



Soil mesofauna and herbaceous vegetation patterns in an agroforestry landscape

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Abstract Numerous studies have emphasised the ecological importance of linear and insular uncropped habitats, including forest shelterbelts, patches, and grassy margins. Usually, their biodiversity-enhancing effects are mentioned, mainly based on research in bird and above-ground arthropod communities, while the diversity of herbaceous vegetation and soil mesofauna is barely mentioned. Our research investigated the impact of six different habitats (cultivated areas, grassy field margins, shelterbelts and their grassy edges, forest and grassland patches) on soil-related diversity in an agroforestry landscape. We concentrated on the diversity and species composition of herbaceous and soil microarthropod communities,

which sensitively indicate the effect of the structure and management of the different ecotones on ecological conditions. Our research found that both shelterbelts and grassy margins provide better habitats for major microarthropod groups than cultivated fields. Concerning shelterbelts of different tree species, QBS-ar showed better soil biological conditions in the belt dominated by the native field maple when compared to the non-native black locust. Collembola was more abundant inside the shelterbelts than in their edges, while diversity showed an opposite pattern. The soil fauna and coenology results reflect the importance of habitat variability in agroforestry landscape by increasing soil-related invertebrate and herbaceous communities' diversity.

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Introduction

Intensive agricultural management techniques such as tillage and pesticide application often simplify and decrease the number of individuals of plant and animal communities (Lavelle 1996; Dervash et al. 2018). According to the technical development of weed management, a significant decline in the number of herbaceous species adapted to agricultural land use occurred in the last decades (Marshall 2002; Pinke

and Pál 2005). In agricultural areas, the different forms of soil degradation (soil compaction, structural degradation, organic matter decline, chemical load) are also reflected in soil fauna abundance and diversity (Giller et al. 1997; Sousa et al. 2006; Flohre et al. 2011; Paul et al. 2011). Under nutrient-poor conditions, Acari and Collembola communities have a crucial role in supporting productivity, but even small changes in their species composition and abundance affect the local mobilization of nutrients significantly (Heneghan and Bolger 1998).

Complex land use offers a broader range of ecological, economic, and social benefits than intensive agricultural production systems do (England et al. 2020). One way to increase landscape complexity is establishing shelterbelts on intensive agricultural fields. Several studies reflect their biodiversity-enhancing effect according to tree species diversity, bird and insect communities (Leles et al. 2017; Pardon 2019), while soil-related communities such as herbaceous vegetation and microarthropods are barely quoted (Alvarez et al. 2000; Olejniczak 2007; Jose 2012).

However, these communities' diversity sensitively reflects soil quality, proving the productivity and long-term sustainability of arable fields through organic degradation and nutrient recycling processes (Menta 2012; Giller et al. 1997). Field edges having a boundary structure with associated habitats can positively affect the weed flora (Marshall 2002; Jackson et al. 2019) since they act as refuges for many weed species in intensively cultivated environments (Marshall and Arnold 1995; Gustavsson et al. 2007). The understorey layer of hedgerows and shelterbelts is generally species-poor, but land use history significantly determinates the species composition (Milberg et al. 2019; Carlier and Moran 2019).

Regarding uncropped, grassy patches and margins, their role in enhancing soil-dwelling and above-ground arthropod diversity is often emphasized (Roy et al. 2003; Gravesen and Toft 2009). The land use type might strengthen or mitigate the negative effects of climate change on Collembola communities, especially in the topsoil (Yin et al. 2019). Mixed land use promotes Collembola diversity; the number of species in such landscapes can reach or exceed that of forests; however, forest-related species are compensated by those common in open habitats (Sousa et al. 2006). On the other hand, Ponge et al. (2006) found that if

the diverse landscape results from frequent land use changes, springtail species number decreases. Habitat size is not always a determining factor of Collembola diversity (Querner et al. 2018).

Our research aimed to assess the importance of different land-use types in the soil biological quality, herbaceous and soil mesofauna communities' diversity, and species composition in an intensively managed agricultural environment. An additional goal was to reveal the relations between the patterns of soil mesofauna and herbaceous vegetation, and the effect of the soil environment in different habitats on Collembola community characteristics. We hypothesized that forest shelterbelts and grassy edges in an agroforestry system could maintain diversity close to nearby natural control forests and grasslands.

