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RESEARCH

Changes in the community structure of epigeic arthropods in the conditions of ecological farming of pea (*Pisum sativum* L.)

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ABSTRACT

At present, when climate change has a negative effect on crop yield, good agricultural practices have a high importance via their direct influence on soil properties and biodiversity. The aim of this research was to assess the influence of ecotones and environmental variables (soil pH, soil moisture, K, P, N and soil temperature) on the abundance of epigeic arthropods. Between the years 2018 to 2021, we collected 4008 individuals belonging to 11 taxonomic groups in the conditions of ecological farming of pea (*Pisum sativum* L.) crop in the south-western part of Slovakia using the pitfall trap method. We observed a decrease in the average number of individuals in the direction of pitfall traps 1 (ecotone) to 5 (barley crop) in April ($p = 0.0127$), May ($p = 0.0452$) and July ($p = 0.0287$). The dispersion of epigeic arthropods was affected by soil pH ($p = 0.0142$), P ($p = 0.0465$), K ($p = 0.0385$), N ($p = 0.0366$) and soil temperature ($p = 0.0166$). In the beetle model group, which was represented by the highest number of individuals, we confirmed an increasing number of individuals with increasing values of K ($r = 0.712$), P ($r = 0.654$), N ($r = 0.699$) and soil temperature ($r = 0.681$). Our results suggest that agricultural intensification affects epigeic arthropods in pea crop. Biodiversity and soil structure stability is important for the production of biomass and also affects crop yields.

Key words: Agrosystems, central Europe, crop, epigeic groups, soil management.

INTRODUCTION

Ecological farming represents a modern system of management which is receiving more attention all over the world. At present, the interest in ecological farming is constantly increasing and more and more countries around the world are paying attention to it. Throughout the world, 43.1 million hectares of agricultural land is managed using ecological farming. In comparison with conventional methods of farming, ecological farming has more positive effects on the protection of natural features and landscapes. Also, the biodiversity of flora and fauna is greater in areas of arable land, permanent grassland and surrounding habitats. Land cultivated under the ecological farming system is characterized by higher microbial activity, higher organic matter content and there is not risk of contamination of water resources by pesticides. This system involves a combination of procedures preserving elements of environment, a high level of biodiversity and production of natural substances and processes (Ubreziová et al., 2012; Wollni and Andersson, 2014; Faly et al., 2017). Organic farms (Donia et al., 2017) argue that organic farming is important from an economic point of view, sustainable development and environmental protection.

The soil is a complex and important system of the environment. Many different processes between organic and inorganic phases occur in the soil. Epigeic and soil biodiversity, representing the variety of living organisms, is an important soil health indicator. It plays an irreplaceable role in the decomposition of organic matter, in the cycle of biogenic elements such as C, N, S and P, and in the transformation and degradation of waste and toxic substances. In general, it directly influences the soil fertility, its main property (Fazekasová and Bobuľovská, 2012; Zazharskyi et al., 2019; Langraf et al., 2021a). Biodiversity contributes to enhanced stability and productivity of ecosystems; the greater it is in the soil, the higher the soil fertility (Wall et al., 2015; Langraf et al., 2021b). The amount and diversity of animal species is declining significantly. This is as a result of a number of causes such as intensification of agricultural production, use of pesticides, ploughing field boundaries and the cultivation of monocultures over large areas. Conventional intensive farming practices have led to a significant decline in the biological diversity of soils. This is caused by the use of fertilizers and pesticides. An excess of N fertilizers induces a decrease in plant metabolites; thus, the stability of soil aggregates decreases together with the elimination of soil metabolites. Pesticides have a negative effect on epigeic fauna, many biochemical reactions in this environment are dependent on the presence of soil enzymes (Briones and Schmidt, 2017; Porhajasová et al., 2018; Kozak et al., 2020; González-Miranda et al., 2021).

Presently, humankind has come to the conclusion concerning preservation of nature, originated environmental movements at political, societal and at global level. In regards to soil, a new biodiversity initiative has begun, which will update the current strategy to address soil degradation and preserve land resources aiming to achieve land degradation neutrality (Factsheet, 2020).

