Michał JASIŃSKI[1], Jacek TWARDOWSKI[1], Iwona GRUSS[1], Marcin CIERPISZ[1], Ewa TENDZIAGOLSKA[2]
Uniwersytet Przyrodniczy we Wrocławiu
[1] Katedra Ochrony Roślin
[2] Katedra Kształtowania Agroekosystemów i Terenów Zieleni
pl. Grunwaldzki 24a, 50-363 Wrocław, Poland
e-mail: michal.jasinski@upwr.edu.pl

OCCURRENCE OF GROUND BEETLE ASSEMBLAGES (COLEOPTERA: CARABIDAE) IN ORGANIC NORFOLK CROP ROTATION

Summary

The aim of the study was to perform a quantitative and qualitative analysis of epigeic beetles assemblages of family Carabidae recorded in different crops within Norfolk crop rotation managed organically. Collecting of arthropods was made using soil traps in 2014-2016, at the Experimental Research Station Swojec of the Wrocław University of Environmental and Life Sciences and at the organic farm located in Kamieniec Wrocławski. In both sites the lowest number and the lowest species diversity of ground beetles was observed in potato crop. In remaining crops beetles were relatively abundant and numerous species were identified. On the basis of the results it may be assumed that organic management within Norfolk crop rotation creates favorable conditions for the development of studied organisms, and as a consequence increases their number, thus contributing to the increase in biological diversity of agroecosystems.
***Key words**: organic agriculture, organic crops, ground beetle, Norfolk crop rotation*

WYSTĘPOWANIE ZGRUPOWAŃ BIEGACZOWATYCH (COLEOPTERA: CARABIDAE) W UPRAWACH EKOLOGICZNYCH PŁODOZMIANU NORFOLSKIEGO

Streszczenie

Celem pracy była analiza ilościowa i jakościowa zgrupowań epigeicznych chrząszczy z rodziny Carabidae występujących w różnych uprawach płodozmianu norfolskiego, prowadzonych metodą ekologiczną. Odłowy stawonogów do pułapek glebowych prowadzono w latach 2014-2016, w Rolniczym Zakładzie Doświadczalnym Swojec, należącym do Uniwersytetu Przyrodniczego we Wrocławiu oraz w gospodarstwie ekologicznym w Kamieńcu Wrocławskim. W obu lokalizacjach najmniejszą liczebność i zróżnicowanie gatunkowe chrząszczy odnotowano w uprawie ziemniaka. W pozostałych uprawach biegacze występowały stosunkowo licznie i w dużej liczbie gatunków. Na podstawie uzyskanych wyników można przypuszczać, że zastosowanie płodozmianu typu norfolskiego, w warunkach gospodarowania ekologicznego, stwarza sprzyjające warunki do rozwoju badanych organizmów, a w konsekwencji zwiększa ich liczebność i przyczynia się do zwiększenia różnorodności biologicznej agrocenoz.
***Słowa kluczowe**: rolnictwo ekologiczne, biegaczowate, różnorodność biologiczna, płodozmian norfolski*

1. Introduction

The use of properly selected crop rotation is one of the most important components of ecological farming. Diversification of crop plants decreases pest presence and at the same time increases the number of beneficial organisms. Such action consequently contributes to increasing yield potential and improving crops quality [1].

Ground beetles are the most important beneficial organisms significantly reducing the pest number in agroecosystems. These arthropods lead epigeic lifestyle, have no trophic specialization and constitute high percentage share in total biomass of animals on the agricultural landscape [2, 3]. The physical and chemical properties of the soil have the strongest impact on their presence [4]. Their abundance increases where no chemical protection [5] and mineral fertilizers are used. Diversified crop rotation leading to the increase in organic matter content in soil, may also positively affect the abundance and species diversity of these organisms [6, 7]. Most of the ground beetles are obligatory carnivores (predators), less numerous are hemicarnivores feeding on diversified food and herbivores feeding mainly on plant material. The latest feed predominantly on seeds of plants, including segetal weeds [8, 9, 10]. The two first of above mentioned groups, as natural enemies of the pest populations, will directly affect their abundance [11]. The representatives of seed-feeding beetles have an important impact on the regulation of some weeds presence [2, 12]. Ground beetles, both as whole family, as well as particular species, show many abilities of good bioindicators. Also in crops, where they are more abundant, Carabidae are successfully used in assessment of changes caused by agrotechnical treatments [13, 14].

