sunflower fields with alkali seed mixture = Year 1: △, Year 2: ⟁, Year 3: ▲. Cereal fields with alkali seed mixture = Year 1: ○, Year 2: ⊕, Year 3: ◓. Alfalfa fields with loess seed mixture = Year 1: ◊, Year 2: ⟐, Year 3: ◆. Sunflower fields with loess mixture = Year 1: ⬡, Year 2: ⊕, Year 3: ⬢. Cereal fields with loess mixture = Year 1: ⬠, Year 2: ⊕, Year 3: ⬟. Reference alkali grasslands: ★. Reference loess grasslands: ►. The most frequent 30 species were denoted by a combination of four letters of genus and four letters of species names like the following example: CHENALBU = *Chenopodium album* (but excl. AGROPYRO = *Agropyron* sp.). Perennial species were denoted with underline, weeds with boldface.

Seed bank and vegetation

A total of 3,802 seedlings of 76 species were counted and removed during the study. The mean total seed bank density ranged from 4,775 to 23,741 seeds/m^2. Most scores were typically within the range of 11,000 and 18,000 seeds/m^2. Out of the 21 most frequent species of the seed bank, there were 13 weed species, represented by 2,740 seedlings (almost 70% of total seed bank density, a mean seed density of 2,800–20,500seeds/m^2). We found considerably dense seed banks of short-lived weed species in all fields regardless of site history or seed mixture (Appendix C). The most frequent seed bank species, *Capsella bursa-pastoris*, was detected in almost all fields with high density; the highest scores were typical in former alfalfa fields. Conversely, *Echinochloa crus-galli* was more frequent in soils of former cereal and sunflower fields, and only a few of its seeds were found in former alfalfa fields. For most of the weed species no such clear trends were found. Only a few non-weedy forbs had a considerable dense seed bank. *Gypsophila muralis* and *Matricaria chamomilla*, characteristic short-lived pioneers of alkali grasslands showed high density only in alkali restorations on former alfalfa and cereal fields. Seeds of wind-dispersed and small seeded hygrophytes (such as *Typha* sp. and *Epilobium tetragonum*) were found in every sown field. The sown grasses had mostly sporadic seed banks, only *Poa angustifolia* had considerably dense seed banks (up to 1,260 seeds/m^2). We found mostly low-density seed banks of perennial weedy forbs (typically up to a few hundred seeds/m^2), and no seed banks were found for perennial weedy graminoids (Appendix C).

In the vegetation and seed bank altogether 146 species were found. Species composition of the seed bank showed the highest similarity with the species composition of the vegetation of the first year (Jaccard similarity ranged from 0.16 to 0.38). The mean scores of similarity significantly decreased from year 1 to year 3 in both types of seed mixtures (RM ANOVA, $P < 0.001$, alkali restorations, $N = 9$, $F = 13.53$; loess restorations, $N = 8$, $F = 19.93$). Several

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006

short-lived weed species that were detected with a high cover in first-year vegetation and suppressed later had a considerably dense seed bank (e.g. *Capsella bursa-pastoris*, *Matricaria indora*). Some other short-lived weeds such as *Fumaria officinalis*, *Fallopia convolvulus*, *Bromus arvensis*, *Papaver rhoeas*, *Veronica hederifolia* possessed only very sporadic seed banks. Conversely, several short-lived weed species detected with very low cover had considerably dense seed banks (*Echinochloa crus-gallii*, *Setaria glauca*, and *S. viridis*).

Discussion

Grassland recovery and weed suppression

We found contrasting short-term success of weed suppression in our study in relation to specific life history traits. Short-lived weeds (both forbs and graminoids) were effectively suppressed by sowing low-diversity seed mixtures and mowing as part of a post-restoration management in every sown field. The cover scores of short-lived weed species were reduced from a mean of 64–67% in year 1 to a mean around 2% in year 3. Similar results were detected in other grassland restoration studies using low or high-diversity seed mixtures (Critchley et al. 2006; Jongepierová et al. 2007; Lawson et al. 2004; Lepš et al. 2007). Short-lived weeds are easily suppressed because of their (i) poor competitive ability (Tilman 1982), (ii) missing persistent seed banks, as was found for several species in this study, (iii) germination failure by a physical barrier or shading by both accumulated litter and green biomass (Van der Putten et al. 2000), and also germination inhibition by discharged allelochemicals (Ruprecht et al. 2008).