The objective of this study was to track the community structure of epigeic arthropods under ecological farming conditions in a *Pisum sativum* L. crop and ecotone. It was also intended to discover the influence of environmental variables (soil humidity, soil pH, soil temperature and levels of K, P and N) on epigeic arthropods.

MATERIALS AND METHODS

Research took place between 2018 and 2021, and the epigeic arthropods were collected from an agricultural pea (*Pisum sativum* L.) crop (Figure 1). The study area was located in the Podunajská pahorkatina, the Danubian upland geomorphological unit (in the south-western part of Slovakia) in the cadastral territory of Nitra. The altitude of the monitored area was approximately 130 m a.s.l. with a brown soil type. The weather of the study area is considered warm arid with mild winters. The mean monthly temperature ranges were: January -5-5 °C, February -3-6 °C, March 0-12 °C, April 10-20 °C, May 15-22 °C, June 18-27 °C, July 22-29 °C, August 20-29 °C, September 15-23 °C, October 8-15 °C, November -3-7 °C, December -5-5 °C. The average precipitation for each month was: January 30 mm, February 26 mm, March 35 mm, April 12 mm, May 65 mm, June 77 mm, July 41 mm, August 57 mm, September 64 mm, October 54 mm, November 40 mm and December 55 mm.

Figure 1. ***Pisum sativum*** **crop in the conditions of ecological farming.**

Arthropods were collected from November to July, every year from 2018 to 2021 in fields sown with pea. Five pitfall traps (750 mL) were used at each site, which were placed in a line at distances of 10 m. The placement of the pitfall traps varied; the first pitfall traps were located in the ecotones (meadow type), and the other traps inside the fields. Ecotone-placed traps were always at the edge of the fields, the average width of the ecotones was 15 m. A formaldehyde solution (4%) for material fixation during regular collections at 2 wk intervals was used. Pitfall traps were always in the fields and were collected at 2 wk intervals. The nomenclature of epigeic arthropods was established according to the work of Schierwater and DeSalle (2021).

Ecological tillage was based on annual tillage plowing, incorporating crop residues and weeds into the soil. The soil was ploughed three times and turned. Pre-sowing preparation and sowing were combined. Machines with driven working tools were used in conjunction with a seed drill. When sowing, it was possible to use seed coulters with an obtuse angle of penetration into the soil.

At each pitfall trap location, stones and fallen leaves from crops were removed and the soil sampled to a 15 cm depth for analysis. Five samples (one from each of the five sites) were taken from each field every 2 wk over the 3 yr of the study period. Subsequently, environmental variables (N, P, K, pH and moisture) were analyzed using a soil moisture meter (Rapitest digital 3-way analyzer; Luster Leaf, Woodstock, Illinois, USA) and a pH meter (Dexxer PH-03, Luboň, Poland). We thoroughly wetted the broken-up soil with water (ideally distilled or deionized water) until obtain a muddy consistency. We wiped the meter probe clean with a tissue or paper towel and inserted it into the soil up to the probe base (7-10 cm). We waited 1 min and wrote down the value. Measured values were converted into mg units. The average values of environmental variables of traps between the years 2018-2021 are shown in Table 1.

Database quality

The data obtained was saved in the Microsoft SQL Server 2017 database program (Express Edition) (Microsoft Corporation, Redmond, Washington, USA), consisting of frequency tables for collections and measured environmental variables (pH, soil moisture, K, P, N and soil temperature). The database also contained code tables for study sites and their variables (crops, habitat, locality name, cadastral area, altitude and coordinates of localities). Matrices for statistical calculations using Microsoft SQL Server Management Studio (Microsoft Corporation) were programmed.

Statistical analyses

Multivariate analysis (redundancy analysis, RDA) was employed to determine the dependencies between objects (abundance of epigeic arthropods, soil characteristics). The number of individuals of each crop in pitfall traps 1-5 was used as a matrix. We tested the statistical significance of soil pH, soil moisture, and levels of K, P, N and soil temperature (°C) using the Monte Carlo permutation test (iterations = 499) in the Canoco 5 program (Ter Braak and Smilauer, 2012).

