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RESEARCH ARTICLE

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Community structure of epigeic arthropods in barley (*Hordeum vulgare* L.) soils

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Abstract

Aim of study: The study of epigeic arthropods provides information on how ecosystems respond to different management practices. Changes in the structure of epigeic groups reflect changes in the ecological status of habitats. We assessed the influence of semi-natural habitats and environmental variables on the dispersion of the epigeic groups.

Area of study: Southwestern part of Slovakia.

Material and methods: Between 2018 and 2020, six barley (*Hordeum vulgare* L.) fields were selected each year. Five pitfall traps were placed on each field and environmental variables (soil pH and moisture, light conditions, soil N, P, K) were analysed. We collected 8,730 individuals belonging to 14 taxonomic groups. The variables of the study sites (habitat, locality name, cadastral area, altitude, coordinates of localities) were also analysed.

Main results: We observed a decrease in the average number of individuals in the direction from pitfall traps 1 (semi-natural areas) to 5 (barley crop) between July and August. The number of individuals was similar in May and June. The dispersion of epigeic arthropods was affected by soil moisture, pH soil, phosphorus, potassium and nitrogen. In the beetles model group, which was represented by the highest number of individuals, we confirmed an increasing number of individuals with increasing values of K, P, N and soil moisture. The neutral pH of the soil was optimal for beetles.

Research highlights: The ecotone rule does not apply during all months, so we have contributed new information about the ecotone rule. Agricultural intensification affects soil arthropods, a taxonomic group with an important role in the functioning of agricultural ecosystems.

Additional key words: epigeic groups; agrosystems; soil diversity; soil ecosystems; ecotone; Slovakia

Authors' contributions: Conception and design of experiments; statistical analysis and interpretation of data; drafting of manuscript, revision & editing: VL. Formal arrangement, project administration and funding acquisition: KP, JS.

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Introduction

The utilisation of agricultural landscape cover represents approximately 40% of European land surface, with values up to 70% in some areas (Hails, 2002). Agricultural landscapes vary with cropping system, topography and intensity of the management (Dudley & Alexander, 2017). The conversion of natural vegetation into agroecosystems and agriculture intensification profoundly impact soil arthropods communities because they involve changes within soil biodiversity (Gill *et al.*, 2011). Soil biodiversity is a part of biological resources in agroecosystems, which is considered in soil management, crop rotation and input of organic matter (Porhajašová *et al.*, 2018). Soil communities play an important role in the decomposition of organic matter in the biogeochemical cycle of biogenic elements such as carbon, nitrogen, sulphur and phosphorus. Therefore, they are also important for the sustainability of the soil ecosystem in the transformation and degradation of waste and toxic substances. The response of soil organisms is a key part of soil ecosystem sustainability (Fazekašová & Bobuľovská, 2012). Epigeic arthropods are indicators of the burden on the soil environment and act as a bioindicator of the environment (Brygadyrenko, 2015; Porhajašová *et al.*, 2015; Purkart *et al.*, 2019; Langraf *et al.*, 2020b; Avtaeva *et al.*, 2021). Different species are essential in the decomposition process and cycle of nutrients. Phytophagous species have economic implications on agriculture, as they act like pests and have also become the target of insecticides and other types of management regimes. Ants play an important role in soil fertility by clearing the soil surface of vegetation (Paoletti & Hassall, 1999; Taha *et al.*, 2021). Predator and parasitoid species are viewed as beneficial to agriculture, and attempts to preserve or introduce them as biological control agents are common (Asteraki, 1993; Starý & Gerding, 1993; Wilson, 2006; Rana *et al.*, 2019). The arthropod communities are fundamental to agricultural ecosystems, with seasonal variation being a common trait, especially in the areas undergoing strong climatic seasonality (Berg & Bengtsson, 2007; Ramzan *et al.*, 2021).

