

EFFECT OF PLANT PROTECTION ON ASSEMBLAGES OF GROUND BEETLES (COLEOPTERA, CARABIDAE) IN SUGAR BEET CROPS IN FOUR-YEAR ROTATION

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The influence of chemical plant protection on carabid beetle assemblages was studied in an experiment conducted on fields of sugar beet at the IOR-PIB Experimental Station in Winna Góra, Poland. The experiment was composed of a block of control fields (no chemical plant protection treatments) and second block, where plant protection was carried out in compliance with the applicable plant protection program. Ground beetles were caught from May to August/September in four years, using modified Barber traps. As a result of the study, 11 881 specimens belonging to 52 species of Carabidae were collected. The most numerous species were: *Harpalus rufipes*, *Pterostichus melanarius*, *Calathus ambiguus* and *Bembidion properans*. Overall, our results demonstrate that the application of chemical plant protection treatments decreased the abundance of carabid beetles in sugar beet fields, but had no effect on species richness. The use of pesticides induced changes in some life traits of Carabidae fauna. After a pesticide application, the abundance of macropterous hemizoophages and medium carnivores with the autumn type of breeding decreased, whereas the abundance of small carnivores increased.

Keywords: ground beetles, plant protection, Coleoptera, Carabidae, integrated agricultural production, root crops, species traits.

INTRODUCTION

Agriculture is crucial for man, mostly because of food production. However, intensive agricultural production entails equally intensive use of natural resources, deteriorating condition of the natural environment, and decreased diversity of countryside landscapes, including poorer biodiversity (ROBINSON & SUNDERLAND 2002). Mutual relationships between the degradation of nature and agricultural production remain a severe problem, especially in developing countries (OLANIPECUN *et al.* 2019). One of the measures most often impli-

cated as a disturbance to agricultural landscapes is the application of pesticides (SUNDERLAND 2002, DESNEUX *et al.* 2007, SCHMIDT-JEFERIS & NAULT 2018) which can have numerous adverse agricultural, environmental and health effects (GROGAN 2014). In Europe, the use of pesticides is regulated by law. The Integrated Pest Management (IPM) system implemented in 2014 has triggered a search for alternative methods, economically viable and eco-friendly, of pest and weed eradication. The general rules of integrated agricultural production include an assessment of the environmental risk to arthropods that are not a target of pesticide application (TOPPING *et al.* 2015). Crop rotation is one of the ways to control pests, weeds and plant diseases, and to improve soil fertility and crop quality. When a crop rotation system is designed correctly, it allows the farmer to reduce the amounts of chemicals applied to fields (BILSKI & PIKOSZ 2020). The microclimate created by particular crops can favour the development and survival of different groups of insects, both harmful and useful ones (HOLLAND & LUFF 2000, EYRE *et al.* 2009). The control of pests by natural enemies is an economically and ecologically acceptable solution, recommended by specialists (SYMONDSON *et al.* 2002, DAINESE *et al.* 2017). Many authors have shown that ground beetles (Coleoptera: Carabidae) are effective predators of pests in different crops (e.g. THIELE 1977, LUFF 1987, KROMP 1999, HOLLAND & LUFF 2000, HUREJ & TWARDOWSKI 2006, GAILIS & TURKA 2013). Moreover, they are excellent bioindicators, sensitive to a variety of factors, and have been used in studies into environmental changes (e.g. RAINIO & NIEMELÄ 2003, SCHWERK & SZYSZKO 2011, KOIVULA 2011). In agricultural fields, they have served as model organisms in many aspects of research (KOTZE *et al.* 2011). Many researchers have identified changes in their species composition, abundance, species richness and diversity as a response to factors such as the spatial diversity of the agricultural landscape, farm management, soil tillage, fertility, crop rotation, type of crops and use of pesticides (e.g. ANDERSEN 1999, HOLLAND & LUFF 2000, PURVIS & FADL 2002, SHAH *et al.* 2003, WEIBULL *et al.* 2003, EYRE *et al.* 2009, 2013, 2016, KOSEWSKA *et al.*, 2014, 2016, GAILIS *et al.* 2017, SOLON & REGULSKA 2019).

The investigations carried out so far concerning the impact of pesticide application on carabid beetle assemblages have not yielded unequivocal results. Some authors (e.g. CÁRCAMO *et al.* 1995, GROGAN 2014, GIGLIO *et al.* 2017) indicate a negative effect of using plant protection chemicals on carabid beetles. However, some conclude that their experiments did not demonstrate a negative influence of pesticides on assemblages of these insects (e.g. PURTAUF *et al.* 2005, Kos *et al.* 2010) or the impact of pesticide use changed over several years (TOPPING *et al.* 2015).

Among all crops, cereals are those where the highest number and greatest species richness of Carabidae are usually observed (ALEKSANDROWICZ *et al.* 2008, GAILIS *et al.* 2017). Because of the specific microclimate, considerable

soil coverage and a large number of pests that appear in cereal fields, this is a habitat willingly colonized by these useful beetles, which find shelter and food resources there. Nevertheless, they are also numerous in fields cropped with other plants, including root crops, such as sugar beet. Large numbers of pests also colonize sugar beet crops.

