Fertilising semi-natural grasslands may cause long-term negative effects on both biodiversity and ecosystem stability

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Abstract
1. Some short-term experiments in applied ecology and agricultural research have demonstrated that nutrient applications in semi-natural grasslands can maintain productivity and will not result in the decrease of plant species richness. Such findings may have an impact on management choices and quality of valuable plant communities, and therefore, further discussion of this topic is necessary.
2. We highlight three aspects regarding the management suggestions in grassland communities with high biodiversity: (1) short-term study results may not reflect potential long-term changes; (2) broad range of grasslands may respond to disturbance in site specific ways; and (3) practical advices should contain careful consideration of existing ecological literature regarding grassland management and sustainable biodiversity.
3. Synthesis and applications. Considering effects of fertilisation on biodiversity, we argue against nutrient application to semi-natural grasslands. Biodiversity supports the resilience of grassland ecosystems and maintains a stable biomass yield. Current short-term experiments are good indicators about the need for a long-term experiments and meta-analysis for detailed understanding of ecosystem functions in different types and areas during global change.

KEYWORDS
biodiversity, bioeconomy, ecosystem services, fertilisation, grassland, nutrient-rich residues, productivity, species richness

1 | INTRODUCTION

Recently, the use of nutrient-rich residues from bioenergy production (digestate) and intensive husbandry (slurry) for fertilising traditionally managed grasslands has gained increased attention (e.g. Duffková, Hejcman, & Libichová, 2015; Duffková & Libichová, 2013; Hensgen, Bühle, & Wachendorf, 2016; Kováčiková, Vargová, & Jančová, 2013). Hensgen et al. (2016) used low-dose nutrient applications (i.e. 25-54 kg N ha⁻¹ year⁻¹, 2-5 kg P ha⁻¹ year⁻¹ and 20-51 kg K ha⁻¹ year⁻¹ for 5 years) in semi-natural grasslands to maintain productivity and claimed that these applications did not result in a loss of species richness during the 5-year study. Similar short-term experiments by Duffková and Libichová (2013) and Duffková et al. (2015) came to similar conclusions: low-dose cattle slurry application (i.e. 0-240 kg N ha⁻¹ year⁻¹ and 0-240 kg N ha⁻¹ year⁻¹, 0-40 kg P ha⁻¹ year⁻¹ and 0-180 kg K ha⁻¹ year⁻¹ for 6 years, respectively) increases the herbage yield without affecting the diversity in a species-rich grassland.

The use or recommendation of new intensive management strategies in semi-natural grasslands is complicated. Such complexity is typical in ecosystems with high biodiversity and conservation values (e.g. Veen, Jefferson, de Smidt, & Van der Straaten, 2009). Generally, fertilisation decreases plant diversity and changes the species composition (Bobbink, Hornung, & Roelofs, 1998; Borer et al., 2014; De Schrijver...
et al., 2011; Isbell et al., 2013; Kidd, Manning, Simkin, Peacock, & Stockdale, 2017; Kleijn et al., 2009; Suding et al., 2005; Tilman, 1987; Zhang, Zhou, Li, Guo, & Du, 2015). The negative effects on biodiversity have been reported also for cases of low nitrogen addition rates (Clark & Tilman, 2008; Kidd et al., 2017). The experimental N addition load by Clark and Tilman (2008) was 10 kg N ha\(^{-1}\) year\(^{-1}\) over 8 years and 120 years long fertilisation was of 35 kg N ha\(^{-1}\) year\(^{-1}\) plus grazing of cattle or sheep.

Therefore, we express our concerns about results claiming that species-rich grasslands can be fertilised to maintain or increase above-ground productivity without negatively affecting plant diversity and that these methods can be widely applied for the management of semi-natural meadows. Such studies in the future should critically consider existing ecological literature related to productivity and biodiversity. Here, we note three core issues that can influence the results and should be reflected in future studies in this research area: the duration of the experiment, site-specific characteristics and the theoretical background.