We found that basic grass diversity can be recovered within three years in most of the sown fields by the grassland restoration method; but in some fields even the recovery of basic grass diversity was delayed by weedy perennials which could not be suppressed by the used restoration procedure in the short run. The most persistent perennial weeds in our study were *Agropyron repens*, *A. intermedium* and *Cirsium arvense*. These species were also identified as problem plants in several other studies, where their increased dominance was detected after seed sowing (*Agropyron repens*, Lepš et al., 2007), during spontaneous grassland recovery in old-fields (*Agropyron repens* and *Cirsium arvense*, Prach et al. 2007; Prach & Pyšek, 2001; Ruprecht 2005, *A. intermedium*, Török et al., 2011b), and in several managed agricultural areas (*Cirsium arvense*, De Bruijn & Bork 2006). In a sowing experiment using regional seed mixtures in a density of 20 kg/ha Jongepierová et al. (2007) a significant increase of several perennial weeds was found (e.g. A. repens and *Taraxacum* sect. *ruderalia*) similarly to our findings.

These perennials have an effective clonal reproduction and vegetative spreading strategy by lateral tillers, so they can survive soil preparation and sowing practices and can rapidly establish through vegetative spreading by tillers (Lepš et al. 2007; Prach et al. 2007). This was also suggested by Pywell et al. (2003), where the performance of a species in restoration in former croplands was significantly favoured if the species was capable of effective vegetative growth and spreading. In addition to vegetative spreading, we found that *Cirsium arvense* can have a considerably dense seed bank (e.g. 1,790 seeds/m^2 in this study) and its seeds can be effectively dispersed by wind and secondarily by ants from nearby seed sources (Albrecht 2005; De Bruijn & Bork 2006; Lengyel et al. 2010). The rapidly increased cover of perennials detected in our study can be also supported by high nutrient levels in the soil, which is a result of previous use of fertilisers common in crop production. To suppress these perennial weeds, more intensive management practices are necessary. Increased mowing frequency (for *Agropyron repens*, Parr & Way 1988) or high-density rotational grazing by cattle (for *Cirsum arvense*, De Bruijn & Bork 2006) can be more proper solutions for decreasing the cover of the perennial weeds detected.

Finally, in agricultural practice, sowing densities of 80–100 kg/ha or even higher (up to 500 kg/ha) are frequently used (van Andel & Aronson 2006), which is much higher than the density in this study (25 kg/ha). High-density sowing results in a dense grass sward, which may suppress weeds more effectively than low-density sowing, but may also hamper later immigration of the targeted subordinate species (Hellström et al. 2009).

Seed mixtures and site history

We found that the effectiveness of seed sowing followed by mowing in weed suppression can be different on sites with different history or seed mixture used. Contrasting success was found in our study in fields with different previous crop but same seed mixture sown. Rapidly establishing perennial graminoid weeds, such as *Agropyron* species were detected only in former alfalfa fields. Conversely, the perennial weedy forb *Cirsium arvense* was found in former cereal and sunflower fields but not in former alfalfa fields. The absence of perennial weedy forbs in former alfalfa fields can be related to the cultivated alfalfa, which itself is a perennial forb and can effectively suppress other weeds (incl. *Cirsium arvense*), as was shown in a previous study of ours (Török et al. 2011b). In that study, at most low cover of *Cirsium arvense* was detected in former alfalfa fields and the perennial alfalfa cover was gradually replaced by perennial grass cover without the stage dominated by perennial weedy forbs. In several other studies, remarkably high cover of *Cirsium arvense* was reported from cereal and maize fields (the latter are cultivated similarly as sunflower), which agrees well with our finding of high cover of *Cirsium* in most of our former cereal and sunflower fields (De Bruijn & Bork 2006; Gerowitt 2003; Jongepierová et al. 2004; Romero et al. 2008). These results clearly indicate that planning restoration efforts for different seed mixtures or fields with different previous crop may require the plan of different restoration measures for the same rate of success.

It was found formerly that the recovery of grassland vegetation in former croplands can be influenced by several constraints depending on site history such as (i) impoverished local propagule sources and/or dispersal limitation of grassland species (Bekker et al. 1997; Bissels et al. 2006; Valkó et al. 2011), (ii) unsuitable soil conditions, e.g. higher nutrient levels (Pywell et al. 2002) and (iii) increased availability of vegetative and generative propagule-bank of weeds (Bekker et al. 1997; Hutchings & Booth 1996). In seed sowing experiments, knowing this information constrains elimination of the seed limitation of grassland species and suppressing weeds by sowing and/or with topsoil removal recomended (Critchley et al. 2006; Klimkowska et al. 2010; Pywell et al. 2002; Török et al. 2011b).

