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Original article

Plant species effects on soil macrofauna density in grassy arable fallows of different age

Jörg-Alfred Salamon*, Janet Wissuwa, Stephan Jagos, Monika Koblmüller, Oxana Ozinger, Christine Winkler, Thomas Frank

Institut für Zoologie, Department für Integrative Biologie und Biodiversitätsforschung, Universität für Bodenkultur Wien, Gregor Mendel-Straße 33, 1180 Wien, Austria

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A B S T R A C T

The density of soil macrofauna groups in nine grassy arable fallows of different age were investigated in a factorial design with the factors 'plant species' (legume: *Medicago sativa*, herb: *Taraxacum officinale*, grass: *Bromus sterilis*) and 'age class' (A1: 2–3/3–4, A2: 6–8/7–9, A3: 12–15/13–16 years in 2008/2009). Four plots were selected randomly at each fallow. In May 2008 and May 2009, within each plot five *M. sativa*, *T. officinale* and *B. sterilis* plants were extracted with their associated soil using steel cylinders. The material from each plant species was used for extraction of soil macrofauna and for determination of environmental parameters.

The main results were (i) the density of the saprophagous macrofauna was significantly higher in *B. sterilis* than in *M. sativa* and *T. officinale* samples indicating that this group possibly benefited from the particularly high amount of fine roots in the *B. sterilis* samples; (ii) densities of Gastropoda and predatory beetles were highest in the 7–9 yr old fallows indicating that predators may have benefited from the increased availability of their prey in the medium stage of grassland succession; (iii) focusing on the results of the CCAs (2008, 2009), the water content had the strongest influence of the measured soil parameters on the structure of the soil macrofauna assemblages.

1. Introduction

Grasslands comprise diverse ecosystems, spanning intensively-managed species poor pastures (e.g. *Trifolium*–*Lolium* mixtures) to extensive-utilized pastures and meadows with high biodiversity [13]. Plant species diversity and composition of grasslands has long been recognized as an important determinant of the density and species richness of organisms at higher trophic levels [50,52,64]. In agricultural landscapes species richness of animals and plants has declined in recent decades [27] due to intensive farming practices which have increased the productivity of arable land at the expense of other organisms. Moreover, recent field and microcosm studies showed that plant species loss of grasslands leads to a decline in plant biomass [42,68] probably dropping the abundances of animal communities. To counteract this development, semi-natural habitats like wildflower areas or grassy arable fallows (semi-natural habitats characteristic of agricultural landscapes in Eastern Austria) have been established to enhance overall arthropod diversity and to increase densities of beneficial spiders and insects like Staphylinidae and Carabidae [20,21]. Although the importance of grassy arable fallows within ecological research has increased in recent years [e.g. 26] there is little information available about above-/below-ground interactions (e.g., interactions between plants and soil macrofauna). In most studies focusing on biotic interactions in grassland ecosystems only the relationship between plant communities and above-ground invertebrate herbivores was investigated, neglecting the response of soil invertebrates [4,31,50]. If the response of soil invertebrates was included, most studies focused on the relationship between plant diversity and soil fauna diversity [e.g. 24,60], whereas the influence of single plant species on the structure of the soil fauna community has generated little attention [19,52]. However, frequent plant species in grassland ecosystems (e.g., grass species like *Bromus sterilis* and *Trisetum flavescens*, herb species like *Taraxacum officinale* and *Plantago lanceolata*, legume species like *Medicago sativa* and *Trifolium repens*) may have a strong influence on the structure of soil macrofauna assemblages at the micro-scale [5,11,70] due to their provision of a unique food source (living plant tissue, litter, root associated mycorrhizal fungi) and microhabitat (e.g. microclimate conditions, soil pores caused by the growth of fine roots).

In many other field studies similar to those of Felzmann [19] and Salamon et al. [52] (both part of the BIODEPTH experiment), the soil

* Corresponding author. Fax: +43 1 476543203.
E-mail address: jasalamon@yahoo.de (J.-A. Salamon).

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fauna of "artificial" experimental plots was investigated, with the grassland communities being re-established by sowing mixtures of specific plant species (e.g., the CLUE project [24] and the Cedar Creek experiment [66]). In the present study, however, we investigated the influence of single plant species (*M. sativa* (legume), *T. officinale* (herb), *B. sterilis* (grass)) on the density of the soil macrofauna in more natural grassland ecosystems of different ages (three 2–3 (3–4), three 6–8 (9–7) and three 12–15 (13–16) year old grassy arable fallows in 2008 and 2009), where the plants had the opportunity to spread out naturally. *M. sativa*, *T. officinale* and *B. sterilis* (in the following text abbreviated as Ms, To and Bs) were selected as target plant species because they were frequent in all three age classes of the investigated fallows, allowing us to minimize the neighbor effects of non-target plant species by removing the Ms, To and Bs plants from the centre of plant species aggregations within the fallows. To investigate the "micro-scale correlations" between single plants and their associated macrofauna assemblages, we extracted single plants with all of the associated soil from the root area and extracted the macrofauna using a heat extraction method, which is a novel ecological approach of the present study just once used before [55]. These "micro-scale correlations" were often investigated in laboratory studies by sowing plant species in microcosm systems and adding different macrofauna species (mostly earthworm species) [e.g. 7,39]. However, transferring the results of these laboratory studies to the field is difficult and reinforces the importance of additional field studies to investigate the "micro-scale" habitat selection of soil macrofauna taxa within grassland ecosystems.

