Acta Biologica Hungarica 61 (Suppl.), pp. 226–235 (2010)
DOI: 10.1556/ABiol.61.2010.Suppl.22

EARLY VEGETATION DEVELOPMENT AFTER GRASSLAND RESTORATION BY SOWING LOW-DIVERSITY SEED MIXTURES IN FORMER SUNFLOWER AND CEREAL FIELDS

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(Received: August 9, 2010; accepted: October 10, 2010)

We studied the early vegetation dynamics in former croplands (sunflower and cereal fields) sown with a low-diversity seed mixture (composed of 2 native grass species) in Egyek-Pusztakócs, Hortobágy National Park, East-Hungary. The percentage cover of vascular plants was recorded in 4 permanent plots per field on 7 restored fields between 2006 and 2009. Ten aboveground biomass samples per field were also collected in June in each year. We addressed two questions: (i) How do seed sowing and annual mowing affect the species richness, biomass and cover of weeds? (ii) How fast does the cover of sown grasses develop after seed sowing? Weedy species were characteristic in the first year after sowing. In the second and third year their cover and species richness decreased. From the second year onwards the cover of perennial grasses increased. Spontaneously immigrating species characteristic to the reference grasslands were also detected with low cover scores. Short-lived weeds were suppressed as their cover and biomass significantly decreased during the study. The amount of litter and sown grass biomass increased progressively. However, perennial weed cover, especially the cover of *Cirsium arvense* increased substantially. Our results suggest that grassland vegetation can be recovered by sowing low diversity mixtures followed up by yearly mowing. Suppression of perennial weed cover needs more frequent mowing (multiple times a year) or grazing.

Keywords: Cirsium arvense – alkali grassland – seed sowing – weed suppression

INTRODUCTION

The success of grassland restoration can be improved by direct introduction of target species to the restored sites by seed sowing [24, 29]. Two types of seed mixtures are used in such studies: low-diversity (LD) and high-diversity (HD) seed mixtures. LD seed mixtures contain the propagules of 2 to 8 species [23, 26, 30, 38], which are often the seeds of dominant grass species in the target vegetation. For a HD mixture much more species (up to 40 species) are collected than for an LD mixture [12, 18, 30, 43]. With HD seed mixtures, more target species can be introduced to the restored site than with LD mixtures [18, 26, 30, 41]. However, there is no evidence that the HD mixtures are more successful for grassland restoration and weed suppression than

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LD mixtures [23]. In most grassland restoration projects, HD mixtures were used only on small patches (from a few m^2 to a few hectares). In a large-scale restoration (from several ten up to hundred hectares), the costs of restoration can be extremely high if HD seed mixture is used. If we rely on local seed sources, the collection of propagules can last up to a year, or it even can be impossible due to the lack of proper propagules. Using seeds from commercial sources is another option, although the seeds of most species are not commercially available or very expensive [5]. Furthermore, seeds from commercial sources may contain different ecotypes, which are adapted to different environmental conditions and may be genetically incompatible with local ecotypes [39].

In large-scale restorations, LD seed mixtures can provide a more cost-effective solution than HD mixtures. The low number of species makes it easier and quicker to compile such a mixture. Further advantages are that (i) the seed harvest, the cleaning and storage of the harvested seed is easy, (ii) sowing of these types of seed mixtures can be executed using common agricultural machinery, and (iii) any genetic incompatibility is easily avoided. Despite these advantages, most studies have examined the success of sowing LD mixtures only in small-scale restorations (low number of spatial replicates of small areas ranging from several 10 m^2 to a few ha). There are only a few large-scale experiments which study restoration success on longer time scales [38, 42]. Furthermore, the effect of seed sowing on weed suppression is poorly studied [19].

Here we studied the effect of sowing a LD seed mixture (2 species) on the biomass and cover of early colonising weed assemblages in former sunflower- and cereal fields. We specifically asked two questions: (i) How do seed sowing and annual mowing affect the species richness, biomass and cover of weeds? (ii) How fast does the cover of sown grasses develop after seed sowing?

MATERIALS AND METHODS

Site description and history

Study fields are located in the "Egyek-Puszakócsi mocsarak" (42 km^2) grassland-marshland habitat complex in Hortobágy National Park near the villages of Egyek and Tiszafüred-Kócsújfalu (East Hungary, N47°34', E20°55'). The study region is characterized by a moderately continental climate with a mean annual temperature of 9.5 °C, and a mean annual precipitation around 550 mm, with large annual fluctuations in both of these figures.