Materials and methods

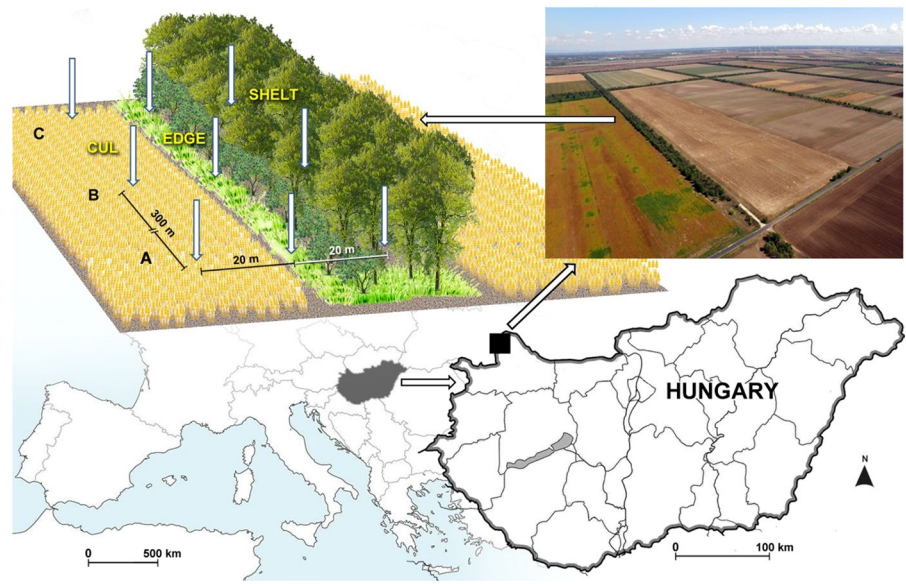
Study area

The examined shelterbelt system lies in the Little Hungarian Plain, North-West Hungary (Fig. 1), with a continental climate. The base of the flat alluvial cone is gravel, which is covered with sandy muddy loess. Where the gravel is covered with thicker and finer alluvium or loess sediment, chernozem-like soils can be found, including calcareous chernozem. The intensively managed fields are separated by forest belts established to protect the fields against wind damage and soil erosion. Forest patches with different tree species construction and mowed grass patches can also be found in the surrounding area.

Experimental design

Two types of shelterbelts have been designated for examination of the herbaceous flora and soil mesofauna. One type is a black locust (*Robinia pseudoacacia* L.) dominated plantation (ROB-SHELT) with green ash (*Fraxinus pennsylvanica* Marsh.); both tree species are non-native, invasive species in Hungary but frequently planted in shelterbelts. The other shelterbelt is a native field maple (*Acer campestre* L.) plantation (ACER-SHELT) with field elm (*Ulmus minor* Mill.). Samples were taken inside the shelterbelts and in the adjacent grassy edges (ROB-EDGE and ACER-EDGE) and crop

Fig. 1 The location of the study area and scheme for the soil, herbaceous vegetation, and microarthropod surveys (SHELT: shelterbelt; EDGE: grassy edges; CUL: cultivated field) in the agroforestry area. A, B, and C are repetitions in a certain habitat



fields (ROB-CULT and ACER-CULT). In both types of shelterbelts and their adjacent habitats, we set up three transects, each 600 m in length and 20 m apart from each other. Along the transects, three soil and vegetation survey plots were established 300 m apart (Fig. 1). An oak (*Quercus cer-ris* L. and *Q. robur* L.) plantation (FOREST) and a mowed grass patch (GRASS) were used as seminatural control sites, in which a transect as defined above was set up. The examined habitat types and their codes in the analysis are summarised in Table 1. For GPS coordinates of the sampling plots (quadrats), see Table S1 in Supplementary Material.

Vegetation survey

Herbaceous plant species and their percentage cover values were recorded in 25 m²-sized quadrats in all habitat types in three replicates in the early summer of 2019. The mean of the cover values found in the three samples was calculated for each habitat. The shape of the quadrats was adapted to the studied habitat characteristics: in shelterbelts, forest patches, grasslands and cultivated fields 5×5 m, in edges, 2×12.5 m-sized quadrats were assigned around the soil sampling points.

Soil sampling and analysis

In the early summer of 2019, simultaneously with the coenological recordings, disturbed and undisturbed

Table 1 Examined habitat types and their abbreviations in the analysis

Habitat	Code	Type
Non-native (black locust) shelterbelt	ROB SHELT	Agroforestry plots
Grassy edge adjacent to non-native shelterbelt	ROB EDGE	
Cultivated area (rapeseed) adjacent to non-native shelterbelt	ROB CULT	
Native (maple) shelterbelt	ACER SHELT	Seminatural control plots
Grassy edge adjacent to native shelterbelt	ACER EDGE	
Cultivated area (alfalfa) adjacent to native shelterbelt	ACER CULT	
Oak forest patch	FOREST	
Mowed grassy patch	GRASS	

samples were taken from the surface soil (0–10 cm depth) in every plots from the center of the quadrats used for the vegetation survey to determine soil physicochemical characteristics. Apart from disturbed samples of approximately 500 cm³, undisturbed soil samples of 100 cm³ were also taken for soil moisture determination and stored airtight until the analysis to prevent moisture loss.

Disturbed samples were air-dried and sieved (<0.004 m) for chemical and physical analysis. Soil pH (H₂O) was determined at a ratio of 1:5 soils to distilled water. Soil organic matter content (SOM) was measured with the potassium dichromate capacity method. Available nitrogen (NO₃⁻+NH₄⁺) was defined by using Parnas-Wagner distillation apparatus. The ammonium-lactate solution was used to measure available phosphorus and potassium content. Particle size distribution was calculated by Robinson's pipette method. Soil moisture was determined from the undisturbed, airtight samples using the gravimetric method after heating the samples at 105 °C for 24 h.

Soil microarthropod sampling, extraction and determination

For soil microarthropod survey, undisturbed samples were collected in each plot (three samples per habitat-transect) using a cylindrical soil core sampler of 100 cm³ volume (3.6 cm diameter×10 cm height) in the early summer season of 2019. Before sampling, aboveground vegetation and litter were carefully removed from the soil surface.

Berlese-Tullgren funnels were used to extract the microarthropods from the soil samples. During the 2 week period of extraction, specimens were collected in vials filled with 70% ethanol, then classified into major taxonomic groups for soil biological quality evaluation using a stereomicroscope. Soil biological quality was evaluated with the help of the QBS-ar index (Parisi et al. 2005). This method is based on the identified microarthropods classified into different morphotypes according to the level of their adaptation to soil environment and scored with an ecomorphological (EMI) value ranging from 1 to 20. The QBS-ar index is calculated as the sum of the obtained EMI scores. In our study, we computed the cumulative QBS-ar index for the habitat types.