In several alkali restorations in this study, the proportion of perennial weeds increased during the three years of vegetation development, and was high in year 3. In loess restorations, much lower scores were typical. This was likely caused by the different seed mixture used. The loess seed mixture contained seeds of a clonally spreading tall-grass, *Bromus inermis*, which could probably compete more effectively with clonally spreading *Cirsium arvense* or *Agropyron repens*, than could short grass species with or without tussock forming like *Poa angustifolia* or *Festuca pseudovina* (e.g. Pywell et al. 2003).

Seed banks

We found that several short-lived weeds that were effectively suppressed (e.g. *Capsella bursa-pastoris*, *Matricaria inodora*) or not even detected in aboveground vegetation (e.g. *Setaria viridis*, *S.*

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006

glauca) had considerably dense seed banks, which offers a possibility for their later establishment. This result clearly indicates that weed suppression aboveground does not necessarily mean the elimination of even the short-lived weeds from restoration sites.

The seed density scores for weeds detected in our former fields (about 2,800–20,500 seeds/m^2) fit in the lower part of the previously detected range of seed density scores for weeds in agricultural lands (250–130,300 seeds/m^2, Cavers & Benoit 1989). Several short-lived weeds detected in this study with sporadic seed banks at most can be completely eliminated from restoration fields (e.g. *Fumaria officinalis*, *Bromus arvensis*). For several short-lived weed species, very long-term persistence, reaching up to several decades, was proven (Davis et al. 2005; Thompson et al. 1997). Regular cultivation by creating bare soil surfaces can cause a rapid germination of several weed species and also decrease the density of their soil seed banks (Lutman et al. 2001). The rapidly formed cover of perennials in our study suppressed short-lived weeds aboveground and prevented the germination of weeds (except in the first year), but may have allowed the preservation of their seed banks. The re-establishment of weeds from this seed bank can be enhanced by creating gaps in the vegetation; thus, management actions that increase suitable vegetation gaps, such as grazing/trampling by cattle or sheep, and also other types of soil disturbance should be avoided, especially in the first years after restoration (Renne & Tracy 2007).

Conclusions for restoration

We found that in most cases the use of low diversity seed mixtures composed of native grasses and yearly mowing enabled the recovery of basic grass diversity and may prove promising in weed suppression. It was revealed that short-lived weed assemblages can be easily suppressed; however, the composition of the seed mixtures can strongly influence the success where perennial clonally spreading weeds are typical. In such cases the sowing of clonally spreading competitor grasses may favour the weed suppression. Another alternative for weed suppression is to increase the frequency of post-restoration management by mowing multiple times per year or the introduction of low intensity grazing. In spite of yearly mowing and the rapid recovery of sown grass' cover a dense persistent weed seed banks was present in the soil of most fields. This fact points out that high intensity grazing and/or trampling should be avoided, especially in the first years after the sowing.

Acknowledgements

This research was permitted by the Tiszántúl Inspectorate for Environmental Protection, Nature Conservation and Water Management and Hortobágy National Park Directorate (HNPD). Assistance by several students (K. Tóth, S. Radócz, B. Tatár, E. Mikecz, E. Vida, T. Ölvedi), and colleagues (L-né Tegdes, C.-né Koncz, B. Lukács, G. Matus, P. Tanyi) in the field and laboratory is greatly acknowledged. The authors thank colleagues in HNPD (I. Kapocsi, L. Gál, I. Sándor, A. Molnár, R. Kiss) for useful advice. Grassland restoration was financed by a grant from the LIFE-Nature programme of the European Union (LIFE04NAT/HU/000119, http://life2004.hnp.hu). This study was supported by a joint grant from the Hungarian Scientific Research Fund and the Norway Financing Mechanism (OTKA NNF 78887) to S.L. and TÁMOP 4.2.1./B-09/1/KONV-2010-0007 project. The TÁMOP project is implemented through the New Hungary Development Plan, co-financed by the European Social Fund and the European Regional Development Fund. This project was supported by the Bolyai János Research Scholarship of the Hungarian Academy of Sciences (P. Török, S. Lengyel).

