CARABIDS AS INDICATORS OF SUSTAINABILITY IN ARABLE CROPS

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Abstract. Intensive agriculture and crop production lead to a significant decline in biological control agents, their abundance and diversity. Ground beetles are important in reducing populations of pests and weeds. They are often used in environmental research as biological indicators of different habitats. The aim of this research was to analyse biocenotic and synecological indices of ground beetle populations collected from two remote sites differing in weather conditions, tillage, and types of arable crops. After detailed identification, 64 species were distinguished and classified according to the Catalogue of Palearctic Coleoptera. Biocenotic synecological analysis per crop in both Vukovar-Syrmia and Virovitica-Podravina counties showed that *H. rufipes*, *P. melas*, *P. melanarius melanarius* and *P. cupreus cuperus* were the most abundant species in the studied crops. Catches in Virovitica-Podravina County were significantly higher than catches in Vukovar-Syrmia County. Compared to the other crops, maize had significantly the highest. The highest catches were recorded in September, while catches were significantly lower in July. Catches were affected by location site, crop, and sampling date, as well as their combinations, proving that the abundance of ground beetles was significantly different at the two sites.
Keywords: *biological control agents, carabids, conservation, sustainable land use, tillage*

Introduction

Agricultural practices are thought to be responsible for the loss of species in many regions of Central Europe (e.g., Heydemann, 1986; Gall and Orians, 1992). Intensive farming, the use of broad-spectrum insecticides, and the cultivation of crops that lack weeds and field margins for food, shelter, and overwintering habitat are leading to significant declines in biological control agents, their abundance and diversity. Naturally occurring biological control agents are commonly referred to as biological conservation control. These include birds, bats, small mammals, but especially insects and other invertebrates which prey on or parasitize crop pests reducing damage. Most known are parasitic wasps, carabids, and ladybirds (EC, 2020).

As naturally occurring, predatory temperate organisms, carabids are often considered biological control agents in organic agriculture (Kromp and Meindl, 1997; Kromp, 1999). They are important in reducing populations of many pests and weed seeds, but they are also a food source for animals at a higher trophic level. Because of their large numbers, known taxonomy, and sensitivity to changes caused by external factors, they are often used in research (Lövei and Sunderland, 1996). Ground beetles that occur in arable landscapes are usually considered eurytopic. They are in direct contact with other

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soil dwellers as well as with higher agrochemical up-take, loss of greenbelts, and increasing size of croplands, which is often considered the main cause of declines in their populations (Fahrig et al., 2015).

Ground beetles are highly diverse, counting more than 3000 species in the Western Palearctic region (Rainio and Niemelä, 2003; Kotze et al., 2011). Compiled data on carabid density from 14 European countries between 1970 and 1994, indicated enormous temporal and spatial variation. In annual crops, for example, the total number of adult carabids averaged 32 per square meter and ranged from 1 to 96. Much higher densities were found at field margins, with an average of 233 and a range of 14.5 to 1113 beetles per square meter (Lövei and Sunderland, 1996). Partial assemblage of ground beetles in Croatian agricultural landscapes has recently been studied in annual crops (Bažok et al., 2007; Kos et al., 2010, 2011, 2013; Gotlin Čuljak et al., 2016; Drmić et al., 2016). The composition of the carabid fauna and the dynamics of their occurrence in arable crops in Croatia are not known, although it is often claimed that insecticides are the main factor for the decline in their numbers. Contact with insecticides may affect organisms that have fed on the treated plants, either directly or through treated surfaces on which they move (Albajes et al., 2003; Papachristos and Milonas, 2008; Moser and Obrycki, 2009; Prabhaker et al., 2011). Crop type determines shelter, microclimate, and food resource availability and is a key factor in carabid abundance and species richness (Brooks et al., 2003, 2008; Woodcock et al., 2014). Also, the timing of cultivation probably has the greatest impact on carabids, affecting population processes between fall and spring breeding (Holland and Luff, 2000; Marrec et al., 2015). According to Stassart et al. (1983) the depth of tillage is one of the major factors affecting ground beetle field fauna.

The objective of this study was to analyze biocenotic synecological indices of ground beetle populations collected from two remote regions that differ in weather conditions, tillage, and types of arable crops. The study will contribute to the general knowledge of ground beetles by providing a complete list of species found in four commonly grown crops in Croatia (and Europe).

Materials and Methods

Experimental site and agricultural practice

The survey was conducted in two remote regions of Croatia, Virovitica-Podravina County and Vukovar-Syrmia County. Regions belong to the same Cfwbx climatic type of the Köppen classification system (Penzar and Penzar, 2000), but differ according to agricultural practices regarding soil tillage (*Table 1*). Intensive agricultural practices are common in the fields of Vukovar-Syrmia County, including deep plowing and intensive use of agrochemicals and mineral fertilizers. There is a great number of large integrated farmlands used for commercial production. In Virovitica-Podravina County, arable farming is carried out according to good agricultural practices, which mostly include conservation tillage and lower use of agrochemicals. Smaller arable areas are cultivated on family farms. Woodland areas and water puddles/canals are common sight. Farmers provided information on farming practices. In each region, four fields of each crop (maize, wheat, sugar beets, and soybeans) were monitored during the 2016 growing season.

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Table 1. *Field cultivation on investigated locations*

	Vukovar-Syrmia County	**Virovitica-Podravina County**
crop	Tillage*	Tillage*
maize	CT	RT
wheat	CT	NT
sugar beet	CT	RT
soybean	CT	RT

*Tillage: conventional tillage (CT), reduced tillage (RT), no-tillage (NT)

Sampling method

Monitoring and collection of ground beetles was performed on each of the four fields included in the experiment. Forty traps were set in the form of a net per field. Total of 160 traps was used in each region. Traps were placed 20 x 20 m apart and 100 m from field edges to avoid marginal disturbance (adjacent field, roads, proximity to roads, etc.). The traps consisted of a PVC container (Ø = 12 cm, h = 18 cm) buried in the ground and half filled with salt water (50 g/l) a preservative with the addition of 20 ml/l unscented detergent to reduce surface tension. A PVC roof was placed over each hunting vessel at a height of 2 cm. Samples were collected four times during growing season over a period of seven days in May (20.05.), July (01.07.), August (19.08.), and September (22.09.). In the meantime, the traps were closed with plastic covers. Other organisms collected in the traps were not subject of the study and were not considered for analysis.