Until the 1860s, the region had received regular floods from river Tisza, which determined the vegetation of the area. The lower-lying sites were covered by extensive alkali marshes (*Bolboschoenatalia maritimi* and *Typhaetum latifoliae*), surrounded by wet alkali meadows *(Alopecurion pratensis).* At higher elevations, the native vegetation was short dry alkali grasslands *(Festucion pseudovinae)* and loess grasslands *(Festucion rupicolae),* but following the river regulations and drainage in the 1860s, most of these grasslands were ploughed up [4]. The increased rate of cultivation and use of mineral fertilizers and pesticides resulted in the fragmentation and degradation of remaining native habitats.

To mitigate this degradation, a landscape-level restoration program was started in 1976. In the first step of this restoration project (1976–1997), the drained marshlands were hydrologically restored by a new water supply system and a moderate reintroduction of former marsh management. The second step of the restoration project (2004–2008), among other objectives, aimed at to reduce the area of croplands by grassland restoration [for more details: 9, 22, http://life2004.hnp.hu].

Grassland restoration

Three former sunflower and four cereal fields restored in the program (total area 116 ha) were chosen for this study. Following soil preparation (deep ploughing and smoothing by disk harrows), a low diversity alkali seed mixture containing seeds of *Festuca pseudovina* and *Poa angustifolia* in 2 : 1 proportions, respectively, was sown. Soil preparation and sowing were conducted in October 2005 in three fields (all cereal) and in October 2006 in four fields (one cereal and three sunflower). Fields were subsequently mown in June once a year.

Vegetation sampling

In each restored field, a 25-m^2-sized block was selected randomly. In each block, four 1-m^2-sized evenly placed rectangular permanent plots were marked and the percentage cover of vascular plants was recorded in every June (between 2005–2007 in three and 2006–2008 in four fields). For reference, we sampled the vegetation of alkali grasslands *(Achilleo setaceae–Festucetum pseudovinae)* in June 2008, using the same methods as in the restored fields. In every year and block, 10 aboveground plant biomass samples (total green biomass and litter; an area of 400 cm^2 per sample) were collected before mowing in late June. The samples were dried (25 °C, two weeks) and sorted into litter, graminoid (Poaceae, Cyperaceae) and forb groups. Dry weights of the samples were measured with an accuracy of 0.01 g.

Data processing

Plant species were classified into simplified Raunkiaer life form groups. The “short-lived” species group contained therophytes (Th) and hemitherophytes (TH). The “perennial” species group contained hemicryptophytes (H), geophytes (G) and chamaephytes (Ch). The mean values of biomass were compared using repeated-measures ANOVA on datasets pooled at the field level. We used the Tukey test to identify significantly different groups ($p < 0.05$) [46]. Correlation between various biomass groups and the vegetation of restored fields were analysed with DCA ordination based on vegetation cover data [21]. Species were classified as weed and non-weed groups based on Grime's CSR strategy types [13] modified and adapted to local conditions by Borhidi [3].

RESULTS

Cover and species richness

In the first year, short-lived weedy forbs (*Matricaria inodora, Anthemis arvenis, Capsella bursa-pastoris* and *Galium spurium*) were typical in all restored fields. Short-lived grasses were also present (*Bromus sterilis, B. tectorum* and *B. mollis*). From