Reduction in biodiversity in agricultural ecosystems is related to the loss of habitats, degradation of habitats, and pesticides (Stoate *et al.*, 2001). Semi-natural habitats in agroecosystems, such as field margins, may provide homes for several arthropods, contributing to a stable structural habitat and a consistent food source (Dennis & Fry, 1992; Boutin *et al.*, 2002; Alignier *et al.*, 2014; Maqsood *et al.*, 2020). The use of hedges and field margins (ecoton) in the landscape creates a specific habitat for insects, birds, plants, and other animals (Haddaway *et al.*, 2016; Nowakowski & Pywell, 2016). These structures benefit biodiversity because they may harbour a diverse plant community that can support and act as a shelter or overwintering site for invertebrate and vertebrate communities (Marshall, 2004; Rimsha *et al.*, 2020). This fauna has a nature value because it can support agricultural production by attracting pollinating insects or beneficial that can regulate pest populations (Brussaard *et al.*, 2007; Smith *et al.*, 2008; Baude *et al.*, 2016; Koh *et al.*, 2016; Chiawo *et al.*, 2017). Maintaining arthropod populations in agricultural environments can be achieved by using semi-natural areas adjacent to crop fields or maintaining healthy plant diversity within fields (Sotherton *et al.*, 1988; Moghimian & Kooch, 2013). Moreover, field margins can act as ecological corridors, assuring connectivity between noncrop areas (New, 2005; Khodashenas *et al.*, 2012). The influence of agricultural intensification on epigeic arthropods was also confirmed by Pérez-Bote & Romero (2012), where they found an increase in diversity in semi-natural areas and field margins.

Barley (*Hordeum vulgare* L.) is an important winter cereal, traditionally, it has been perceived as a crop of comparatively poor and marginal lands with low fertility for use as animal feed. However, during past two decades, the situation has changed and besides feed, it has emerged as an industrial crop for malt purposes and is now being grown under contract farming in high fertility (Singh *et al.*, 2010; Kumar *et al.*, 2012). The objective of this study was tracking the community structure of epigeic arthropods in barley soils and semi-natural habitats (ecotons). It was also to determine the influence of environmental variables (soil humidity, soil pH, potassium, phosphorus and nitrogen) on epigeic arthropods.

Material and methods

This study was performed from the year 2018 to 2020. Arthropods were collected from April to August, every year from 2018 to 2020 in agricultural fields sown with barley. In each field five pitfall traps (750 mL) were used and placed in a line at a distance of 10 meters apart (Fig. 1). Each year, six barley fields were selected. Five pitfall traps were placed on each field, a total of 30 pitfall traps (5 × 6=30). The same agricultural practices were applied in all the barley fields of the study area. Formaldehyde solution (4%) was used to fix the material while it was being collected regularly, at two week intervals (Novák *et al.*, 1969). The nomenclature of arthropods was in accordance with Pokorný & Šifner (2004) and Majzlan (2009) works. The study area of agricultural crop was located in the geomorphological unit of the Podunajská pahorkatina – the Danubian upland (the south-western part of Slovakia) in the cadastral territory of Nitra (Fig. 2). The altitude of the monitored area was approximately 130 m above sea level with the brown type of soil. The study area belongs to a warm, arid climate area with mild winters. The temperature during the months April-August was as follows: April 10-20°C, May 15-22°C, June 18-27°C, July 22-29°C, August 20-29°C. The average precipitation during the months was as follows: April 12 mm, May 65 mm, June 77 mm, July 41 mm, August 57 mm.

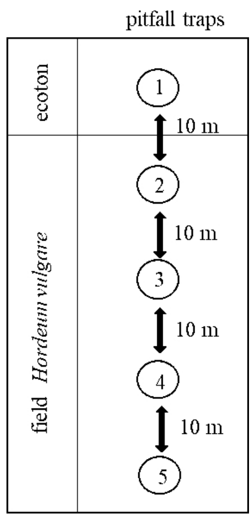

Figure 1. Diagram for the sites of pitfall traps

Figure 2. Map of the study area.

