ORIGINAL ARTICLE

Different soybean plant arrangements affect ground beetle assemblages

Marcin Cierpisz[1]*, Jacek Twardowski[1], Iwona Gruss[1], Marcin Kozak[2]

[1] Department of Plant Protection, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

[2] Institute of Agroecology and Plant Production, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

Vol. 59, No. 4: 441–450, 2019

DOI: 10.24425/jppr.2019.131263

Received: March 7, 2019
Accepted: May 7, 2019

*Corresponding address:
marcin.cierpisz@upwr.edu.pl

Abstract

It was expected that there would be a relationship between plant density and arrangement within soybean plantations and ground beetles due to changes of abiotic habitat conditions. The aim of this study was to determinate the effect of different plant arrangements of soybean plants on the abundance and species diversity of ground beetles (Coleoptera, Carabidae). The studies were conducted from 2015 to 2017 at the Experimental Research Station, Wrocław, Poland. The occurrence of beetles was examined on soybeans, growing in four different treatments: row spacing of 15 cm or 30 cm, and seeding density of 50 or 90 seeds per m^2. The experiment was conducted in a split-plot design in four replicates. Ground beetles were collected with 16 pitfall traps, with one trap in the middle part of each plot. The obtained results show that the general number of ground beetles was similar between the treatments. Some minor effects were found in species number, which was higher in the lower row spacing treatment. Only less abundant species were significantly affected. The most abundant species in all years and treatments were *Pseudoophonus rufipes*, *Harpalus affinis*, *Calathus fuscipes* and *Pterostichus melanarius*. The abundance of the above-listed common ground beetle species did not differ significantly between treatments.

Keywords: Carabidae, ground beetles, plant density, soybean

Introduction

Soybean is the most important crop plant from the Fabaceae family worldwide. Among all crops it ranks fourth according to cultivated area (125 million hectares, March 2018), just after wheat, corn and rice. In terms of profitability it is ranked third (the total value of soy meal sold in 2012 was USD 660 billion) (FAOSTAT 2017). The largest producers of soybean meal (as a product for animal feed) are the USA (32% of the global area), Brazil (23%), Argentina (16%), China (10%), India (9%) and Paraguay (2%). About 4% of the global soybean area belong to European countries, of which Ukraine is the largest producer (Masuda and Goldsmith 2009). According to data presented by the European Commission, in 2017 soybean production in the EU increased by 11% compared to 2016, and forecasts for the next 5 years indicate a further increase in the area of cultivation of this plant by up to 50% (European Commission 2019). In Poland, soybean has a very long tradition, because the first attempts to breed and grow this plant were taken in 1879. For a long time it was not possible to obtain varieties suitably adapted to Polish conditions. A breakthrough took place in the 1970s, when it became possible to obtain varieties with a high and stable yield potential, as well as adequate earliness and the placement of the first pod (Boros and Wawer 2016). At present, there are 17 varieties of soybean in the Research Centre for Cultivar Testing (COBORU), of which five have been registered in the last year (2018). Soybean has only relatively recently been cultivated more widely in Poland. It has begun to be more important in recent years thanks to the breeding of new varieties better adapted to local climatic conditions. The increase in the cultivated area of this plant recorded in the last 3 years in Poland (in 2017 it was 12 000 ha, three times more than in 2015) indicates its popularity (Domański *et al.* 2017; Śpiewak 2017; COBORU 2018). One of the important issues is the presence of insects associated with soybean. Currently, there are only a few studies on the occurrence of soybean pests in Poland (Tyczewska *et al.* 2014). Most of the research comes from countries that are leaders in global soybean meal production (Hartman *et al.* 2011; Musser *et al.* 2011). There is even less information on beneficial arthropods linked with soybean crops.