Appendix A. Mean cover proportions of frequent species detected in sown fields in years 1–3 (species with a mean cover of 5% in at least one field were listed). Weeds were indicated with boldface (based on Grime (1979) and Borhidi (1995)). *Field codes:* First letter former crop: A – alfalfa, C – cereal, S – sunflower, second letter seed mixture: A – alkali, L – loess, the last number is the number of the field. FSG – functional species groups: S – short-lived, P – perennial, F – forb, G – graminoid

	FSG	AA1	AA2	AA3	AA4	CA1	CA2	SA1	SA2	SA3	AL1	AL2	AL3	AL4	AL5	AL6	CL1	SL1
Year 1																		
Anthemis arvensis	SF								10.4	9.5								
Fallopia convolvulus	SF	1.4				0.6	1.5					0.7	0.3		15.7	29.8	2.3	
Capsella bursa-pastoris	SF	32.9	10.1	2.4	3.3	1.9		1.0	20.2	30.0	11.8	2.9	4.0	31.0	19.9	18.8		
Chenopodium album	SF	0.3	0.3	0.4			6.5	3.2	0.6	0.1		1.7	2.0	0.2	2.6	4.6	1.1	10.3
Consolida regalis	SF					0.2	3.2		0.6	0.2				0.4	6.3	0.7	3.3	
Fumaria officinalis	SF	0.6					29.4		0.1				0.2		9.8	27.9	6.9	1.4
Galium spurium	SF						7.9	0.2	38.9	37.2		0.2		0.1				0.2
Lamium amplexicaule	SF	1.4	0.2		0.1	1.1			2.3	5.5		0.2	0.4	0.1	7.3	4.8		0.8
Matricaria chamomilla	SF	0.5	1.4	4.7	0.2	27.0												0.1
Matricaria inodora	SF	0.2	12.9	18.2	24.5	3.8	4.9	72.2	0.9	3.5	60.5	78.9	50.5	25.1			0.5	30.2
Papaver rhoeas	SF					0.3	18.8			2.8					9.8		0.7	
Polygonum aviculare	SF	46.0	13.4	10.9	3.1	1.4	2.8		0.1	0.1	0.3	0.9	16.8	1.3	8.4	6.6	0.4	
Stellaria media	SF	1.3	0.9		3.2	2.8			0.2	0.1	0.5	6.2	22.0		0.2			
Thlaspi arvense	SF		0.1		0.1	0.2			14.8	0.9	0.1	0.3	1.3	0.4	4.0			0.2
Veronica hederifolia	SF	0.3				0.6	12.3					0.3	0.2		4.5	1.0		
Bromus arvensis	SG	3.5	2.4	4.3	16.0	1.7									0.1	0.3	1.7	13.4
Bromus mollis	SG	1.2	2.0	1.5	12.0	2.0	3.2	0.9	0.5	0.4	1.3	0.2	0.3	4.0	0.5	0.8	1.2	0.6
Hordeum vulgare	SG					2.8							0.2				21.5	0.2
Cirsium arvense	PF			0.1			0.3	3.6	1.7	4.3					0.0	0.0	7.1	
Convolvulus arvensis	PF			0.2		1.0		6.5		0.1						1.1	27.1	
Bromus inermis	PG										2.1	1.4	0.5	25.3	2.5	0.7	8.6	8.1
Festuca pseudovina	PG	1.1	0.6	10.9	11.1	11.9	1.3	8.2	2.1	2.8								