The aim of the study was to perform a quantitative and qualitative analysis of ground beetles assemblages recorded in organically managed crops within Norfolk crop rotation.

2. Material and methods

The experiment was conducted in two sites located in Lower Silesia, Poland, i.e. at the Experimental Research Station Swojec of the Wrocław University of Environmental and Life Sciences (51°07'02.4"N 17°08'25.2"E) and at the organic farm located in Kamieniec Wrocławski (51°05'37.7"N, 17°10'21.3"E). The distance between both sites was about 10 km. The study was carried out on crops growing on a light soil of the good-rye complex, where organic management lasted for ten years. Both in Swojec and Kamieniec the field experiment was carried out with the identical design and identical agrotechnical treatments performed at the same dates. The study was made on four different crop types: potato (variety Vineta), oat (variety Rajtar), fodder pea (variety

Roch) and winter rye (variety Dańkowskie Złote). The plants were cultivated on plots of the area 36 m^2 (8 × 4 m), placed randomly in 3 replicates. Only in potato, biopesticide Novodor SC reducing the occurrence of Colorado potato beetle was applied (based on *Bacillus thuringiensis* var. *tenebrionis*, registered for organic farming).

The epigeic arthropods were collected over three vegetation seasons with the use of Barber's traps. Each year the entomological material was collected with one week intervals from the beginning of May to the end of July. The trap was a plastic container with the size of 500 cm^3 (9 cm diameter and 14 cm height) dig into the soil to its surface on the middle part of each experimental plot. There were 12 traps (4 crops in 3 replications) in each of the site. The cover of the trap was plastic roof. To kill and preserve the arthropods the traps were filled with 100 ml of 100% ethylene glycol. In the laboratory the collected biological material was sorted and identified up to the species level according to Hùrka [15].

In the data analysis the total abundance of ground beetles and 10 most abundant species for each crop were calculated. Additionally beetles were classified to ecological groups (carnivores, hemicarnivores, omnivores and herbivores) and their share in each treatment was determined. For the data analysis the Statistica 12.5 and Microsoft Excel 2007 were used. In order to show the significant differences of beetles' abundance between treatments, the analysis of variance was used (ANOVA, $p \leq 0.05$). In the case of significant differences, the post-hoc HSD Tukey test was performed ($p \leq 0.05$). In the ecological analysis of beetles' assemblages, the following indices were calculated: Shannon-Weaver [16], Pielou [17] and Simpson [18]. Additionally, separately for each localization the species composition of the ground beetle assemblages in different crops was analyzed using the canonical correspondence analysis (CCA). All species found during three years of the study were included in the analysis. The ordination analysis was done using CANOCO version 4.5 [19]. The significance of the first canonical axis and all canonical axes was calculated with the Monte Carlo test ($p \leq 0.05$).

3. Results

3.1. The abundance and species composition

In 2014, in Swojec, 505 ground beetles were found (Table 1). These organisms were significantly more abundant in oat fields (196 individuals) and fodder pea (172). Significantly less beetles were recorded in winter rye (76) and potato (61). The highest number of species was found in fodder pea (22), in comparison to rye field (18), oat (16) and potato (13). In all crops the most abundant species were: *Pseudoophonus rufipes, Poecilus cupreus and P. lepidus.* In Kamieniec Wrocławski 595 beetles were caught. Beetles were present in the greatest number in oat treatments (238 individuals), then in rye and fodder pea (165 and 161 respectively) and less numerous in potato (31). The differences were not significant. The number of species caught within oat, pea and winter rye fields (25, 27 and 26, respectively) was significantly higher than in potato field (7). *P. rufipes* was the dominant species in all the treatments, the most numerous in in oat.