2 | DURATION OF EXPERIMENTS

Numerous long-term studies have confirmed that fertilisation negatively affects species richness and positively influences biomass production. In some cases, negative effects appear rapidly, and in other cases, these effects take time (Dickson & Gross, 2013; Silvertown et al., 2006; Tilman et al., 1994). Yet, changes in community level dynamics continue long after fertilisation ceases, as shown in the long-running Park Grass experiment (established in 1856), in which different organic fertilisers have resulted in slight but notable increases in productivity. However, the effect on species richness has been strongly negative, even decades after the end of fertilisation (Silvertown et al., 2006). Recently, a slight recovery was noted in the plots of the Park Grass experiment where fertilisation treatment had ended, but the diversity there was still lower than in non-fertilised plots (Storkey et al., 2015).

The studies discussed above note the possibility of the low-dose application of nutrients in semi-natural grasslands without causing a loss in diversity. However, since they are based on short-term experiments, they might underestimate the long-term changes in vegetation dynamics and processes (e.g. Mašková, Doležal, Kvet, & Zemek, 2009; Van der Maarel & Sykes, 1993). Furthermore, species composition changes induced by shifts in grassland management can take up to 50 years to appear (see Helm, Hanski, and Pärtel 2006 and related studies on extinction debt). Moreover, changes in these degradation processes or the restoration of original species richness can take even longer (e.g. Hejcman, Kladuliová, Schellberg, & Honsová, 2007; Wortley, Hero, & Howes, 2013).

3 | SITE-SPECIFIC CHARACTERISTICS

The response of each plant community to an environmental change depends on the set of conditions under which it has developed. These conditions differ by habitat, management regime and region (e.g. Biondi et al., 2012; Grévilliot, Krebs, & Muller, 1998; Socher et al., 2013). Meadows are strongly human dependent, and they are not ecologically stable. Even the temporary abandonment of management activities (e.g. Galvánek & Lepš, 2008; Pykälä, Luoto, Heikkinen, & Kontula, 2005; Uchida & Ushimaru, 2014) or the incidental or irregular management of productivity (e.g. Van der Hoek, Mierlo Anita, & Groenendael, 2004) can lead to long-term changes in the species composition. To an extent, mowing may balance the negative effect of fertilisation on species richness in the short term (Lepš, 2014), especially after a period without mowing prior to the start of the experiment (e.g. Liira et al., 2012). Therefore, it is essential to know the previous management strategy of a site. These strategies are independent of the experimental layout, and the response to management changes may depend on the local historical context. Furthermore, extremely nutrient-poor (e.g. dry calcareous grasslands) and most small-scale species-rich habitats (e.g. wooded meadow) should be excluded from such studies, as the negative effects on these plant communities are often extensive (e.g. Johansson et al., 2008; Sammul, Kull, & Kattai, 2013).

One can presume that fertilisation is not new to most of these study sites, and fertilisation-sensitive species may have already disappeared, thereby reducing the original species richness. Additionally, this assumption is supported by considering the species richness reported in the studies of Duffková et al. (2015) and Hensgen et al. (2016). In the first study, the mean number of species was 19.7 per 1 m\(^2\) in all treatments and years, and in the second study, approximately 40 species were observed in different treatments in a 25 m\(^2\) plot. A recent global meta-experiment on the relationship between grassland diversity and productivity (Fraser et al., 2015) reported that the average species richness at the 5 × 5 m scale was approximately 40 species, although the study included several sites with extremely low diversity, including some wetland ecosystems with just a single species. Therefore, although the grasslands studied by Hensgen et al. (2016) and Duffková et al. (2015) were considered species rich by the authors, in comparison with global assessments of similar types of grasslands, for example, Fraser et al. (2015), these communities have average plant diversity at best (see also Chytrý et al., 2015; Wilson, Peet, Dengler, & Pärtel, 2012). Local extinctions of the most sensitive species may have occurred before the experiment began; thus, the effect of fertilisation on diversity is not fully studied under appropriate conditions. One option of estimating the number of species already missing from the community is the “dark diversity” approach (Pärtel, Szava-Kovats, & Zobel, 2011).