Trial assessment

Air and soil temperature and precipitation were monitored at both sites throughout the growing season by the Croatian Meteorological and Hydrological Service. Data on mean air and soil temperatures and total precipitation were evaluated for the nearest meteorological stations (Virovitica and Gradište), located no more than 20 km from the experimental sites (*Figure 1*). Adult carabid samples were identified to species level. The identification of the ground beetle was performed by a taxonomy expert (Teun van Gijzen, Zoological Museum Amsterdam and the Museum for Natural History “Naturalis” in Leiden) using standard keys (Freude et al., 2006).

Data analysis

To achieve the objectives of the study, we conducted a biocenotic synecological analysis that included the calculation of analytical ecological indices - species richness, dominance, and constancy index. Based on the calculated dominance, the represented species of the family Carabidae are classified according to Tischler and Haydeman cited in Balarin (1974). To determine the relationship between the dominance index and the constancy index, an ecological significance index (W) was calculated for each species (Varvara et al., 2012). The diversity and similarity of populations within the fields and among the fields are determined using the Shannon index (H) (Shannon, 1948) and the Sörensen coefficient (QS) (Sørensen, 1948) while the Shannon's equitability index (Shannon, 1948) measures the evenness of a community. Bray Curtis dissimilarity is used to quantify differences in species populations between two different sites. The formulas for each index can be found in *Table 2*.

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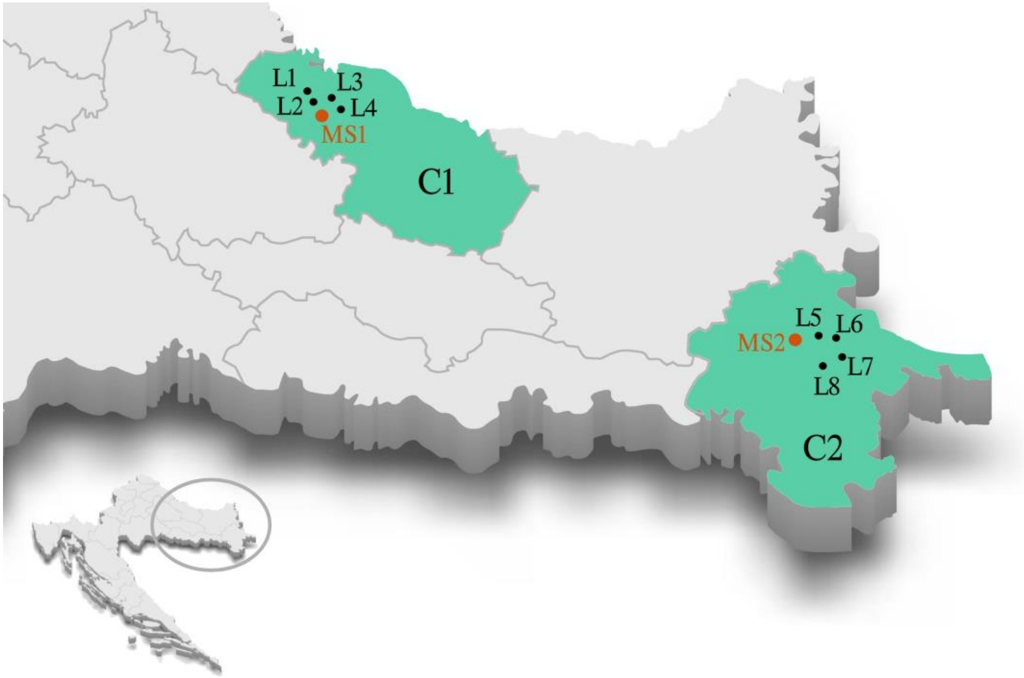

Figure 1. *C1: County Virovitica-Podravina (45.65, 17.79); MS1: Meteoroloigical station Virovitica, Taborište, (45.82, 17.41); L1 – sampling location 45.87, 17.49; L2 – sampling location 45.89, 17.39, L3 – sampling location 45.89, 17.42, L4 – sampling location 45.87, 17.45. C2: County Vukovar-Syrmia (45.13, 18.54), MS2: Meteoroloigical station Gradište, (45.15, 18.71); L5 – sampling location 45.19, 18.68; L6 – sampling location 45.22, 18.73; L7 – sampling location 45.16, 18.78; L8 – sampling location 45.24,* 18.74

The data on the average number of ground beetles per field collected using pitfall traps were analyzed by analysis of variance (ANOVA) with three factors. The first factor was site (i.e., location) which was considered as a fixed factor due to a characteristic weather conditions and similar tillage practices. The second factor was crop and the third factor was sampling date. Using ARM 9 software (Gylling Data Management Inc., 2019) a Tukey Post-Hoc test was used to determine which mean values of the variants were significantly different after a significant test result ($P < 0.05$). Where appropriate, data were log x+1 transformed.

Results

In general, Virovitica-Podravina County had lower mean air and soil temperatures while the amount of precipitation was higher. Climatic differences between sampling period of a) Virovitica-Podravina and b) Vukovar-Syrmia County during growing season 2016 are presented in *Figure 2*.

During the 2016 growing season, a total of 11,763 ground beetle samples were collected from four different fields in each remote region of Croatia, Virovitica-Podravina County and Vukovar-Syrmia County. After detailed determination, 64 species were distinguished and arranged according to the Catalogue of Palearctic Coleoptera, Archostemata – Myxophaga – Adephaga, Revised and Updated Edition (Löbl and Löbl, 2017). Presence per each site and crop is presented in *Table 3*.

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Table 2. *Biocenotic synecological analysis indices with accompanying formulas and classifications used in research*

Index	Formula	Explanation	Classes
Abundance (A)	-	N – total number of individuals of all recorded species.	-
Dominance (D)	D = (nA / N) 100	nA – the number of individuals of species A N – total number of individuals of all recorded species.	D1 – subrecedent species (below 1.1%); D2 – recedent species (1.1-2%); D3 – subdominant species (2.1-5%); D4 – dominant species (5.1-10%); D5 – eudominant species (above 10.1%)
Constancy (C)	C = (nsA / Ns) 100	nsA – the number of samples that contained species A Ns – the total number of samples	C1 – accidental species (present in 1-25% of the samples); C2 – accessory species (present in 25.1-50%); C3 – constant (present in 50.1-75%); C4 – euconstant species (present in 75.1-100%).
Ecological significance (W)	W = (C x D) 100	C – the constancy of species A, D – dominance of species	W1 – for values < 0,1% (subrecedent species); W2 – for values between 0.1-1% (recedent species); W3 – for values between 1.1-5% (subdominant species); W4 – for values between 5.1-10% (dominant species); W5 – for values > 10% (eudominant species). The category W1 includes accidental species. The categories W2 and W3 include accessory species. The categories W4 and W5 include characteristic species.
Shannon's diversity index (H)	$\mathrm{H} = -\sum_{i=1}^{s}(p_i \ln p_i)$	p - proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln - natural logarithm, Σ - sum of the calculations, s - number of species	The bigger number is more diverse.
Shannon's equitability index (E_H)	$E_H = H/H_{max} = H/\ln S$	H - Shannon index, H_{max} - maximum diversity possible, S - total number of species in the community (richness)	Value between 0 and 1 with 1 being complete evenness.
Sörensen coefficient (Qs)	$DSC = \frac{2 \cdot c}{S1 + S2}$	c- the number of species common to both communities S1 - the number of species in community 1 S2- the number of species in community 2	Value between 0 and 1. The closer the value is to 1, the more the communities have in common. Complete community overlap is equal to 1; complete community dissimilarity is equal to 0.
Bray Curtis dissimilarity (BC_{ij})	$BCij = 1 - \frac{2ij}{Si + Sj}$	i and j - two sites, S_i - total number of specimens counted on site i, S_j - total number of specimens counted on site j, C_{ij} - sum of only the lesser counts for each species found in both sites.	Number between 0 and 1. If 0, the two sites share all the same species; if 1, they don't share any species.

