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Research Paper

Smart management is key for successful diversification of field margins in highly productive farmland

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ABSTRACT

In highly productive farmlands, field margins could offer habitats and refuges for many plant and animal species. But species-rich field margins are rapidly declining due to field enlargements and unfavourable management practices. In European farmland, management is usually restricted to repeated mulching during the growing season or mulching once a year between September and February. Under nutrient-rich conditions, both methods benefit competitive perennial grasses at the expense of species richness. Diversification of species-poor grass margins on nutrient-rich sites is difficult to achieve and we lack evidence which method works best. Starting in late summer 2010, we implemented a large-scale field experiment on nutrient-rich Chernozem soil, where we examined the effect of sward disturbance intensity, sowing of target species, and mowing time on the development of field margin vegetation over seven years. After disturbance of the existing species-poor grass sward with two intensities (tilling once or three times), a seed mixture of 49 wild plants from a regional seed propagation was sown in early October 2010. After an establishment phase in 2011, the sites were mown once a year, in either June or September, with removal of biomass. In addition, both cutting times were applied to species-poor grass margins without disturbance and sowing treatments. We recorded the plant species composition yearly from 2010 until 2016. Although the early establishment rate of the sown species was higher on sites disturbed three times, the number of successfully established target species on sites with different sward disturbance intensities converged during the observation period. Mowing in September resulted in higher grass cover and considerably decreased the cover of the sown target species. On the other hand, mowing in June resulted in significantly higher plot occupancy and cover of the sown target species. In general, the immigration success of target forbs into adjacent undisturbed and unsown grass margins was very low even after seven years, although mowing once a year with biomass removal increased the number of mostly ruderal species. Diversification of grass margins was very successful with active species introduction in combination with initial sward disturbance and management adapted to nutrient-rich site conditions. Therefore, restored field margins in highly productive farmlands should be mown in early summer to sustain long-term biodiversity.

1. Introduction

For more than 60 years, agricultural land in Europe has experienced a severe biodiversity decline (Baessler and Klotz, 2006; Stoate et al., 2009; Meyer et al., 2015; Sutcliffe et al., 2015). Agricultural intensification, field enlargement and mechanization (Tscharntke et al., 2005; White and Roy, 2015), but also changes in management practices (Alignier and Baudry, 2015), have led to a loss of semi-natural habitats, a general decrease of plant and animal species richness, and depletion of soil seed banks (Robinson and Sutherland, 2002; Simmering et al., 2013; Meyer et al., 2015). Field margins can be both habitat and refuge for many plant and animal species (Marshall and Moonen, 2002; Tscharntke et al., 2005; Hackett and Lawrence, 2014). But, especially in intensively used agrarian landscapes, repeated mulching or spraying reduces plant species diversity (Marshall and Moonen, 2002; Hahn et al., 2014), often resulting in species-poor, grass-dominated sites (Meyer et al., 2013), which are unable to fulfill important ecosystem services (*e.g.* habitat and food sources for pollinators). Contrary to perennial wildflower strips, which are created on arable land and are usually supported for five years by agri-environmental schemes, permanent field margins are situated on common land between farm tracks and arable fields. Although they are in an unfavourable conservation status in most European countries, only a few countries developed agri-environmental schemes to promote field margin biodiversity (*e.g.* Great

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Britain, Switzerland). In Germany, as well as in 15 other EU-28 countries, field margins are eligible as Ecological Focus Areas (EFA; Hart, 2015). Even though the Common Agricultural Policy (CAP, 2014–2020) requires that 5% of arable land be designated as EFA, most farmers favor fallows or cultivation of nitrogen-fixing crops instead of maintaining landscape elements like field margins (Pe'er et al., 2016).

In intensively managed agricultural landscapes, relying on spontaneous colonization of target plants is usually not successful (Kleijn et al., 1998; Török et al., 2011; Prach et al., 2015) due to depleted seed banks and the limited long-distance dispersal ability of many plant species (Bakker and Berendse, 1999; Nathan et al., 2008). Hence, active introduction of target species in restoration sites is recommended (Kiehl et al., 2010; Rydgren et al., 2010). Although grassland diversification experiments showed that the establishment success of target species is dependent on initial sward disturbance (Hofmann and Isselstein, 2004; Edwards et al., 2007; Pywell et al., 2007; Schmiede et al., 2012), there are still uncertainties about sward disturbance intensity.

After successful species re-introduction, implementing a suitable management regime is crucial for the maintenance of species diversity (Pywell et al., 2007; Öster et al., 2009; Auestad et al., 2016; John et al., 2016). In many European countries, field margins are usually mown once a year between September and February (Kleijn et al., 1998: France, Netherlands, UK; Bokenstrand et al., 2004: Sweden) or not at all (Hovd and Skogen, 2005: Norway). This might work well on marginal sites, but under nutrient-rich conditions it benefits competitive perennial grasses (Hansson and Fogelfors, 1998; Amiaud et al., 2008). In addition, late mowing destroys hibernating structures for invertebrates (Blake et al., 2013) and removes winter feeding sources for farmland birds (Vickery et al., 2009). By contrast, many forbs are able to regenerate quickly after early mowing, thus prolonging the flowering period until early autumn.