Analysis in the statistical program R. 6.3.6 (2020, R Foundation for Statistical Computing, Vienna, Austria) focused on linear regression, establish the relationship between the number of beetles and the values of K, P, N, pH, soil moisture and temperature of soil. Shapiro-Wilk W-test determined the normality of data distribution. Based on the normality data distribution ($p = 0.001$), we used the nonparametric Kruskal-Wallis test to test the number of individuals between pitfall traps during the months.

Table 1. Physical parameters of huanglongbing infected samples of two citrus varieties.

	Pitfall traps				
Environmental variables	1	2	3	4	5
pH	7.05	6.83	6.90	6.92	6.88
Moisture, %	28.75	35.00	32.00	28.00	29.33
Potassium, mg kg^{-1}	19.99	23.75	18.33	19.33	23.66
Phosphorus, mg kg^{-1}	1.53	1.79	1.41	1.49	1.81
Nitrogen, mg kg^{-1}	19.99	23.75	18.33	19.33	23.66
Soil temperature, °C	29.07	27.36	27.59	27.03	25.92

RESULTS

Over the 4 yr research period, we found a total of 4008 individuals belonging to 11 taxonomic groups in the studied area. Taxa of Coleoptera (65.84%) had an eudominant representation of individuals. Julida (9.76%) and Araneae (8.16%) were the dominant groups of individuals in crops. Other groups of epigeic arthropods had subdominant to subrecendent representation. A greater diversity was captured at the edge of the field (Pitfall traps 1), which fed in the ecotone. There was a decrease in diversity towards the inside of the field (Table 2).

Multivariate analysis of arthropod abundance over the study period was conducted using redundancy analysis (RDA, SD (length of gradient) = 1.40 on the first ordination axis). We observed relationships between the abundance of epigeic arthropods and environmental variables (soil pH, soil moisture, K, P, N content, and soil temperature). The values of the explained variability in taxonomic data were 54.9% on the first ordination axis and 82.8% on the second cumulative ordination axis. The variability of the set of species explained by environment variables was on the first ordination axis 75% and on the second cumulative axis 94.5%. Using the Monte Carlo permutation test, we identified significant effects of soil pH ($p = 0.0142$, $F(1.6283) = 1.8397$, df = 4), temperature ($p = 0.0166$, $F(1.511) = 1.689$, df = 4), P ($p = 0.0465$, $F(2.1232) = 2.5885$, df = 4), K ($p = 0.0385$, $F(1.3286) = 1.9531$, df = 4), and N ($p = 0.0366$, $F(2.0058) = 2.4961$, df = 4) on the structure of arthropod distribution. We confirmed an insignificant influence of soil moisture ($p = 0.464$, $F(2.4376) = 1.7541$, df = 4). The selected variables were not mutually correlated with the maximum value of the inflation factor = 2.3418 (Figure 2).

The ordination graph (triplot) had an arthropod predominance ordered around pitfall traps one, located in the ecotone. The number of taxa of Arthropoda decreased in the pitfall traps located inside of the field (2-5). Environmental variables and soil temperature correlated with the prevalence of Dermaptera, Haplotaxida, Julida, Diptera, Hymenoptera, Araneae, Isopoda, and Coleoptera. The pH correlated with the prevalence of Opilionida, Orthoptera, Lithobiomorpha. Environmental variables of moisture, K, P and N affected the structure of all taxa.

We confirmed a significant difference in the number of individuals among pitfall traps 1-5 in April ($p = 0.0127$, $F(4.2) = 3.1577$, df = 4) (Figure 3), May ($p = 0.0452$, $F(8.7851) = 8.4911$, df = 4) (Figure 4), and July ($p = 0.0287$, $F(6.0012) = 5.0649$, df = 4) (Figure 5). An insignificant difference was observed in the number of individuals among pitfall traps 1-5 in June ($p = 0.2917$, $F(4.47) = 4.9573$, df = 4) (Figure 6). The results showed a greater number of individuals in pitfall traps 1 (located in the ecotones) than in pitfall traps 2, 3, 4, 5 (located in the fields) during April, May and July. In June there was no such difference observed.