In addition, Collembola individuals were determined to species level. Specimens were cleared using Nesbitt fluid and then mounted on permanent slides in Hoyer's medium. The slides were examined under a Leica DM2500 LED microscope with conventional bright light and phase contrast.

Statistical analyses

Diversity profiles were used to compare the herb layers of the different habitats calculated with the PAST software, using the exponential of the so-called Rényi index (Tóthmérész 2013). To evaluate the naturalness of plant species, Social Behavior Types (SBT) and naturalness values were used (Borhidi 1995), based on the Hungarian Flora Database (Horváth et al. 1995).

Collembolan abundance was determined as the number of individuals per m². To characterize the Collembola communities of the studied habitats, the following diversity measures were calculated: cumulative species richness, Shannon's diversity index (Shannon and Weaver 1949), and Pielou's evenness index (Pielou, 1966). Shannon diversities were compared using Hutcheson's *t* test (Hutcheson 1970).

In accordance with the study design, Collembola abundance was tested by using Kruskal–Wallis non-parametric test (Kruskal and Wallis 1952), followed by Dunn's post-hoc test for multiple pairwise comparisons (Dunn 1964) to examine differences among the eight studied habitats. The significance level was set at 0.05.

A hierarchical cluster analysis was performed using the Bray–Curtis similarity matrix (Michie 1982) to explore the connection among the different habitats based on the Collembolan data. Pearson correlation analysis was used to determine the relationships between plant-related variables (species richness; Borhidi's plant naturalness) and both Collembola abundance and diversity. Canonical correspondence analysis (CCA) was also performed (ter Braak 1986) with forward variable selection, using the CANOCO software vers. 4.5 (ter Braak and Šmilauer 2002) in order to investigate the specific relationship between the soil environmental parameters, vegetation characteristics, and Collembolan abundance. Two explanatory variables represent the vegetation characteristics: besides species richness, the naturalness value for each habitat was calculated,

based on Borhidi (1995). To avoid possible uncertain relationships, Collembola species occurred in less than five samples, and those represented by less than ten individuals were excluded from the analysis. To test the significance of the first canonical eigenvalue, a Monte Carlo test with 1000 random permutations was conducted.

Results

Soil properties

Based on the measured parameters (Table 2), the studied habitats are characterized by sandy-silty textured soils, with neutral to slightly alkaline pH. Carbonate content is low, with the exception of the two control sites. The highest SOM content was obtained in the control forest soil, while the values were slightly lower in the shelterbelts and control grass. The lowest values were observed in the cultivated soils. Due to fertilization, the latter soils were also characterized by the highest phosphorus and potassium content.

Vegetation

A total of 52 herbaceous species were found in the eight studied habitats. The highest species number appeared in the control grass and forest habitats: 22 and 17, respectively. 12 species were unique to the control forest and 17 to the grass. 11 and 12 species

were observed in the grassy edges of the non-native and the native stands, respectively. For the cover values (%) of the herbaceous species surveyed in the examined plots, see Table S2 in Supplementary Material.

As a result of the intensive weed management activities, only a few species were found in the cultivated fields. Accordingly, the diversity profiles of control sites were consistently above that of the agroforestry plots (Fig. 2).

Herbaceous species composition is described with plant sociological characteristics. Figure 3 shows the proportion of the number of species belonging to the different social behaviour type categories (Borhidi 1995) in the studied habitats. The majority of the herbaceous species belongs to the disturbance tolerant and weed categories in the studied habitats. Specialists did not appear in anywhere, natural competitors only in the seminatural control plots. Typically forest-related herbaceous species (*Aegopodium podagraria*, *Polygonatum latifolium*) were found only in the forest patch. The only generalist species in the agroforestry plots is *Symphytum officinale*, which was found in the field maple belt. The herbaceous level of both shelterbelts is mainly covered by arable weeds (*Arrhenatherum elatius*, *Bromus sterilis*, *Galium aparine*, *Ballota nigra*). The ruderal competitor species *Bromus sterilis* appears in both forest belt types with a similar cover. Still, in the edge of the non-native belt, the number of species in this

Table 2 Mean values of the measured soil parameters in the studied habitats.

	ROB-SHELT	ACER-SHELT	ROB-EDGE	ROB-EDGE	ROB-CULT	CER-CULT	FOREST	GRASS
pH _{H2O}	7.42	7.53	7.46	7.50	7.76	7.51	7.41	7.43
CaCO ₃	3.33	5.99	5.51	7.20	3.28	1.63	17.41	12.52
SOM (%)	2.10	1.97	1.57	1.67	0.90	0.93	2.53	2.27
Clay (%)	25.3	23.3	27.3	29.3	28.3	31.3	8.67	8.33
Silt (%)	23.0	22.7	18.0	19.7	23.0	26.33	48.33	44.0
Fine sand (%)	48.0	43.2	47.5	42.3	43.3	38.0	39.33	43.0
Coarse sand (%)	3.67	10.67	7.67	8.67	4.33	4.67	3.67	4.67
Moisture (%)	14.1	11.2	13.5	11.2	15.3	11.9	14.27	15.47
N _{min} (mg kg ⁻¹)	9.70	10.07	8.80	8.57	7.10	6.63	14.43	11.93
AL-P (mg kg ⁻¹)	125.3	133.6	413.7	314.3	542.0	584.7	83.7	207.0
AL-K (mg kg ⁻¹)	615.6	513.7	541.0	433.0	614.7	770.0	483.3	572.0

For habitat abbreviations, see “Materials and methods” section

SOM, soil organic matter; N_{min}, mineral nitrogen; AL-P, AL-K: AL-soluble phosphorus and potassium