The granular insecticide Force, specific to control soil pests, was applied to the crops. The insects were killed through the respiratory and tactile poison way. The preparation had a fast effect and a strong residual (repellent) action against a wide range of soil pests from the order of Coleoptera, Aranea, Hymenoptera. The applied dose was administrated uniformly 12-15 kg/ha.

At each pitfall trap, we removed stones and fallen leaves from barley plants, and sampled the soil to a depth of 15 cm for analysis. Five samples (five sites) were taken from each barley field every two weeks. Subsequently, environmental variables (N, P, K, pH, soil, moisture) were analyzed using soil moisture meter (Rapitest 3 1835, Luster Leaf, ILL, USA) and pH meter (Dexxer (PH-03, Luboň Poland) meters. We thoroughly wet the broken-up soil with water (ideally distilled or de-ionized water) to a mud consistency. We wiped the meter probe with a tissue or paper towel and then inserted it into the soil up to the probe base (7 to 10 cm). We waited 1 min and recorded the values in mg/kg.

Database quality

The data obtained by research were 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 consisted 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 (SQL Server 2017) were programmed.

Statistical analyses

Multivariate analysis (redundancy analysis or RDA) was used to determine the dependencies between objects (epigeic groups and soil characteristics). We tested the statistical significance of soil pH, soil moisture, potassium, phosphorus and nitrogen with the Monte Carlo permutation test in the Canoco5 program (Ter Braak & Šmilauer, 2012).

Analysis in the statistical program Statistica Cz. Ver. 7.0 (StatSoft Inc., 2004) 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. Shapiro-Wilk W-test determined the normality of data distribution. Based on the normality data distribution (p=0.001), we used the nonparametric Friedman test (ANOVA) to calculate the number of individuals in pitfall taps between May and August.

Results

Throughout three years of research, we detected 8,730 individuals belonging to 14 taxonomic groups in the barley fields. Taxa of Coleoptera (44.80%), Collembola (25.19%) and Hymenoptera (11.37%) had a eudominant representation of individuals. A greater diversity was captured at the edge of the field (Pitfall traps 1), which fed on semi-natural habitats. There was a decrease in diversity towards the inside of the field (Table 1).

Multivariate analysis of the arthropods captured in the barley fields between 2018 and 2020 was determined using the redundancy analysis (RDA, SD=1.70 on the first ordination axis). The explained variability of taxonomic data values was 48.5% on the first ordination axis and 77.8% on the second ordination axis. The cumulative variability of the species set explained by environment variables was represented in the first ordination axis 91.8% and in the 2nd axis 95%. Using the Monte Carlo permutation test, we identified a statistically significant effect of soil moisture (p=0.0152), pH soil (p=0.0502), phosphorus (p=0.0382), potassium (p=0.0138) and nitrogen (p=0.015) on the structure of arthropods. The selected variables were not mutually correlated with the maximum value of the inflation factor=4.3096. The ordination graph (biplot) contained arthropods ordered into three clusters (Fig. 3). The first cluster (I) consisted of arthropods correlated with pH and pitfall trap one located in the ecotone of the field and grassland between the fields. The second cluster (II) was represented by taxa linking to nitrogen (mg/kg), potassium (mg/kg) and pitfall traps 2 and 4 located in the field. The third cluster (III) consisted of arthropods with a preference for moisture (%), phosphorus (mg/kg) and pitfall traps 3 and 5 located in the field. Many soil arthropods were caught at the edge of the field (Pitfall trap 1), which fed on the grassland between the fields. We noticed a reduction of taxa towards the inside of the field (Pitfall traps 2 to 5).