For further data processing, we chose the eudominantly represented (65.84%), model bioindication taxon Coleoptera. The number of individual beetles was processed using linear regression. Using the regression model, we expressed the relationship (correlation) between the number of individuals of the Coleoptera in the fields of *P. sativum* crops and environmental variables (K, P, N, pH, humidity and soil temperature). The overall suitability of the regression model is significant in following cases: K ($p = 0.036$), P ($p = 0.025$), N ($p = 0.034$), and soil temperature ($p = 0.010$). In the case of pH ($p = 0.081$) and moisture ($p = 0.588$), the model was insignificant, so we excluded them from the following analysis.

Table 2. Distribution of arthropods in the *Pisum sativum* crop between 2018-2021.

	Pitfall traps										∑	
Arthropods	1	%	2	%	3	%	4	%	5	%	Individuals	%
Araneae	62	4.90	91	13.28	69	8.40	38	6.92	67	9.75	327	8.16
Opilionidea	2	0.16	5	0.73	14	1.71	9	1.64	9	1.31	39	0.97
Isopoda	50	3.95	25	3.65	27	3.29	38	6.92	31	4.51	171	4.27
Julida	103	8.14	106	15.47	68	8.28	77	14.03	37	5.39	391	9.76
Lithobiomorpha	20	1.58	1	0.15	10	1.22	14	2.55	34	4.95	79	1.97
Coleoptera	952	75.20	363	52.99	563	68.57	327	59.56	434	63.17	2639	65.84
Dermaptera	12	0.95	15	2.19	13	1.58	1	0.18	14	2.04	55	1.37
Diptera	16	1.26	12	1.75	5	0.61	9	1.64	12	1.75	54	1.35
Hymenoptera	17	1.34	55	8.03	29	3.53	20	3.64	36	5.24	157	3.92
Orthoptera	23	1.82	3	0.44	22	2.68	10	1.82	5	0.73	63	1.57
Haplotaxida	9	0.71	9	1.31	1	0.12	6	1.09	8	1.16	33	0.82
∑ Individuals	1266	100	685	100	821	100	549	100	687	100	4008	100

Figure 2. Redundancy analysis (RDA) of arthropods with respect to environmental variables.

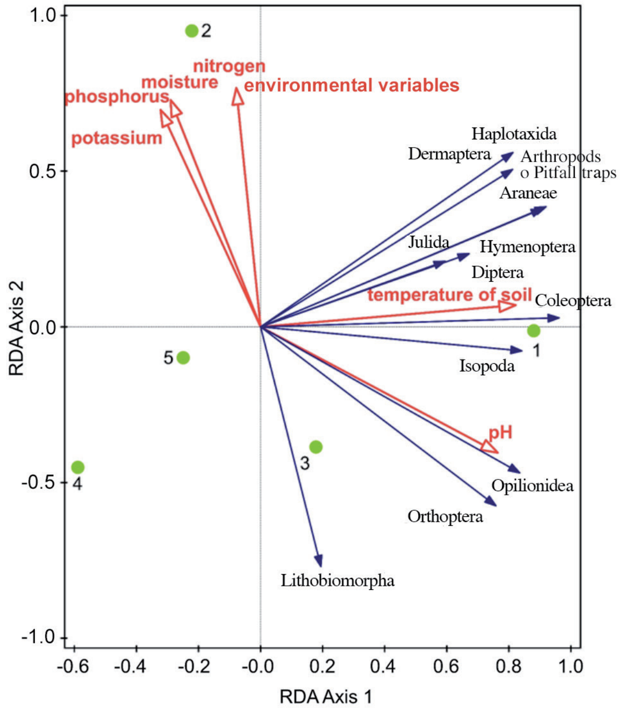
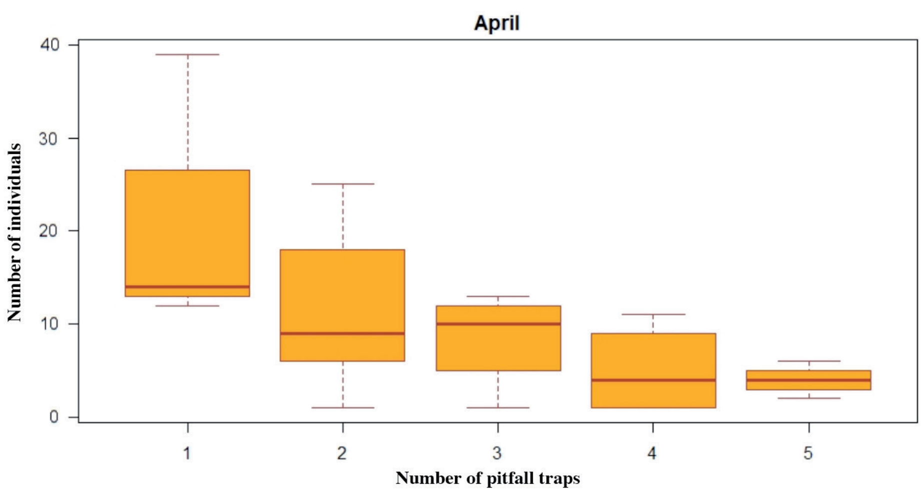