Fig. 2 Diversity profiles of the herbaceous layer in the studied habitats. For habitat abbreviations and the explanation of the values on y axis, see “Materials and methods” section

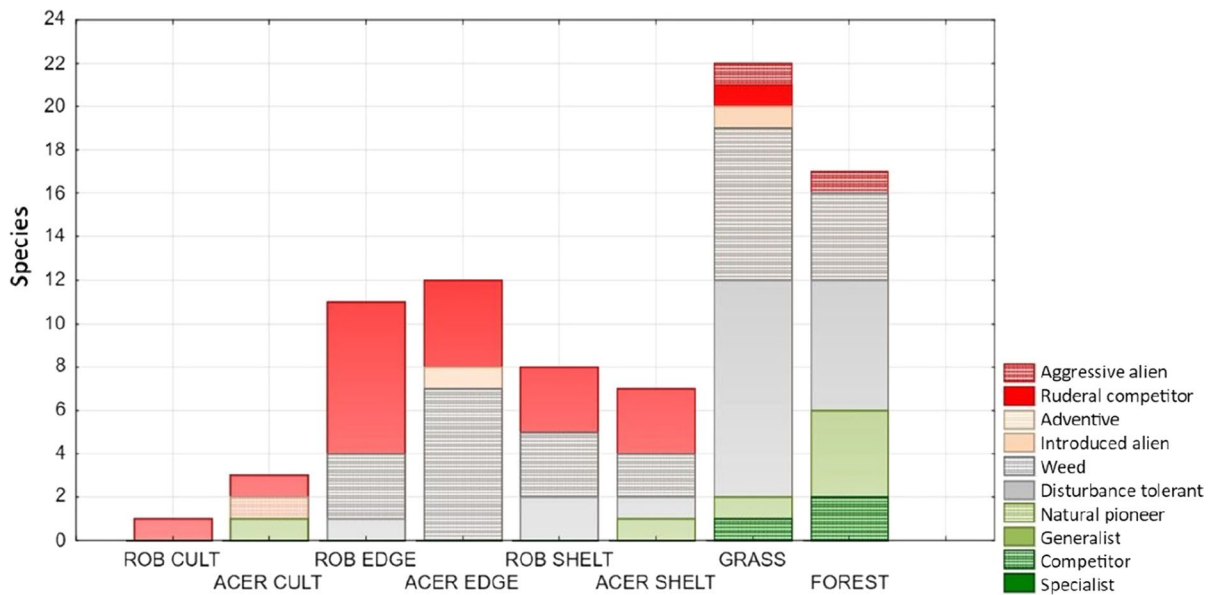
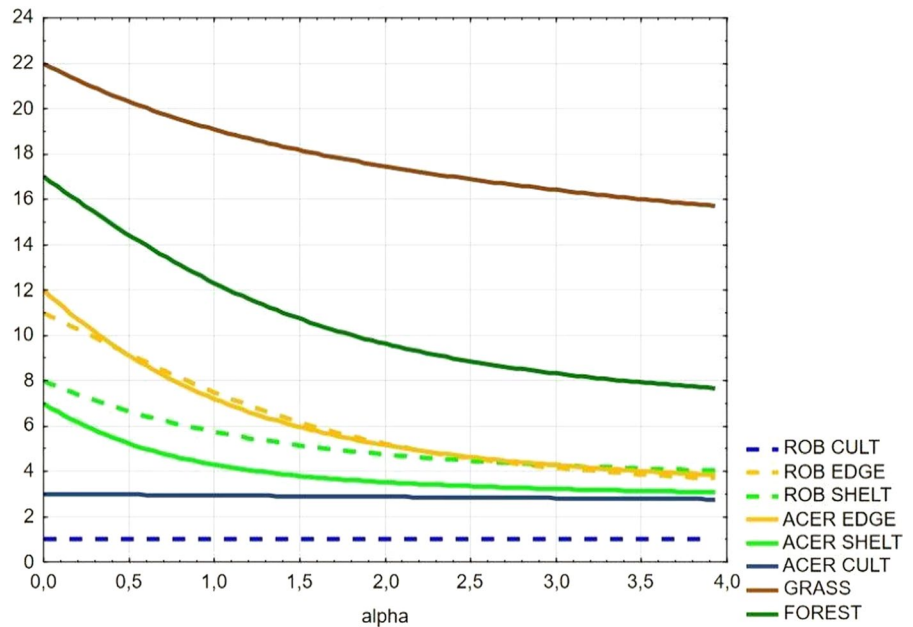


Fig. 3 The distribution of herbaceous species by social behaviour type categories. For habitat abbreviations, see “Materials and methods” section

category is higher than in the case of the native belt. Cultivated areas are dominated by a few resistant, ruderal competitor species (typically *Convolvulus arvensis*). Although the number of species belonging to the more valuable SBT categories in the herb layer of the two control habitats is much

higher than in the agroforestry plots, aggressive competitor species like *Conyza canadensis* and *Erigeron annuus* were found only in the grass controls (Fig. 3).