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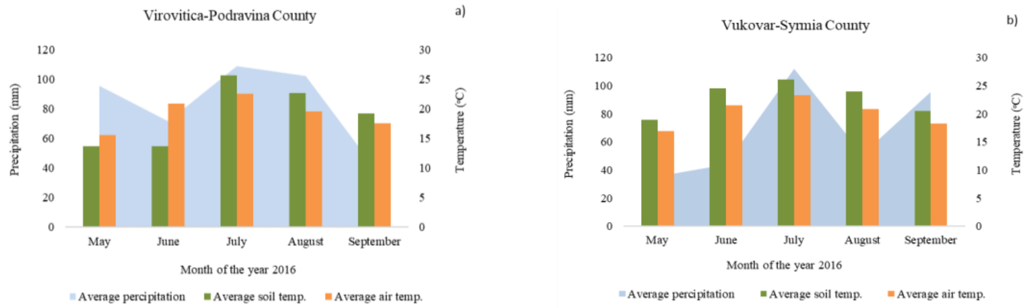

Figure 2. *Weather conditions during growing season 2016 monitored at nearest climate stations a) Meteorological station Virovitica in Virovitica-Podravina County and b) Gradište in Vukovar-Syrmia County*

In Vukovar-Syrmia County a total of 2,382 ground beetles were collected. After identification, 25 different species were distinguished. The largest number was collected in sugar beet fields (1,131), followed by wheat (656), maize (342) and soybean (253). The only eudominant (D5), characteristic (W5) species in maize was *H. rufipes* with 80.41%, followed by *P. melas* which was classified as dominant (D4) with 5.26%, accessory (W3) species. *H. distinguendus distinguendus* and *C. fuscipes fuscipes* were classified as subdominant species (D3) with no more than 3.51% but also accessory species (W3). Most of the remaining species were classified as subrecedent (D1), accidental (W1).

In soybean, *H. rufipes* was again the most common specie with 57.31%, followed by *A. dorsalis* with 16.21%, making those two species eudominant (D5) and characteristic species (W5 and W4). *C. fuscipes* and *H. distinguendus* were found to be dominant (D4) with 5.14 - 5.53%, accessory species (W3). *H. griseus*, *B. crepitans* and *P. melas* had no more than 3.95%, making them subdominant species (D1) but also accessory (W3). One species, *Z. tenebrioides* was recedent (D2) and remaining ten were classified as subrecedent (D1). Only *H. rufipes* and *H. distinguendus* were classified as constant species (C3). Most species (7) are accessory (W2), while remaining five are accidental (W1).

In sugar beet, *P. melas* was the only eudominant (D5) species with over 81.26%. *H. rufipes* was dominant (D4) with 9.46%. Two mentioned represent caracteristic species of sugar beet. *C. fuscipes* and *P. melanarius* were subdominant (D3) ranging from 2.3 to 3.54%, and accessory (W3) species. All four of the above species were found to be euconstant (C4). *A. dorsalis* was the only recedent (D2), constant (C3), accessory specie (W2), while remaining ten were subrecedent (D1) species and mostly accidental (C1, W1).

In wheat, *P. melas* (41.46), *H. rufipes* (26.22) and *P. melanarius melanarius* (10.21%) were eudominant species (D5), but according to the constancy index, *C. fuscipes* and *C. coriaceus coriaceus* were only euconstant species (C4). Among other species present in wheat four were classified as accidental (W1), seven as accessory (W2 and W3). All mentioned species belong to accidental (C1) or accessory (C2) category. Ecological significance confirmed the relationship between dominance and constancy and showed that *H. rufipes* and *P. melas* were the only two species classified as characteristic in all four fields studied (W4 and W5). A detailed biocenotic synecological analysis for each crop in Vukovar-Syrmia County is presented in *Table 4*.

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Table 3. *Complete list of identified ground beetle species in arable crop agricultural landscape*

Species /Location and crop	**Virovitica-Podravina County**				**Vukovar-Sirmium County**			
	Maize	**Soybean**	**Sugar beet**	**Wheat**	**Maize**	**Soybean**	**Sugar beet**	**Wheat**
Leistus (Leistus) ferrugineus Linnaeus, 1758	+							
Nebria (Nebria) brevicollis Fabricius, 1792	+	+		+			+	
Calosoma (Calosoma) inquisitor inquisitor Linnaeus, 1758	+							
Calosoma (Calosoma) maderae maderae Fabricius, 1775			+					
Carabus (Carabus) granulatus granulatus Linnaeus, 1758	+	+	+	+	+			
Carabus (Procrustes) coriaceus coriaceus Linnaeus, 1758	+	+		+	+	+	+	+
Carabus (Tachypus) cancellatus cancellatus Illiger, 1798	+	+		+				
Cylindera (Cylindera) germanica germanica Linnaeus, 1758		+		+				
Loricera (Loricera) pilicornis pilicornis Fabricius, 1775				+				
Clivina (Clivina) collaris Herbst, 1784	+							
Clivina (Clivina) fossor fossor Linnaeus, 1758	+	+		+				
Asaphidion flavipes Linnaeus, 1760	+			+				
Bembidion (Bembidion) quadrimaculatum quadrimaculatum Linnaeus, 1760	+	+		+				
Bembidion (Metallina) lampros Herbst, 1784				+				
Bembidion (Metallina) properans Stephens, 1828	+	+	+					
Bembidion (Peryphanes) dalmatinum dalmatinum Dejean, 1831	+							
Brachinus (Brachinus) crepitans Linnaeus, 1758						+	+	+
Brachinus (Brachinus) elegans Chaudoir, 1842	+	+	+	+				
Brachinus (Brachynidius) explodens Duftschmid, 1812								+
Callistus lunatus lunatus Fabricius, 1775		+						
Chlaenius (Chlaeniellus) nigricornis Fabricius, 1787	+							
Chlaenius (Chlaenites) tristis tristis Schaller, 1783				+				
Chlaenius (Chlaenites) spoliatus spoliatus P. Rossi, 1792	+		+					
Trechus (Trechus) quadristriatus Schrank, 1781	+	+		+		+		+
Drypta (Drypta) dentata P. Rossi, 1790				+				
Anisodactylus (Anisodactylus) binotatus Fabricius, 1787	+			+				
Anisodactylus (Pseudanisodactylus) signatus Panzer 1796	+	+	+	+				
Diachromus germanus Linnaeus, 1758		+		+				
Harpalus (Harpalus) affinis Schrank, 1781	+	+	+	+				
Harpalus (Harpalus) dimidiatus P. Rossi, 1790	+				+	+	+	
Harpalus (Harpalus) distinguendus distinguendus Duftschmid, 1812	+	+	+	+	+	+	+	+
Harpalus (Harpalus) tardus Panzer, 1796		+		+	+	+	+	