The purpose of this study was to determine the effect of using pesticides on assemblages of ground beetles occurring in sugar beet fields grown in a four-year rotation system. The following hypotheses were tested: 1) in fields with chemical protection, the abundance and species richness of carabids are lower; 2) application of chemical plant protection leads to changes in the structure of ground beetle assemblages found in sugar beet fields, with a decrease in the abundance of macropterous, autumn breeding, hemizoophages and larger carnivores.

MATERIAL AND METHODS

The study was conducted on experimental production fields at the Agricultural Experimental Station in Winna Góra, in western Poland. A study consisting of four-year crop rotations (sugar beet, maize, seed pea and winter oilseed rape) has been conducted at the station since the 1960s. The present study was composed of a block of control fields, where no chemical plant protection preparations were applied, and another block, where a plant protection programme was carried out in line with the conventional or integrated agricultural production guidelines. The same fertilization regime was applied in both blocks. The surface area of each field is 0.5 ha. The soils under the plantations were similar and belonged to the good wheat complex (class IIIa and IIIb) in the Polish soil taxonomy system (KABAŁA *et al.* 2019).

The experiment was conducted on sugar beet fields, where ground beetles were captured in the years when sugar beet was grown in a crop rotation system, i.e. 2004, 2008, 2012 and 2016, from May to August/ September. Two fields with a sugar beet crop were selected: without chemical protection (NCP – no chemical protection) and with chemical protection (CP – chemical protection). During the four years chosen for our investigation, the field under chemical protection was treated with insecticides, herbicides and fungicides, as specified in Table 1. To reduce the number of weeds in the field without chemical protection (NCP), mechanical weeding was carried out twice a year (May/June). In both fields, typical mechanical treatments such as sowing, ploughing and harrowing were done. Ground beetles were collected using pitfall traps (plastic cups 10 cm diameter, 15 cm deep with ethylene glycol), which were emptied every two weeks. Two transects at a distance of 10 meters from each other were set up in each field. Transects were located 25 meters from the edge of the field. At each transect 5 traps, at a distance of 10 meters from one another were set and the first trap was set 20 meters from the edge of the field. Each field was separated from the next by a 25-meter insulation strip on which phacelia or clover was grown. The distance between the fields with and without chemical protection was 200 meters.

The species composition, abundance and richness of the ground beetles were determined. The beetles were divided into groups based on the following traits: feeding strategy and body size, type of breeding and dispersion capability. These life traits of ground beetles are considered to be the best for describing carabid groups in field crops. Because of their

Table 1. Characterization of the sugar beet crops in the consecutive years alongside the specification of pesticides used in chemically protected fields. Abbreviation: ST = seed treatment, AS = active substance, DA = date of application, Do = dosage, l/ha.

Year	Cultivar	ST	Herbicide			Insecticide			Fungicide		
			AS	DA	Do	AS	DA	Do	AS	DA	Do
2004	Korab	carboxin, thiram, hymexazol, carbofuran	desmedipham, ethofumesate, phenmedipham, metamitron	27 April	1.5	dimethoate	3 June	0.8	flusilazole, carbendazim	27 Aug	1.0
			phenmedipham, desmedipham, ethofumesate	6 May, 18 May	1.0	zeta-cypermethrin	14 June	0.1			
			haloxyfop-R	14 June	1.25	chlorpyrifos, cypermethrin	15 June	0.6			
						alpha-cypermethrin	24 June	0.15			
2008	Soplica F1	carboxin, thiram, hymexazol, carbofuran	metamitron	2 May	1.25	chlorpyrifos, cypermethrin	6 June	0.6	flusilazole	13 Sept	0.2
			metamitron, ethofumesate	6 May	1.75	chlorpyrifos	26 June	1.5			
			quizalofop-P-tefuryl (x2)	16 May	1.75; 1.5						
			phenmedipham, desmedipham, ethofumesate	(1) 21 May; (2) 23 May; (3) 6 June	(1) 1.5; (2) 3; 1.0						
2012	Huzar	hymexazol, thiram, thiamethoxam, tefluthrin	phenmedipham, desmedipham	26 April	0.7	chlorpyrifos	30 May	1.3	non applied		
			chloridazon, quinmerac	(1) 26 April; (2) 2 May	(1) 1.0; (2) 1.25						

Table 1 (continued)