	FSG	AA1	AA2	AA3	AA4	CA1	CA2	SA1	SA2	SA3	AL1	AL2	AL3	AL4	AL5	AL6	CL1	SL1
Festuca rupicola	PG										4.5	0.7	0.9	3.5	3.1	0.6	5.4	15.3
Poa angustifolia	PG	0.8	54.0	39.3	22.0	32.4	1.5	1.9		0.5	17.4	3.9	0.1	6.5	1.2	0.6	3.4	11.2
Year 2																		
Anthemis arvensis	SF								14.8	40.1								
Capsella bursa-pastoris	SF	32.1	5.0				7.5	0.4	1.7	2.4						1.8		
Matricaria inodora	SF	11.4	1.0	0.1			24.5	5.1	0.9	3.8	0.9	0.4	0.1			0.6	0.1	0.2
Medicago lupulina	SF									0.1					0.7	0.9	18.8	
Trifolium angulatum	SF						1.6	8.1	0.1	0.3								0.1
Vicia hirsuta	SF			0.4	0.1	0.9		9.7	10.1	10.5	0.3			0.1		0.2	6.5	36.8
Vicia grandiflora	SF								26.8									
Vicia villosa	SF				0.1					1.3	5.4	0.5					7.8	1.3
Bromus mollis	SG	11.7	1.7			0.1	31.4	0.8	0.7	4.2	0.1	1.1	2.0	0.1	3.7	2.7	1.8	0.6
Bromus tectorum	SG	1.6					4.9	0.2	6.0	0.1		0.7	0.1		0.5	1.4		0.1
Cirsium arvense	PF						2.1	14.1	17.2	10.4		0.4	0.1				1.1	
Convolvulus arvensis	PF	0.2	0.1	0.1	0.7	0.9	2.5	4.6	0.1	0.3		0.4	0.1	0.9		16.2	15.3	0.2
Lathyrus tuberosus	PF																6.0	
***Agropyron* sp.**	PG	11.3	10.8		12.0								13.4			2.0		
Bromus inermis	PG										40.1	27.3	44.2	71.0	27.3	55.3	22.5	16.8
Festuca pseudovina	PG	7.9	40.4	10.5	44.3	84.1	15.7	50.5	18.9	20.3								
Festuca pratensis	PG	0.2		1.3	5.9	0.3												
Festuca rupicola	PG										4.9	8.2	14.0	4.2	51.5	9.6	15.3	34.2
Poa angustifolia	PG	20.2	39.4	86.6	33.9	12.0	4.1	4.1	0.1	1.9	45.8	48.4	24.1	23.6	10.3	2.6	1.2	8.3
Year 3																		
Trifolium striatum	SF											7.8	0.0	1.1				
Vicia hirsuta	SF	0.2		7.8	5.1	17.3		1.2	0.4		1.4	3.4	1.2	4.5		1.3		0.7
Bromus tectorum	SG	6.3			0.1		0.1		0.2	0.5			0.1		1.2	0.3		
Cirsium arvense	PF						10.6	23.6	47.7	22.8		0.5					14.8	
Convolvulus arvensis	PF	0.5	0.3		0.5	1.9	4.9	3.0	0.6	0.5		0.1	0.7	1.5		13.5	1.0	0.1
***Agropyron* sp.**	PG	52.9	24.5		7.2								3.4			6.1		
Bromus inermis	PG										15.3	24.9	33.6	46.8	33.1	9.7	29.8	22.6
Festuca pseudovina	PG	16.8	30.3	15.2	47.7	66.3	64.1	58.5	31.3	39.7							0.2	
Festuca pratensis	PG				5.3													
Festuca rupicola	PG										47.0	30.6	14.1	27.3	52.6	60.1	49.9	59.6
Poa angustifolia	PG	18.0	44.7	72.4	31.4	9.3	11.0	12.4	14.2	34.7	29.2	24.4	39.2	16.2	9.4	1.9		16.0

Appendix B. Mean cover proportions of frequent species detected in reference grasslands (species with a mean cover of 5% in at least one grassland were listed). Weeds were indicated with boldface (based on Grime (1979) and Borhidi (1995)). *Notations*: AR1–3: alkali grasslands, LR1–3: loess grasslands

	FSG	AR1	AR2	AR3	LR1	LR2	LR3
Trifolium campestre	SF	5.4	5.0	1.4			
Vicia hirsuta	SF				10.9	2.9	2.5
Achillea collina	PF	12.9	3.3	14.5			
Achillea setacea	PF		7.5				
Convolvulus arvensis	PF				2.1	7.9	3.7
Galium verum	PF				0.1	5.4	3.5
Lathyrus tuberosus	PF					6.5	2.3
Plantago lanceolata	PF	12.0	9.0	3.8			
Salvia nemorosa	PF				50.0	36.3	20.5
Bromus inermis	PG				32.5	53.8	58.8
Carex praecox	PG				7.3	3.5	0.1
Festuca pseudovina	PG	50.0	65.5	57.5			
Festuca rupicola	PG				3.1	6.3	2.0
Poa angustifolia	PG				2.8	3.7	5.8

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006

Appendix C. Mean seed bank density scores of frequent species and total seed density detected in seed banks of the sown fields (species detected with at least 30 viable seeds total are listed). Weeds were indicated with boldface (based on Grime (1979) and Borhidi (1995)). One seedling recorded in the samples of a certain field corresponds with a seed density of 66 seeds per m^2