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Species /Location and crop	Virovitica-Podravina County				Vukovar-Sirmium County			
	Maize	**Soybean**	**Sugar beet**	**Wheat**	**Maize**	**Soybean**	**Sugar beet**	**Wheat**
Harpalus (Pseudoophonus) calceatus Duftschmid, 1812					+	+		+
Harpalus (Pseudoophonus) griseus Panzer, 1796			+		+	+	+	+
Harpalus (Pseudoophonus) rufipes De Greer, 1774	+	+	+	+	+	+	+	+
Harpalus (Pseudoophonus) signaticornis Duftschmid, 1812			+					
Parophonus (Parophonus) dejeani Csiki, 1932		+						
Stenolophus (Stenolophus) teutonus Schrank, 1781				+				
Demetrias (Demetrias) atricapillus Linnaeus, 1758				+				
Microlestes minutulus Goeze, 1777	+							
Oodes helopioides helopioides Fabricius, 1792				+				
Agonum (Amara) viridicupreum viridicupreum Goeze, 1777	+	+						
Anchomenus (Anchomenus) dorsalis Pontoppidan, 1763	+	+		+	+	+	+	+
Abax (Abacopercus) carinatus carinatus Duftschmid, 1812		+		+	+	+		
Poecilus (Poecilus) cupreus cupreus Linnaeus, 1758	+	+	+	+	+	+	+	+
Pterostichus (Argutor) vernalis Panzer, 1796				+				
Pterostichus (Cophosus) cylindricus Herbst, 1784								+
Pterostichus (Feronidius) melas melas Creutzer, 1799	+	+	+	+	+	+	+	+
Pterostichus (Morphosoma) melanarius melanarius Illiger, 1798	+	+	+	+		+	+	+
Pterostichus (Platysma) niger niger Schaller, 1783		+						
Stomis (Stomis) pumicatus pumicatus Panzer, 1796		+						
Calathus (Calathus) fuscipes fuscipes Goeze, 1777	+	+	+	+	+	+	+	+
Calathus (Neocalathus) ambiguus ambiguus Paykull, 1790	+							+
Calathus (Neocalathus) micropterus Duftschmid, 1812						+		
Dolichus halensis Schaller, 1783	+							
Laemostenus (Pristonychus) terricola terricola Herbst, 1784						+	+	+
Amara (Amara) aenea Degeer, 1774	+			+				
Amara (Amara) ovata Fabricius, 1792	+							
Amara (Amara) saphyrea Dejean, 1828	+			+				
Amara (Amara) similata Gyllenhal, 1810	+	+					+	
Amara (Zezea) chaudoiri incognita Fassati, 1946				+				
Amara (Zezea) kulti Fassati, 1947				+				
Amara (Zezea) plebeja Gyllenhal, 1810				+				
Zabrus (Zabrus) tenebrioides tenebrioides Goeze, 1777					+	+	+	+

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Table 4. *Biocenotic synecological analysis per crop in Vukovar-Syrmia County*

Crop	Species	*D (%)	**Class of D	*C (%)	**Class of C	*W (%)	**Class of W
Maize	*H. rufipes*	80.41	D5	100.00	C4	80.41	W5
	P. melas melas	5.26	D4	75.00	C3	3.95	W3
	H. distinguendus	3.51	D3	75.00	C3	2.63	W3
	C. fuscipes	3.22	D3	25.00	C1	0.80	W2
	A. carinatus carinatus	1.75	D2	75.00	C3	1.32	W3
	A. dorsalis	1.75	D2	50.00	C2	0.88	W2
	H. griseus	1.17	D2	50.00	C2	0.58	W2
	C. coriaceus coriaceus	0.58	D1	50.00	C2	0.29	W2
	H. tardus	0.58	D1	25.00	C1	0.15	W2
	A. saphyrea	0.29	D1	25.00	C1	0.07	W1
	C. granulatus granulatus	0.29	D1	25.00	C1	0.07	W1
	H. dimidiatus	0.29	D1	25.00	C1	0.07	W1
	P. cupreus cupreus	0.29	D1	25.00	C1	0.07	W1
	H. calceatus	0.29	D1	25.00	C1	0.07	W1
	Z. tenebrioides tenebrioides	0.29	D1	25.00	C1	0.07	W1
Soybean	*H. rufipes*	57.31	D5	75.00	C3	42.98	W5
	A. dorsalis	16.21	D5	50.00	C2	8.10	W4
	C. fuscipes	5.53	D4	50.00	C2	2.77	W3
	H. distinguendus	5.14	D4	75.00	C3	3.85	W3
	H. griseus	3.95	D3	25.00	C1	0.99	W2
	B. crepitans	2.37	D3	50.00	C2	1.19	W3
	P. melas melas	2.37	D3	50.00	C2	1.19	W3
	Z. tenebrioides tenebrioides	1.19	D2	50.00	C2	0.59	W2
	C. micropterus	0.79	D1	25.00	C1	0.20	W2
	C. coriaceus coriaceus	0.79	D1	50.00	C2	0.40	W2
	H. tardus	0.79	D1	25.00	C1	0.20	W2
	H. calceatus	0.79	D1	25.00	C1	0.20	W2
	T. quadristriatus	0.79	D1	25.00	C1	0.20	W2
	A. carinatus carinatus	0.40	D1	25.00	C1	0.10	W1
	H. dimidiatus	0.40	D1	25.00	C1	0.10	W1
	L. terricola terricola	0.40	D1	25.00	C1	0.10	W1
	P. cupreus cupreus	0.40	D1	25.00	C1	0.10	W1
	P. melanarius melanarius	0.40	D1	25.00	C1	0.10	W1
Sugar beet	*P. melas melas*	81.26	D5	100.00	C4	81.26	W5
	H. rufipes	9.46	D4	100.00	C4	9.46	W4
	C. fuscipes	3.54	D3	100.00	C4	3.54	W3