Figure 3. Numbers of individuals in pitfall traps located in the ecotones (traps 1) and in the field (traps 1, 3, 4, 5) in April.



The correlation coefficient value was high for the number of individuals and K (r = 0.712) (Figure 7), P (r = 0.654) (Figure 8), N (r = 0.699) (Figure 9), soil temperature (r = 0.681) (Figure 10), which indicated a strong relationship. The reliability coefficient for K (r^2 = 0.791) indicated the capture of 79% variability, P (r^2 = 0.812) 81% variability, N (r^2 = 0.784) 78% variability, soil temperature (r^2 = 0.891) 89% variability. The results showed that increasing values of K, P, N and soil temperature, also increased the number of Coleoptera individuals. The ideal value for Coleoptera was 15-40 mg kg^{-1} K, 1.5-3.0 mg kg^{-1} P, 15-40 mg kg^{-1} N, 1.5-3.0 mg kg^{-1} P, and of soil temperature 27-35 °C.

Figure 4. Numbers of individuals in pitfall traps located in the ecotones (traps 1) and in the field (traps 1, 3, 4, 5) in May.

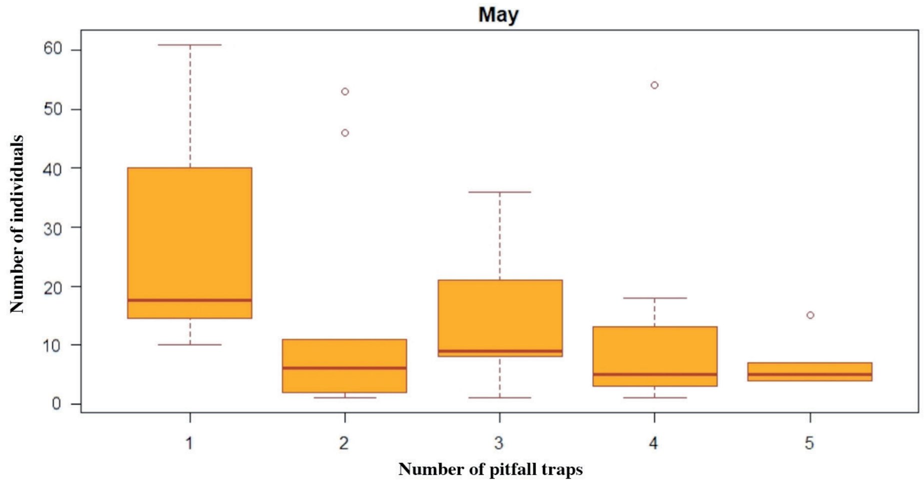


Figure 5. Numbers of individuals in pitfall traps located in the ecotones (traps 1) and in the field (traps 1, 3, 4, 5) in July.