Species	FSG	AA1	AA2	AA3	AA4	CA1	SA1	SA2	SA3	CA2	AL1	AL2	AL3	AL4	AL5	AL6	SL1	CL1
Amaranthus retroflexus	SF	332	66		464		66			398		133		199		133	464	66
Capsella bursa-pastoris	SF	3647	4708	2719	3183	1326	1724	4841	2785	1459	4377	4974	6234	6963	10,345	5106	464	66
Chenopodium album	SF	2984	597	133	1592	66	1260	597	928	398	199	398	1,525	928	398	4443	5769	133
Conyza canadensis	SF	66	199	663	928			133		531	1194	66	265	66	199	133	66	199
Gypsophila muralis	SF		332	6499	729	133	663	663	531				133	928				
Lamium amplexicaule	SF	199	199			66		729	531	199		531	133		265	66		
Lepidium campestre	SF				2321	464							133	66				
Matricaria chamomilla	SF		1857	1989	199	4642				66							66	
Matricaria inodora	SF	133	597	1260	1857		1326		199	199	332	1260	1260	265	66	199	531	
Polygonum aviculare	SF	1061	729	862	796	66	0	464	531	66	0	133	199	66	995	464		
Spergularia rubra	SF			4642		133					663	0	66	199				
Stellaria media	SF	663	66		1592			332	531		265	862	1459					
Thlaspi arvense	SF	66	332	66	133			3979	398		66	332	1127	265	1724			
Echinochloa crus-gallii	SG	0	199	398	66	7029	3913	1592	1459	1326		133	199	199	332		2984	199
Setaria glauca	SG		133	0	0	862	199	6300	3183	1525	1658	3714	3714				66	1260
Setaria viridis	SG							66	133	265		199	663		1790	1525	0	464
Cirsium arvense	PF							1194	66	1790					66			
Epilobium tetragonum	PF	66	796		133	133		66	66	332		66	66	133				199
Typha sp.	PF	2321	2122	597	1194	796	398		265	995	199	265	265	729	265	729	729	1061
Festuca pseudovina	PG	66	133		199		1260	464	66	66								
Poa angustifolia	PG	531	1260	265	199	332	995	398	464	1194	265	265	796		332	133	928	464
Total seed density		14,523	15,120	22,215	16,512	17,043	11,671	12,467	23,741	13,462	9417	13,860	18,833	11,141	18,568	15,053	4775	13,727

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006

References

Albrecht, H. (2005). Development of arable weed seedbanks during the 6 years after the change from conventional to organic farming. *Weed Research*, *45*, 339–350.

Bekker, R. M., Verweij, G. L., Smith, R. E. N., Reine, R., Bakker, J. P., & Schneider, S. (1997). Soil seed banks in European grassland: Does land use affect regeneration perspectives? *Journal of Applied Ecology*, *34*, 1293–1310.

Bissels, S., Donath, T. W., Hölzel, N., & Otte, A. (2006). Effects of different mowing regimes on seedling recruitment in alluvial grasslands. *Basic and Applied Ecology*, *7*, 433–442.

Blumenthal, D. M., Jordan, N. R., & Svenson, E. L. (2003). Weed control as a rationale for restoration: The example of tallgrass prairie. *Conservation Ecology*, *7*, 6. Available from. www.consecol.org/vol7/iss1/art6

Blumenthal, D. M., Jordan, N. R., & Svenson, E. L. (2005). Effects of prairie restoration on weed invasions. *Agriculture, Ecosystems & Environment*, *107*, 221–230.

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.

Borhidi, A. (2003). *The plant associations of Hungary*. Budapest: Akademiai Kiadó. [in Hungarian]

Cavers, P. B., & Benoit, D. L. (1989). Seed banks in arable land. In A. M. Leck, T. V. Parker, & R. L. Simpson (Eds.), *Ecology of soil seed banks* (pp. 309–329). San Diego: Academic Press.

Cramer, V. A., Hobbs, R. J., & Standish, R. J. (2008). What's new about old fields? Land abandonment and ecosystem assembly. *Trends in Ecology and Evolution*, *23*, 104–112.

Critchley, C. N. R., Burke, M. J. W., & Stevens, D. P. (2003). Conservation of lowland semi-natural grasslands in the UK: A review of botanical monitoring results from agri-environment schemes. *Biological Conservation*, *115*, 263–268.

Critchley, C. N. R., Fowbert, J. A., Sherwood, A. J., & Pywell, R. F. (2006). Vegetation development of sown grass margins in arable fields under a countrywide agri-environment scheme. *Biological Conservation*, *132*, 1–11.

Davis, A. S., Cardina, J., Forcella, F., Johnson, G. A., Kegode, G., Lindquist, J. L., et al. (2005). Environmental factors affecting seed persistence of annual weeds across the US corn belt. *Weed Science*, *53*, 860–868.