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Crop	Species	*D (%)	**Class of D	*C (%)	**Class of C	*W (%)	**Class of W
	P. melanarius melanarius	2.30	D3	100.00	C4	2.30	W3
	A. dorsalis	1.15	D2	75.00	C3	0.86	W2
	P. cupreus cupreus	0.71	D1	50.00	C2	0.35	W2
	C. coriaceus coriaceus	0.44	D1	75.00	C3	0.33	W2
	A. similata	0.18	D1	50.00	C2	0.09	W1
	B. crepitans	0.18	D1	25.00	C1	0.04	W1
	H. dimidiatus	0.18	D1	25.00	C1	0.04	W1
	H. distinguendus	0.18	D1	25.00	C1	0.04	W1
	L. terricola terricola	0.18	D1	50.00	C2	0.09	W1
	H. tardus	0.09	D1	25.00	C1	0.02	W1
	N. brevicollis	0.09	D1	25.00	C1	0.02	W1
	Z. tenebrioides tenebrioides	0.09	D1	25.00	C1	0.02	W1
Wheat	*P. melas melas*	41.46	D5	50.00	C2	20.73	W5
	H. rufipes	26.22	D5	75.00	C3	19.66	W5
	P. melanarius melanarius	10.21	D5	25.00	C1	2.55	W3
	A. dorsalis	7.01	D4	75.00	C3	5.26	W4
	C. fuscipes	2.90	D3	100.00	C4	2.90	W3
	H. distinguendus	2.90	D3	75.00	C3	2.17	W3
	C. coriaceus coriaceus	2.13	D3	100.00	C4	2.13	W3
	Z. tenebrioides tenebrioides	1.83	D2	50.00	C2	0.91	W2
	L. terricola terricola	1.37	D2	25.00	C1	0.34	W2
	P. cylindricus	1.22	D2	25.00	C1	0.30	W2
	C. ambiguus ambiguus	0.76	D1	50.00	C2	0.38	W2
	H. griseus	0.61	D1	50.00	C2	0.30	W2
	P. cupreus cupreus	0.46	D1	25.00	C1	0.11	W2
	T. quadristriatus	0.30	D1	50.00	C2	0.15	W2
	A. saphyrea	0.15	D1	25.00	C1	0.04	W1
	B. crepitans	0.15	D1	25.00	C1	0.04	W1
	B. explodens	0.15	D1	25.00	C1	0.04	W1
	H. calceatus	0.15	D1	25.00	C1	0.04	W1

*D - dominance; C - constancy; W - ecological significance. **For details on classes please see Table 2

In Virovitica-Podravina County, a total of 9,381 ground beetles were collected during the 20-week sampling period. After identification, 56 species were determined. The largest number was collected in maize (5,656), soybean (1,471), sugar beet (1,250) and wheat (1,004).

In maize *P. melanarius melanarius*, *H. rufipes*, and *P. cupreus cupreus* were eudominant species (D5), euconstant (C4), and characteristic species (W5) accounting

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over 50% of the represented species for the investigated area. *P. melas melas* was recedent (D2) but euconstant (C4), accessory (W3) specie. All other 30 species in maize were subrecedent (D1) and between accidental to accessory (W1 – W3).

In soybean eudominant species were *P. melas melas* (24,47%), *H. distinguendus* (23.79%) and *P. melanarius melanarius* (18.63%). Just as in maze, they were also euconstant (C4), characteristic species (W4). *H. rufipes*, *P. cupreus cupreus* and *B. elegans* were dominant species (D4) with a raging percentage of 5.71 to 7.68. All of them were euconstant (C4) and characteristic (W4), except for *B. elegans*, which is found to be accidental (C1), accessory (W4) species in soybean. *A. signatus*, *C. cancellatus cancellatus* and *A. dorsalis* are subdominant (D3), constant (C3), accessory species (W3). The other 19 species were subrecedent (D1) of which 13 are accidental species.

In sugar beet, the eudominant (D5), euconstant (C4) and characteristic (W5) species are *P. cupreus cupreus* (41.76%), *H. rufipes* (35.36%), and *P. melanarius melanarius* (10.40%). *P. melas melas* is a less common but classified as dominant (D4) (9.36%), yet euconstant (C4), characteristic species (W4) for sugar beet. The other 11 species present are subrecedent (D1) and mostly accidental (W1).

We found the highest number of eudominant (D5), characteristic (W5) species in wheat as follows *A. dorsalis* (24.70%), *P. cupreus cupreus* (19.62%), *H. rufipes* (18.63%) *P. melas melas* (17.93%) and *P. melanarius melanarius* (12.15%). All the above species are classified as euconstant (C4) except *A. dorsalis* which is constant (C3). The other 30 spices present are subrecedent ranging between accidental (20 - W1) and accessory (10 - W2). A detailed biocenotic synecological analysis for each crop in Virovitica-Podravina County is presented in *Table 5*.

The carabid species composition varies between the two different sampled locations (Bray Curtis Similarity Index: maize = 0.894, soybean = 0.7947, sugar beet = 0.7724) and share only little more than a third of the species (Sorensen Similarity Index: maize = 0.367, soybean = 0.478, sugar beet = 0.4). In wheat, Bray Curtis Similarity Index is 0.4289, while Sorensen Similarity Index is 0.3396 meaning that two sites share even less species than other mentioned crops.

Focusing on the locations separately, Shannon Diversity Index in Virovitica-Podravina County shows a higher overall diversity of carabid beetle species abundances as follows: soybean = 2.105, wheat= 1.9467, maize = 1.260 and sugar beet = 1.3572 than Vukovar-Syrmia County (Shannon Diversity Index in wheat = 1.7585, soybean = 1.5851, maize = 0.915 and sugar beet = 0.7817). When observing Shannon Evenness, both locations are mostly dominated by high abundances of single species. The trend is more pronounced in Vukovar-Syrmia County (wheat = 0.4228, soybean = 0.3811, maize = 0.22) with maximum diversity in sugar beet = 0.188. In Virovitica-Podravina County Shannon Evenness was between 0.5061 in soybean, 0.4681 in wheat, 0.3263 in sugar beet and 0.301 in maize). *Figure 3* shows the results of ANOVA for the average number of catches of ground beetles on the studied site (a), crops (b) and sampling dates (c).

