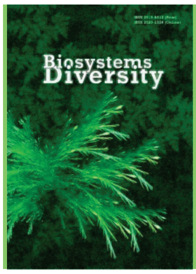

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Influence of ecological farming on the community structure of epigeic arthropods in crops *Triticum aestivum* and *T. spelta*

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Soil is an irreplaceable natural resource that enables the production of food and raw materials, forms agricultural and forest landscapes, filters and maintains water, ensures the cycle of substances in the ecosystem and contributes to maintaining biodiversity. Agricultural intensification is one of the most important factors for biodiversity loss. Spatial dispersion of epigeic arthropods reflects the ecological status of habitats and points to its quality. The aim of our research was to point out the differences in epigeic arthropod diversity in the examined crops *Triticum aestivum*, *T. spelta* and the influence of their ecotones on epigeic arthropods. Between the years 2019 to 2021 an investigation using the pitfall trap method recorded 5,232 individuals belonging to 13 taxonomic groups. The crop *T. aestivum* was represented by 2493 individuals and 13 taxa while in *T. spelta* we recorded 2739 individuals and 11 taxa. We observed significantly more taxa in the crop *T. aestivum* than in the crop *T. spelta*. We also confirmed the ecotone rule only for the *T. aestivum* crop. We confirmed the significant influence of crops and environmental variables (pH, potassium, phosphorus, nitrogen) on the spatial dispersion of individuals around pitfall traps. On the basis of our results, both ecological farming and their ecotone systems are important for epigeic arthropods and with topical and trophic conditions, which is important for the production of biomass and also affects crop. In any anthropogenic activity, it is important to give priority to less invasive procedures with non-toxic effects on organisms and to use effective technologies in land management.

Keywords: invertebrates; abundance; diversity; agroecosystems; ecotones; field margins.

Introduction

Based on the ecosystem services used for agriculture, the protection of biodiversity in crops has received increasing attention (Ganser et al., 2019; Harlio et al., 2019). Biodiversity and ecosystem services are linked, support agriculture, contribute to the livelihoods of farmers and therefore sustainable agriculture is an important to reverse the trend of biodiversity loss (Brygadyrenko, 2015a). Protection of biodiversity cannot depend only on natural reserves, but also on the contribution of crops to biodiversity (Pardon et al., 2019; FAO, 2021).

Soil is a crucial natural resource, which is also an economic potential. It is an environment for all organisms, but at the same time it is also their product. Next to air and water, soil is the third most important component of the environment, which represents an irreplaceable natural resource within the ecosystem of interest (Javoreková et al., 2008). An integral part of the soil is the organic component, which affects the soil properties. The organic component consists of soil edaphon and soil humus, the presence of which is mutually dependent. As a result of anthropogenic activity, a large amount of contaminants enters the soil, which degrades plant production and reduces overall biodiversity (Campbell & Reece, 2006; Beljaev et al., 2017; Fedyushko & Babchenko, 2021). Soil is characterized by physical and chemical properties that determine the nature of the environment and influence biocenoses. Thus, the soil ecosystem represents a complex of heterogeneous environment in which climatic, biotic and topographical factors intertwine (Avtaeva et al., 2021; Karthik et al., 2022).