Year	Culti- var	ST	Herbicide			Insecticide			Fungicide		
			AS	DA	Do	AS	DA	Do	AS	DA	Do
2012	Huzar		metamitron	(1) 26 April; (2) 2 May	(1) 1.5; (2) 1.25						
			desmedipham, ethofume- sate, lenacil, phen- medipham	2 May	1.25						
			ethofumesate	24 May	1.25						
2016	So- bieski	hymexazol, thi- ram thiameth- oxam tefluthrin	propaquizafop	26 May	1.5						
			phenmedipham, des- medipham	(1) 20 April; (2) 10 May	(1) 1.5; (2) 1.0	thiacloprid, deltamethrin	23 May	0.6	pyraclo- trobin, epo- xiconazole	22 Jul	1.0
			desmedipham, etho- fumesate, lenacil, phen- medipham	23 May; 30 May	1.2						
			cycloxydim	26 July	1.5						

essential role as plant pest predators, ground beetles grouped in respect of their feeding preferences were additionally sorted according to their body size, distinguishing the following groups: phytophages (eating plant food), hemizoophages (generalists, eating both plants and animals), large carnivores (body length more than 12 mm), medium carnivores (5- 12 mm), and small carnivores (body length less than 5 mm). The division into large, medium and small carnivores was adopted according to ALEXANDROWICZ (2004), based on the average body length of each species given by HÜRKA (1996). Besides, the ground beetles were classified as either autumn breeders, which reproduce in autumn and hibernate as larvae, or spring breeders, which hibernate as adults and reproduce in spring (LARSSON 1939). The presence of ground beetles of various types of breeding is also a reflection of the field conditions (KOTZE *et al.* 2011). The dispersion capability of insects is another critical aspect, especially in distorted habitats (MEIJER 1974). The following groups, according to the HÜRKA (1996) description, were distinguished among the carabids: macropterous, with fully developed wings, brachypterous, with reduced second-pair wings, and dipterous, whose second-pair wings can be developed or reduced.

Differences in mean species richness and abundance of whole assemblages and number of life traits were tested using the generalized linear model (GLM) with the Poisson distribution,

which included factors such as plant protection and year of study. The distribution of data was tested using the Shapiro-Wilk test. Indirect ordination of ground beetle assemblages found in the study area was performed using non-metric multidimensional scaling (NMDS). NMDS was calculated in WinKyst 1.0 (ŠMILAUER 2002) on a Bray-Curtis similarity matrix. Assessment of the significance of differences between the analyzed assemblages in the NMDS method was carried out using the ANOSIM non-parametric statistical test (ANDERSON 2001). Canonical correspondence analysis (CCA) (TER BRAAK & ŠMILAUER 1998) was used to investigate correlations between the ecological groups of Carabidae and the following environmental variables: type of protection (with or without chemical plant protection), chemical treatments applied (herbicides, insecticides and fungicides) and years of experiment.

The following weather variables were also analyzed: temperature and distribution of rain precipitation in the years covered by the study. ANOVA analysis of variance did not demonstrate statistically significant differences in the temperature or rainfall between the analysed years.

All analyses were carried out using untransformed data. Statistical calculations and their graphic presentation were performed using Statistica 13.3 and Canoco 4.5 softwares.

RESULTS

As a result of the study, 11 881 specimens belonging to 52 species of Carabidae were collected (Table 2). More specifically, 5 582 specimens representing 50 species were captured in the fields with chemical plant protection (CP), while the remaining 6 299 individuals belonging to 46 species were caught in fields without chemical plant protection (NCP). Statistically significant differences between the analyzed experimental variants (Wald's $W = 43.22$; $p < 0.01$) in the research years (Wald's $W = 62.69$; $p < 0.01$) were observed concerning the abundance of Carabidae (Table 3). A significantly higher number of Carabidae was determined in fields without chemical protection (Fig. 1). Regarding the number of species, the differences between the two field variants were not significant (Table 3). The non-metric multidimensional scaling (NMDS) diagram shows differences in the analyzed carabid beetle assemblages (ANOSIM $R = 0.68$; $p < 0.01$), which emerged not only in connection with the application of pesticides on the experimental fields but also with respect to the research year (Fig. 2). Detailed ANOSIM analysis for individual objects also confirmed the significance of differences between them, except for two combinations: NCP 2016 with CP 2016 and CP 2016 with CP 2012 (Table 4).

The most numerous species living in the sugar beet crops were *Harpalus rufipes*, which made up nearly 56% of all captured ground beetles, followed by *Pterostichus melanarius* (9.52%), *Calathus ambiguus* (4.88%) and *Bembidion properans* (4.55%) (Table 2). The most numerous Carabidae species were noted on both chemically protected and unprotected fields, and they constituted over 70% of ground beetle assemblages in the analyzed variants of the study.

Table 2. Species composition and number of individuals of carabids collected in the analyzed study fields with or without chemical treatments.