The significantly highest captures were identified in maize comparing to other three crops ($HSD_{p=0.05}$ = 73.30). The captures in Virovitica-Podravina county were significantly higher than the captures in Vukovar-Syrmia County ($HSD_{p=0.05}$ = 10.49). The highest captures were recorded in September following with May and August. Comparing to September, significantly lower captures were recorded in July ($HSD_{p=0.05}$ = 62.64).

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Table 5. *Biocenotic synecological analysis per crop in Virovitica-Podravina County*

Crop	Species	*D (%)	**Class of D	*C (%)	**Class of C	*W (%)	**Class of W
Maize	*P. melanarius melanarius*	51.18	D5	100.00	C4	51.18	W5
	H. rufipes	22.67	D5	100.00	C4	22.67	W5
	P. cupreus cupreus	21.76	D5	100.00	C4	21.76	W5
	P. melas melas	1.15	D2	100.00	C4	1.15	W3
	H. distinguendus	0.88	D1	50.00	C2	0.44	W1
	A. dorsalis	0.39	D1	50.00	C2	0.19	W1
	B. elegans	0.32	D1	75.00	C3	0.24	W1
	B. properans	0.21	D1	25.00	C1	0.05	W1
	T. quadristriatus	0.21	D1	25.00	C1	0.05	W1
	A. aenea	0.16	D1	25.00	C1	0.04	W1
	A. similata	0.14	D1	50.00	C2	0.07	W1
	C. fossor fossor	0.12	D1	50.00	C2	0.06	W1
	C. cancellatus cancellatus	0.11	D1	50.00	C2	0.05	W1
	H. affinis	0.09	D1	25.00	C1	0.02	W1
	C. ambiguus ambiguus	0.07	D1	25.00	C1	0.02	W1
	C. fuscipes	0.07	D1	50.00	C2	0.04	W1
	A. flavipes	0.05	D1	25.00	C1	0.01	W1
	H. dimidiatus	0.05	D1	50.00	C2	0.03	W1
	B. quadrimaculatum quadrimaculatum	0.04	D1	25.00	C1	0.01	W1
	C. spoliatus spoliatus	0.04	D1	50.00	C2	0.02	W1
	C. collaris	0.04	D1	25.00	C1	0.01	W1
	A. ovata	0.02	D1	25.00	C1	0.00	W1
	A. binotatus	0.02	D1	25.00	C1	0.00	W1
	A. signatus	0.02	D1	25.00	C1	0.00	W1
	B. dalmatinum dalmatinum	0.02	D1	25.00	C1	0.00	W1
	C. inquisitor inquisitor	0.02	D1	25.00	C1	0.00	W1
	C. coriaceus coriaceus	0.02	D1	25.00	C1	0.00	W1
	C. granulatus granulatus	0.02	D1	25.00	C1	0.00	W1
	C. nigricornis	0.02	D1	25.00	C1	0.00	W1
	D. halensis	0.02	D1	25.00	C1	0.00	W2
	L. ferrugineus	0.02	D1	25.00	C1	0.00	W1
	M. minutulus	0.02	D1	25.00	C1	0.00	W2
	N. brevicollis	0.02	D1	25.00	C1	0.00	W1
	A. viridicupreum viridicupreum	0.02	D1	50.00	C2	0.02	W1
Soybean	*P. melas melas*	24.47	D5	100.00	C4	24.47	W5
	H. distinguendus	23.79	D5	100.00	C4	23.79	W5
	P. melanarius melanarius	18.63	D5	100.00	C4	18.63	W5

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Crop	Species	*D (%)	**Class of D	*C (%)	**Class of C	*W (%)	**Class of W
	H. rufipes	7.68	D4	100.00	C4	7.68	W4
	P. cupreus cupreus	5.98	D4	100.00	C4	5.98	W4
	B. elegans	5.71	D4	25.00	C1	1.43	W3
	A. signatus	4.08	D3	75.00	C3	3.06	W3
	C. cancellatus cancellatus	2.65	D3	75.00	C3	1.99	W3
	A. dorsalis	2.18	D3	75.00	C3	1.63	W3
	N. brevicollis	1.02	D1	25.00	C1	0.25	W2
	H. affinis	0.75	D1	50.00	C2	0.37	W2
	C. granulatus granulatus	0.54	D1	75.00	C3	0.41	W2
	A. carinatus carinatus	0.41	D1	75.00	C3	0.31	W2
	C. fuscipes	0.41	D1	50.00	C2	0.20	W2
	C. coriaceus coriaceus	0.41	D1	25.00	C1	0.10	W2
	C. fossor fossor	0.27	D1	75.00	C3	0.20	W2
	B. quadrimaculatum quadrimaculatum	0.14	D1	25.00	C1	0.03	W1
	C. germanica germanica	0.14	D1	25.00	C1	0.03	W2
	S. pumicatus pumicatus	0.14	D1	50.00	C2	0.07	W3
	A. viridicupreum viridicupreum	0.07	D1	25.00	C1	0.02	W1
	A. similata	0.07	D1	25.00	C1	0.02	W1
	B. properans	0.07	D1	25.00	C1	0.02	W1
	C. lunatus lunatus	0.07	D1	25.00	C1	0.02	W1
	D. germanus	0.07	D1	25.00	C1	0.02	W3
	H. tardus	0.07	D1	25.00	C1	0.02	W1
	P. dejeani	0.07	D1	25.00	C1	0.02	W1
	P. niger niger	0.07	D1	25.00	C1	0.02	W1
	T. quadristriatus	0.07	D1	25.00	C1	0.02	W1
Sugar beet	*P. cupreus cupreus*	41.76	D5	100.00	C4	41.76	W5
	H. rufipes	35.36	D5	100.00	C4	35.36	W5
	P. melanarius melanarius	10.40	D5	100.00	C4	10.40	W5
	P. melas melas	9.36	D4	100.00	C4	9.36	W4
	C. fuscipes	0.88	D1	75.00	C3	0.66	W2
	H. distinguendus	0.72	D1	25.00	C1	0.18	W2
	H. griseus	0.64	D1	50.00	C2	0.32	W2
	A. signatus	0.32	D1	50.00	C2	0.16	W2
	B. properans	0.08	D1	25.00	C1	0.02	W1
	B. elegans	0.08	D1	25.00	C1	0.02	W1
	C. maderae maderae	0.08	D1	25.00	C1	0.02	W1
	C. granulatus granulatus	0.08	D1	25.00	C1	0.02	W1
	C. spoliatus spoliatus	0.08	D1	25.00	C1	0.02	W1