Gastropoda, Symphyla, Lumbricidae, Julidae and Isopoda were selected as target soil fauna groups in the present work because they are important herbivores (Gastropoda; [44,65]) and/or important primary and secondary decomposers (Gastrodopa, Symphyla, Lumbricidae, Julidae, Isopoda [10,15,59,62]) and performing key functions in terms of regulating litter decomposition and nutrient cycling [25,35,40]. Moreover, the distribution patterns of predatory macrofauna groups (Staphylinidae, Carabidae, Formicidae and Chilopoda) were investigated because they feed on herbivores [14,43,71] and decomposers [33,46,59] and thus presumably indirectly depend on the presence of single plant species or age classes of fallows. It has to be emphasized that in the present work only the distribution patterns of the selected macrofauna groups were investigated without including studies about their feeding behaviour. However, measuring of microbial soil parameters (microbial biomass, ergosterol content) allowed us to search for potential positive correlations between saprophagous macrofauna/gastropod taxa and microbial parameters within the investigated fallows. Overall, the study is designed to test the following hypotheses:

1) The presence of a legume species (in this study Ms) containing a high nitrogen content [38] causes a bottom-up effect propagating through the food web leading to high densities of mainly herbivorous (Gastropoda) and saprophagous groups (Isopoda, Lumbricidae, Julidae) [16,40,61] and their potential predators (Carabidae, Staphylinidae, Chilopoda, Formicidae) [e.g.19,71].
2) Densities of Gastropoda and saprophagous macrofauna increase with increasing age of the fallows due to the increasing number of plant species [55] providing diverse food sources (different types of living plant material and litter [8,12]). In turn, densities of predatory macrofauna groups increase with advancing age of fallows because they benefit from the high density of prey in the old fallows [21,72].

2. Material and methods

2.1. Sites and sampling

The Marchfeld plain, an area of intensive arable agricultural production north-east of Vienna characterized by a continental eastern European climate (mean annual temperature 9.6 °C, mean annual precipitation 490 mm) [17] served as study area. In May 2008 and May 2009, the study was performed in three 2–3 (3–4), three 6–8 (9–7) and three 12–15 (13–16) yr old grassy arable fallows (altogether nine sites) each including the plant species *M. sativa* (Ms) (as legume), *T. officinale* (To) (as non-legume herb) and *B. sterilis* (Bs) (as grass). Within the grassy fallows the dominating soil type is a black earth (chernozem) in different variations (Table 1). In each of the nine sites two plots (5 × 5 m) spaced at least 40 m apart from each other were selected at random. In order to avoid autocorrelation large spacing was chosen, thus assuming samples to be independent [30]. The minimum distance of the plots to the margin of the fallow was 15 m to minimize effects of neighboring sites (arable fields or other grassy arable fallows). In May 2008 and May 2009, at each plot five Ms, Bs and To plants were dug out with their associated soil from the centre of aggregations of the respective target plant species with the help of steel cylinders (5.6 cm × 5.6 cm × 10 cm depth) to minimize neighbor effects of non-target plant species.

Table 1
Characteristics of the 9 investigated sites (grassy arable fallows) in the Marchfeld area (Austria).

Sites	Grassy arable fallow since	Soil type	GPS position (latidude: lat; longitude: lon)	Size of the fallow (m^2)
Site 1 (age class: 2–3 yr)	2006	Wet chernozem	lat N: 48.225 lon E: 16.871	1709
Site 2 (age class: 2–3 yr)	2006	Parachernozem	lat N: 48.300 lon E: 16.668	2092
Site 3 (age class: 2–3 yr)	2006	Parachernozem	lat N: 48.307 lon E: 16.490	1969
Site 4 (age class: 6–8 yr)	2001	Wet chernozem	lat N: 48.225 lon E: 16.872	2366
Site 5 (age class: 6–8 yr)	2000	Chernozem	lat N: 48.306 lon E: 16.591	1454
Site 6 (age class: 6–8 yr)	2002	Parachernozem/ chernozem	lat N: 48.280 lon E: 16.783	28,907
Site 7 (age class: 12–15 yr)	1994	Chernozem	lat N: 48.341 lon E: 16.723	1168
Site 8 (age class: 12–15 yr)	1996	Calcareous tilled soil	lat N: 48.366 lon E: 16.570	1277
Site 9 (age class: 12–15 yr)	1993	Chernozem	lat N: 48.201 lon E: 16.574	10,413