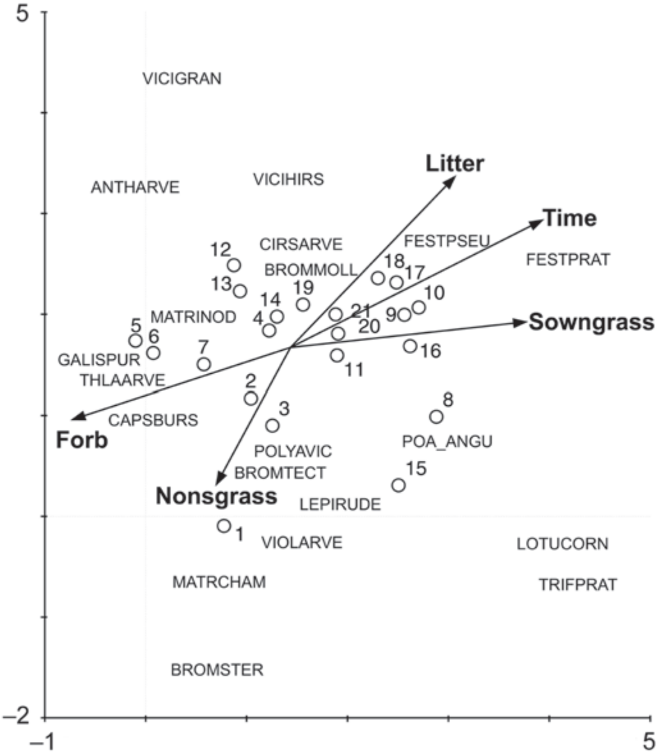

Fig. 1. Vegetation changes and the relationship between time and various biomass fractions using DCA (biomass scores and time are presented by arrows). The points (main data) were based on mean species percentage cover scores. All data were pooled at the level of the field and square-root transformed. *Notations:* Forb = forb biomass, Nonsgrass = biomass of non-sown grasses, Sowngrass = biomass of sown grasses, Litter = biomass in litter. Twenty plant species with the highest cover rank are shown. Species are abbreviated using four letters of the genus name and four letters of the species name, e.g. BROMSTER = *Bromus sterilis*. Samples: 1–7 = Year 1; 8–14 = Year 2 and 15–21 = Year 3, respectively. Eigenvalues for axis 1 and axis 2 are 0.46 and 0.31, respectively

Table 1
Species richness and cover of functional species groups in the vegetation in Years 1–3 (mean ± SE)

	Year 1	Year 2	Year 3
Species richness			
Total	16.7±1.9[a]	10.5±1.2[b]	7.5±0.8[b]
Short-lived weed	8.0±0.8[a]	2.9±0.8[b]	1.1±0.5[b]
Perennial weed	0.8±0.1[a]	1.0±0.2[ab]	1.2±0.2[b]
Cover (%)			
Sown grass	16.1±7.2[a]	54.1±11.8[b]	59.2±9.5[b]
Short-lived weed	67.7±10.3[a]	12.3±6.4[b]	4.3±3.5[b]
Perennial weed	1.4±0.6[a]	10.3±5.1[ab]	22.4±9.4[b]

Different superscripted letters indicate significant differences (RM ANOVA, and Tukey test, $p < 0.05$).

Table 2
Plant biomass scores of the restored fields (g/0.04 m^2, mean ± SE)

	Year 1	Year 2	Year 3
Sown grasses	4.6±2.3[a]	12.5±2.2[b]	17.2±3.2[b]
Non-sown grasses	8.9±5.0	1.8±0.9	0.5±0.3
Forbs	18.0±4.3[a]	7.9±2.4[ab]	3.3±0.7[b]
Litter	2.6±0.8[a]	5.8±1.3[ab]	8.9±2.4[b]

Different superscripted letters indicate significant differences (RM ANOVA, and Tukey test, $p < 0.05$).

Year 2 onwards, these short-lived weeds were replaced by perennial sown grasses and perennial weeds (Fig. 1). The increase of perennial weed cover was caused mainly by the increase of cover of *Cirsium arvense*. The cover of *Cirsium arvense* was below 5% in all sites in Year 1 (detected in 6 sites). In Year 3, its mean cover was higher than 20% in three sites (site 5 to 7, a mean cover of 40, 23 and 43%, respectively). The cover of the sown grass species was typically low at each site in the first year after restoration, typically under 15%. In the second year, the cover of sown grass species increased significantly and remained high also in Year 3 (a mean of 50–60%). In total 93 species (20 graminoid and 73 forb) were recorded during the study period in the restored fields. The total species richness and the species richness of short lived weeds decreased from Year 1 to Year 3 (Table 1). In the restored site only a few spontaneously established characteristic species of alkali grasslands were detected with low cover (<5%, *Achillea collina, A. setacea, Alopecurus pratensis* and *Trifolium angulatum*).

Biomass

We detected increasing amounts of litter and sown grass biomass with time (Table 2, Fig. 1). The biomass of sown grasses and litter has increased 3 to 4 times during the three years. The amount of biomass of unsown grasses and that of forbs decreased significantly from Year 1 to Year 3. The litter and sown grass biomass were negatively correlated with the forb and non-sown grass biomass (Fig. 1).

