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Does organic grassland farming benefit plant and arthropod diversity at the expense of yield and soil fertility?

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ABSTRACT

Organic management is one of the most popular strategies to reduce negative environmental impacts of intensive agriculture. However, little is known about benefits for biodiversity and potential worsening of yield under organic grasslands management across different grassland types, i.e. meadow, pasture and mown pasture. Therefore, we studied the diversity of vascular plants and foliage-living arthropods (Coleoptera, Araneae, Heteroptera, Auchenorrhyncha), yield, fodder quality, soil phosphorus concentrations and land-use intensity of organic and conventional grasslands across three study regions in Germany. Furthermore, all variables were related to the time since conversion to organic management in order to assess temporal developments reaching up to 18 years. Arthropod diversity was significantly higher under organic than conventional management, although this was not the case for Araneae, Heteroptera and Auchenorrhyncha when analyzed separately. On the contrary, arthropod abundance, vascular plant diversity and also yield and fodder quality did not considerably differ between organic and conventional grasslands. Analyses did not reveal differences in the effect of organic management among grassland types. None of the recorded abiotic and biotic parameters showed a significant trend with time since transition to organic management, except soil organic phosphorus concentrations which decreased with time. This implies that permanent grasslands respond slower and probably weaker to organic management than crop fields do. However, as land-use intensity and inorganic soil phosphorus concentrations were significantly lower in organic grasslands, overcoming seed and dispersal limitation by re-introducing plant species might be needed to exploit the full ecological potential of organic grassland management. We conclude that although organic management did not automatically increase the diversity of all studied taxa, it is a reasonable and useful way to support agro-biodiversity.

1. Introduction

Organic management has become one of the most popular sustainable strategies to produce agricultural goods but reduce negative environmental effects of intensive agriculture such as biodiversity decline (Zechmeister et al., 2003; Tscharntke et al., 2005; Whittingham, 2011). To achieve this goal, organic management abandons pesticides and synthetic fertilizers, and restricts livestock density and the use of organic fertilizers from animal husbandry (maximum of 170 kg N ha^{-1} a^{-1}) (European Union, 2008). Hence, the resulting lower pressure of land-use intensity can benefit agro-biodiversity (Gomiero et al., 2011). However, critics of organic management argue that especially restricted fertilizer input may significantly reduce quantity and quality of yields (Offermann and Nieberg, 2000). Furthermore, it is debated, whether organic management decreases nutrient availability in

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soils leading to additional long-term economical deterioration (Gosling and Shepherd, 2005; Hathaway-Jenkins et al., 2011). It is therefore important to carefully assess not only potential benefits of organic management, but also to quantify decreasing quantity and quality of yield associated with organic management. However, such negative effects have hardly been quantified for grasslands on a larger scale, which is necessary to account for the wide range of grassland productivity found among different environmental conditions.

Grasslands are among the most species rich habitats in the world (Wilson et al., 2012), and the proportion of organic farms and organic markets grow rapidly. From 2008 to 2011 the area of organically managed grasslands in Germany increased by 9.2% resulting in 11.5% organic grasslands of the total grassland area (Schaack et al., 2010). Nevertheless, compared with well studied crop fields, where biodiversity in general increased on multiple scales (Hole et al., 2005; Geiger et al., 2010), the effect of organic management in permanent grasslands has yielded equivocal results (Manusch and Pieringer, 1995; Haas et al., 2001; Kleijn and Sutherland, 2003; Mayer et al., 2008; Batáry et al., 2012). Grassland types can be categorized as meadows (mowing only), pastures (grazing only) and mown pastures where mowing and grazing are combined. However, such differences were consistently neglected although mowing and grazing are known to have distinct effects on biodiversity (Zahn et al., 2010; Socher et al., 2012). Furthermore, studies are at risk to overestimate ecological benefits of organic management, because organic plots have often a lower agronomic potential and are thus per se less intensively used and more diverse which can skew the outcomes of these surveys (Kleijn and Sutherland, 2003; Dahms et al., 2010). Therefore, we conducted a study on effects of organic management in grasslands located in different landscapes taking into account both the overall land-use intensity at the plot scale and differences in the management type.