Epigeic arthropods are sensitive to environmental changes and have a good classification basis and standardized sampling methods. For this reason they are often used as indicators in landscape change and biodiversity research (Brygadyrenko, 2015b; Faly et al., 2017; Guo et al., 2020). The epigeic arthropods compete through diverse feeding behaviours, life strategies, habitat distribution and provide various ecosystem services (Bai et al., 2021). In crops, pest control is an important ecosystem service, which is provided by predatory arthropods (Sunderland & Samu, 2000). Spiders, beetles, and hymenoptera make up the largest number of individuals and species of epigeic arthropods in agroecosystems (Michalko et al., 2019; Rodríguez-Gasol et al., 2020). The composition of agricultural landscapes affects the interactions between epigeic arthropods, which affects the food chain (Brygadyrenko & Reshetniak, 2014; Brygadyrenko & Nazimov, 2015). Agricultural intensification impacted the interaction between predators and pests and habitat destruction was a key driver of species disappearance (Häussler et al., 2020). The disappearance of predators in the food chain would lead to extinction of natural communities and increase the probability of extinction of other epigeic species (Donohue et al., 2017). The use of ecotones in the landscape creates a specific habitat for plants, animals and serving as biodiversity refuges. Also this can help lessen the effects of agricultural practices in crops (Lykhovyd, 2021; Tkalich et al., 2021; Tsyliuryk et al., 2021). The plant communities in ecotones serve as shelters and overwintering sites for epigeic arthropods (Haddaway et al., 2016; Nowakowski & Pywell, 2016). Flora support agricultural production by attracting pollinating insects and other beneficial animals that regulate pests (Smith et al., 2008). Areas with flowering plants serve as ecological corridors, assuring connectivity between natural habitats and fields, also the preventing separation from landscape patches (New, 2005). Epigeic arthropods have an important role in the decomposition of organic matter in the biochemical cycles of carbon, nitrogen, sulphur and phosphorus. They contribute to the degradation and transformation of toxic substances and also are important for the sustainability of the soil ecosystem, which makes their dispersion in crops important (Porhajašová et al., 2015; Kozak et al., 2020). The epigeic arthropod communities are important to agroecosystems and seasonal variation is a common trait in areas with strong climatic seasonality (Berg & Bengtsson, 2007).

Ecological farming avoids and largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives etc) and relies upon crop rotations, crop residues, animal manures, off-farm organic waste. Ecological farming is a suitable alternative to achieve ecological balance, biodiversity and also sustainability in production. This system of farming is a modern system of tillage which is spread all over the world. Unlike conventional of farming, it has a positive effect on the biodiversity of animals, plants, and their protection (Hazarika et al., 2013). In ecological farming pesticides, synthetic fertilizers or growth regulators are not used. Ecological farming management uses green manure, crop residues, crop rotation, animal manure, and also pest control to maintain soil productivity. The soil in ecological farming has higher microbial activity and also organic matter content. The risk of contaminating water resources with pesticides is low. The benefits of ecological farming are as follows: reduction of production cost by over 25%, elimination of the use of synthetic fertilizers, artificial flavours, preservatives and pesticides, increase in crop yield up to five-fold within 5 years, and it is environment friendly. Increased long term fertility of soil supports the local farmers and economy (Wollni & Andersson, 2014). The ecological stability of the agricultural landscape increases based on higher species richness of animals and plants (Porhajašová et al., 2018).

We expect that our results will contribute new information on the distribution of epigeic arthropods in the conditions *Triticum aestivum* and *T. spelta* and their ecotones.

Materials and methods

The research was done in the years 2019 to 2021 and the epigeic arthropods were collected from crops *Triticum aestivum* (Fig. 1) and *T. spelta* (Fig. 2). Epigeic arthropods were collected from November to July, every year. For each field we used five pitfall traps, these traps were placed in a line at distances of 10 m from one another. The first and second pitfall traps were located in the ecotones (meadow type, average width of ecotones was 10 m), and the other traps were inside the fields. The material fixation was used 4% formaldehyde solution. Pitfall traps were collected every two weeks and epigeic arthropods was determined according to the work of Schierwater & DeSalle (2021).

The monitored area was located in the south-western part of Slovakia (48°17'01.0" N 18°06'56.6" E). The altitude of the study area was 130 m above sea level and type soil is brown soil. The monitored area has a warm arid climate with mild winters. The fields on which the research took place are shown in Figure 3.

Ecological tillage was based on annual tillage plowing, incorporating crop residues and weeds into the soil, pre-sowing preparation with sowing were combined. Variables pH, potassium, phosphorus, nitrogen we measured using a meter types Dexxer PH-03 (Luboň, Poland, 2017) and Rapitest 3 1835 (Luster Leaf, Illinois, USA, 2017). The average values of pH, potassium, phosphorus, nitrogen at pitfall traps for investigated crops are shown in Table 1.