De Bruijn, S. L., & Bork, E. W. (2006). Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. *Biological Control*, *36*, 305–315.

Ewers, R. M., & Didham, R. K. (2005). Confounding factors in the detection of species response to habitat fragmentation. *Biological Review*, *81*, 117–142.

Gerowitt, B. (2003). Development and control of weeds in arable farming systems. *Agriculture, Ecosystems & Environment*, *98*, 247–254.

Grime, J. P. (1979). *Plant strategies and vegetation processes*. Chichester: Wiley.

Hedberg, P., & Kotowski, V. (2010). New nature by sowing? The current state of species introduction in grassland restoration, and the road ahead. *Journal for Nature Conservation*, *18*, 304–308.

Hellström, K., Huhta, A.-P., Rautio, P., & Tuomi, J. (2009). Seed introduction and gap creation facilitate restoration of meadow species richness. *Journal for Nature Conservation*, *17*, 236–244.

Hutchings, M. J., & Booth, K. D. (1996). Studies on the feasibility of re-creating chalk grassland vegetation on ex-arable land. I. The potential poles of the seed bank and the seed rain. *Journal of Applied Ecology*, *33*, 1171–1181.

Jongepierová, I., Jongepier, J. W., & Klimes, L. (2004). Restoring grassland on arable land: An example of a fast spontaneous succession without weed-dominated stages. *Preslia*, *76*, 361–369.

Jongepierová, I., Mitchley, J., & Tzanopoulos, J. (2007). A field experiment to recreate species rich hay meadows using regional seed mixtures. *Biological Conservation*, *139*, 297–305.

Karlík, P., & Poschlod, P. (2009). History or abiotic filter: Which is more important in determining the species composition of calcareous grasslands? *Preslia*, *81*, 321–340.

Kiehl, K., Kirmer, A., Donath, T. W., Rasran, L., & Hölzel, N. (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.

Klimkowska, A., Dzierża, P., Brzezińska, K., Kotowski, W., & Mędrzycki, P. (2010). Can we balance the high costs of nature restoration with the method of topsoil removal? Case study from Poland. *Journal for Nature Conservation*, *18*, 202–205.

Lawson, C. S., Ford, M. A., & Mitchley, J. (2004). The influence of seed addition and cutting regime on the success of grassland restoration on former arable land. *Applied Vegetation Science*, *7*, 259–266.

Lengyel, S., Gove, A. D., Latimer, A. M., Majer, J. D., & Dunn, R. R. (2010). Convergent evolution of seed dispersal by ants, and phylogeny and biogeography in flowering plants: A global survey. *Perspectives in Plant Ecology and Evolution*, *12*, 43–55.

Lepš, J., Doležal, J., Bezemer, T. M., Brown, V. K., Hedlund, K., Igual Arroyo, M., et al. (2007). Long-term effectiveness of sowing high and low diversity seed mixtures to enhance plant community development on ex-arable fields. *Applied Vegetation Science*, *10*, 97–110.

Lutman, P. J. W., Cussans, G. W., Wright, K. J., Wilson, B. J., Wright, Mc, N. G., et al. (2001). The persistence of seeds of 16 weed species over six years in two arable fields. *Weed Research*, *42*, 231–241.

Parr, T. W., & Way, J. M. (1988). Management of roadside vegetation: The long-term effects of cutting. *Journal of Applied Ecology*, *25*, 1073–1087.

Plieninger, T., & Gaertner, M. (2011). Harnessing degraded lands for biodiversity conservation. *Journal for Nature Conservation*, *19*, 18–23.

Prach, K., & Hobbs, R. J. (2008). Spontaneous succession versus technical reclamation in the restoration of disturbed sites. *Restoration Ecology*, *16*, 363–366.

Prach, K., Lepš, J., & Rejmánek, M. (2007). Old field succession in Central Europe: Local and regional patterns. In V. A. Cramer, & R. J. Hobbs (Eds.), *Old fields: Dynamics and restoration of abandoned farmland* (pp. 180–201). Island Press: Washington.

Prach, K., & Pyšek, P. (2001). Using spontaneous succession for restoration of human-disturbed habitats: Experience from Central Europe. *Ecological Engineering*, *17*, 55–62.

Pullin, A. S., Báldi, A., Can, O. E., Dieterich, M., Kati, V., Livoreil, B., et al. (2009). Conservation focus on Europe: Major conservation policy issues that need to be informed by Conservation Science. *Conservation Biology*, *23*, 818–824.