Species	Abbreviation	Ecological description	Chemically treated				Non-treated			
			2004	2008	2012	2016	2004	2008	2012	2016
<i>Amara aenea</i> (Degeer,1774)	Am_aen	Ph/Sb/Mpt	1	1	1	5	0	1	1	1
<i>Amara apricaria</i> (Paykull,1790)	Am_apr	Hzi/Ab/Mpt	0	0	1	0	0	0	0	0
<i>Amara bifrons</i> (Gyllenhal,1810)	Am_bif	Hzi/Ab/Mpt	7	3	2	1	1	5	4	7
<i>Amara communis</i> (Panzer,1797)	Am_com	Hzi/Sb/Mpt	1	0	0	1	0	0	0	1
<i>Amara consularis</i> (Dufschmid,1812)	Am_cons	Hzi/Ab/Mpt	0	1	1	0	0	0	1	0
<i>Amara convexior</i> Stephens,1828	Am_conv	Hzi/Sb/Mpt	0	0	0	1	0	3	3	3
<i>Amara ovata</i> (F.,1792)	Am_ova	Hzi/Sb/Mpt	0	1	0	1	0	0	1	0
<i>Amara plebeja</i> (Gyllenhal,1810)	Am_ple	Ph/Sb/Mpt	0	0	0	3	0	0	1	3
<i>Amara similata</i> (Gyllenhal,1810)	Am_sim	Ph/Sb/Mpt	1	0	0	9	3	0	3	7
<i>Amara spreta</i> Dejean,1831	Am_spr	Hzi/Sb/Mpt	0	0	0	0	1	0	0	0
<i>Anchomenus dorsalis</i> (Pontoppidan,1763)	An_dor	Mc/Sb/Mpt	1	0	0	4	2	0	6	6
<i>Bembidion femoratum</i> Sturm,1825	Be_fem	Sc/Sb/Mpt	11	12	13	4	3	3	15	2
<i>Bembidion lampros</i> (Herbst,1784)	Be_lam	Sc/Sb/Mpt	31	63	22	15	16	40	14	36
<i>Bembidion properans</i> (Stephens,1828)	Be_pro	Sc/Sb/Mpt	82	146	28	55	90	70	13	56
<i>Bembidion pygmaeum</i> (F.,1792)	Be_pyg	Sc/Sb/Dim	0	1	0	0	0	0	0	0
<i>Bembidion quadrimaculatum</i> (L.,1761)	Be_qua	Sc/Sb/Mpt	8	25	55	14	12	41	78	26
<i>Bembidion tetracolum</i> Say,1823	Be_tet	Sc/Sb/Dim	11	50	30	7	13	15	31	10
<i>Brosicus cephalotes</i> (L.,1758)	Br_cep	Lc/Ab/Mpt	2	0	0	0	1	0	0	0
<i>Calathus ambiguus</i> (Paykull,1790)	Ca_amb	Mc/Ab/Mpt	21	136	19	53	17	216	35	83
<i>Calathus cinctus</i> Motschulsky,1850	Ca_cin	Mc/Ab/Dim	0	88	5	4	5	124	15	9
<i>Calathus erratus</i> (Sahlberg,1827)	Ca_err	Mc/Ab/Dim	10	9	14	11	9	18	0	4
<i>Calathus fuscipes</i> (Goeze,1777)	Ca_fus	Mc/Ab/Dim	12	65	4	44	8	94	45	66

Table 2 (continued)

Species	Abbreviation	Ecological description	Chemically treated				Non-treated			
			2004	2008	2012	2016	2004	2008	2012	2016
<i>Calathus halensis</i> (Schaller,1783)	Ca_hal	Lc/Ab/Mpt	26	4	13	20	41	0	158	31
<i>Calathus melanocephalus</i> (L.,1758)	Ca_mel	Mc/Ab/Dim	0	45	11	33	2	28	8	39
<i>Calathus micropterus</i> (Duftschmid,1812)	Ca_mic	Mc/Ab/βpt	1	0	0	0	0	0	0	0
<i>Calosoma auropunctatum</i> (Herbst,1784)	Ca_aur	Lc/Sb/Mpt	3	0	0	1	0	0	3	0
<i>Carabus cancellatus</i> Illiger, 1798	Ca_can	Lc/Sb/βpt	1	0	0	0	3	0	0	1
<i>Carabus coriaceus</i> L.,1758	Ca_cor	Lc/Ab/βpt	0	0	0	0	0	0	7	1
<i>Cicindella hybrida</i> L.,1758	Ci_hyb	Mc/Sb/Mpt	0	0	1	0	0	1	1	1
<i>Clivina fossor</i> (L.,1758)	Cl_fos	Mc/Sb/Dim	8	6	2	16	0	2	9	4
<i>Curtonotus aulicus</i> (Panzer,1797)	Cu_aul	Hz/Ab/Mpt	0	1	0	0	0	0	3	2
<i>Harpalus affinis</i> (Schränk,1781)	Ha_aff	Hz/Sb/Mpt	74	39	5	32	30	27	23	25
<i>Harpalus autumnalis</i> (Duftschmid,1812)	Ha_aut	Hz/Sb/Mpt	0	0	0	3	0	0	0	3
<i>Harpalus calceatus</i> (Duftschmid,1812)	Ha_cal	Hz/Ab/Mpt	0	0	1	0	0	0	0	0
<i>Harpalus distinguendus</i> (Duftschmid,1812)	Ha_dis	Hz/Sb/Mpt	2	0	0	0	0	0	0	2
<i>Harpalus griseus</i> (Duftschmid,1812)	Ha_gri	Hz/Ab/Mpt	2	14	14	1	2	11	4	4
<i>Harpalus luteicornis</i> (Duftschmid,1812)	Ha_lut	Hz/Ab/Mpt	1	0	0	0	0	0	0	0
<i>Harpalus rubripes</i> (Duftschmid,1812)	Ha_rub	Hz/Sb/Mpt	0	0	3	0	0	0	0	0
<i>Harpalus rufipes</i> (De Geer,1774)	Ha_ruf	Hz/Ab/Mpt	301	1366	660	701	168	1218	1720	514
<i>Harpalus signaticornis</i> (Duftschmid,1812)	Ha_sig	Hz/Sb/Mpt	6	1	0	5	1	8	3	0
<i>Harpalus smaragdinus</i> (Duftschmid,1812)	Ha_sma	Hz/Sb/Mpt	6	0	0	1	2	2	2	0
<i>Harpalus tardus</i> (Panzer,1797)	Ha_tar	Hz/Sb/Mpt	2	6	2	1	0	7	0	0
<i>Loricera pilicornis</i> (Duftschmid,1812)	Lo_pil	Mc/Sb/Mpt	0	0	0	0	0	0	4	0
<i>Microlestes minutulus</i> (Goeze,1777)	Mi_min	Sc/Sb/Dim	0	10	13	0	4	7	26	22