Redundancy analysis (RDA) was used to express dependencies between crops (*Triticum aestivum*, *T. spelta*), environmental variables (pH, potassium, phosphorus, nitrogen) and spatial dispersion of individuals in samples around pitfall traps 1–5. We determined the statistical significance of environmental variables and crops using the Monte Carlo permutation test (iterations = 499) in the Canoco5 program (Ter Braak & Šmilauer, 2012).

Analysis in the statistical program R 3.6.3 (Foundation Inc., Boston, USA, 2020) was used focused on Shapiro-Wilk W-test, which determined the normality of data distribution (R version 3.6.3. 2020. The R Foundation for Statistical Computing Foundation Inc, Boston). Based on the not normality data distribution (P = 0.05), we used the Mann-Whitney U test to test difference between the number of individuals and species among crops *T. aestivum* and *T. spelta*. We also created rarefaction curves and extrapolation curves of epigeic arthropods diversity in each of the crop types.

Table 1
Average values of pH, potassium, phosphorus, nitrogen of investigated crops

Crops / environmental	Pitfall traps				
	1	2	3	4	5
Triticum aestivum					
pH	7.00	6.96	7.04	7.02	6.99
Potassium	30.56	23.93	24.27	27.28	18.94
Phosphorus	2.22	1.85	1.85	2.08	1.48
Nitrogen	30.56	23.93	24.27	27.28	18.94
Triticum spelta					
pH	7.01	7.04	7.02	7.00	6.94
Potassium	32.78	17.26	19.23	20.45	12.99
Phosphorus	2.44	1.35	1.45	1.53	1.04
Nitrogen	32.78	17.26	19.23	20.45	12.99

Fig. 1. *Triticum aestivum* crop in the conditions of ecological farming

Fig. 2. *Triticum spelta* crop in the conditions of ecological farming

Fig. 3. Map of the study fields

Results

Over the research period, we found a total of 5,232 individuals belonging to 13 taxonomic groups in the studied crops *T. aestivum* and *T. spelta*. Eudominant representation (>10%) of individuals was shown by the taxon Coleoptera (74.10%). Julida (6.57%) representated the dominant group (5.00–9.99%) of individuals in crops. Other taxa of epigeic arthropods had subdominant to subrecendent representation (Table 2). We confirmed a statistically significant difference in the number of taxonomic groups of epigeic arthropods (P = 0.047, Fig. 4) and also in the number of individuals (P = 0.021, Fig. 5) among the crops *T. aestivum* and *T. spelta*.

In the conditions of the *T. aestivum* crop, we found more taxa and a smaller number of individuals than in the *T. spelta* crop. The above mentioned fact can be influenced by the different species representation of weeds and the food supply, which subsequently affects the presence of epigeic arthropods.

Table 2
The epigeic arthropods in the investigated crops

Arthropods	The number of invertebrates in *T. aestivum* crops, ind.	Share of the total number of invertebrates, %	The number of invertebrates in *T. spelta* crops, ind.	Share of the total number of invertebrates, %	Total number of invertebrates, ind.	Share of the total number of invertebrates, %
Acarina	8	0.32	5	0.18	13	0.25
Araneae	61	2.45	91	3.32	152	2.91
Coleoptera	1642	6.86	2235	81.60	3877	74.10
Collembola	12	0.48	53	1.94	65	1.24
Dermaptera	39	1.56	0	0.00	39	0.75
Haplotaxida	62	2.49	12	0.44	74	1.41
Hymenoptera	166	6.66	44	1.61	210	4.01
Isopoda	83	3.33	129	4.71	212	4.05
Julida	314	12.60	30	1.10	344	6.57
Lithobiomorpha	1	0.04	5	0.18	6	0.11
Opilionidea	9	0.36	100	3.65	109	2.08
Orthoptera	82	3.29	35	1.28	117	2.24
Pseudoscorpion	14	0.56	0	0.00	14	0.27
Number of invertebrates	2493	100	2739	100	5232	100