Table 1. The most numerous species of ground beetles found in different components of Norfolk crop rotation at two localities in 2014

Tab. 1. Najliczniejsze gatunki biegaczowatych odłowionych w poszczególnych komponentach płodozmianu norfolskiego w dwóch lokalizacjach w 2014 roku

Species	Preferences** habitat/food	SWOJEC				KAMIENIEC			
		P*	O	FP	WR	P	O	FP	WR
Pseudoophonus rufipes (De Geer, 1774)	c, p, a, hz	18	52	35	11	8	105	63	50
Poecillus cupreus (Linnaeus, 1758)	c, p, a, z	9	40	28	10		6	24	3
Poecillus lepidus (Leske, 1785)	c, p, a, x, z		37	22	9		29	10	2
Agonum sexpunctatum (Linnaeus, 1758)	c, a, p, hz		5				26	3	56
Harpalus affinis (Schrank, 1781)	c, p, a, poly	3	9	11	6		39	14	5
Bembidion properans (Stephens, 1828)	c, p, a, z	7	20	24	6	3	5	8	5
Bembidion quadrimaculatum (Linnaeus, 1761)	c, p, a, z	4	6	7	5	13	2		
Anchomenus dorsalis (Pontoppidan, 1763)	c, p, a, z		10	8	8	1	3	4	
Amara communis (Panzer, 1797)	c, p, ph				3				20
Broscus cephalotes (Linnaeus, 1758)	c, ps, s, p, x, z	4	3	8	2				
Bembidion femoratum (Sturm, 1825)	c, p, ri, hyg, hz	4		4		2			
Bembidion lampros (Herbst, 1784)	c, p, a, z			4	3	2			
Microlestes minutulus (Goeze, 1777)	c, p, s, hz	5				2			
Calathus ambiguus (Paykull, 1790)	c, p, a, hz		4					3	
Poecilus versicolor (Sturm, 1824)	c, a, p, hz						3		2
Calathus erratus (C.R. Sahlberg, 1827)	c, p, xer, hz						4		
Amara similata (Gyllenhal, 1810)	c, p, a, ph	1						4	
Calathus fuscipes (Goeze, 1777)	c, p, a, hz							4	
Dolichus halensis (Schaller, 1783)	c, a, p hz								3
Clivina fossor (Linnaeus, 1758)	c, p, a, hz	2							
Amara equestris (Duftschmid, 1812)	c, a, p, x, hz								2
Remaining species		4	10	21	13	0	16	24	17
Total		61b***	196a	172	76b	31	238	161	165
No. species		13	16	22	18	7	25	27	26
Simpson - Index D		0.87	0.84	0.89	0.92	0.76	0.75	0.81	0.78
Shannon - Weaver Index H'		2.20	2.09	2.47	2.62	1.58	1.91	2.31	2.02
Pielou Index J'		0.60	0.52	0.55	0.63	0.56	0.41	0.48	0.43

Source: own work / Źródło: opracowanie własne

* Norfolk crop rotation components (p - potato, o - oat, fp - fodder pea, wr - winter rye)

** preferences of habitat and feeding (c - common species, p - pratinicolous, a - agrocenosis, ps - psammophilous, s - subterranean, x - xerothermophilous, hyg - hygrophil, ri - ripicolous, z - zoophagous, hz - hemizoophagous, poly - polyphagous, ph - phytophagous)

*** significant differences were marked with different small letters. The differences were calculated separately for crops in Swojec and Kamieniec Wrocławski (ANOVA, $p \leq 0.05$)

Table 2. The most numerous species of ground beetles found in different components of Norfolk crop rotation at two localities in 2015

Tab. 2. Najliczniejsze gatunki biegaczowatych odłowionych w poszczególnych komponentach płodozmianu norfolskiego w dwóch lokalizacjach w 2015 roku