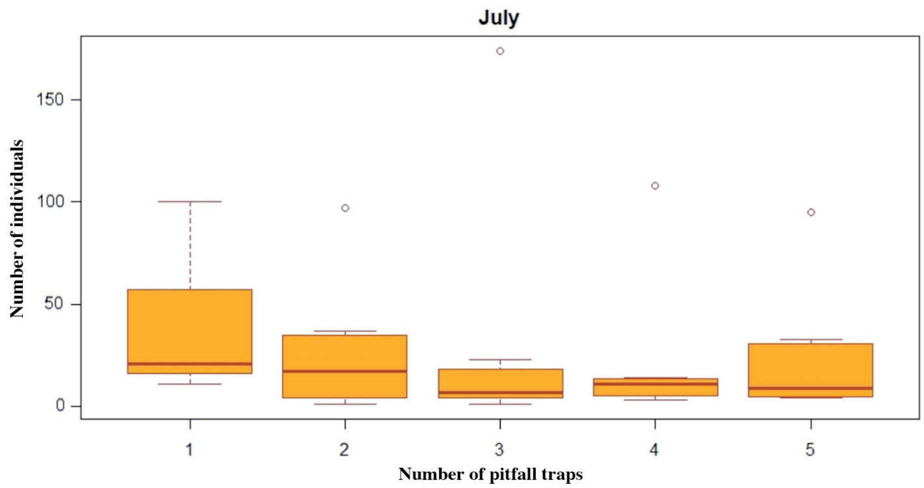


Figure 6. Numbers of individuals in pitfall traps located in the ecotones (traps 1) and in the field (traps 1, 3, 4, 5) in June.

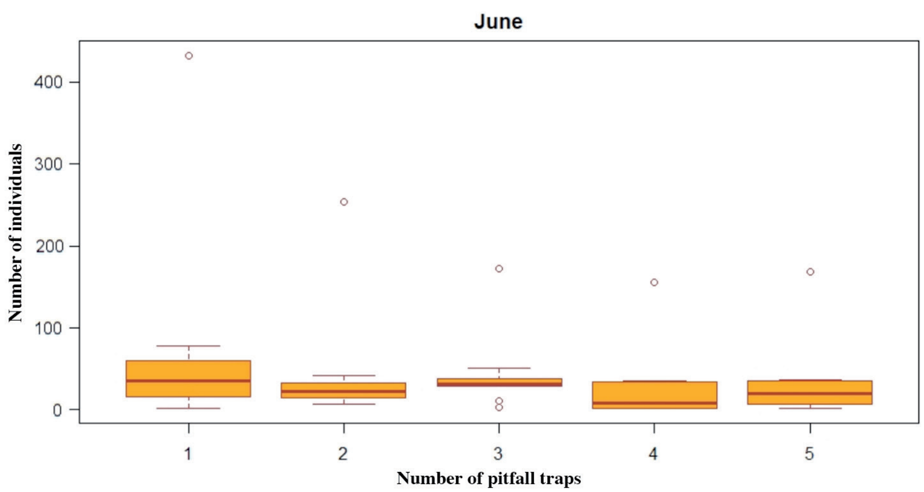


Figure 7. Linear regression model of K and number of individuals of Coleoptera.

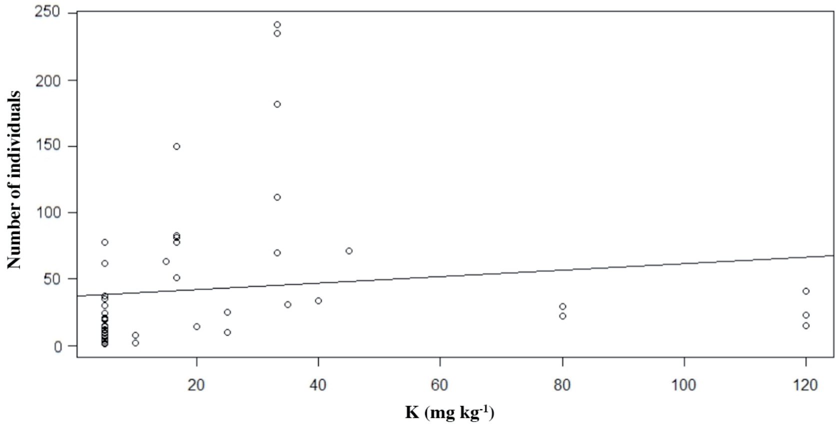


Figure 8. Linear regression model of P and number of individuals of Coleoptera.

