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Changes in the dispersion of epigeic groups of animals in different types of agricultural crops

Zmeny disperzie epigeických skupín živočíchov v rôznych typoch poľnohospodárskych plodín

Vladimír LANGRAF[1] (✉), Kornélia PETROVIČOVÁ[2], Stanislav DAVID[3], Zuzana KRUMPÁLOVÁ[3], Janka SCHLARMANNOVÁ[1], Nikol HREUSOVÁ[1], Veronika KLIMENTOVÁ[1], Patrícia KURICOVÁ[1], Martin URBAN[1], Hana ŠATAROVÁ[1]

[1] Department of Zoology and Anthropology, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 949 01 Nitra, Slovak Republic

[2] Department of Environment and Biology, Faculty of Agrobiology and Food Resources, University of Agriculture in Nitra, Tr. A. Hlinku 2 Nitra, Slovac Republic

[3] Department of Ecology and Environmental Sciences, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 949 01 Nitra, Slovak Republic

✉ Corresponding author: langrafvladimir@gmail.com

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ABSTRACT

In the country, agricultural land is an irreplaceable resource for the production of food and raw materials. Changes in the structure of epigeic groups reflect changes in the ecological status of habitats and response to the environmental pressure that affects them (e.g., intensification of cultivation, impact of herbicides and pesticides, agrotechnics, large-scale and monoculture areas). The aim of this research is to assess the influence of seven different agricultural crops (*Pisum sativum*, *Triticum aestivum*, *T. spelta*, *Hordeum vulgare*, *Zea mays*, *Brassica napus*, grass mixture) and environmental variables (pH soil, soil moisture, light conditions, soil fertility) on the dispersion of epigeic groups. Between 2018 and 2020, 40,194 individuals belonging to 22 taxonomic groups collected by pitfall traps were recorded in the observed crops. Our results provide new information on the preference of epigeic groups for some agricultural crops such as the grass mixture (P=0.0096), *Hordeum vulgare* (P=0.0166), *Zea mays* (P=0.025), and *Pisum sativum* (P=0.045). The dispersion was also affected by soil fertility (P=0.032), soil humidity (P=0.012), light (P=0.042) and pH soil (P=0.046). In the beetles model group with the highest number of individuals, the trend of increasing number of individuals with increasing values of potassium (r = 0.631), phosphorus (r = 0.566), nitrogen (r = 0.641), soil moisture (r = 0.572), and light (r = 0.9962) using a regression model was recorded. The neutral pH of the soil (r = 0.6212) was optimal for beetle coenoses.

Keywords: epigeic groups, agriculture, crops, spatial modelling, Slovak Republic

ABSTRAKT

Poľnohospodárska pôda predstavuje v krajine nenahraditeľný zdroj, umožňujúci produkciu potravín a surovín. Zmeny v štruktúre epigeických skupín odzrkadľuju zmeny ekologického stavu biotopov a sú odozvou environmentálneho tlaku, ktorý ich ovplyvňuje (napr. intenzifikácia obrábania, vplyv herbicídov a pesticídov, agrotechnika, veľkoplošné a monokultúrne plochy). Cieľom výskumu je posúdiť vplyv siedmich poľnohospodárskych plodín (*Pisum sativum*, *Triticum aestivum*, *Triticum spelta*, *Hordeum vulgare*, *Zea mays*, *Brassica napus*, *Grass mixture*) a environmentálnych premenných (pH pôdy, pôdna vlhkosť, sveteľné podmienky, úrodnosť pôdy) na disperziu epigeických skupín. V priebehu rokov 2018

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- 2020 sme získali a odchytili pomocou zemných pascí 40 194 jedincov patriacich do 22 taxonomických skupín. Naše výsledky priniesli nové informácie o preferencii epigeických skupín na určité poľnohospodárske plodiny, akými sú *Grass mixture* (P=0.0096), *Hordeum vulgare* (P=0.0166), *Zea mays* (P=0.025), *Pisum sativum* (P=0.045). Na disperziu vplývali aj úrodnosť pôdy (P=0.032), vlhkosť pôdy (P=0.012), svetelné podmienky (P=0.042) a pH pôdy (P=0.046). Modelovú skupinu Coleoptera, ktorá bola zastúpená najvyšším počtom jedincov, sme použili pri regresnom modeli. Potvrdili sme silný vzťah a trend rastu počtu jedincov so stúpajúcimi hodnotami draslíka (r = 0.631), fosforu (r = 0.556), dusíka (r = 0.641), vlhkosti (r = 0.572) a svetla (r = 0.9962). Pre cenózy chrobákov bolo optimálne neutrálne pH pôdy (r = 0.6212).