Soil mesofauna

In the collected samples, a total of 10,387 individuals belonging to 17 different microarthropod groups were identified (Table 2). The cumulative richness of microarthropod groups ranged from 6 (ACER-CULT) to 14 (ACER-SHELT). In each habitat, Acari was the most abundant group, followed by Collembola, representing 73.2% and 23.3% of the collected microarthropods, respectively, while the proportion of the

other taxa was markedly lower. Acari, Coleoptera, and Collembola appeared to be ubiquitous; moreover, the frequency of Aranea, Diplura, and Psocoptera was considerably high. We found significant marked differences among the surveyed habitats regarding soil biological quality expressed by the cumulative (QBS-ar) index. QBS-ar values varied within the range of 62 to 188. The lowest value was associated with ACER-CULT, while the highest was with the FOREST control (Table 3). Concerning shelterbelts of

Table 3 EMI scores and mean values (\pm Standard error) of microarthropod taxa abundance (ind./m²), and cumulative QBS-ar index values in the studied habitats

Microarthropod taxa (EMI scores)	ROB SHELT	ACER SHELT	ROB EDGE	ACER EDGE	ROB CULT	ACER CULT	FOREST	GRASS
PROTURA (20)	0	45 \pm 22	0	22 \pm 11	0	0	56 \pm 29	11 \pm 11
DIPLURA (20)	55 \pm 40	78 \pm 22	67 \pm 38	78 \pm 45	22 \pm 22	0	100 \pm 58	89 \pm 49
COLLEMBOLA (1–20)	5267 \pm 450	3856 \pm 292	3033 \pm 250	3278 \pm 193	711 \pm 87	867 \pm 51	6433 \pm 341	3422 \pm 200
PSOCOPTERA (1)	78 \pm 45	0	56 \pm 29	22 \pm 22	178 \pm 62	45 \pm 22	67 \pm 38	55 \pm 22
HEMIPTERA (1–10)	0	0	0	0	0	0	11 \pm 11	0
THYSANOPTERA (1)	78 \pm 29	33 \pm 19	22 \pm 11	11 \pm 11	0	0	45 \pm 22	0
COLEOPTERA (1–20)	33 \pm 19	67 \pm 19	33 \pm 33	55 \pm 22	33 \pm 19	11 \pm 11	44 \pm 29	33 \pm 19
COLEOPTERA larvae (10)	36 \pm 22	156 \pm 48	122 \pm 40	33 \pm 19	33 \pm 33	11 \pm 11	111 \pm 49	56 \pm 29
HYMENOPTERA (1–5)	22 \pm 22	0	133 \pm 51	67 \pm 33	0	0	33 \pm 19	156 \pm 59
HYMENOPTERA larvae (10)	0	0	0	0	0	0	0	22 \pm 22
DIPTERA larvae (10)	22 \pm 11	0	100 \pm 51	11 \pm 11	0	11 \pm 11	0	22 \pm 22
LEPIDOPTERA larvae (10)	0	0	0	11 \pm 11	0	0	0	11 \pm 11
ACARI (20)	12,533 \pm 1664	13,733 \pm 1908	9145 \pm 1380	7144 \pm 649	3067 \pm 379	3656 \pm 260	23,789 \pm 1694	11,467 \pm 1271
ARANEAE (1–5)	22 \pm 11	44 \pm 29	33 \pm 19	33 \pm 33	11 \pm 11	0	122 \pm 49	56 \pm 29
PSEUDOSCORPIONIDA (20)	0	33 \pm 19	0	0	0	0	22 \pm 11	0
ISOPODA (10)	0	0	0	0	0	0	45 \pm 22	0
CHILOPODA (10)	22 \pm 22	11 \pm 11	11 \pm 11	0	0	0	89 \pm 29	22 \pm 11
DIPLOPODA (10–20)	0	11 \pm 11	22 \pm 22	0	0	0	67 \pm 38	11 \pm 11
PAUROPODA (20)	0	33 \pm 19	22 \pm 11	0	11 \pm 11	0	22 \pm 11	11 \pm 11
SYMPHYLA (10)	33 \pm 19	78 \pm 29	45 \pm 22	67 \pm 19	0	0	100 \pm 19	22 \pm 11
QBS-ar value	117	171	147	137	93	62	188	186

For habitat abbreviations, see “Materials and methods” section

different tree species, QBS-ar showed better soil biological conditions in ACER-SHELT when compared to ROB-SHELT. The grassy edges of the shelterbelts show relatively high QBS-ar values, although not reaching the value of the control grassland.

Regarding the Collembola communities, a total of 2419 specimens representing 15 families, 34 genera, and 62 species were identified (for abundance values of the collected species, see Table S3 in Supplementary Material). Due to the area's geographical nature and climate, we recorded several typical xerother-mophilic species (e.g., *Doutnacia xerophila*, *Orchesella cincta*). The community structural characteristics are presented in Table 4. The highest species richness and diversity were found in the control grassland, followed by the control forest. The least diverse communities were associated with the cultivated fields, they provided habitats for a few species only.

Significant differences in abundance were detected among the habitats (Kruskal–Wallis test, $H=20.97$; $p<0.01$). Abundance in the cultivated fields was significantly lower than in any other studied habitats (Dunn's test, $p<0.05$). While we detected higher abundance inside the shelterbelts than in the edges, the difference was significant only for the black locust stand (Dunn's test, $p<0.05$). Community diversity showed an opposite pattern, as their values were higher in the edges of the shelterbelt. Nevertheless, Hutcheson's t test (Table S4) showed a significant difference ($t=4.583$; $p<0.01$) only for the black locust.