Species	Preferences** habitat/food	SWOJEC				KAMIENIEC			
		P*	O	FP	WR	P	O	FP	WR
Pseudoophonus rufipes (De Geer, 1774)	c, p, a, hz	10	147	112	85	35	214	125	179
Poecillus cupreus (Linnaeus, 1758)	c, p, a, z	5	13	54	30	33	39	97	83
Harpalus affinis (Schrank, 1781)	c, p, a, poly	3	27	26	26	8	42	24	56
Poecillus lepidus (Leske, 1785)	c, p, a, x, z	3	29	19	14	4	11		42
Bembidion quadrimaculatum (Linnaeus, 1761)	c, p, a, z	13	12	19	6	7		6	
Bembidion properans (Stephens, 1828)	c, p, a, z	1	7	20	5	6	35	49	22
Broscus cephalotes (Linnaeus, 1758)	c, ps, s, p, x, z	16		8					
Anchomenus dorsalis (Pontoppidan, 1763)	c, p, a, z		20				61	30	59
Bembidion lampros (Herbst, 1784)	c, p, a, z	1	8	7		5	24	42	
Harpalus tardus (Panzer, 1797)	c, p, a, poly		6		6				10
Calathus fuscipes (Goeze, 1777)	c, p, a, hz				10				
Bembidion femoratum (Sturm, 1825)	c, p, ri, hyg, hz	2		5		5		20	
Calathus melanocephalus (Linnaeus, 1758)	c, a, p, hz				7				
Calathus ambiguus (Paykull, 1790)	c, p, a, hz		6						
Dolichus halensis (Schaller, 1783)	c, a, p hz			5			23		
Poecilus versicolor (Sturm, 1824)	c, a, p, hz				5			20	
Microlestes minutulus (Goeze, 1777)	c, p, s, hz	3							
Anisodactylus binotatus (Fabricius, 1792)	c, hyg, p, hz					5			
Clivina fossor (Linnaeus, 1758)	c, p, a, hz					4	10		19
Agonum sexpunctatum (Linnaeus, 1758)	c, a, p, hz						15	20	64
Amara aenea (De Geer, 1774)	c, p, a, ph								20
Remaining species		4	31	27	29	21	80	31	94
Total		61b***	306a	302a	223	133b	554a	464	648a
No. species		14	26	23	26	26	35	30	39
Simpson - Index D		0.84	0.74	0.81	0.81	0.85	0.82	0.85	0.87
Shannon - Weaver Index H'		2.14	2.05	2.17	2.28	2.46	2.38	2.30	2.57
Pielou Index J'		0.56	0.44	0.48	0.48	0.52	0.46	0.47	0.49

Source: own work / Źródło: opracowanie własne

*Norfolk crop rotation components (p - potato, o - oat, fp - fodder pea, wr - winter rye)

**preferences of habitat and feeding (c - common species, p - pratinicolous, a - agrocenosis, ps - psammophilous, s - subterranean, x - xerothermophilous, hyg - hygrophil, ri - ripicolous, z - zoophagous, hz - hemizoophagous, poly - polyphagous, ph - phytophagous)

***significant differences were marked with different small letters. The differences were calculated separately for crops in Swojec and Kamieniec Wrocławski (ANOVA, p≤0.05)

In 2015, in Swojec, the ground beetles were significantly more abundant in oat and in fodder pea (306 and 302 individuals respectively) in comparison to potato (62) (Table 2). The highest number of species was found in three crops (oat – 26, fodder pea – 23 and winter rye – 26) in comparison to potato (14). *P. rufipes* was again the most abundant species, especially in oat and fodder pea.

In Kamieniec Wrocławski in winter rye and oat significantly greater number of ground beetles was collected in comparison to potato (648, 554 and 133, respectively). The number of species was quite equal in all crops and ranged from 39 (in rye) to 26 (in potato). The dominant species *P. rufipes* was the most numerous in oat field.

In 2016, in Swojec, the ground beetles were most abundant in fodder pea (391 individuals), then in oat (272) and winter rye (176) and the least numerous in potato (97) (Table 3). Taking into account the number of species, the highest diversity was found in fodder pea and oat (23 and 20 respectively) in comparison to rye (17) and potato (16). The dominant species was again *P. rufipes*, present in the highest number within fodder pea treatments. In Kamieniec Wrocławski ground beetles were the most abundant in rye (409 individuals) and oat (358) in comparison to pea (284) and potato (185). Similar trend was noted in the number of identified species, which were considerably more abundant in rye and oat (30 and 25 respectively) in comparison to fodder pea (20) and potato (16). There were observed two dominant species, i.e.: *P. rufipes*, more abundant in rye, fodder pea and oat in comparison to potato and *Harpalus affinis*, the most abundant in rye crop.