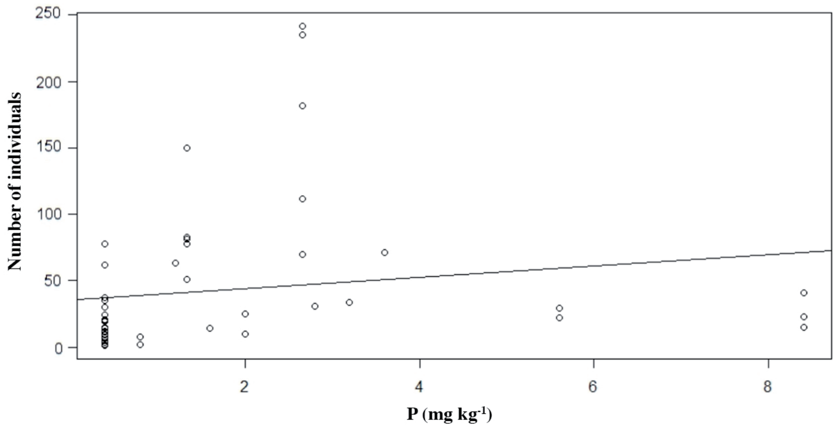


Figure 9. Linear regression model of N and number of individuals of Coleoptera.

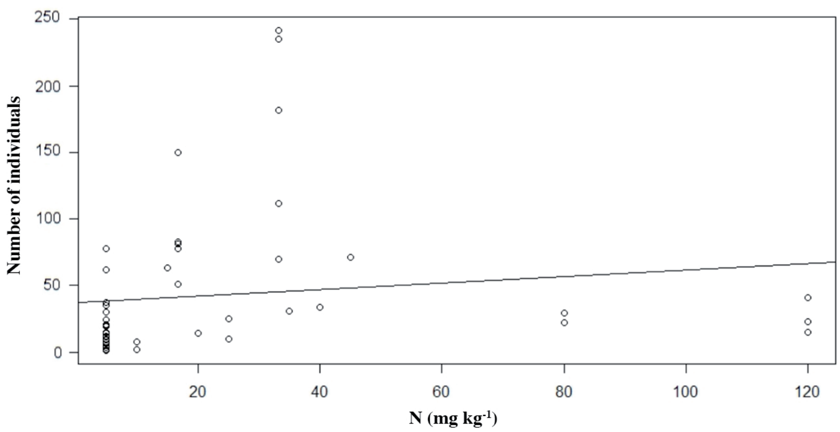
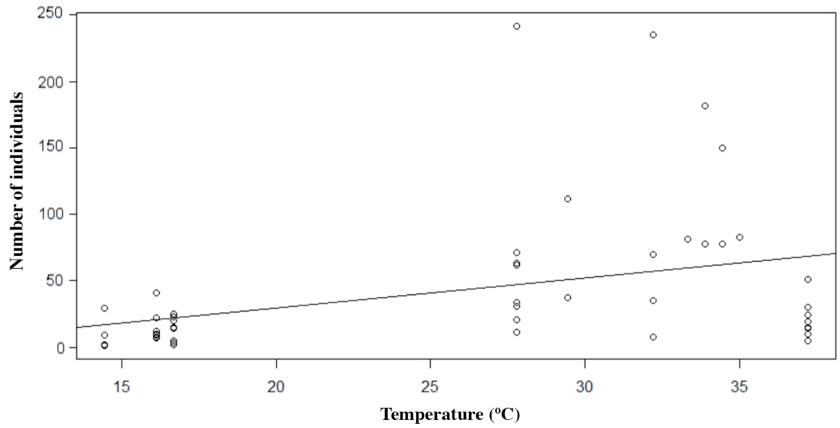


Figure 10. Linear regression model of soil temperature and number of individuals of Coleoptera.