The cluster analysis based on the Bray–Curtis index showed the separation of the cultivated fields (Fig. 4). Within the second main group, the grass (edges, control) and forest habitats form two separate

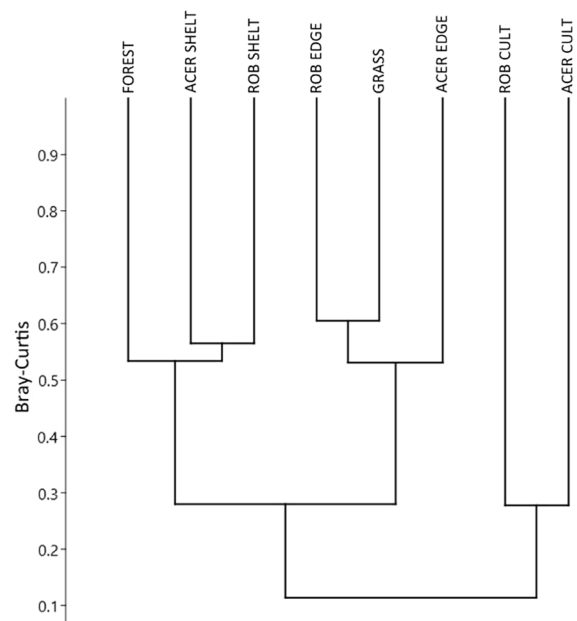


Fig. 4 Cluster analysis of Collembola community data based on the Bray–Curtis measure. For habitat abbreviations, see “Materials and methods” section

clusters. Within the latter cluster, the isolation of the shelterbelts and the control forest was observable.

There were significant positive relationships between plant species richness and both Collembola abundance and diversity ($F=19.764$; $p<0.001$; $R^2=0.47332$; and $F=27.467$; $p<0.001$; $R^2=0.55526$, respectively), while Borhidi's plant naturalness (SBT) showed significant correlation only with Collembola abundance ($F=7.066$; $p<0.05$; $R^2=0.24312$). A more complex relationship between Collembola species and soil-related environmental

Table 4 Mean abundance (SE) and cumulative, habitat-based Collembola community diversity measures in shelterbelt-related and seminatural habitats

	ROB SHEL	ACER SHEL	ROB EDGE	ACER EDGE	ROB CULT	ACER CULT	FOREST	GRASS
A	5267 ± 450 ^c	3856 ± 292 ^{bc}	3033 ± 250 ^b	3278 ± 193 ^b	711 ± 87 ^a	867 ± 51 ^a	6433 ± 341 ^c	3422 ± 200 ^{bc}
S	23	26	28	29	10	10	33	34
H'	2.52	2.681	2.887	2.725	2.041	1.473	3.008	3.164
J	0.804	0.823	0.866	0.809	0.886	0.640	0.860	0.897

In the case of abundance, uppercase letters indicate different groups: the same letter indicates no significant difference after Dunn's test ($p<0.05$)

For habitat abbreviations, see “Materials and methods” section

A, abundance (ind./m²); S, species richness; H', Shannon diversity index; J, Pielou's evenness index

variables is revealed by the CCA ordination (Fig. 5). The cumulative percentage variance of the first two canonical axes contributed 59.0% of the total variance of the species-environment data. The Monte Carlo permutation test confirmed the statistical significance ($p < 0.05$) of all canonical axes. Axis 1 primarily represents SOM, N, and P contents, while axis 2 is mainly related to soil moisture content, clay and silt content, and plant species richness. Along axis 1, a gradient of habitat from the open cultivated fields across the grassy edges towards the shelterbelts can be observed. Axis 2 clearly separated the edges and grassland control from both the cultivated fields and the forest habitats. Species preferring open habitats (e.g., *Hypogastrura socialis*, *Lepidocyrtus cyaneus*) are contributed most to the positive side of the first axis, while euryök species (e.g., *Parisotoma notabilis*, *Sphaeridia pumilis*) are distributed centrally or on the negative side of this axis. As it can be deduced from their ordination near the cultivated plots, only

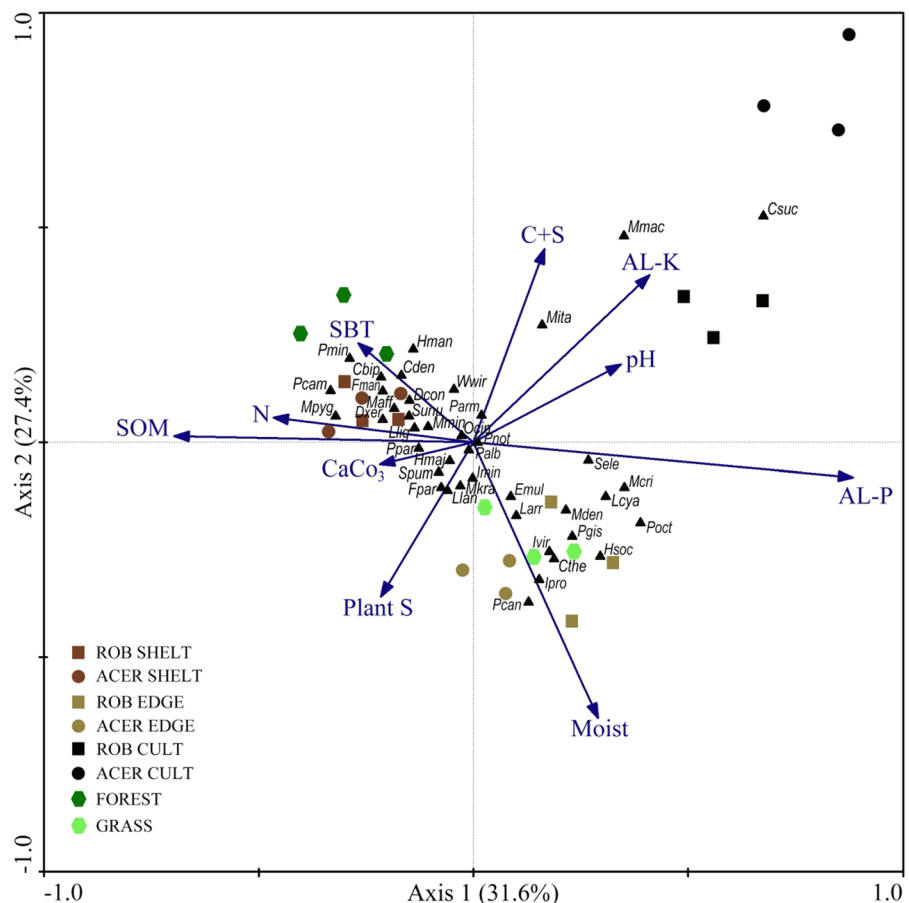
a few species like *Ceratophysella succinea* or *Mesaphorura macrochaeta* are well adapted to degraded soil conditions. Besides soil parameters, both herbaceous species richness and naturalness appeared to be influential factors of Collembola species composition.