The normality data distribution (number of individuals) was violated (p=0.001). Based on that, a nonparametric Friedman test (ANOVA) was used to confirm the statistically significant difference (p=0.0349, F=8.6164, df=3) (Fig. 4) of several individuals between pitfall traps and the period from May to August in the barley fields. The results showed a decrease in the average value of individuals in each direction from pitfall traps 1 (located in semi-natural habitats) to pitfall traps 5 (towards the inside of the field) during August. In May and June, the number of individuals was similar in individual pitfall traps 1 to 5. During July, the average number of individuals decreased only in pitfall traps 4 and 5.

For further data processing, we chose model bioindication taxon Coleoptera. The number of individual beetles was processed using polynomial regression. Using the regression model, we expressed the relationship (correlation) between number of individuals of the Coleoptera in the barley fields and K (mg/kg), P (mg/kg), N (mg/kg), pH, and humidity (%). The correlation coefficient value was high for the number of individuals and pH (r=0.9348) (Fig. 5D), N (r=0.7573) (Fig. 5C), K (r=0.7571) (Fig. 5A), P (r=0.7273) (Fig. 5B), moisture (r=0.7137) (Fig. 5E), which indicated a strong relationship. The reliability coefficient for the potassium r^2=0.9105 indicated the capture of 91% variability, phosphorus r^2=0.9103 (91% variability), nitrogen r^2=0.9104 (91% variability), pH r^2=0.7437 (74% variability), moisture r^2=0.9122 (91% variability). The overall suitability of the regression model is statistically significant in all cases: K (p=0.0163), P (p=0.0162), N (p=0.0163), pH (p=0.0484) and moisture (p=0.0084). The results showed that increasing values of K, P, N and soil humidity, also increased the number of Coleoptera individuals. The ideal value for Coleoptera was 20-40 mg/kg K, 1.5-3 mg/kg P, 20-40 mg/kg N, pH 7 and 2-3% of moisture.

Discussion

Epigeic arthropods living in agricultural landscapes have a wider tolerance than the epigeic arthropods of natural habitats. They also achieve high local density due to the influence of agriculture, and field margins support the most abundant and diverse community of soil arthropods

Table 1. Distribution of arthropods in the barley fields.

Arthropods	Pitfall traps										Total	
	1		2		3		4		5			
	N	(%)	N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Arachnida												
Acarina	24	0.27	59	0.68	20	0.23	3	0.03	74	0.85	180	2.06
Araneae	52	0.60	176	2.02	62	0.71	61	0.70	90	1.03	441	5.05
Opilionidea	6	0.07	9	0.10	3	0.03	7	0.08	5	0.06	30	0.34
Crustacea												
Collembola	758	8.68	624	7.15	386	4.42	226	2.59	205	2.35	2199	25.19
Isopoda	3	0.03	0	0.00	2	0.02	1	0.01	1	0.01	7	0.08
Diplopoda												
Julida	1	0.01	8	0.09	1	0.01	84	0.96	0	0.00	94	1.08
Chilopoda												
Lithobiomorpha	8	0.09	3	0.03	3	0.03	3	0.03	3	0.03	20	0.23
Insecta												
Coleoptera	551	6.31	790	9.05	1249	14.31	933	10.69	388	4.44	3911	44.80
Diptera	214	2.45	156	1.79	139	1.59	129	1.48	68	0.78	706	8.09
Hemiptera	19	0.22	31	0.36	27	0.31	10	0.11	6	0.07	93	1.07
Hymenoptera	792	9.07	73	0.84	28	0.32	66	0.76	34	0.39	993	11.37
Lepidoptera	3	0.03	0	0.00	0	0.00	1	0.01	0	0.00	4	0.05
Orthoptera	10	0.11	20	0.23	2	0.02	15	0.17	4	0.05	51	0.58
Annelida												
Haplotaxida	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	1	0.01
∑ **individuals**	2441	27.96	1949	22.33	1922	22.02	1539	17.63	879	10.07	8730	100