3.2. The ecological analysis of ground beetle assemblages

In 2014, in Swojec, the achieved values of ecological indices were relatively homogenous (Table 1). The Simpson index ranged from 0.84 (in oat) to 0.92 (in rye). The value of Shannon-Weaver index was between 2.62 (in rye) and 2.09 (in oat). Only the Pielou index, which indicates the uniformity of species distribution, was significantly higher in rye (0.63) and potato (0.60) in comparison to fodder pea (0.55) and oat (0.52). In Kamieniec Wrocławski, the Simpson species diversity index ranged from 0.75 (in oat) to 0.81 (in fodder pea). The species diversity measured with Shannon-Weaver index was substantially lower in potato and oat (0.75 and 0.76 respectively) in comparison to rye and pea (0.81 and 0.78 respectively). The Pielou index ranged from 0.41 (in potato) to 0.56 (in oat). The next year of the study (2015) was distinctly more favorable for studied arthropods (Table 2). The Simpson index in Swojec, in potato field (0.84), fodder pea (0.81) and rye (0.81) was distinctly higher in comparison to oat (0.74). The Shannon-Weaver index ranged from 2.05 in oat to 2.28 in winter rye. Slight differences were observed between potato (H'=2.14) and fodder pea (H'=2.17). In Kamieniec, the obtained Simpson index values were very similar to each other and ranged from 0.82 in potato, to 0.87 in winter rye. The Shannon-Weaver index was clearly higher in winter rye and potato (2.57 and 2.46) in comparison to oat and fodder pea (2.38 and 2.30 respectively). In 2016 the biodiversity indices were significantly different between particular treatments of the Norfolk crop rotation (Table 3). In Swojec, the highest Simpson index was calculated for potato (0.85) and the lowest for winter rye (0.67). The Shannon-Weaver index varied between 1.78 (in rye) to 2.21 (in potato). The homogeneity of species measured with Pielou index reached the highest value in potato crop (0.55), while the lowest in fodder pea (0.41). In Kamieniec Wrocławski differences similar to Swojec were observed. However, changes of Simpson's species diversity were lower and reached 0.83 for potato, 0.82 for oat and fodder pea and 0.78 for winter rye. The Shannon-Weaver index ranged from 2.06 (rye) to 2.21 (potato). Higher Pielou index of the species homogeneity was in potato and fodder pea (0.52 and 0.50) in comparison to oat (0.48) and rye (0.42).

Table 3. The most numerous species of ground beetles found in different components of Norfolk crop rotation at two localities in 2016
Tab. 3. Najliczniejsze gatunki biegaczowatych odłowionych w poszczególnych komponentach płodozmianu norfolskiego w dwóch lokalizacjach w 2016 roku

Species	Preferences** habitat/food	SWOJEC				KAMIENIEC			
		P*	O	FP	WR	P	O	FP	WR
Pseudoophonus rufipes (De Geer, 1774)	c, p, a, hz	28	134	209	98	35	121	103	135
Harpalus affinis (Schrank, 1781)	c, p, a, poly	6	26	24	6	13	80	37	121
Microlestes minutulus (Goeze, 1777)	c, p, s, hz	16	8	8		57	25	23	
Poecillus cupreus (Linnaeus, 1758)	c, p, a, z	4	18	44	11	9	9	38	
Bembidion quadrimaculatum (Linnaeus, 1761)	c, p, a, z	12	9	9	7	20	22	9	
Amara aenea (De Geer, 1774)	c, p, a, ph	2	7			2	12	6	53
Bembidion properans (Stephens, 1828)	c, p, a, z			12	6	8	20	19	9
Bembidion lampros (Herbst, 1784)	c, p, a, z					9	18	11	10
Harpalus tardus (Panzer, 1797)	c, p, a, poly	2	10	13	4			5	6
Poecillus lepidus (Leske, 1785)	c, p, a, x, z	2	14	11				8	5
Calathus ambiguus (Paykull, 1790)	c, p, a, hz	6		20	12				
Anchomenus dorsalis (Pontoppidan, 1763)	c, p, a, z		9	8	11		10		
Bembidion femoratum (Sturm, 1825)	c, p, ri, hyg, hz					24	7		
Broscus cephalotes (Linnaeus, 1758)	c, ps, s, p, x, z	12	7		4				
Agonum sexpunctatum (Linnaeus, 1758)	c, a, p, hz								13
Amara similata (Gyllenhal, 1810)	c, p, a, ph								9
Calathus fuscipes (Goeze, 1777)	c, p, a, hz				8				
Clivina fossor (Linnaeus, 1758)	c, p, a, hz								8
Amara apricaria (Paykull, 1790)	c, p, a, x, ph					2			
Remaining species		7	30	33	9	6	34	25	40
Total		97	272	391	176	185	358	284	409
No. species		16	20	23	17	16	25	20	30
Simpson - Index D		0.85	0.73	0.69	0.67	0.83	0.82	0.82	0.78
Shannon - Weaver Index H'		2.21	2.02	1.88	1.78	2.07	2.21	2.17	2.06
Pielou Index J'		0.55	0.47	0.41	0.43	0.52	0.48	0.50	0.42