Discussion

Vegetation

Comparing the diversity of all wooded and non-woody areas, grassy edges seem to contribute to the agroforestry system’s plant diversity more than shelterbelts. Typical forest-related herbaceous species found in the control forest did not appear in the shelterbelts. Presumably, one of the reasons for it is fragmentation, which results in forest species failing to find suitable ecological conditions (e.g., humidity) in a forest belt bordered with arable land on both sides

Fig. 5 CCA ordination of Collembola species and soil-related variables (pH: pH in H₂O; SOM: soil organic matter content; N: mineral nitrogen; AL-K and AL-P: AL-soluble content of potassium and phosphorus, respectively; C+S: clay plus silt fraction; Moist: soil moisture; Plant S: plant species richness; SBT: naturalness value after Borhidi). Percentage of variance explained by the axes is given in parentheses. Abbreviations of Collembola species names consist of initial letter of genus followed by the first three letters of species. For habitat abbreviations, see “Materials and methods” section



since the light, temperature, and moisture conditions are similar to the forest edges in the whole area of the shelterbelt (Reif and Ahtziger 1999). In addition, most of the forest-related herbaceous species can just very slowly colonise the newly planted woodlands (Wilson 2019). On the other hand, the abundance and species richness of agricultural weeds in shelterbelts are also smaller than in the edges since they are adapted to open habitats and the effects of cultivation (Pinke and Pál 2005). Carlier and Moran (2019) also found the herbaceous vegetation of hedgerows very poor in species, while Romero et al. (2008) reflected the significance of field margins, especially in organic farming, enhancing the diversity of the agricultural land. Smith et al. (1999) showed that uncropped edges do not increase the number of weed species and abundance in the crop field. In contrast, agricultural management, for example, the drift of fertilizer and pesticides, has a significant negative impact on weed flora (Marshall and Arnold 1995). According to Marshall (2002), the diversity of hedgerows in agricultural land can be raised by a strip of sown perennials between the crop field and the hedge.

The herbaceous layer of black locust forests is typically poor in species owing to the allelopathic effect of this tree species (Ferus et al. 2019), which causes the homogenization of the plant forest biota (Benesperi et al. 2012). This phenomenon is not evident in the case of the examined shelterbelts in the Moson Plain. However, the species composition in the herb layer of the two types of shelterbelts shows differences between native and non-native tree stands. Morrison and Flores (2013) found a significant difference in the understorey layer for native windbreaks regarding diversity and species composition; the appearance of invasive herbaceous species was higher in non-native shelterbelts, but their survey involved not only the herbaceous species but the tree seedlings too.

According to the species composition of the edge of the shelterbelts, the margin of the native maple strip seems to be more favorable. The reason for this is the black locust spreading from the belt. The lack of some weed species can be explained by the wider edge of the maple belt: chemicals used on the adjacent field have a smaller effect with the increasing distance from the cultivated area.

In the grassy patch, the number and coverage of unfavorable species are minimal, but species

belonging to the most valuable categories are missing, which indicates the secondary nature of the habitat.

Mesofauna

In the studied matrix of habitats, both shelterbelts and adjacent grassy edges provided better conditions for the major microarthropod groups than cultivated fields, similarly to results by Szanser (2003) and Olejniczak (2004) in Poland. These findings are also well reflected in the calculated QBS-ar indices. Some studies (Parisi et al. 2005; Wahsha et al. 2014) have pointed out that a QBS-ar value within the range of 100–200 suggests a stable soil ecosystem. The lowest mean values of QBS-ar detected in the cropland fields indicate the negative impact of conventional agriculture on soil biodiversity (e.g., Menta et al. 2018). From these habitats, certain groups like Protura, Symphyla, Chilopoda were completely missing. According to Christian and Szeptycki (2004), the absence of Protura in the cultivated area might be related to the recurrent mechanical disturbance and use of agrochemicals. They also reported that sensitive groups like Pauropoda are not necessarily affected, as it was in our case in the cultivated site adjacent to the black locust shelterbelt.

The establishment of shelterbelts also has a favourable effect on the soil fauna diversity in the agri-environment (Altieri 1999; Szanser 2003; Olejniczak 2004). Nevertheless, among the examined shelterbelts, only the field maple-dominated plantation presented remarkable soil biological quality. On the other hand, the studied black locust shelterbelt was characterized by a relatively low mean QBS-ar value, omitting groups like Pauropoda, Protura, and Pseudoscorpionida present in the maple shelterbelt. The negative impact of black locust on soil biological quality is also confirmed by Lazzaro et al. (2018), who found a decrease in hemiedaphic and euedaphic microarthropod groups, such as Protura, Acari, Collembola, Diplopoda, Coleoptera, and Thysanoptera in black locust forests. This phenomenon might be explained by the allelopathic effect of the black locust, which releases secondary metabolites, e.g., toxalbumins, robin, and phasin (Hui et al. 2004), thus revealing inhibition effects on protein synthesis that certain species cannot tolerate. This negative impact can therefore limit the abundance or diversity of

microarthropods through different biotic interactions, such as changing soil nutrient availability and food web (Bardgett and van der Putten 2014; Litt et al. 2014).