DISCUSSION

Weed suppression

We demonstrated that the development of perennial cover can be recovered within three years by sowing and yearly mowing. Similar results were found by [38] in grasslands restoration of former alfalfa fields. The recovery of perennial cover was faster in our sown fields than found by others in spontaneous succession in loess and sandy grasslands [28, 31, 37]. A closed vegetation dominated by perennial sown grass species developed within three years after sowing in most fields. The vegetation was dominated by short-lived weed species in Year 1 after seed sowing, also found in other studies [23, 26]. We found effective weed suppression of used grassland restoration method from Year 2 onwards. The short-lived weed species were replaced in several fields by perennial sown grasses. Similarly, a rapid increase of litter and sown grass cover was detected in former alfalfa fields after seed sowing and followed up by yearly mowing [38]. Increased cover of grasses and accumulated litter might cause an increased shading of the soil surface, which resulted in decreased establishment [11] or competitive exclusion [25] of weeds. The sharp decline of short-lived weeds can be caused also by the yearly mowing scheduled before their seed ripening.

In several fields even with sowing and yearly mowing an increasing cover of perennial weeds was detected conversely to the decreasing cover of the short-lived weeds. This increasing perennial weed cover was mainly caused by the increasing cover of *Cirsium arvense*. In former grassland recovery studies high cover of *Cirsium arvense* was reported only in abandoned cereal fields [8, 20, 38]. We found high *Cirsium* dominance both in sown cereal and sunflower fields. Previous studies found that the frequency of this species decreased after the abandonment of soil disturbance and by regular mowing [27, 34]. In our study these results were not supported; even with continuous mowing the cover of *Cirsium arvense* has increased continuously in the first three years.

Species richness, biomass and litter accumulation

Species richness decreased from the first to the third year after sowing, mostly due to the disappearance of short-lived species. Similar trends were found in studies that used technical grassland recovery by sowing [12, 23]. The decreasing species richness was associated also with a significant decrease of forb biomass. In several studies, the negative effect of litter on species richness and biomass of forbs were stressed [17, 44]. In our study, a significant litter accumulation was observed, similarly to observations on former alfalfa fields by Török et al. [38]. The accumulated litter alters the availability of light [1] and moisture [45] on the soil surface. The increased shading of the soil surface by litter decreases the establishment of light demanding weed species [11, 36]. Litter accumulation with decreasing microsite availability can also reduce the colonisation success of desirable, spontaneously dispersed target species [7, 14]. In our study, the spontaneous immigration of a few typical alkali grassland species started from the second year. However, the cover of these species was still low in Year 3. The low proportion of spontaneously immigrating species can also be caused by the limited availability of propagules. Long-term agricultural cultivation causes a local seed bank dominated by weed species [16, 26]. It is also possible that the spread of propagules is limited [40] because of the high distance of propagule sources [12, 33] and/or the lack of local dispersing agents [2, 32, 35].

Implications for restoration

Applying LD seed mixtures associated with regular mowing once per year is a fast and effective method for restoration of basic grassland vegetation in croplands, where only short-lived weeds are present. Our study showed that perennial grass dominance can develop within three years, and that the spontaneous immigration of unsown target species is slow. Therefore, a direct introduction of these species is necessary. The most obvious solution for the species introduction is to develop a daily rhythm of sheep and/or cattle grazing of the restored area in the region. If grazing starts in the morning in semi-natural grasslands and continues in the restored grasslands later in the day, livestock can facilitate the immigration of propagules in their gut or their fur. We can also introduce the propagules of target species by direct sowing [47], and in some cases hay transfer is also a proper solution [15].

The increased cover of perennial weeds, especially the increased cover of *C. arvense* can be considered as one of the major problems, which can hamper the grassland restoration success in former sunflower and cereal fields. Decreasing the cover of *Cirsium arvense* is difficult; the quick establishment and spreading of this species by tillers in ploughed fields [10] is more effective than that of the sown tussock forming *Festuca*. The high cover of *Cirsium* is also supported by the higher nutrient levels typical in the first years after agricultural use terminates [30, 38]. To reduce high *C. arvense* cover, mowing before seed ripening [20] and frequent grazing by cattle or sheep [6] are suggested. However, the latter method can be beneficial only where there is no dense seed bank of weeds in the soil.

ACKNOWLEDGEMENTS

The authors are grateful for the help of L. Gál, I. Kapocsi, B. Lukács, K. Tóth, Sz. Tasnády, E. Mikecz, Sz. Radócz in the field and laboratory. The restoration was supported by a LIFE-Nature program (LIFE04NAT/HU/119) and this study was supported by an OTKA-Norway Financing Mechanism grant (OTKA NNF 78887) and TÁMOP 4.2.1. SL was supported by a Bolyai Research Fellowship from the Hungarian Academy of Sciences during manuscript preparation.

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