*Norfolk crop rotation components (p - potato, o - oat, fp - fodder pea, wr - winter rye) *Source: own work / Źródło: opracowanie własne*

** preferences of habitat and feeding (c - common species, p - pratinicolous, a - agrocenosis, ps - psammophilous, s - subterranean, x - xerothermophilous, hyg - hygrophil, ri - ripicolous, z - zoophagous, hz - hemizoophagous, poly - polyphagous, ph – phytophagous

Table 4. Ecological analysis of ground beetles assemblages
Tab. 4. Analiza ekologiczna zgrupowań biegaczowatych

Group	Year	SWOJEC				KAMIENIEC			
		P*	O	FP	WR	P	O	FP	WR
Trophic structure (%)									
Zoophagous	2014	0.41	0.61	0.56	0.59	0.55	0.21	0.34	0.07
	2015	0.64	0.31	0.45	0.33	0.71	0.35	0.54	0.38
	2016	0.32	0.24	0.25	0.24	0.25	0.23	0.32	0.08
Hemizoophagous	2014	0.52	0.34	0.35	0.28	0.45	0.59	0.52	0.75
	2015	0.31	0.55	0.43	0.49	0.24	0.53	0.39	0.48
	2016	0.57	0.58	0.63	0.70	0.76	0.47	0.52	0.42
Polyphagous	2014	0.05	0.06	0.08	0.12	0.00	0.17	0.09	0.04
	2015	0.03	0.12	0.09	0.15	0.04	0.10	0.06	0.11
	2016	0.09	0.14	0.10	0.06	0.08	0.24	0.13	0.32
Phytophagous	2014	0.02	0.00	0.01	0.01	0.00	0.03	0.06	0.14
	2015	0.02	0.02	0.03	0.03	0.01	0.02	0.01	0.04
	2016	0.02	0.04	0.03	0.01	0.03	0.06	0.03	0.18
Habitat preferences (%)									
Eurytopic	2014	0.85	0.80	0.77	0.82	0.94	0.83	0.89	0.94
	2015	0.90	0.86	0.90	0.87	0.92	0.91	0.93	0.87
	2016	0.80	0.88	0.90	0.95	0.86	0.95	0.96	0.95
Waterside	2014	0.07	0	0.02	0	0.06	0.01	0.02	0.01
	2015	0.03	0.01	0.02	0	0.03	0.02	0.05	0.01
	2016	0.02	0	0	0	0.13	0.02	0.01	0.01
Field-meadow	2014	0.08	0.20	0.19	0.18	0	0.16	0.09	0.05
	2015	0.07	0.13	0.08	0.12	0.05	0.05	0.02	0.11
	2016	0.18	0.13	0.10	0.05	0.01	0.03	0.03	0.04
Forest	2014	0	0	0.01	0	0	0	0	0
	2015	0	0.01	0	0.02	0	0.02	0.01	0.01
	2016	0	0	0	0	0	0	0	0

*Norfolk crop rotation components (P - potato, O - oat, FP - fodder pea, WR - winter rye) *Source: own work / Źródło: opracowanie własne*