In the crops *T. aestivum* and *T. spelta* we monitored the difference in epigeic arthropods' diversity in pitfall traps (1–5) using rarefaction curves. We confirmed the decrease in epigeic arthropods' diversity and the number of individuals in the direction of pitfall traps 1, 2 (located in the ecotone) and 3, 4, 5 (located inside the field) in the *T. aestivum* crop (Fig. 6). In the *T. spelta* crop (Fig. 7), we confirmed this decrease in the direction of pitfall traps 1–5 only in the number of individuals. Epigeic arthropods' diversity had a decrease in the direction of pitfall traps 1, 2, 3, 5, 4 and pitfall traps 2 (located in the ecotone) had the same epigeic arthropod's diversity as in pitfall traps 3 (located inside the field). At the same number of individuals, the epigeic arthropods' diversity in pitfall traps changed, in the direction of the highest epigeic arthropods diversity to the lowest as follows: 1, 3, 4, 2, 5 in the *T. aestivum* crop and 1, 3, 2, 5, 4 in the *T. spelta* crop. The high epigeic arthropods' diversity in pitfall trap 1 and low epigeic arthropods diversity in pitfall traps 2, 3, 4, 5 were driven primarily by differences in the local abundance of populations, which is influenced by current climatic conditions. Based on the above, we confirmed the ecotone rule only for the *T. aestivum* crop. We did not confirm this ecotone rule for the crop *T. spelta*.

Using the redundancy analysis (RDA, SD = 2.2 on the first ordination axis) we observed dispersion of individuals in samples around the pitfall traps of investigated crops (*Triticum aestivum*, *T. spelta*). The explained variability of the individuals in the samples was 72.3% on the first ordination axis and 82.4% on the second cumulative ordination axis. The variability explained by the examined crops was 87.8% on the first ordination axis and 95.0% on the second cumulative axis. Using the Monte Carlo permutation test, we confirmed the significant influence of *T. spelta* (P = 0.026, F(1.245) = 1.746, df = 1) and *T. aestivum* (P = 0.048, F(2.005) = 2.685, df = 1) on the dispersion of individuals around pitfall traps (1–5). The researched crops were not mutually correlated with inflation factor (3.451). On the graph, we can see the higher concentration of individuals from the obtained samples around pitfall trap 1 located in the ecotone. Towards the interior of the field, the number of individuals decreased (Fig. 8).

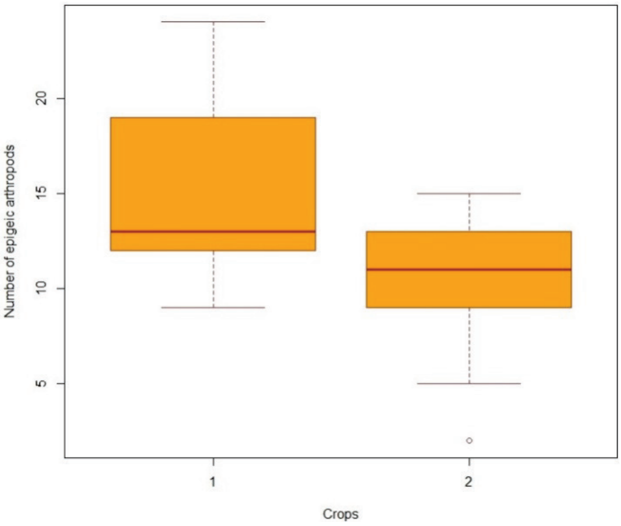

Fig. 4. Number of epigeic arthropods species in conditions of crops *Triticum aestivum* (*1*) and *T. spelta* (*2*)