Kľúčové slová: epigeické skupiny, poľnohospodárstvo, plodiny, priestorové modelovanie, Slovenská republika

INTRODUCTION

Soil biodiversity is a part of biological resources in agro-ecosystems, which is considered in soil management, crop rotation, input of organic matter (Porhajášová et al., 2019a). Soil edaphon is an indicator of the load on the soil environment and acts as a bio-indicator of the environment (Petřvalský et al., 2007). Soil communities play an important role in the decomposition of organic matter in the biogeochemical cycle of biogenic elements, i.e. carbon (C), nitrogen (N), sulphur (S), and phosphorus (P). Therefore, they are also important for the sustainability of the soil ecosystem in the transformation, degradation of waste, and toxic substances. The response of soil organisms is a key part of the sustainability of the soil ecosystem (Fazekašová and Bobuľovská, 2012).

Agricultural lands disrupt the course of natural processes and have poorer biodiversity compared to natural ecosystems (Tiemann et al., 2015; Vician et al., 2011, 2018). In addition to natural factors, field ecosystems are also affected by other significant anthropogenic interventions and influences, such as the type of cultivated crop and the structure of its vegetation, introduction of organic and inorganic substances into the soil, disturbance (agro-technique, water and wind erosion), land consolidation and subsequent fragmentation of suitable habitats. Indirect factors include the general degradation of the environment and the consequences of global climate changes. All these interventions cause a reduction in the abundance of edaphon animals and changes in the structure of communities (Baranová et al., 2013; Boháč 2013).

Managed agroecosystems with unvaried crop rotation have low species diversity and abundance, as the prevailing species are ecologically tolerant. Conversely, crop rotation management leads to increased species density and abundance (Brussard et al., 2007). Sustainable farming systems should be biologically and ecologically balanced, economically efficient and technically manageable (Bavec and Bavec, 2014). In addition to breeding and genetic modification of crops, increasing crop production is currently associated with the application of inorganic and organic fertilizers and pesticides in agro ecosystems, which affects the presence or absence of fauna (Černý et al., 2019). Zimmerer (2010) emphasized the need to anticipate the interactions of biodiversity, the complexity of agro-ecosystems and global changes resulting from the acceleration and integration of land use. In the context of climate changes, processes affecting agricultural production can be expected. Traditional farming can help intensify the farming systems to withstand climatic extremes more easily (Altieri et al., 2015). Biodiversity loss has become a global problem, as the reduction of soil biodiversity negatively affects the overall productivity of agro-ecosystems. Therefore, it is necessary to pay attention to the decline of soil biodiversity and soil communities (Yadav et al., 2013; Wagg et al., 2014).

The *Coleopterans* (especially the *Carabidae* family) are important bio-indicators of the environment. Among the important factors determining the presence of beetles belong the application of insecticides, pesticides, presence of toxic substances, changes in pH, soil moisture, trophic supply, vegetation structure in connection with various human interventions, while their effects change not only in natural but also in agriculturally used ecosystems dependent on additional energy (Langraf et al., 2020a, 2020b; Varvara, 2010; Vician et al., 2015). They are also important in the transformation of organic substances (Teofilova, 2021). Sustainable agriculture creates much more suitable conditions for beetles (mainly from family *Carabidae*) than intensive ones (Fazekašová et al., 2013).

The main goal of this research was to identify similarities or differences in groups of epigeic groups animals from seven crops in agro coenoses. We have established the following working hypotheses: i) especially soil humidity, light conditions, and soil pH affect the dispersion of epigeic animal groups; ii) with increasing values of inorganic substances in the soil (potassium, phosphorus, nitrogen) also increase the numbers of Coleoptera; iii) neutral pH of the soil is optimal for beetles.