N: individuals

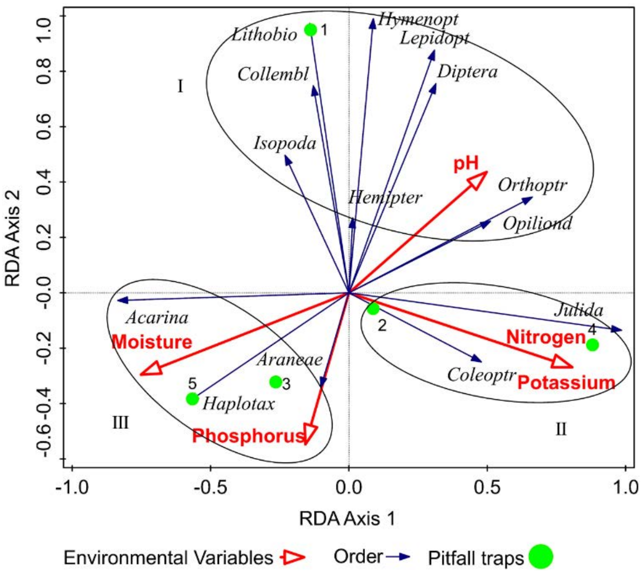

Figure 3. Redundancy analysis (RDA) of arthropods with environmental variables.

(Pérez-Bote & Romero, 2012; Magura *et al.*, 2020). We recorded that the arthropod community was dominated by Coleoptera, Collembola and Hymenoptera (Formicidae). The great abundance of these groups influenced the maintenance of the natural balance and substance cycle of the biogenic elements in ecosystems such as carbon, nitrogen, sulfur and phosphorus. The dominance of Hymenoptera (Formicidae) and Coleoptera has been indicated as a general trait of ground-dwelling assemblages (Doblas-Miranda *et al.*, 2007; Lenoir & Lennartsson, 2010). Their activities accelerated the decomposition of plant residues, aerated the soil and improved soil structure and quality (Holecova *et al.*, 2003). The eudominant representation of the Coleoptera taxon among epigeic arthropods in the conditions of integrated farming and ecological farming was also recorded by Porhajašová *et al.* (2015; 2018). The presence of other epigeic groups was heterogeneous and may depend on the management regime and the surrounding vegetation (Morris & Campos, 1999; Bažok *et al.*, 2015).

Plant diversity is an important factor determining the diversity of epigeic organisms (Harvey *et al.*, 2008). Using the multivariate model, we demonstrated the influence of semi-natural habitats on the abundance of soil arthropods. Thus, our results agreed with Attwood *et al.* (2008), who observed a decline in arthropods with increasing land use. Areas of low intensification management such as native vegetation and pasture have greater habitat complexity due to their uniform management as in many cropping systems. Therefore, in complex land uses, niches are numerous, while fewer niches may be available in structurally and compositionally 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. More complex habitat and structure may allow greater access to food resources (Langellotto & Denno, 2004; Baranová *et al.*, 2015). In disturbed environments, community composition cannot progress beyond early pioneer stages. The result is environments that favour early successional species while being a disadvantage to later successional species (Büchs *et al.*, 2003; Dobrovodská *et al.*, 2019).

The prominence of arthropod abundance from month to month is usually interpreted as being related to