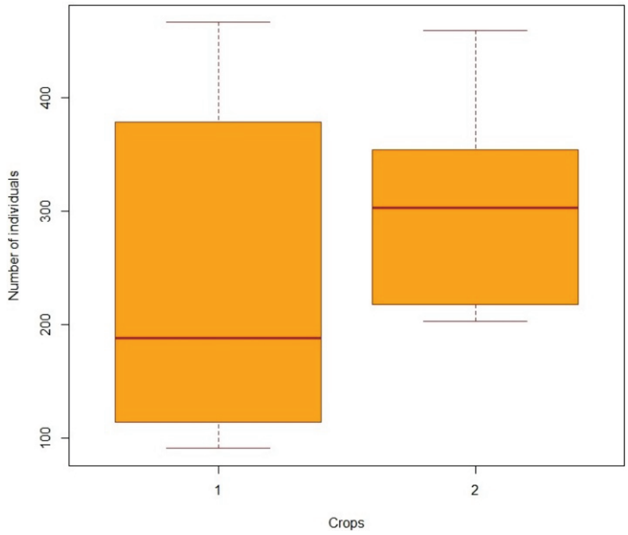

Fig. 5. Numbers of individuals of epigeic arthropods in conditions of crops *Triticum aestivum* (*1*) and *T. spelta* (*2*)

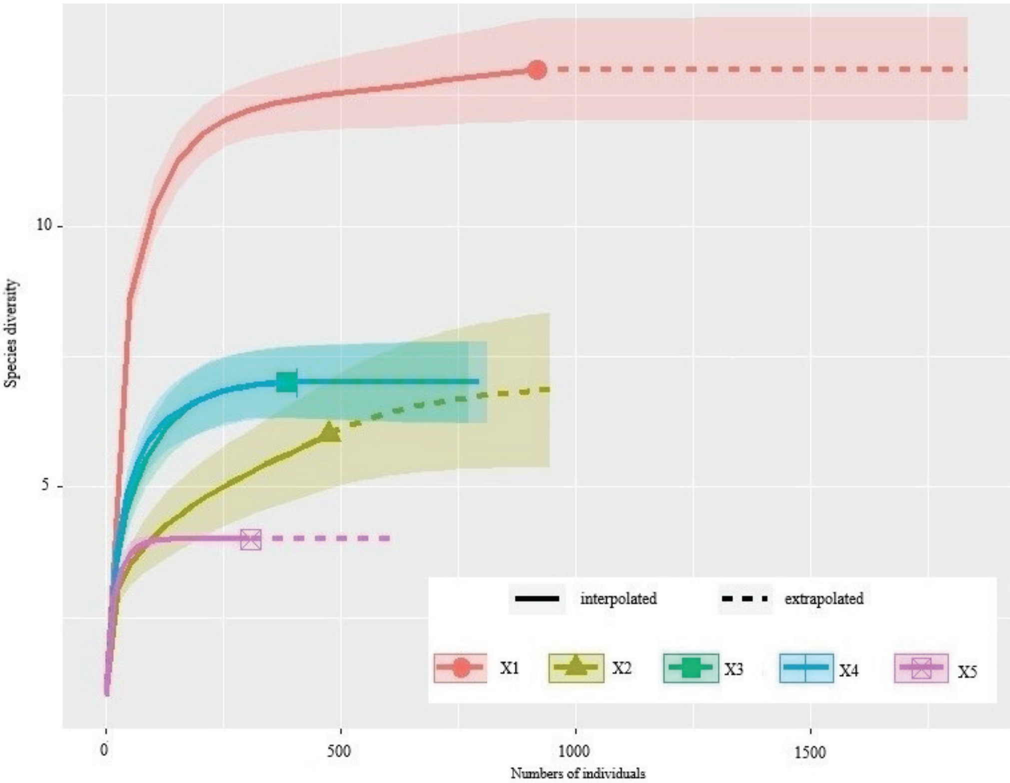

Fig. 6. Rarefaction curves of species diversity in pitfall traps located in the ecotones (traps 1, 2) and in the field (traps 3, 4, 5) in the *Triticum aestivum* crop