MATERIALS AND METHODS

The research took place in the years 2018-2020 and we collected epigeic groups in seven types of agricultural crops. In the winter crops (*Brassica napus*, *Pisum sativum*, *Triticum aestivum*, *T. spelta*), invertebrates were collected from November to July. In spring-planted crops (*Hordeum vulgare*, *Zea mays*), epigeic groups were trapped from April to October. In the grass mixture, epigeic groups were collected year-round. We used 10 pitfall traps (750 ml) for each site, which were placed in a line at a distance of 10 meters. A 4% formaldehyde solution was used as a fixative. We collected material regularly at two-week intervals. The nomenclature of epigeic groups was established according to the work of Majzlan (2009) and Pokorný and Šifner (2004). The study areas were located in the geomorphological unit Podunajská pahorkatina – Danubian upland (the south-western part of Slovakia) in the cadastral territory of Nitra (Figure 1). The altitude of the monitored area was approximately 130 m a.s.l. The insecticide FORCE was applied to the crops.

Figure 1. Map of the study area

Database quality

The obtained data have been saved in Microsoft SQL Server 2017 database program (Express Edition), consisting of frequency tables for collections, measured environmental variables (pH, humidity, light conditions). The database also contained of code tables for study sites and their variables (habitat, locality name, cadastral area, altitude, coordinates of localities). Matrices for statistical calculations using Microsoft SQL Server Management (SSMS, 2017) were programmed.

Statistical analyses

Multivariate analysis (redundancy analysis – RDA) to determine the dependencies between objects (epigeic groups, agricultural crops, and soil characteristics) was used. We tested the statistical significance of agricultural crops, soil pH, soil humidity, light conditions, and soil fertility (that is expressed by a coefficient from the measured values of potassium, phosphorus, nitrogen) with the Monte Carlo permutation test in the CANOCO5 program (Ter Brak and Šmilauer, 2012).

Analysis in the statistical program Statistica Cz. Ver. 7.0 (StatSoft, Inc., 2004) was focused on polynomial regression, expressing the relationship between the number of beetles and the values of potassium, phosphorus, nitrogen, pH, soil moisture and light conditions.

RESULTS AND DISCUSSION

During three years of research, we collected a total of 40,194 individuals belonging to 22 taxonomic groups in the studied fields. Taxa of *Coleoptera* (45.3%), *Collembola* (19%) and *Diplopoda* (12.4%) had a eudominant representation of individuals. *Araneae* (6.3%) represented the dominant group, other groups had subdominant to subrecendent representation (Table 1). The high abundance of these groups influences the maintenance of the natural balance and substance cycle of the biogenic elements carbon, nitrogen, sulfur, phosphorus, in ecosystems. The dominance of *Hymenoptera* (*Formicidae*) and *Coleoptera* has been indicated as a general trait of ground dwelling assemblages (Doblas-Miranda et al., 2007). The eudominant representation of the *Coleoptera* among epigeic groups in the conditions of integrated farming and ecological farming on crops was also recorded by Porhajašová et al. (2015) or Porhajašová et al. (2019 a, b) for *Pisum sativum*, *Hordeum vulgare*, *H. sativum*, *Triticum*

Table 1. Distribution of the epigeic groups in the agricultural crops during the years 2018-2020

epigeic groups	*Hordeum vulgare*	*Pisum sativum*	*Triticum spelta*	*Grass mixture*	*Zea mays*	*Triticum aestivum*	*Brassica napus*	∑ ind.
Stylommatophora	0	0	0	1	0	0	0	1
Haplotaxida	1	0	0	91	25	12	1	130
Acarina	180	0	0	534	0	0	0	714
Araneae	441	118	49	1699	106	16	95	2524
Opilionidea	30	0	0	57	122	0	0	209
Collembola	2199	0	0	5448	3	0	0	7650
Isopoda	7	43	44	209	639	2	5	949
Lithobiomorpha	20	0	0	87	103	0	4	214
Diplopoda	94	131	5	4441	60	238	0	4969
Julida	0	0	0	0	0	0	6	6
Coleoptera	3911	722	573	4050	7519	662	770	18207
Dermaptera	0	55	0	2	1	39	0	97
Diptera	706	2	0	742	180	64	19	1713
Hemiptera	93	0	0	212	0	0	3	308
Hymenoptera	993	46	7	396	75	25	36	1578
Lepidoptera	4	0	0	19	0	0	0	23
Orthoptera	51	39	9	414	129	76	55	773
Siphonaptera	0	0	0	7	0	0	0	7
Anura	1	0	0	0	0	0	0	1
Squamata	0	0	0	0	1	0	0	1
Insectivora	0	0	0	1	0	0	1	2
Rodentia	25	5	0	31	38	3	16	118
∑ individuals	8756	1161	687	18441	9001	1137	1011	40194