Table 2 (continued)

Species	Abbre- viation	Ecological description	Chemically treated				Non-treated			
			2004	2008	2012	2016	2004	2008	2012	2016
<i>Poecilus cupreus</i> (L.,1758)	Po_cup	Mc/Sb/Mpt	6	33	24	15	8	17	62	21
<i>Poecilus lepidus</i> (Leske,1785)	Po_lep	Mc/Sb/Dim	9	7	4	4	8	1	17	2
<i>Poecilus punctulatus</i> (Schaller,1783)	Po_pun	Mc/Sb/Mpt	1	9	0	0	0	1	0	5
<i>Poecilus versicolor</i> (Sturm,1824)	Po_ver	Mc/Sb/Mpt	0	1	0	0	0	0	5	0
<i>Pterostichus melanarius</i> (Illiger,1798)	Pt_mel	Lc/Ab/Dim	61	422	36	103	28	236	42	203
<i>Synuchus vitalis</i> (Illiger,1798)	Sy_viv	Mc/Ab/Dim	0	1	0	0	1	0	0	0
<i>Trechus quadristriatus</i> (Schränk, 1781)	Tr_qua	Sc/Ab/Dim	11	135	2	3	6	42	0	9
<i>Zabrus tenebrioides</i> (Goeze,1777)	Za_ten	Hz/Ab/Mpt	0	3	1	0	0	3	1	0
Total number of individuals	720	2704	987	1171		485	2364	1209		
	5582		6299							
Total number of species	32	32	29	32		28	35	34		
	50		46							

* Ph = phytophages, Hz = hemizoophages, Lc = large carnivores, Mc = medium carnivores, Sc = small carnivores, Sb = spring breeders, Ab = autumn breeders, Mpt = macropterous, Dim = dimorphic, Bpt = brachypterous

Table 3. Results of the GLM test of significance (Wald statistics = WS) of sugar beet protection form in years of study on abundance, number of species and some life history traits of ground beetles.

		WS	<i>p</i>
Abundance	Protection	43.22	0.000
	Year	62.69	0.000
Species number	Protection	0.25	0.619
	Year	1.83	0.176
Hemizoophages	Protection	41.05	0.000
	Year	95.42	0.000
Large carnivores	Protection	2.74	0.098
	Year	4.43	0.035
Medium carnivores	Protection	42.03	0.000
	Year	8.59	0.003
Small carnivores	Protection	15.78	0.000
	Year	24.42	0.000
Macropterous	Protection	68.64	0.000
	Year	74.20	0.000
Brachypterous	Protection	5.50	0.019
	Year	0.06	0.811
Dipterous	Protection	3.58	0.058
	Year	0.38	0.539
Spring breeders	Protection	2.93	0.087
	Year	4.32	0.038
Autumn breeders	Protection	64.33	0.000
	Year	93.49	0.000