We also monitored the influence of environmental variables (pH, potassium, phosphorus, nitrogen) on the dispersion of individuals around pitfall traps (1–5) by the redundancy analysis. The explained variability of the individuals in the samples was 72.3% on the first ordination axis and 82.4% on the second cumulative ordination axis. The variability explained by the examined crops was 91.0% on the first ordination axis and 97.0% on the second cumulative axis. Monte Carlo permutation test, we confirmed the significant influence of nitrogen (P = 0.046, F(1.321) = 1.954, df = 3), potassium (P = 0.049, F(1.741) = 2.015, df = 3), phosphorus (P = 0.04, F(1.109) = 1.994, df = 3) and pH (P = 0.0075, F(1.915) = 2.578, df = 3) on the dispersion of individuals around pitfall traps (1–5). The researched environmental variables (pH, potassium, phosphorus, nitrogen) were not mutually correlated with inflation factor 2.716. Higher concentration of individuals was found around pitfall trap 1 located in the ecotone, but this concentration is also influenced by nitrogen, phosphorus, potassium. pH had an effect on individuals around pitfall trap 3.

Discussion

The agricultural landscape forms landscape configuration and results in landscape heterogeneity. This directly affects the dispersion of diversity, quality of the food chain of epigeic arthropods and species interaction (Baillod et al., 2017). The establishment of semi-natural habitats, of ecotones and their protection, provides the species (plants, animals) in the agricultural landscape with food resources needed for survival and production. Ecotones provide food sources, refuges and migration corridors (Zhao et al., 2020). The most common structure of econes are field edges, which agricultural management subjects to disturbance activities such as fertilizer misplacement, pesticide drift and eutrophication (Kleijn & Snoeijing, 1997). The species in crops have a greater tolerance than species of natural habitats. They achieve high local density and the influence of crops management and ecotones support abundant and diverse communities of epigeic arthropods (Magura et al., 2020). In our results Coleoptera, Julida and Hymenoptera dominated, whose great abundance was influenced by the natural balance and the substance cycle in ecosystems of crops and of ecotones. The eudominance of Formicidae (Hymenoptera), Araneae and Coleoptera is general trait of epigeic assemblages and their activities help the decomposition of plant residues, improve soil structure, quality of soil and aerate the soil. The occurrence of other epigeic arthropods depends on the management of crops and the vegetation in ecotones, and their use in biological control can improve ecosystem conservation and ecological farming (Dobrovodská et al., 2019).

The use, management and structure of land affect the composition of fields, which are a source of pests, weeds and disease. Plant heterogeneity is the most important factor for the dispersion and diversity of epigeic arthropods and they provide habitats for species beneficial to agriculture (Haddaway et al., 2016). Using the Mann-Whitney U test, we found a larger influence of the crop *T. aestivum* on epigeic arthropods and their individuals compared to the crop *T. spelta*. This can be influenced by weed species representation in the field, food supply for arthropods and soil management. Pérez-Bote & Romero (2012) observed a decline in epigeic arthropods with disturbance of the soil. Beneficial effects of plants diversity (wild flowers), on species diversity were addressed by Diehl et al. (2012, 2013). An agroecosystem is the habitat of a large number of epigeic arthropods and its sustainable development ensures the stability of the food chain. This effect is confirmed in research (Martin et al., 2016; Djoudi et al., 2018).