During three years of the study and in all treatments eurytopic species predominated (more than 80% of all beetles) (Table 4). Among them there were common species such as *P. rufipes*, *P. cupreus*, *H. affinis* and the representatives from *Bembidion* genus. Significantly less abundant group of ground beetles did species prefer grassy habitat. Due to the soil moisture and crops characteristic these beetles are present in oat, fodder pea and rye (especially in Swojec). It can be observed that among the described species, there is a small share of hygrophilous species, which were mainly found in Kamieniec Wrocławski. The group with the smallest share (due to the character of crops) was species typical for forest ecosystem. Among them, the most common are carnivores of the *Carabus* and *Calosoma* genus. Very large group within the collected arthropods were hemicarnivores, which are non-selective predators, but with the ability to reduce weeds occurrence. *P. rufipes,* characterized by the ability of seed-feeding was common species present in great number. In 2016, in the ground beetle assemblages, the highest share had omnivores, while the smallest- herbivores. They were most numerous in winter rye field in Kamieniec (18%).

The CCA diagram of species assemblages in Swojec shows the uneven distribution of species depending on the year of the study (correlated with I ordinate) and tested crops (II ordinate) (Fig. 1). The eigenvalues for the first to axes were 0.165 and 0.141. The Monte Carlo test showed the high significance of the first canonical axis (p=0.002) and all axes together (0.002). It can be seen, that potato had a negative impact on the presence of the most of ground beetles species in comparison to remaining crops. Winter rye, oat and pea were positively correlated with the abundance of Carabidae species.

In Kamieniec Wrocławski the Carabidae species were distributed fairly evenly in the gradient of testes species and year of study (Fig. 2). The eigenvalues were 0.432 and 0.470. The Monte Carlo test showed the high significance of the first canonical axis (p=0.002) and all axes together (0.002). The potato crop, correlated with the first ordinate, had a negative impact on the presence of most of ground beetle species. The positive effect was found in the case of winter rye and oat. The fodder pea had the least impact on the ground beetles assemblages.