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Crop	Species	*D (%)	**Class of D	*C (%)	**Class of C	*W (%)	**Class of W
	H. affinis	0.08	D1	25.00	C1	0.02	W1
Wheat	*A. dorsalis*	24.70	D5	75.00	C3	18.53	W5
	P. cupreus cupreus	19.62	D5	100.00	C4	19.62	W5
	H. rufipes	18.63	D5	75.00	C3	13.97	W5
	P. melas melas	17.93	D5	100.00	C4	17.93	W5
	P. melanarius melanarius	12.15	D5	100.00	C4	12.15	W5
	L. pilicornis pilicornis	1.00	D1	50.00	C2	0.50	W2
	N. brevicollis	0.60	D1	25.00	C1	0.15	W2
	D. germanus	0.50	D1	25.00	C1	0.12	W2
	C. granulatus granulatus	0.40	D1	25.00	C1	0.10	W2
	P. vernalis	0.40	D1	50.00	C2	0.20	W2
	A. carinatus carinatus	0.30	D1	50.00	C2	0.15	W2
	A. plebeja	0.30	D1	50.00	C2	0.15	W2
	B. elegans	0.30	D1	25.00	C1	0.07	W2
	C. coriaceus coriaceus	0.30	D1	50.00	C2	0.15	W2
	H. affinis	0.30	D1	50.00	C2	0.15	W2
	A. flavipes	0.20	D1	25.00	C1	0.05	W1
	B. lampros	0.20	D1	25.00	C1	0.05	W1
	C. germanica germanica	0.20	D1	25.00	C1	0.05	W1
	D. atricapillus	0.20	D1	25.00	C1	0.05	W1
	D. dentata	0.20	D1	25.00	C1	0.05	W1
	H. tardus	0.20	D1	25.00	C1	0.05	W1
	A. chaudoiri	0.10	D1	25.00	C1	0.02	W1
	A. kulti	0.10	D1	25.00	C1	0.02	W1
	A. aenea	0.10	D1	25.00	C1	0.02	W1
	A. binotatus	0.10	D1	25.00	C1	0.02	W1
	A. signatus	0.10	D1	25.00	C1	0.02	W1
	B. quadrimaculatum quadrimaculatum	0.10	D1	25.00	C1	0.02	W1
	C. fuscipes	0.10	D1	25.00	C1	0.02	W1
	C. cancellatus cancellatus	0.10	D1	25.00	C1	0.02	W1
	C. tristis tristis	0.10	D1	25.00	C1	0.02	W1
	C. fossor fossor	0.10	D1	25.00	C1	0.02	W1
	H. distinguendus	0.10	D1	25.00	C1	0.02	W1
	O. helopioides helopioides	0.10	D1	25.00	C1	0.02	W1
	S. teutonus	0.10	D1	25.00	C1	0.02	W1
	T. quadristriatus	0.10	D1	25.00	C1	0.02	W1

D - dominance; C - constancy; W - ecological significance. **For details on classes please see Table 2

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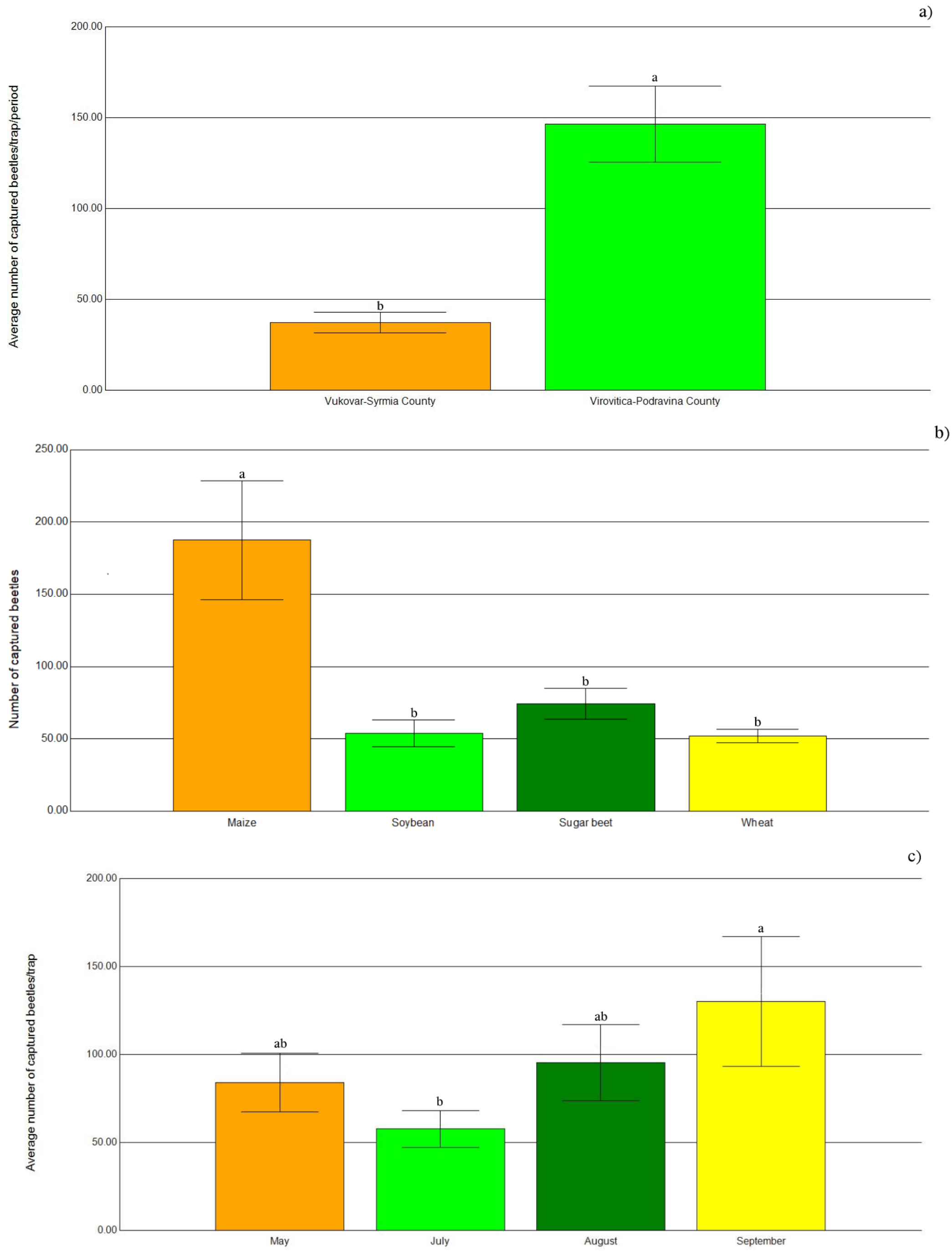

Figure 3. *Captures of ground beetles at different sites (a), in different crops (b) and on different sampling dates (c)*

The recording of ground beetles affected by site, crop and sampling date and their combinations, shown in *Table 6*, indicates that ground beetle abundance was significantly different at two sites and that crops and sampling date influenced ground beetle abundance under different environmental conditions.