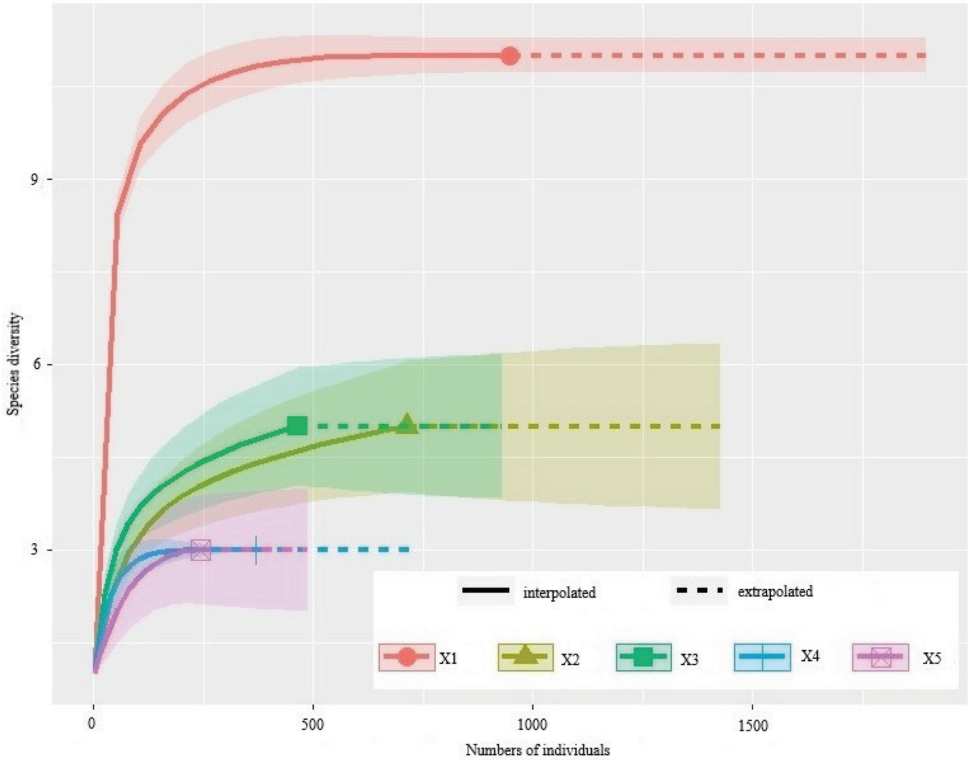

Fig. 7. Rarefaction curves of species diversity in pitfall traps located in the ecotones (traps 1, 2) and in the field (traps 3, 4, 5) in the *Triticum spelta* crop

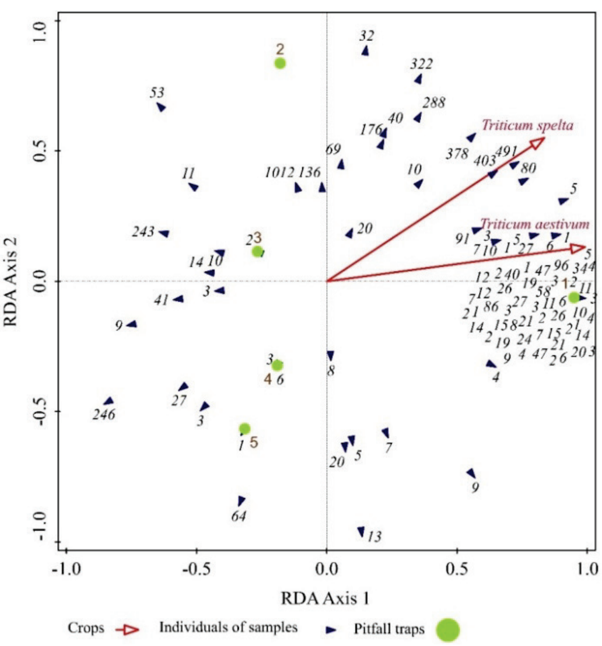

Fig. 8. Redundancy analysis of the dispersion of individuals around pitfall traps (1–5) of the studied crops

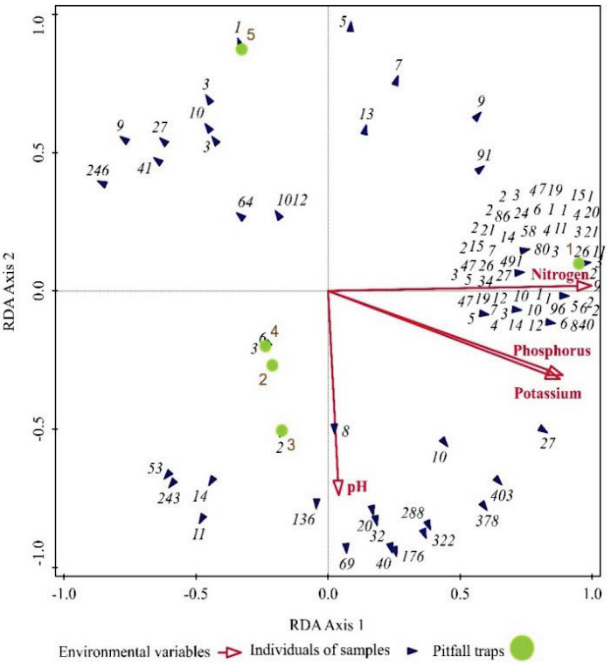

Fig. 9. Redundancy analysis of the dispersion of individuals around pitfall traps (1–5) and influence of environmental variables