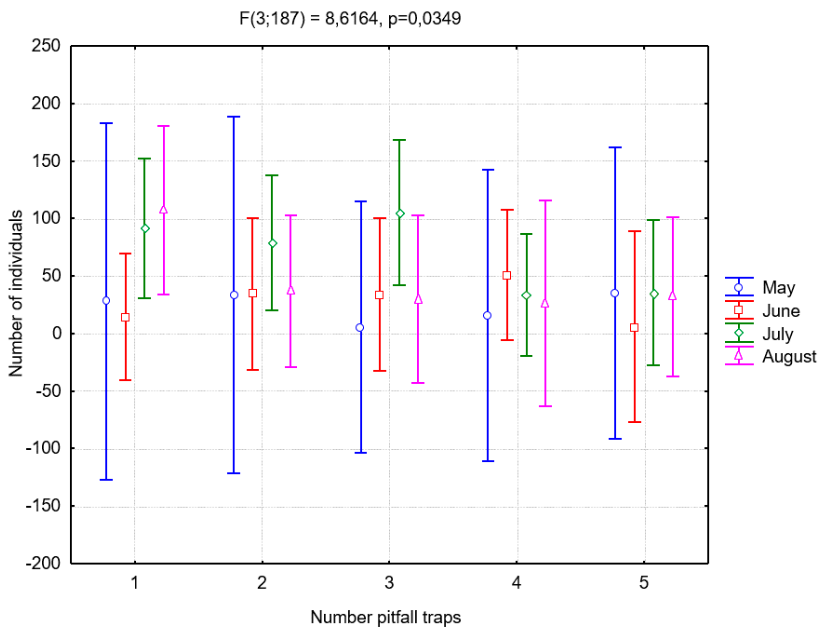

Figure 4. Friedman test (ANOVA) difference in the number of individuals between pitfall traps, from May to August.