4 | THEORETICAL BACKGROUND

Numerous studies have shown that the productivity of species-rich, semi-natural grasslands can remain stable with traditional extensive management (i.e. no additional fertilisation, removal of nutrients via herding or mowing) over time (e.g. Hansson & Fogelfors, 2000;
Sammul et al., 2013; Smits, Willems, & Bobbink, 2008; Tilman, Isbell, & Cowles, 2014). Haying removes nitrogen that would otherwise accumulate in the system (Tilman & Isbell, 2015) and increases light availability (Hautier, Niklaus, & Hector, 2009), both of which promote the coexistence of different and high numbers of herbaceous plant species (e.g. Dengler, Janišová, Török, & Wellstein, 2014). Nutrient addition studies, however, have reported negative effects on diversity in many long-term ecological experiments in grasslands (e.g. Crawley et al., 2005; Hejcmans et al., 2007; Isbell et al., 2013; Kidd et al., 2017; Liira et al., 2012; Silvertown et al., 2006; Tilman et al., 2014). Nutrient inputs might increase the biomass of non-native and often generalist species (Brian Patrick, Fraser, & Kershner, 2008) and significantly decrease rare, threatened and specialist species (Kleijn et al., 2009; Uematsu & Ushimaru, 2013). A decrease in species richness can also be a consequence of cumulative N inputs (De Schrijver et al., 2011). As stated previously, the negative effects of nitrogen on the plant species diversity have been confirmed at low fertilisation rates (Bobbink et al., 1998; Clark & Tilman, 2008). Additionally, the decline in plant species richness as nitrogen inputs increased was observed to be linear (Crawley et al., 2005) or logarithmic (Clark & Tilman, 2008).

Concentrating grassland management efforts on maximising the productivity through fertilisation is a short-sighted approach. The key to efficient and steady grassland ecosystem functioning is in maintaining and increasing biodiversity (Hooper et al., 2012; Tilman et al., 2014; Weisser et al., 2017). Species-rich communities have high nutrient use efficiencies, thereby providing stable biomass production compared to species-poor grasslands (e.g. Gross et al., 2014; Isbell et al., 2013; Tilman et al., 2014).

Hence, it is important to maintain regular management via grazing or mowing to preserve species diversity (Pärtel, Bruun, & Sammul, 2005). Instead of fertiliser addition, the removal of above-ground biomass is important for the sustained diversity of high-level plant species (Jacquemyn, Brys, & Hermy, 2003) and the stability of the biomass yield in grasslands (Hautier et al., 2014, 2015; Isbell et al., 2015; Silvertown et al., 2006; Tilman et al., 2014). It is important to decrease the amounts of nutrient-rich residues from biobased production via increasing the resource usage and technological efficiency throughout the biomass-to-bioproducts value chain. Surplus residues could be applied to intensively managed agricultural fields instead of mineral fertilisers but not to extensively managed semi-natural grasslands with nature conservation values.

5 | CONCLUSIONS

Studies focusing on the management of semi-natural communities and use of grassland ecosystems (including the application of new and more efficient technologies) are welcomed, as they are important contributions for both the conservation of these communities and the emerging resource-efficient bioeconomy (e.g. Burrascano et al., 2016). Furthermore, we should identify the relationships between fertilisation and organisms of different trophic levels (e.g. pollinators), as many of these relationships remain unknown (e.g. Tscharntke, Klein, Krueß, Steffen-Dewenter, & Thies, 2005). Our intention in this paper is to emphasise that the long-term effects of fertilisation on community biodiversity and productivity, and especially the stability of ecosystem services, are generally negative. Additionally, overcoming the unfavourable effects of unsound management practices might take several generations. While many semi-natural grasslands require restoration and management efforts to restore their high nature conservation values, it seems unreasonable to include these areas as a part of residue utilisation systems considering the aforementioned potential negative effects. We strongly recommend that the knowledge gained from long-term fertilisation experiments in ecology be considered before applying any additional nutrients to semi-natural grasslands.

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AUTHORS’ CONTRIBUTIONS

I.M. and L.L. conceived and designed the research. I.M., K.L. and L.L. led the writing of this manuscript. All authors participated in writing and critically contributed to the manuscript. All authors have approved the final manuscript for publication.

DATA ACCESSIBILITY

Data have not been archived because this article does not use data.

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