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Table 6. *Factorial analysis of the number of ground beetles collected in different crops. A Tukey post hoc test was used to determine which values of the ground beetles were significantly different after a significant test result (p < 0.05)*

Source of variation	df	F	Prob (F)	HSD $_{p=0.05}$
Total	127			
Rep	3	0.091	0.9648	
Locality (A)	1	569.774	0.0001	2.87
Crop (B)	3	26.850	0.0001	7.77
AxB	3	90.095	0.0001	5.72
Sampling date (C)	3	27.414	0.0001	7.85
AxC	3	61.544	0.0001	5.28
BxC	9	25.200	0.0001	10.03
AxBxC	9	13.978	0.0001	8.00
Error	93			

df–degrees of freedom; p–probability value; HSD–honestly significant difference

Discussion

Virovitica-Podravina County was characterized as region with less invasive agricultural practices. Most of investigated fields included reduced tillage or no-till practices as well as less use of agrochemicals. Compared to conventional practices, conservation tillage systems can reduce the number of tillages by 40% or more while improving soil aggregation, promoting biological activity, and increasing water-holding capacity and infiltration rates. Crop residues that remain in the soil throughout the year form a cover that reduces wind and water erosion, runoff, or particle and nutrient losses resulting in higher available soil moisture, better soil structure and higher organic matter content (UC Sustainable Agriculture Research and Education Program, 2017). Results of our study show significantly higher number of collected individuals as well as higher overall diversity of ground beetle species in Virovitica-Podravina County compared to Vukovar-Syrmia County. Such result is in line with previous studies where higher ground beetle trapping rates were recorded on fields with reduced tillage or no tillage at all compared with conventionally tilled ones (House and All, 1981; Blumberg and Crossley, 1983; House and Stinner, 1983; House and Parmalee, 1985; Ferguson and McPherson, 1985; Stinner et al., 1988; Tonhasca, 1993).

According to Geiger et al. (2010) and Postma-Blaauw et al. (2010) arable crops are characterized by the presence of depleted arthropod communities with low diversity, in which ground beetles have a highly heterogeneous spatial distribution (Holland et al., 1999). This is in accordance with our results obtained form Vukovar-Syrmia County where 6,999 ground beetles less were recorded during sampling period compared to Virovitica-Podravina County.

Climatic conditions in Vukovar-Syrmia County can be characterized as rather dry with higher average air and soil temperature, especially in May and June when most spring activity is expected. Ground beetles show an increase in population dynamics when air and soil temperatures decrease (Virić Gašparić et al., 2017). The results of this study show the same pattern, as the lowest catches in all fields in Vukovar-Syrmia County were recorded in May, when the lowest rainfall was recorded. Again, a decrease in the amount of ground beetles was observed during sampling in autumn, when average rainfall was lower. The largest number of collected ground beetles in Vukovar-Syrmia County was collected in sugar beet field, which is contrary to the research of

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Kromp (1999), who found that root crops have a negative impact on the abundance of ground beetles due to the long period of bare soil and extreme microclimate on the soil surface.

In Vukovar-Syrmia County *H. rufipes* was eudominant species with highest number of individuals in three out of four investigated crops (on sugar beet it was dominant). *H. rufipes* is species that usually occurs in cultivated lands, pastures, gardens, and polluted areas (Leibman, 1988; Brygadyrenko and Reshetniak, 2014; Cavaliere et al., 2019; Langraf et al., 2020). Other eudominant species were *P. melas melas*, *P. melanarius melanarius* and *A. dorsalis* which is in accordance with research done in Croatia (Bažok et al., 2007; Kos et al., 2010, 2011, 2013; Drmić et al., 2016; Lemic et al., 2017) as well as abroad. According to Lövei and Sunderland (1996) no more than 10 to 40 species are active in a habitat in the same season which is in line with findings form Vukovar-Syrmia County where each investigated arable crop had between 15 and 18 determined species.

Compared to Vukovar-Syrmia County, significantly higher abundance was found in Virovitica-Podravina County, which is characterized by conservation tillage. These results agree with those of Juran et al. (2014) who found that endogeic activity was highest in the organic system, followed by the conventional and integrated systems. In our results, the most abundant species were *P. melanarius melanarius, H. rufipes,* and *P. cupreus cupreus*. The same results in Eastern European countries were obtained by Kromp (1999) and in Croatia by Bažok et al. (2007), Igrc Barčić et al. (2008) and Kos et al. (2011). Higher abundance of ground beetles was found in fields with reduced or no tillage (House and All, 1981; Blumberg and Crossley, 1983; House and Stinner, 1983; House and Parmalee, 1985; Ferguson and McPherson, 1985; Stinner et al., 1988; Tonhasca, 1993). Our results confirm the findings of Lemic et al. (2017) stating that conventional tillage in Podravina location has an influence on the abundance of ground beetles.

Finally, because of this study, a detailed list of ground beetle species occurring in most of the common arable crops in Croatia was prepared. This list is a valuable result that complements previous research (Bažok et al., 2007; Kos et al., 2010, 2011, 2013; Drmić et al., 2016; Gotlin Čuljak et al., 2016; Lemic et al., 2017; Virić Gašparić et al., 2017) and to a better understanding of ground beetle communities in arable crops in Croatia. Such contribution can serve as a basis for conservation programs. The wealth of information on carabids provides an opportunity to use it to signal and predict changes in the environment because carabids can be easily and reliably collected. Standardized monitoring of environmental change using carabids may be possible (Niemelä et al., 2000).

Conclusions

Higher ground beetle abundance and diversity were found in fields with reduced tillage, lower temperatures, and more rainfall during vegetation. The results provide a better understanding of ground beetle communities in Croatian arable crops. Results can serve as a basis for conservation programs that should include reduced or no tillage as much as possible as well as reduced use of agrochemicals. This study also makes an important contribution to the overall knowledge of ground beetles with a comprehensive list of ground beetle species found in maize, sugar beet, wheat, and soybean crops in Croatia.

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