4. Discussion

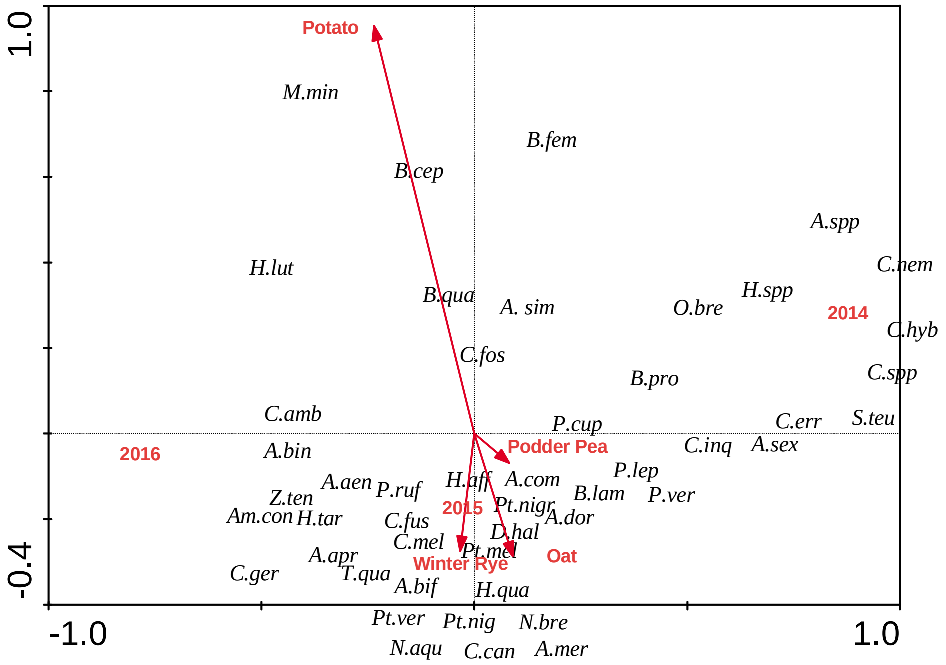
The intensification of conventional farming is primarily based on the increasing amount of mineral fertilization and pesticides used. The excessive use of some substances may negatively affect the environment and biodiversity of organisms living in agroecosystems. Organic farming is one of the ways of sustainable development. By this definition organic farming should create the optimal conditions for fauna and flora and, in some cases, should increase the biodiversity level [20]. Pffifner and Luka [2] have proven that organic crops can significantly increase the number of ground beetles within agrocenoses. Purtauf et al. [21] stated that the management type itself is not as important as the area surrounding the arable fields. Our studies were performed in two sites, differed between each other by the surrounding. More trees and shrubs were grown in Kamieniec Wrocławski, thus they could create more favorable habitat for majority of species. Thiele [9] in his research observed, that in the annual crops cultivated in Central Europe, the number of ground beetle species ranged from 20 to 35. In this study the number of species in oat and winter rye indicates the higher species diversity. The analysis of species composition of ground beetles shows species with wide range of presence. The main eurytopic species, such as *P. rufipes, P. cupreus, H. affinis* are widespread and common also in other habitats in Poland [22, 23, 24, 25]. Also Labuyer et al. [25] indicate *P. rufipes* as the most dominant species. These authors also state that species mentioned in their study are very important hemicarnivores in arable fields and have a great impact on the decrease in seed number within the soil environment. Despite the above mentioned *P. rufipes*, *P. cupreus* was another important species. Marrec et al. [26] proved that this species was significantly more abundant in winter rape than in cereals. An important trophic group of ground beetles constituted carnivores which can significantly reduce pest abundance. Among them small carnivores as *Bembidion properans* and *B. lampros* occurred, commonly attacking aphids feeding on cultivated plants or *Broscus cephalotes* whose Colorado potato beetle is main food source. Booij and Noorlander [27] indicated that carnivorous species occurred more frequently in organic crops in comparison to conventional ones. On the other hand, Melnychuk et al. [28] found that organic farming is characterized by the higher diversity of predatory beetles. In our study the lowest number and species diversity of beetles were found in potato, while the highest in both cereal crops. Also Kosewska et al. [29] indicated the highest species diversity of ground beetles in cereals. It can be stated that potato cultivation creates unfavorable environment for ground beetles due to the way of cultivation, as well as less shade level during the most of the cultivation time. Gruss et al. [30] observed the negative impact on the presence of the most of mites groups living in the near-surface layer of soil. Also springtails [31] were less numerous in potato cultivation compared to winter rye. It is also worth to note that winter rye and oat crop are types with the highest values of ground beetles species diversity.

5. Conclusions

1. In all years of the study, both in Swojec and Kamieniec, the ground beetles were found in the greatest numbers in cereals (oat and winter rye). The least favorable habitat for studied insects was created by potato.

2. The greatest species diversity of ground beetles occurred in rye, while the lowest number of species was found in potato. The most numerous species found in cereals and fodder pea were: *Pseudoophonus rufipes, Poecilus cupreus* and *Harpalus affinis.* In potato the dominant species were: *P. rufipes, Broscus cephalotes* and the species from *Bembidion* genus.

3. The most numerous species of ground beetles in organic crops were included to hemicarnivores, which reduce the number of pests on plantation. Omnivores and herbivores were less numerous trophic groups of investigated beetle. Therefore, it can be concluded that organic farming favors the occurrence of beneficial ground beetles, capable to reduce pests' populations.



Source: own work / Źródło: opracowanie własne

Figure 1. Diagram of the CCA Canonical Correspondence Analysis demonstrating the relationships between the studied crops and Carabidae species at Swojec in 2014-2016

Rys. 1. Wykres CCA Kanonicznej Analizy Korespondencji przedstawiający zależności między badanymi uprawami a biegaczowatymi na Swojcu w latach 2014-2016

Source: own work / Źródło: opracowanie własne

Figure 2. Diagram of the CCA Canonical Correspondence Analysis demonstrating the relationships between the studied crops and Carabidae species at Kamieniec Wrocławski in 2014-2016

Rys. 2. Wykres CCA Kanonicznej Analizy Korespondencji przedstawiający zależności między badanymi uprawami a biegaczowatymi w Kamieńcu Wrocławskim w latach 2014-2016

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