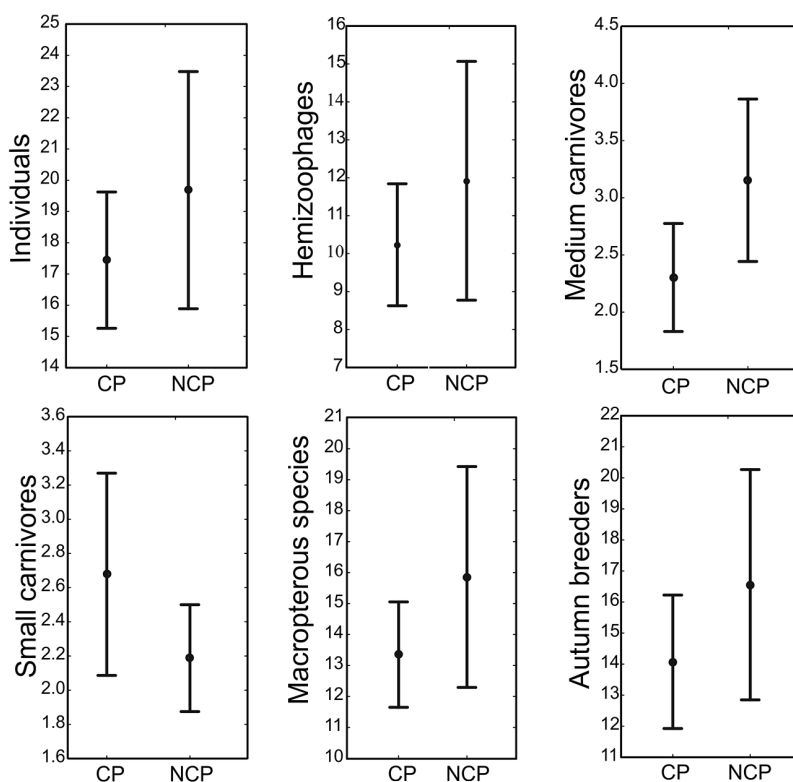
species were very sparse and therefore excluded from the analysis. The plant protection technology in the study years did not have a significant effect on the abundance of dipterous carabids but did influence the number of macropterous carabids (Table 3). Given the ability to disperse easily, macropterous carabids appeared in significantly greater numbers in fields without chemical plant protection (Fig. 1).

The canonical correspondence analysis (CCA) demonstrated statistically significant relationships between the analyzed assemblages of Carabidae and such environmental variables as the application of insecticides ($F = 5.14$; $p = 0.002$), application of fungicides ($F = 2.69$; $p = 0.002$), year of study ($F = 3.20$; $p = 0.002$),

Analysis of the effect of the variables on trophic groups indicated that the application of pesticides significantly affected the abundance of hemizoophages, and medium and small carnivores (Table 3). A significant decrease in the number of hemizoophages and medium carnivores was found in chemically protected fields, alongside a simultaneous increase in the number of small carnivores (Fig. 1). Due to their small number, phytophages were excluded from the above analysis. In terms of the different breeding types of ground beetles, it was determined that chemical protection had a significant effect on the number of carabids with the autumn type of breeding, which was significantly higher in the field not treated with pesticides (Fig. 1). The abundance of beetles with the spring type of breeding was not significantly affected by the plant protection technology and was dependent on the year of research (Table 3). In terms of dispersion capability, brachypterous spe-

Table 4. Results of the ANOSIM test of significance of sugar beet protection form in years of study on ground beetle assemblages.

Combination	Chemical plant protection				Without chemical plant protection			
	2004	2008	2012	2016	2004	2008	2012	2016
CP 2004		0	0	0.006	0.011	0	0	0
CP 2008	0	–	0.003	0	0	0.017	0	0
CP 2012	0	0.003	–	0.134	0	0	0.048	0
CP 2016	0.006	0	0.134	–	0	0	0.014	0.451
NCP 2004	0.011	0	0	0	–	0	0	0
NCP 2008	0	0.017	0	0	0	–	0	0
NCP 2012	0	0	0.048	0.014	0	0	–	0
NCP 2016	0	0	0	0.451	0	0	0	–

**Fig. 1.** Average abundance of ground beetles and carabids belonged to different ecological groups (hemizoophages, large carnivores, medium carnivores, small carnivores, macropterous and autumn breeders) depending on form of plant protection (CP = with applied pesticides, NCP = without chemical protection) in years of study in beet root crops

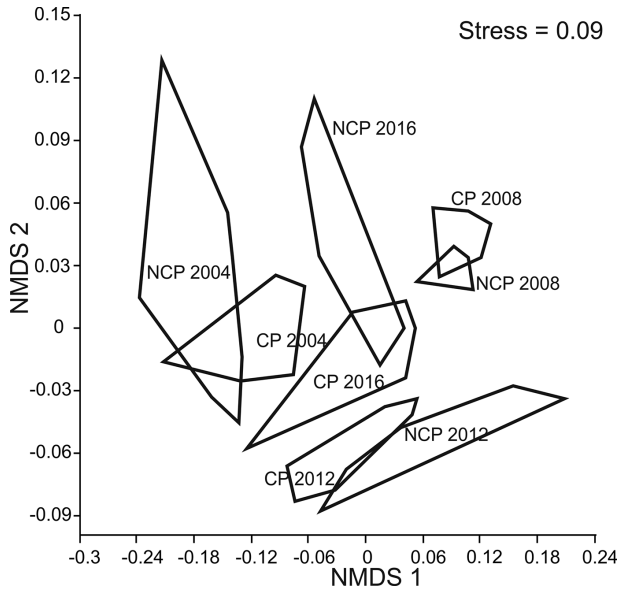


Fig. 2. Diagram of non-metric multidimensional scaling (NMDS) performed on the Bray-Curtis similarity matrix of ground beetles in years of study in different form of plant protection (CP = with chemical protection, NCP = without chemical protection)