aestivum, *Vicia faba*, and *Medicago sativa*. Boháč and Jahnová (2015) found out that *Coleoptera* is a large and functionally dominant group of soil macrofauna, which sensitively reacts to human activity. The eudominant position of the *Coleoptera* order in agrocoenoses was confirmed by Lenoir and Lennartsson (2010).

Redundancy analysis (RDA, SD = 1.30 on the first ordination axis) has the values of the explained variability of taxonomic data were 62% on the first ordination axis and 72.8% on the second ordination axis. The cumulative variability of the species set explained by environment variables was represented in the first ordination axis 70.9% and in the 2nd axis 91.3%.

Using the Monte Carlo permutation test, we found a statistically significant effect of crops on the dispersion of epigeic groups: grass mixture (P=0.0096), *Hordeum vulgare* (P=0.0166), *Zea mays* (P=0.025), and *Pisum sativum* (P= 0.045). We did not find a statistically significant effect of crops on the dispersion of epigeic groups for Triticum aestivum (P=0.75), *Triticum spelta* (P=0.912), and *Brassica napus* (P=0.908). The selected variables were not mutually correlated with the maximum value of the inflation factor of 1.6114.

The ordination graph (biplot) contained epigeic groups ordered into three clusters (Figure 2). The first cluster (I) consisted of epigeic groups preferring conditions under rapeseed, common wheat, spelt wheat, green peas. The second cluster (II) is represented by taxa bound to the maize. The third cluster (III) included epigeic groups correlating with grass mixture and barley. Grass mixture offers epigeic communities similar conditions as meadow habitats. *Zea mays* and *Brassica napus* are taller crops and create shaded conditions for epigeic groups. *Triticum aestivum*, *Triticum spelta*, *Hordeum vulgare*, and *Pisum sativum* are crops that can withstand drier conditions and therefore are suitable for species with a higher drought tolerance.

Epigeic groups living in anthropogenically disturbed habitats had a wider ecological tolerance than epigeic species in natural habitats. They achieved the high local density in agricultural crops (Alberti et al., 2017; Magura et al., 2020). We recorded the highest abundance in taxa *Coleoptera*, *Collembola*, *Diplopoda*, and *Araneae* (eudominant, dominant), while other taxa had a lower number of individuals. Despite the low abundance of these groups, their importance in the ecosystem is irreplaceable. They contribute to the biodiversity of agricultural land but also to ecological stability. These epigeic groups are characterized by different adaptations to the soil environment and sensitivity to the stress (Swaminathan, 2014; Fazekašová and Bobuľovská, 2012). Litavský et al. (2018) confirmed that the presence of epigeic groups in different types of ecosystems is related to trophic preference. The increase of the *Acari* population is associated with the ending of agricultural measures (Gormsen et al., 2006). Krumpálová et al. (2020) found the impact of crops and micro-habitat conditions on the species diversity of soil mites in gardens, with the highest abundance, species diversity and species richness being confirmed in common bean growth. In our research, we also confirmed the low number of individuals in the *Acari* group (1.8%).