Pywell, R. F., Bullock, J. M., Hopkins, A., Walker, K. J., Sparks, T. H., Burke, M. J. W., et al. (2002). Restoration of species-rich grassland on arable land: Assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology*, *39*, 294–309.

Pywell, R. F., Bullock, J. M., Roy, D. B., Warman, L., Walker, K. J., & Rothery, P. (2003). Plant traits as predictors of performance in ecological restoration. *Journal of Applied Ecology*, *40*, 65–77.

Renne, I. J., & Tracy, M. J. W. (2007). Disturbance persistence in managed grasslands: Shifts in aboveground community structure and the weed seed bank. *Plant Ecology*, *190*, 71–80.

Römermann, C., Dutoit, T., Poschlod, P., & Buisson, E. (2005). Influence of former cultivation on the unique Mediterranean steppe of France and consequences for conservation management. *Biological Conservation*, *121*, 21–33.

Romero, A., Chamorro, L., & Sans, F. S. (2008). Weed diversity in crop edges and inner fields of organic and conventional dryland winter cereal crops in NE Spain. *Agriculture, Ecosystems & Environment*, *124*, 97–104.

Ruprecht, E. (2005). Secondary succession in old-fields in the Transylvanian Lowland (Romania). *Preslia*, *77*, 145–157.

Ruprecht, E., Donath, T. W., Otte, A., & Eckstein, R. L. (2008). Chemical effects of a dominant grass on seed germination of four familial pairs of dry grassland species. *Seed Science Research*, *18*, 239–248.

Simon, T. (2000). *Vascular flora of Hungary*. Budapest: Nemzeti Tankönyvkiadó. [in Hungarian].

ter Braak, C. J. F., & Šmilauer, P. (2002). *CANOCO reference manual and CanoDraw for windows user's guide: Software for canonical community ordination (version 4.5)*. Ithaca, NY, USA: Microcomputer Power.

ter Heerdt, G. N. J., Verweij, G. L. R., Bekker, R. M., & Bakker, J. P. (1996). An improved method for seed bank analysis: Seedling emergence after removing the soil by sieving. *Functional Ecology*, *10*, 144–151.

Thompson, K., Bakker, J. P., & Bekker, R. M. (1997). *Soil seed banks of North West Europe: Methodology, density and longevity*. Cambridge: Cambridge University Press.

Tilman, D. (1982). *Resource competition and community structure*. Princeton: Princeton University Press.

Török, P., Deák, B., Vida, E., Valkó, O., Lengyel, S., & Tóthmérész, B. (2010). Restoring grassland biodiversity: Sowing low-diversity seed mixtures can lead to rapid favourable changes. *Biological Conservation*, *143*, 806–812.

Török, P., Vida, E., Deák, B., Lengyel, S., & Tóthmérész, B. (2011). Grassland restoration on former croplands in Europe: An assessment of applicability of techniques and costs. *Biodiversity & Conservation*, doi:10.1007/s10531-011-9992-4

Török, P., Kelemen, A., Valkó, O., Deák, B., Lukács, B., & Tóthmérész, B. (2011). Lucerne-dominated fields recover native grass diversity without intensive management actions. *Journal of Applied Ecology*, *48*, 257–264.

Török, P., Matus, G., Papp, M., & Tóthmérész, B. (2008). Secondary succession in overgrazed Pannonian sandy grasslands. *Preslia*, *80*, 73–85.

Valkó, O., Török, P., Tóthmérész, B., & Matus, G. (2011). Restoration potential in seed banks of acidic fen and dry-mesophilous meadows: Can restoration be based on local seed banks? *Restoration Ecology*, *19*, 9–15.

van Andel, J., & Aronson, J. (Eds.). (2006). *Restoration ecology – The new frontier*. Oxford: Blackwell.

Van der Putten, W. H., Mortimer, S. R., Hedlund, K., Van Dijk, C., Brown, V. K., Lepš, J., et al. (2000). Plant species diversity as a driver of early succession in abandoned fields: A multi-site approach. *Oecologia*, *124*, 91–99.

Zar, J. H. (1999). *Biostatistical analysis*. New Jersey, Upper Saddle River: Prentice & Hall.

Please cite this article in press as: Török, P., et al. Recovery of native grass biodiversity by sowing on former croplands: Is weed suppression a feasible goal for grassland restoration? *Journal for Nature Conservation* (2011), doi:10.1016/j.jnc.2011.07.006