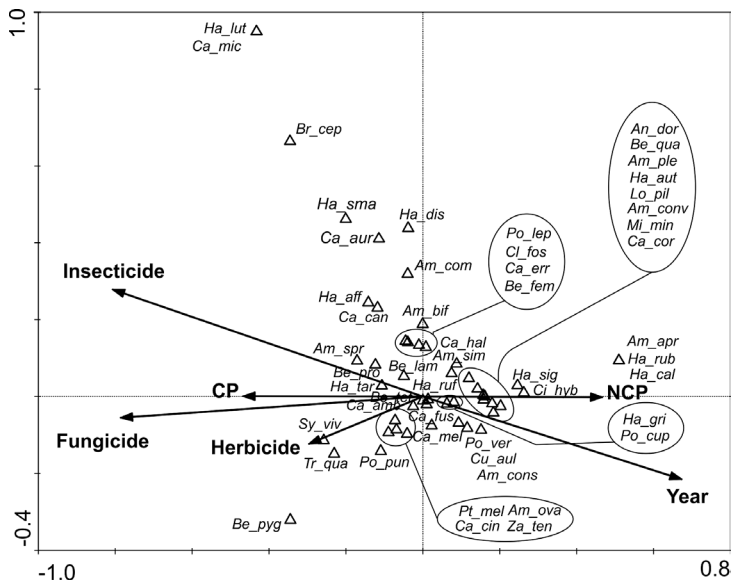


Fig. 3. Diagram of the CCA analysis demonstrating the relationships between the analyzed environmental variables: type of plant protection (CP = with chemical protection, NCP = without chemical protection), using of insecticides, herbicides, fungicides, year of study, and the species of Carabidae (abbreviations are listed in Table 1)

application of herbicides ($F = 2.77$; $p = 0.01$) and form of plant protection ($F = 2.988$; $p = 0.002$). The 1st and the 2nd ordination axes described 66.9% of the variation. The 1st axis (38.9% of the variation) was correlated with the form of plant protection (Fig. 3). Fields without chemical protection (NCP) were associated with a large number of ground beetle species, of which the following demonstrated the strongest correlation with the tested axis: *Cicindella hybrida*, *Harpalus signaticornis*, *Amara apricaria*, *Harpalus calceatus* and *Harpalus rubripes*. A reverse correlation with the 1st ordination axis was observed in the variant treated with plant protection chemicals (CP). The application of herbicides was correlated with the occurrence of carabids classified as small carnivores, *Trechus quadristriatus* and *Bembidion pygmeum* and medium carnivore *Synuchus vivalis*. The CCA diagram indicates that the majority of ground beetle species avoid fields in which chemical plant protection was used.

DISCUSSION

Our results demonstrated that ground beetles are more abundant in sugar beet fields without chemical plant protection (NCP), although in terms of species richness, the method of plant protection was no significant. The most abundant species in both types of the studied field was *Harpalus rufipes*, which constituted over 55% of the ground beetle assemblages in the fields studied. Analysis of particular life traits of ground beetles revealed higher abundance of hemizooophages and medium carnivores belonging to macropterid carabids with the autumn type of breeding in the non-chemical protected fields (NCP). Small carnivores were caught more frequently in chemically protected fields (CP).

Predatory carabids can contribute to natural plant protection against pests by considerably reducing their abundance (KROMP 1999, HOLLAND & LUFF 2000, HEIN *et al.* 2009, KOS *et al.* 2013). They appear in the early stage of the plant growing season and forage actively on different developmental phases of pests; hence their high number is desirable in crops. Root crops create a very specific microhabitat for insects (PURVIS & FADL 2002), mainly because of the low soil coverage, and they are exposed to the risk of pest infestation throughout the entire growing season. They are invaded by nematodes such as *Heterodera schachtii*, some beetles, e.g. *Atomaria linearis*, *Chaetocnema concinna* and larvae of the Elatheridae and Mellolontidae families, dipterans (*Pegomya hyoscyami*) and aphids (*Aphis fabae*) (COOKE 1991, GOLIZADEH *et al.* 2016, PRETORIUS *et al.* 2017, SABBOUR & SOLIEMAN 2019, WENNINGER *et al.* 2019). Ground beetles can help reduce pest numbers, especially in fields where chemical protection is not applied. This function was confirmed in our study, where a significantly higher abundance of ground beetles was observed in the fields without chemical protection. Our results also showed that the number of carabid beetles were different between the research years, which may have

related to more or less infestation by pests in some years, and therefore better food availability for ground beetles (BRODBECK *et al.* 2020).

Our growing ecological awareness, also regarding food production, encourages us to advocate in favour of limiting the use of factors that disturb ecosystems, for example, the application of pesticides (SCHMIDT-JEFFRIS & NAULT 2018). For years, there have been discussions about these agrichemicals, which have resulted in the design of more selective preparations, producing rapid but short-lasting effects, and which are less toxic to animals and do not accumulate in the environment. Besides, some legal regulations, e.g. pertaining to integrated pest management (officially promoted in the EU since 2014) in place of conventional pest control systems, are conducive to direct and indirect pressure on the management of agroecosystems. The NMDS analysis performed in this study on carabid assemblages in sugar beet fields did not show significant differences between Carabidae from fields with and without chemical pest control in 2016. The question arises whether this reflects the effect of the IPM implementation and reduced amounts of applied pesticides so that consequently the assemblages of ground beetles in chemically protected (CP) and non-protected (NCP) fields were closely similar to each other. The study reported in this paper provides the basis for further studies and analyses of this problem, including other crops as examples of habitats and other groups of invertebrates.