DISCUSSION

The transition from a conventional to ecological management cropping systems is not easy, and may take 2 or 3 yr, possibly even more. The transition period is associated with a decline in sales and costs, as the consumption of fertilizers and chemical protective equipment decreases (Kubicová et al., 2014). Epigeic arthropods living in agricultural landscapes have a wider tolerance than the epigeic arthropods of natural habitats. They achieve high local density due to the influence of agriculture, and field margins support the most diverse and abundant community of epigeic arthropods (Porhajasová et al., 2015; Magura et al., 2020). We recorded that the arthropod community was dominated by Coleoptera, Julida and Araneae. The great abundance of these groups influenced the maintenance of the natural balance and substance cycle of the biogenic elements in ecosystems such as C, N, S and P. The dominance of Coleoptera has been indicated as a general trait of ground-dwelling assemblages, their activities accelerated the decomposition of plant residues, aerated the soil and improved soil structure and quality. The presence of other epigeic arthropods was heterogeneous and depended upon the management regime and the surrounding vegetation (Curell et al., 2012; Bazok et al., 2015). Schuster et al. (2019) discovered soil disturbance during manure injection may mitigate the impacts on arthropod populations and may cause reductions in arthropod abundance.

The structure, scale, use and management of land affect the composition of fields, which may be a source of weeds, pests, and disease. Also, plant diversity is an important factor for the diversity of epigeic organism where ecotones may be of great importance in providing habitats for beneficial species for agriculture (Haddaway et al., 2016). Using the multivariate model (RDA analysis), we demonstrated the influence of ecotone on the abundance of epigeic arthropods and positive influence of environmental variables. Thus, our results agreed with Pérez-Bote and Romero (2012), who observed a decline in arthropods with increasing land use. In conditions of complex land use, ecotones are numerous, whilst fewer ecotones are available in less complex systems. As a result, coexistence through resource allocation in simplified systems is likely to be limited, resulting in a reduction in species richness (Baranová et al., 2015). More data on the impact of introduced margin strips on different taxa is required. The beneficial effects of botanical diversity, particularly wild flowers, has an effect on invertebrate diversity (Diehl et al., 2012; 2013). Arthropod abundance from month to month is interpreted as being related to fluctuations in climatic factors (such as temperature, precipitation and day length) (Liu et al., 2015). The number of arthropods captured in May, April and July was distinct from the number of arthropods captured in June, in the direction of the pitfall traps 1 (ecotone) to 5 (located in the field). The trend of decreasing numbers of individual arthropods at the center of the field did not apply in June when the ecotone rule did not manifest itself. Differences in the number of arthropods throughout the months were affected by different weather during the seasons and months (Simao et al., 2015). Majeed et al. (2020) found a seasonal trend in the abundance of arthropod groups.

Bohác and Jahnová (2015) found that Coleoptera is a dominant group of soil macrofauna, which react sensitively to human activity. The Carabidae family is most often used as a bioindicative family of the order Coleoptera; they are sensitive to insecticides, pesticides, pH, soil moisture, P, K, N, and the excessive use of artificial fertilizers. In our results using the linear regression model, we observed a high correlation between Coleoptera and N, K, P and soil temperature. Another factor influencing the order Coleoptera is vegetation structure in connection with various human interventions, while their effects are stronger in agriculturally used ecosystems (Tiemann et al., 2015; Vician et al., 2015; 2018).

CONCLUSIONS

Our results provided new knowledge regarding the preference of epigeic arthropods in conditions of ecological farming of the *Pisum sativum* crop. We confirmed a decrease in the number of individuals in pitfall traps located further from the ecotone during the months of April, May and July. Interestingly, this trend did not apply in June, which did not confirm the ecotone rule (that the highest diversity is found in ecotone). Based on these facts, our results have provided new information regarding the ecotone rule. The dispersion of epigeic arthropods was also positively influenced by soil pH, soil temperature, and levels of P, K, and N. The Coleoptera model group had a strong correlation with P (mg kg^{-1}), K (mg kg^{-1}), N (mg kg^{-1}) and soil temperature (°C). With increasing values of K, P, N and soil temperature, the number of individuals also increased. Epigeic arthropods are an important part of the ecosystem for processes such as nutrient cycling, pest control, and maintenance of soil structure. Good agricultural practices contribute to the increase of soil biodiversity. A combination of soil structure and soil biodiversity can be used as an indicator when evaluating the sustainability of soil use, influence of cultivation practices on fertile soil and crop yield.

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