While many studies document the early establishment phase after species introduction into field margins (de Cauwer et al., 2005; Carvell et al., 2007; Blake et al., 2013), long-term studies are scarce (Bokenstrand et al., 2004; Smith et al., 2010). Successful examples of sustainable conversions of species-poor grass strips into flower-rich, highly-diverse field margins are completely missing. Even though grass strips are beneficial for some arthropod groups (Meek et al., 2002; Badenhausser and Cordeau, 2012), they meet neither the demands of nectar and pollen-feeding invertebrates nor those of farmland birds (Vickery et al., 2009). Converting species-poor grass margins into structurally and floristically diverse vegetation during summer and seed-rich habitats in winter are optimal prerequisites to provide feeding, nesting, and hibernating habitats for many animal species.

In general, problems with sowing high-diversity seed mixtures of regional wild plants include their rather high cost and difficulty in obtaining regionally produced seeds (Kiehl et al., 2010; Tischew et al., 2011). A cost efficient option is to introduce target species only in parts of restoration sites (Rayburn and Laca, 2013; Valkó et al., 2016). Combined with appropriate management, this might promote colonization of adjacent areas, but little is known about the immigration success of target species into adjacent species-poor grass margins (but see Smith et al., 2010).

In a large-scale field experiment in Germany, we examined the effect of sward disturbance intensity, mowing time and sowing on the development of field margin vegetation over seven years. We focused on the following questions: (Q1) Is sowing of a species-rich seed mixture a successful method to diversify species-poor grass margins? (Q2) Can adjacent target forbs establish in regularly mown, but unsown grass margins, and does mowing time influence their establishment success? (Q3) Does sward disturbance intensity influence the establishment of sown target species? (Q4) Which mowing time (June or September) is most successful in maintaining species-richness of restored field margins?

2. Material and methods

2.1. Study area

Our study area is situated on the border of the Strenzfeld campus of the Anhalt University of Applied Sciences in Saxony-Anhalt (N 51°49′01.00″, E 11°42′14.09″, 90–93 m above sea level). The climate is dry with 511 mm annual precipitation and a mean annual temperature of 9.7 °C (long-term mean 1981–2010, Deutscher Wetterdienst). Adjacent arable fields are used for conventional wheat, rape or maize production. The soil is a very productive Chernozem developed on loess substrate. Before the experiment started, the field margins were characterized by thick litter layers and a few competitive grasses, such as *Dactylis glomerata, Elymus repens*, and *Poa angustifolia,* as a result of repeated mulching.

2.2. Experimental design and sampling

In August 2010, we established 30 blocks (3 m × 17 m) 1 m apart along a 540 m long field margin. A 1 m × 8 m permanent plot was positioned in the centre of each block. Species abundance, measured as percentage cover, was recorded in all permanent plots to document the initial conditions before site preparation started (Tables 1 and 2), then the whole site was mown with removal of biomass and litter. Soil samples were taken at the plot level, to a depth of 0–15 cm (mixing of 12 soil core samples per plot), in August 2010. Overall, the soil had a pH of 7.4 (± 0.05) (after German DIN 19684-1) and contained 0.25% (± 0.03) total nitrogen (after German DIN ISO 13878), 106 mg kg^{-1} soil (± 16.8) CAL exchangeable phosphorous and 318 mg kg^{-1} soil (± 75.2) exchangeable potassium (both after VDLUFA A 6 2.1.1.), for further details see Kiehl et al. (2014).

The total 540 m field margin was divided into five equal sections of 108 m, each of which contained six blocks, to which the following six treatments were randomly assigned: (T1) sward disturbance once before sowing, with mowing in mid-June, (T2) sward disturbance once before sowing, with mowing in mid-September, (T3) sward disturbance three times before sowing, with mowing in mid-June, (T4) sward disturbance three times before sowing, with mowing in mid-September; (T5) without sward disturbance or sowing, and with mowing in mid-June, and (T6) without sward disturbance or sowing, and with mowing in mid-September.

We used a rototiller to loosen the compacted soil surface (only the first time), immediately followed by a grubber to pull out grass rhizomes. In 10 blocks, the grass sward was disturbed three times at c. 14-day intervals starting on September 9th, 2010. The last intervention took place on October 6th, 2010, at which time sward disturbance occurred in the 10 blocks that were disturbed only once. The remaining 10 blocks were left undisturbed and unsown. During the observation time, the 1 m space between blocks was regularly disturbed by rototiller. In the year after sowing, all blocks were mown at the beginning of June as well as at the end of August to reduce arable weeds emerging from the soil seed bank. Regular management (mowing either mid-June or mid-September with removal of biomass) started in 2012.

For the seed mixture, we selected 49 species from 15 plant families, belonging to different plant communities: dry grasslands (16 species), mesic grasslands (12 species), fringes (8 species), and dry ruderal communities (13 species) (Table 1). These species have a long blooming period and are moderately competitive under nutrient-rich conditions (no highly competitive ruderals, tall grasses or weeds). On October 7th, 2010, a seed mixture of 5 grasses, 5 legumes, and 39 nonlegume forbs from a regional agricultural propagation of wild plants was sown by hand with a density of 20 kg seeds ha^{-2}, corresponding to 1917 seed per m^{-1}, calculated due to the thousand grain weight of the selected species. Seed number for each species (see Table 1, column SN) was based on ecological (seed size, seed longevity, germination rate) and economical (costs) requirements. After sowing, the soil surface was