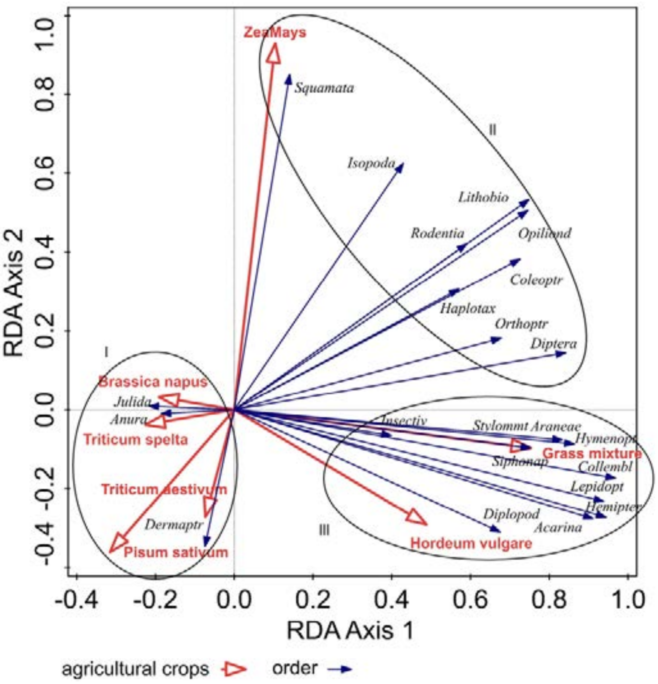

Figure 2. RDA analysis of epigeic groups of researched agricultural crops

Using the redundancy analysis (RDA, SD = 1.30 on the first ordination axis), we observed the relationship between epigeic groups and environmental variables (pH of the soil, soil moisture, light conditions, and soil fertility expressed by a coefficient from the measured values of potassium, phosphorus, nitrogen). The values of the explained variability of taxonomic data were 62% on the first ordination axis and 72.8% on the second ordination axis. The cumulative variability of the species set explained by environment variables is represented in the first ordination axis with 77.1% and in the second axis with 90%. Using the Monte Carlo permutation test, we identified a statistically significant effect of soil fertility (P=0.032), light conditions (P=0.042), soil moisture (P=0.012), and soil pH (P=0.046) on the dispersion of epigeic groups. The selected variables were not mutually correlated with the maximum value of the inflation factor of 3.7985.

The ordination graph (biplot) contained epigeic groups ordered into three clusters (Figure 3). The first cluster (I) consisted of epigeic groups correlated with light conditions and soil fertility. The second cluster (II) was represented by taxa with linking to soil pH. The third cluster (III) consisted of epigeic groups with a preference for a humidified environment.

Epigeic groups represented a diversified component of soil fauna, due to the large size of taxonomic groups and individual species with specific modifications and different sensitivity to stress, therefore they are useful in studying the disturbance and influence of the soil environment (e.g., Petřvalský et al., 2007). They contribute to the biodiversity of agrarian land, but also to ecological stability. The intensively used agrarian landscape provides a different spectrum of fauna, which represent a diversified component of the soil fauna. Epigeic groups are characterized by different adaptations to the soil environment and sensitivity to the stress. The abundance and biodiversity of these epigeic groups support the natural conditions of ecosystems. The abundance of epigeic fauna is also affected by the application of fertilizers and pesticides (Černý et al., 2019).

Collembola are found to be influenced by soil conditions and organic fertilizers, which affect their abundance (Jasinski et al., 2016). *Coleoptera* are sensitive to environmental factors such as pH, humidity, the presence of inorganic substances in the soil (potassium, phosphorus, nitrogen), so they are used as bio-indicators (Lövei and Sunderland, 1996). In our results, we noted the connection of springtails and beetles to soil fertility and light conditions.