The number of species being similar in the chemically treated and not chemically protected sugar beet fields is an indicator of some stability of ground beetle assemblages in this crop, regardless of the application of plant protection chemicals. This may be due to migration of these ground beetles from adjacent fields after the adverse effects of pesticide application subside. On the other hand, mechanical weeding carried out in fields without chemical protection, could also be a factor unfavourable for some species of ground beetles. A study conducted by NIETUPSKI *et al.* (2015) in hazelnut plantations demonstrated that for carabids the best soil management to control weeds is to keep the soil fallow through either mechanical or chemical treatments. This shows that pesticides do not always have an adverse impact on the presence of Carabidae, and we should consider all possible factors influencing these insects. Some species appear more frequently in combinations where pesticides are used; in our research, they were, for example *S. vivalis* and *T. quadristriatus* (Fig. 3).

Some researchers point to the influence of a forecrop on ground beetle assemblages in agricultural crop fields (O'ROURKE *et al.* 2008, GAILIS *et al.* 2017). The fields included in our study are managed in a 4-year crop rotation system, where oilseed rape is always the forecrop for sugar beet. Some studies deal with Carabidae in oilseed rape fields (LANGMAACK *et al.* 2001, KOSEWSKA 2016), where similar numbers of species and species composition have

been reported to those detected in sugar beet fields. Both dominant species and remaining species of Carabidae in sugar beet crops are typical of fields in central-eastern Europe, which is confirmed by TAMUTIS *et al.* 2004, ALEKSANDROWICZ *et al.* 2008, KOSEWSKA *et al.* 2014, GAILIS *et al.* 2017. These authors state that the majority of ground beetle assemblages in the arable fields are composed of dominant species. Similar results provided by LUFF (2002), who described Carabidae in agricultural habitats and concluded that the five most numerous species corresponded to 84% of all ground beetles captured. In our study, the number of species and shares of dominant species was similar in both chemically protected and non-chemically protected fields of sugar beet. The dominant species in sugar beet fields included *H. rufipes*, which made up over half of all ground beetles caught, regardless of the type of plant protection method. Although *H. rufipes* is classified as a hemizoophage, feeding on mixed plant and animal food, its considerable size, coupled with abundant appearance, can contribute to reducing the masses of pests in plant fields (KOSEWSKA *et al.* 2016). Trophic preferences are an indicator of the availability and variety of food present. The presence of carnivores of different sizes is also evidence of rich food resources and the emergence of disturbances when one size class of carabids outlasts another. In this study, the majority of ground beetles consisted of hemizoophages, owing to the large share of *H. rufipes*. Large carnivores did not respond to the application of plant protection chemicals by changing their abundance. Hemizoophages and medium carnivores were more numerous in the field without chemical protection, while small carnivores appeared more numerous in the field treated with pesticides. This observation is confirmed by the CCA diagram, where the presence of small carnivores, such as *T. quadristriatus* and *B. pygmaeum*, is correlated with the application of herbicides.

Similar results were obtained by EYRE *et al.* (2012) in cereal crops. As suggested by KOSEWSKA *et al.* (2016), it is worth considering whether the success of small carnivores in fields with chemical plant protection is a consequence of their greater tolerance to chemical substances or weaker competition on behalf of other insects due to the application of pesticides and elimination of larger carnivores. According to NAVNTOFT *et al.* (2006), small carnivores are macropterous and, after the disturbance caused by an application of sprayed chemicals subsides, they can recolonize the affected field more rapidly. SHIBUYA *et al.* (2014) also claim that macropterous carabid beetles are more common in disturbed habitats. However, the current study shows that even macropterous carabid beetles preferred fields without chemical protection. Due to their dispersion abilities, they can react faster to unfavourable conditions by escaping. According to MEIJER (1974), the migration strategies of ground beetles may be various. Most species represent the emigration without the return model;

therefore, they may no longer present in the fields after disturbances such as the use of pesticides. Due to the energy budget, ground beetles with the autumn type of breeding are a desirable group in agrocenoses. They stay in the fields longer, and therefore they can prevent pest gradation for longer; but, as LOVEI & SUNDERLAND (1996) indicated, autumn breeders are more sensitive to disturbance. In our study, this thesis has also been confirmed: autumn breeders preferred fields without chemical protection.

CONCLUSIONS

The application of pesticides in sugar beet fields carried out for many years does not adversely affect the species richness of ground beetles but does influence their abundance and the structure of particular groups of these beneficial organisms. After the application of pesticides, the abundance of macropterous carabids with the autumn type of breeding decreases, together with hemizoophages and medium carnivores, while the abundance of small carnivores increases.

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