We compared (i) diversity measures of vascular plants, (ii) diversity measures of foliage-living arthropod taxa, (iii) soil P concentrations, (iv) quantity and fodder quality of yield (aboveground biomass) and (v) land-use intensity of organic and conventional grasslands in three regions in Germany. Plots were selected randomly stratified and subsequently reduced according to soil type, grazing animal type and grassland type. Furthermore, we related all diversity and abiotic variables to the time since conversion to organic management because effects on ecosystem properties may need some time to turn out (Gosling and Shepherd, 2005; Hole et al., 2005). In this study, we hypothesized that (1) land-use intensity, yield and fodder quality as well as soil nutrient availability are lower, whereas (2) the diversity of plants and foliage-living arthropods (both herbivorous and predatory taxa) is higher in organic compared with conventional grasslands, although (3) this might differ among grassland types; and (4) the time since conversion to organic management has a positive effect on species diversity but a negative on yield and soil P concentrations.

2. Materials and methods

2.1. Plot selection and land-use intensity

The study took place in grasslands within three regions in Germany that are part of the *Biodiversity Exploratories* project (Fischer et al., 2010): (1) the UNESCO Biosphere Reserve Schorfheide-Chorin, in North-Eastern Germany, (2) the National Park Hainich and surrounding areas (Hainich-Dün) in Central Germany and (3) the UNESCO Biosphere Reserve Schwäbische Alb in South-Western Germany. In each region, we selected and sampled 50 grassland plots according to a randomly stratified procedure with strata representing the range of land-use intensities to create representative gradients of Central European land use. For further details on study regions and plot selection see Fischer et al. (2010). The intensity of land use varied strongly among grasslands. From these 150 plots, we selected all organic grasslands, which were at least managed for two years according to the standards of an organic management certificate (e.g. European Union, 2008). In turn, conventional grasslands were defined by management, which is not conforming to organic management guidelines, e.g. application of synthetic fertilizers. This led to the exclusion of many unfertilized but not certified (conventional) plots Table 1. To compare organic and conventional grasslands, two subsets of plots were sub-selected according to study region, grassland type, grazing animal type, soil type and soil depth. This resulted in a dataset of 18 organic grasslands from 13 different farms and 30 conventional grasslands (Table 1). At the time of sampling (2009), the time of organic grassland management ranged from 2 to 18 years (including time in conversion). Field size did not significantly differ between organic and conventional grasslands (Table 2).

Table 1
Study plots arranged according to grassland type, organic management and study region.

	Meadows		Pastures		Mown pastures		Sum
	Org.	Conv.	Org.	Conv.	Org.	Conv.	
Schwabische Alb	3	13	–	–	1	5	22
Hainich-Dün	–	–	5	1	5	7	18
Schorfheide-Chorin	2	2	–	–	2	2	8
Total	5	15	5	1	8	14	48

To quantify land-use intensity, we used questionnaires to gather information from farmers on the amount of fertilizer application ($kg\,N\,ha^{-1}$) (F), the frequency of mowing ($cuts\,y^{-1}$) (M) and the livestock density (livestock units × $days\,ha^{-1}$) (G) in 2007, 2008 and 2009. For each plot [i], an index of mean land-use intensity LUI[i] was calculated as

$$\mathrm{LUI}[i] = \sqrt{F[i] : F_{\mathrm{mean}} + M[i] : M_{\mathrm{mean}} + G[i] : G_{\mathrm{mean}}},$$

where F_{mean}, M_{mean} and G_{mean} are respective means values of all 50 plots of each study region (Blüthgen et al., 2012).

2.2. Field surveys and chemical analyses

Soil samples for pH and phosphorus (P) analysis were taken with a soil corer (⌀ 55 mm, Eijkelkamp, Giesbeek, The Netherlands) in Schorfheide-Chorin and Hainich-Dün from May to June 2008, and in the Schwäbische Alb in April 2009 as mixed samples from five sub-samples. Soil samples were air-dried and sieved to <2 mm. 0.5 g of sieved soil were sequentially extracted for 30 min with 20 mL 0.5 mol L^{-1} $NaHCO_3$ (adjusted to pH 8.5 with 1 M NaOH) and thereafter for 16 h with 30 mL 0.1 mol L^{-1} NaOH to estimate the labile ($NaHCO_3$-P) and moderately labile-bonded (NaOH-P) P fractions in soil (Negassa and Leinweber, 2009). Phosphorous concentrations in the extraction solutions were determined colorimetrically by the phosphomolybdate blue method after Murphy and Riley (1962) using a continuous flow analyzer (CFA, Bran+Luebbe, Norderstedt, Germany). Organic P concentrations were calculated as the difference between total and inorganic P concentrations. Further details on soil sampling are given in Alt et al. (2011).

From mid of May to beginning of June 2009, we identified all vascular plant species and estimated their abundance on 4 m × 4 m sub-plots in the grassland center and harvested aboveground