The grassy edges adjacent to shelterbelts and the control grassland presented roughly the same soil biological quality. Specific taxa (larvae of Hymenoptera and Lepidoptera) were found exclusively in grassy habitats. Therefore, their role in maintaining the biodiversity of the agri-environment is unquestionable (Szanser 2003; Ernoult et al. 2013).

Species composition, diversity, and abundance values of Collembola suggested that shelterbelts and their grassy edges can be considered as transition habitats among the sampled cultivated fields and the control forest and grassland. As both the cluster analysis and CCA showed, the cultivated fields were distinctly separated from the forest and grassy habitats. The low abundance and diversity detected here are related to the destructive practices (tillage, pesticide use) causing significant degradation, often adversely affecting soil Collembola (e.g., Gruss and Twardowski 2012; Ramezani and Mossadegh 2017). Soil organic matter loss caused by land cultivation is known to have a remarkable influence on Collembola abundance and species composition (Brennan et al. 2006; Fiera et al. 2020), as reflected in the unfavourable diversity values, and also supported by the CCA ordination. In the cultivated fields, mostly cosmopolitan and euryplastic species (e.g., *Ceratophysella succinea*, *Mesaphorura macrochaeta*, *Parisotoma notabilis*) were found.

Inside the shelterbelts, just a few forest-related species (e.g., *Isotomiella minor*, *Neanura muscorum*) were observed, which can be explained by the fact that the shelterbelts were established in post-arable fields, where the changes in soil properties and thus the recovery of Collembola communities are usually prolonged (Sławski et al. 2020). Simultaneously, the absence of direct surrounding forest habitats and the slow dispersal ability of certain euedaphic species also result in the lack of rapid colonization (Auclerc et al. 2009). On the other hand, species predominantly characteristic for open habitats (e.g., *Doutnacia xerophila*, *Folsomides parvulus*) were also collected, which can be explained by the lower canopy closure of shelterbelts and the proximity of open areas. Pioneer colonizers like *Parisotoma notabilis* and *Metaphorura affinis* were also present, conforming to the results by Olejniczak (2007). Considering

the shelterbelts of native and non-native tree species, Collembola were more abundant in the black locust stand, while species richness and diversity were higher in the native field maple belt. A similar pattern was observed by Harta et al. (2020) in forest plantations established in a formerly managed agricultural area.

The diversity patterns of Collembola communities show similarity to the herbaceous vegetation results: the grassy edges of shelterbelts were more diverse than the core of the tree stands. Apart from species that also appeared inside the shelterbelts or in the cultivated fields, we detected a number of typical grassland species (e.g., *Hypogastrura vernalis*, *Isotomodes productus*, *Isotoma caerulea*, *Cyphoderus albinus*, *Bourletiella arvalis*). The outstanding number of herbaceous species number and the relatively good naturalness in the grassy control plot did not result in significantly better collembolan community indexes than the grassy shelterbelt edges. It ran contrary with Salamon et al. (2004), who found that herbaceous food quality affects Collembola communities more than the quantity in the case of grasslands. Contrary, Sabais et al. (2011) found that after soil characteristics, plant species richness is the most relevant factor on Collembola diversity and density in the case of grassy vegetation. The functional diversity of the vegetation exhibited inconsistent effects in this regard. Perez et al. (2013) reported the importance of plant life forms on collembolan species composition rather than plant diversity under different vegetation covers. On the other hand, the activity of decomposer soil fauna strongly influences herbaceous species composition (Eisenhauer et al. 2011). The contradiction with our results might indicate the shelterbelts' shading effect, which creates favorable conditions for soil mesofauna. In the case of woody habitats, where the conditions are more similar, a closer relationship can be observed between the quality of the herbaceous vegetation and Collembola community indices. The intensive management in cultivated fields affects both communities adversely.

Conclusions

Shelterbelts planted in agricultural fields are of high importance for wildlife, but they are neither suitable habitats for forest-related herbaceous species nor the

majority of agricultural weeds. Just a few disturbance-tolerant and weed species, ruderal and adventive competitors are present in the understory layer. Presumably, this is the result of the combined effect of fragmentation, the slow colonisation ability of forest-related herbaceous species, and the adaptation of agricultural weeds to cultivated open habitats. In contrast, grassy edge habitats are refuge for a wide range of native agricultural weed species. Our research highlighted the importance of even secondary grass and forest fragments in protecting herbaceous diversity in the agricultural landscape.

Based on our results, both types of shelterbelts and their grassy edges have an essential role in preserving soil biological quality in the agricultural landscape. The assessment of species composition and diversity of Collembola communities led us to the conclusion that the fauna is less varied in the shelterbelts than in the control seminatural forests. Nevertheless, their abundance and species richness are considerably higher than those found in the agricultural fields. Besides, several studies reflect the importance of shelterbelts or hedgerows in the migration of microarthropods from the woody habitats to cultivated fields, having a positive effect on organic degradation and nutrient recycling processes.

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Declarations

Conflict of interest No conflict of interest.

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