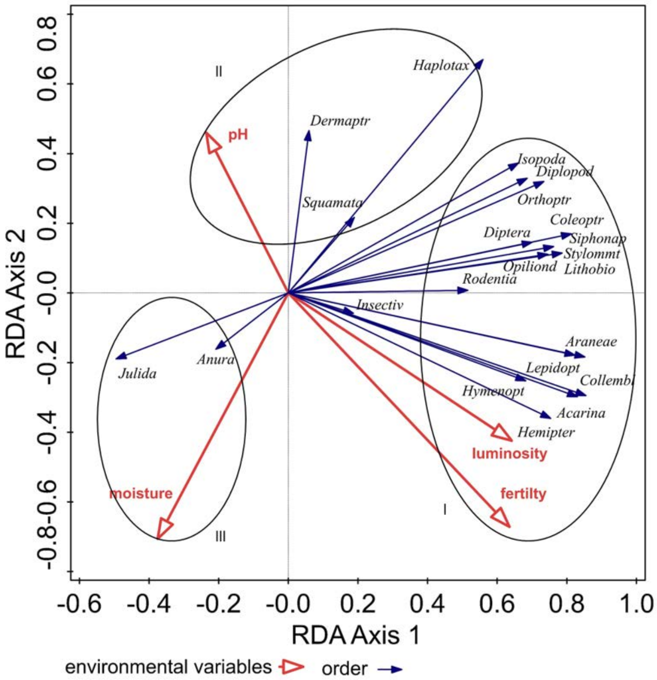

Figure 3. RDA analysis of epigeic groups with enviromental variables

Using the regression model, we expressed the relationship (correlation) between number of individuals of the *Coleoptera* and potassium, phosphorus, nitrogen, pH, humidity and luminosity. The correlation coefficient value was very high for the number of individuals and luminosity (r = 0.9962) (Figure 4, F), which indicated very strong relationship. A medium value was observed in the number of individuals and potassium (r = 0.631) (Figure 4, A), phosphorus (r = 0.566) (Figure 4, B), nitrogen (r = 0.641) (Figure 4, C), pH (r = 0.6212) (Figure 4, D), moisture (r = 0.572) (Figure 4, E), indicating a medium relationship. The reliability coefficient for the potassium r^2 = 0.7719 indicated the capture of 77% variability, phosphorus r^2 = 0.7656 (76% variability), nitrogen r^2 = 0.772 (77% variability), pH r^2 = 0.8054 (80% variability), moisture r^2 = 0.8191 (81% variability), luminosity r^2 = 0.8421 (84% variability). The overall suitability of the regression model was statistically significant in all cases: potassium (P=0.0006), phosphorus (P=0.0007), nitrogen (P=0.0006), pH (P=0.0471), moisture (P=0.00001), and luminosity (P=0.0151).

The results showed that the increasing values of potassium, phosphorus, nitrogen, soil humidity and light conditions reflected in increased number of *Coleoptera* individuals. The ideal values for *Coleoptera* are: 20-40 mg potassium, 1.5-3 mg phosphorus, 20-40 mg nitrogen, pH = 7, 2-3% for moisture, and 6,500-7,000 lx for light.