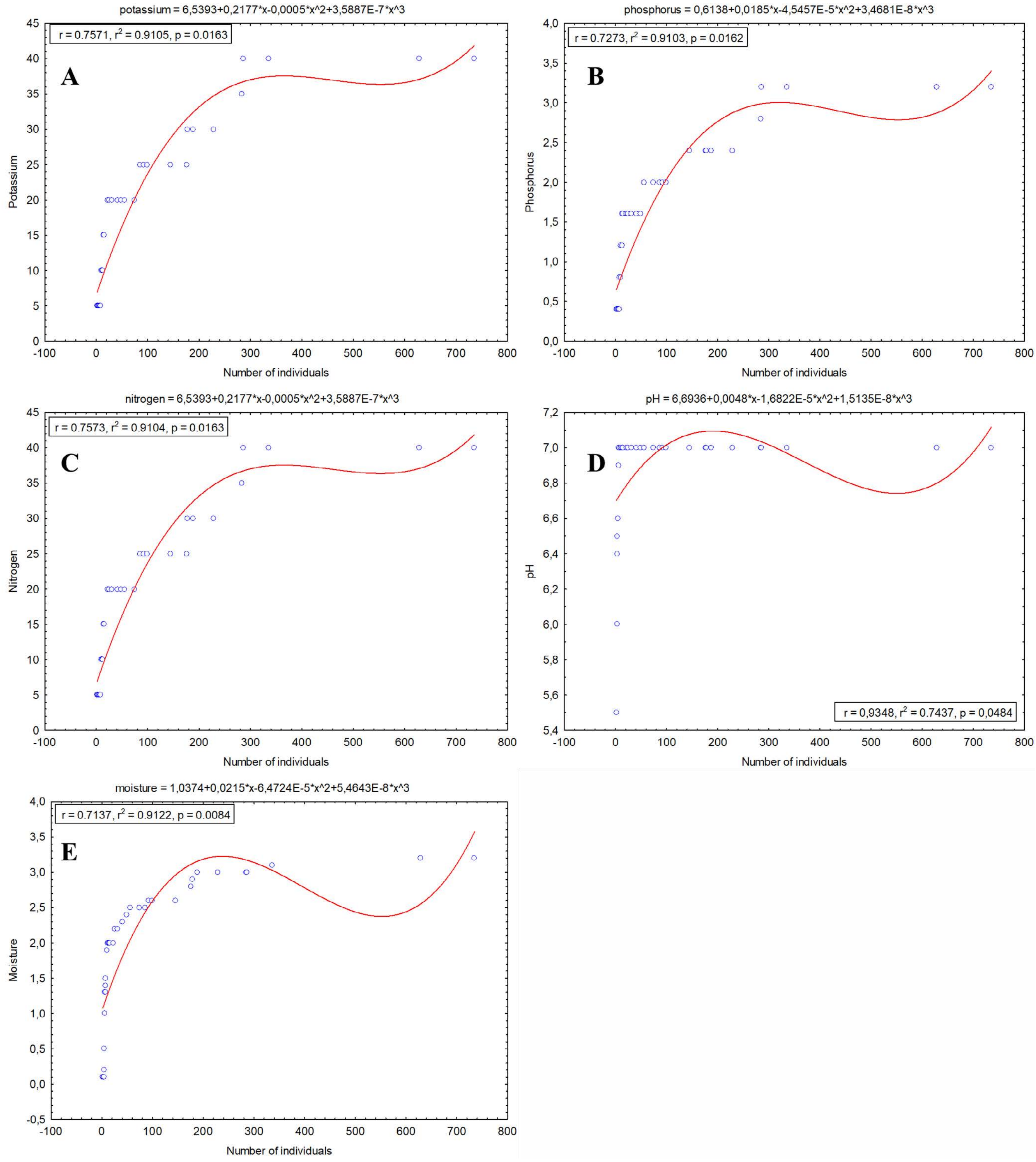

Figure 5. Polynomial regression model for potassium, phosphorus, nitrogen, pH, moisture and number of individuals of Coleoptera.

fluctuations in climatic factors (such as temperature, precipitation and day length) (Lionello *et al.*, 2006). The number of arthropods captured in May and June was distinct from the number of arthropods captured in July and August, in the direction of the pitfall traps 1 (semi-natural habitats) to 5 (located in the field). The trend of decreasing numbers of individual arthropods at the centre of the field did not apply in May and June when the ecotone rule did not manifest itself. Samples belonging to the same months presented similarities and were distinct from samples from the other months, providing evidence of differences in the abundance of taxonomic groups found. Differences in the number of arthropods were affected by different weather during the seasons and months (Simão *et al.*, 2015). Greenberg & McGrane (1996) and Majeed *et al.* (2020) found a seasonal trend for the abundance of arthropod groups. Still, individual taxa exhibiting distinct seasonal patterns reflected the high variability among life cycles of the captured groups.

Boháč & Jahnová (2015) found that the Coleoptera is a large and functionally dominant group of soil macrofauna, which react sensitively to human activity. The Carabidae family from the Coleoptera order was the most often used as a bioindication. They are sensitive to insecticides, pesticides, pH, soil moisture, phosphorus, potassium, nitrogen, and excessive use of artificial fertilizers. Another important factor influencing the Coleoptera is vegetation structure in the connection to various human interventions, while their effects do not change only in nature but also in agriculturally used ecosystems (Carcamo & Spence, 1994; Vician *et al.*, 2015; Tiemann *et al.*, 2015; Langraf *et al.*, 2020 a,b). In the regression model, we noted the high correlation of Coleoptera on the pH, nitrogen, potassium, phosphorus and moisture. Vician *et al.* (2011, 2018) also assumed that pH and soil moisture are the main factors affecting the diversity of beetles (Carabidae).

In conclusion, our results contributed to new knowledge about the preference of epigeic groups in barley fields and the influence of semi-natural areas on their occurrence. We confirmed the decrease of the average number of individuals value in the direction from pitfall traps 1 to 5 between July and August. Interestingly, this trend did not apply to May and June values, when the number of individuals was similar. For May to June results, we did not confirm the rule that the highest diversity was found in semi-natural areas. The dispersion of epigeic groups was also influenced by soil moisture, pH soil, phosphorus, potassium and nitrogen. The Coleoptera model group had a strong correlation with soil moisture (%), pH soil, phosphorus (mg/kg), potassium (mg/kg) and nitrogen (mg/kg). With increasing values of potassium, phosphorus, nitrogen and moisture, the number of individuals also increased. We confirmed that the optimal pH soil value was neutral. Epigeic arthropods are important drivers of ecosystem functions such as nutrient cycling, pest control and maintenance of soil structure. Therefore, it is important to promote strategies for addressing the conservation of arthropods in agricultural landscapes.

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