The change in abundance of epigeic arthropods over different months is also caused by fluctuations in temperature, precipitation and day length (Liu et al., 2015). In complex land use the number of ecotones is large, in less complex systems fewer ecotones are available. Based on that, coexistence through resource is limited and this leads to a reduction in diversity (Baranová et al., 2015). The number of epigeic arthropods and individuals captured in the *T. aestivum* crop had a decreasing tendency in the direction from the ecotone to the interior of the field. We have not confirmed this ecotones rule for the crop *T. spelta*. This difference in the ecotones was possibly affected by the weather in different months and seasons (Simão et al., 2015). Majeed et al. (2020) also confirmed a seasonal change in the abundance of epigeic arthropods. Landscape heterogeneity depends on habitat fragmentation, however excessive fragmentation leads to a decline in landscape connectivity (Jeanner et al., 2003; Lázaro & Alomar, 2019). Soil disturbance caused by applying manure causes a decline in individuals of epigeic arthropods. Preserving their abundance is necessary because they play an important ecological role in providing ecosystem services to control pests in fields (Schuster et al., 2019). The orders Coleoptera, Araneae and Hymenoptera react negatively in agroecosystems to influence of pesticides, insecticides, artificial fertilizers, pH, and soil moisture (Tiemann et al., 2015).

The species composition and structure of epigeic arthropods are the result of various ecological factors and their mutual combination. Complex processes taking place in the soil ensure its balance due to the presence and activity of epigeic arthropods, such as beetles, ants, spiders, centipedes, millipedes, mites and various larvae. All individuals compete for organic residues in the soil. Different numbers of individuals and taxa is typical for different agroecosystems, which is also influenced by pH, phosphorus, nitrogen and potassium in the soil (Coleman et al., 2004). Our results show a significant influence of nitrogen ($P = 0.046$), potassium ($P = 0.049$), phosphorus ($P = 0.040$) and pH ($P = 0.008$) on the spatial dispersal of individuals of epigeic arthropods. Soil communities that are significantly involved in soil-forming processes (such as the decomposition of surface humus and soil microstructure) are significantly affected by changes in the soil environment. Biodiversity of epigeic arthropods and their abundance in the soil is influenced by habitat type, which is related to their trophic preference, or their tolerance to habitat conditions Purchart & Kula (2007). Our examined crops *T. aestivum* and *T. spelta* had a significant influence on the spatial dispersal of individuals of epigeic arthropods.

Conclusions

The aim of the presented work was to evaluate the biodiversity of epigeic arthropods under the conditions of the crops *T. aestivum* and *T. spelta*. The results of our research confirmed a statistically significant difference of epigeic arthropods and individuals between the studied crops. The *T. aestivum* crop had a higher preference of taxa opposite *T. spelta*. We found a decrease in diversity and numbers of epigeic arthropods in the direction from the ecotone to the interior of the field for the crop *T. aestivum*. We have not confirmed this rule for the crop *T. spelta*. The multivariate analysis revealed a significant influence of environmental variables (pH, potassium, phosphorus, nitrogen) and crops on the spatial dispersion of individuals around pitfall traps 1–5. Based on the above facts we can conclude that ecotones with a higher number of taxa of epigeic arthropod and individuals are important for increasing biomass, which affects crop yields. They are also important for nutrient cycling, pest control and maintenance of soil structure. Epigeic arthropods represent a living component of the soil ecosystem, which reacts very sensitively to changes in environmental conditions. As a result of the disturbance of their habitats by anthropogenic activity, the abundance decreases, as well as the overall diversity and equitability of the community.

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