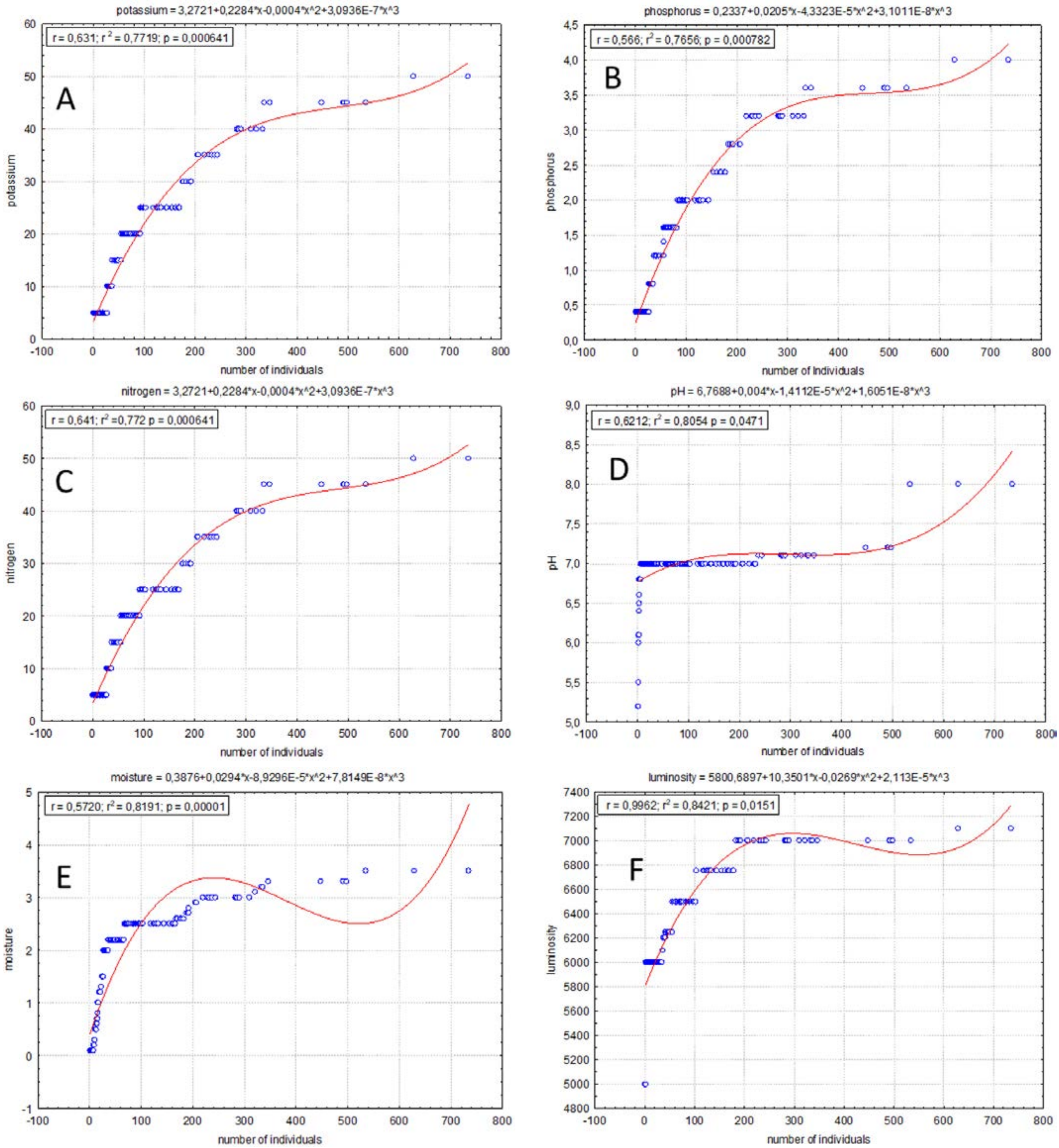

Figure 4. Polynomial regression model potassium, phosphorus, nitrogen, pH, moisture, luminosity on the number of individuals

Tiemann et al. (2015) and Vician et al. (2011, 2018) assumed the main factors affecting the diversity of ground beetle (*Carabidae*) communities are pH and soil moisture. We confirmed the same factors in our results. Moreover, insecticides and pesticides are other factors determining their occurrence. Other important factors influencing of the *Coleoptera* are vegetation structures in connection with various human interventions, while their effects change not only in natural but also in agriculturally used ecosystems (Varvara, 2010; Vician et al., 2015). In ecosystems, they are involved in maintaining the natural balance and material cycle of the biogenic elements carbon, nitrogen, sulfur, phosphorus, (Peterková, 2004; Teofilova, 2021). They have more suitable conditions in sustainable agriculture (Fazekašová et al., 2013).

CONCLUSIONS

We monitored the impact of seven agricultural crops on the occurrence of epigeic animal groups during between 2018 and 2020. We recorded 40,194 individuals belonging to 22 taxonomic groups. Our results contribute new knowledge about the preference of studied groups in agricultural crops (different shading of the soil, agro-techniques, fertilization, plant protection products). We confirmed the significant effect on epigeic animals on grass mixture (P=0.0096), *Hordeum vulgare* (P=0.0166), *Zea mays* (P=0.025), and *Pisum sativum* (P=0.045). The dispersion of epigeic groups was also influenced by fertility soil (P=0.032), soil humidity (P=0.012), light (P=0.042), and pH soil (P=0.046). The *Coleoptera* model group had a very strong correlation with light conditions (r = 0.9962). A moderately strong relationship was confirmed to the environmental variables potassium (r = 0.631), phosphorus (r = 0.566), pH (r = 0.6212), nitrogen (r = 0.641), and soil moisture (r = 0.572). The number of individuals also increased with increasing values of potassium, phosphorus, nitrogen, moisture, luminosity,. We confirmed that the optimal value of the soil pH was neutral. Consequently, it can be concluded that beetles, especially the family *Carabidae*, are suitable for bio-indicative assessment of the state of agro-ecosystems. Epigeic groups can be used for land and agricultural planning documents (e.g., the development of environmental systems) on which we will focus in our future research.

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