Ground beetles, including species diversity (Lövei 2008), are some of the most numerous and most common beneficial organisms in cultivated areas (Hlivko and Rypstra 2003; Fox *et al.* 2005; Getanjaly *et al.* 2015). The vast majority of species are predators, hunting for insects and other invertebrates, and often supplementing their diet with plant seeds. Ground beetles show a wide range of habitat requirements. Their relatively low diversity is demonstrated in areas used for agriculture. They form specific groups of a few species, often observed in large quantities (Honêk and Jarošik 2000). As numerous studies have shown (Oberholzer *et al.* 2003; Carrillo *et al.* 2007; Ghahari *et al.* 2009; Renkema *et al.* 2014), under appropriate conditions ground beetles can significantly reduce the occurrence of many pest species in various types of crops. It has been shown that the impact on species biodiversity and the number of ground beetles in agroecosystems are mainly due to the type of crop (Hurej and Twardowski 2006; Saska 2007; Hummel *et al.* 2012), the number and type of agrotechnical treatments (Twardowski 2010), the use of chemical plant protection products (Kosewska *et al.* 2016), non-cultivated landscape elements (forest edges, meadows, hedgerows, etc.) (Błaszkiewicz and Schwerk 2013; Fischer *et al.* 2013) and the area neighboring cultivated areas (Leslie *et al.* 2013). An important factor affecting the occurrence of beetles could be the density of the crop, because it will modify the microclimatic conditions (shading, humidity, temperature at ground level) in the area of cultivation (Akinkunmi *et al.* 2012; Pretorius *et al.* 2017). Due to their high sensitivity to pollution, ground beetles are often used as bioindicators of changes occurring in the soil environment (Rainio and Niemelä 2003). In terms of trophic specializations, zoophagous species dominate in the Carabidae family (both small and large species). A large part are hemicarnivores, which supplement the animal diet with seeds and other plant parts, and the rarest are phytophagous species (Twardowski *et al.* 2017). Also, the habitat preferences of ground beetles are very diverse. The most common are: forest species (e.g. species of the *Carabus* genus), meadow-forest species (e.g. *Pterostichus melanarius*, *Harpalus latus*), and meadow-field species (e.g. *Pseudoophonus rufipes* or *Poecilus cupreus*). Species from the latter group are most commonly found in agroecosystems (Voronin and Chumakov 2015).

Ground beetles belong to insects with various habitat preferences (Czerniakowski and Olbrycht 2004). Therefore, their response to the plant arrangements in arable fields might vary depending more on the habitat preferences of individual species than total abundance (Honek 1988). The response of beetles to lower or higher row spacing combined with two variants of seeding rate will be species specific.

The aim of this study was to determine the effect of different soybean plant arrangements under arable field conditions on the abundance and species diversity of ground beetles (Coleoptera, Carabidae).

Materials and Methods

Study area and experiment design

The field experiment was carried out during three growing seasons (2015–2017) as part of a wider research project at the Institute of Agroecology and Plant Production, Agricultural Experimental Station, Pawłowice, belonging to the University of Environmental and Life Sciences in Wrocław, Lower Silesia, Poland (51°1737’ N, 17°1176’ E). The epigeic fauna was collected throughout each of the growing seasons, i.e. from the beginning of soybean leaf development (BBCH 10) to the dormancy phase (BBCH 91–99). The experiment used a randomized block design in four replications in four plant density combinations (Table 1). The area of each of the 16 plots was 30 m^2 (3 m × 10 m).

Other crops (cereals and oil seed) neighbored the experimental fields. About 1 km to the south, there was a mid-field belt of woods. Five hundred meters north of the experimental field, there was a drainage ditch and a long belt of shrubs. These two ecological structures could play roles in the habitat edge for ground beetles.

Table 1. Description of experimental treatments in soybean cultivation

Treatment*	Code	Row spacing [cm]	Seeding rate [seeds per m^2]
15/50	A	15	50
15/90	B	15	90
30/50	C	30	50
30/90	D	30	90

*15/50 – 15 cm row spacing and 50 seeds per m^2
15/90 – 15 cm row spacing and 90 seeds per m^2
30/50 – 30 cm row spacing and 50 seeds per m^2
30/90 – 30 cm row spacing and 90 seeds per m^2

Table 2. Agrotechnical operations in soybean field during the study period 2015–2017

Agrotechnical operations	Year of treatment		
	14/15	15/16	16/17
Winter ploughing (3 plough furrow)	7.11.2014	17.11.2015	14.11.2016
Heavy harrow	15.03.2015	–	6.03.2017
Field cultivator + roller	23.03.2015	18.04.2016	20.04.2017, 24.04.2017
Pre-sowing fertilization	22.04.2015	22.04.2016	24.04.2017
Active harrow	23.03.2015	–	–
Sowing of soybean	22.04.2015	25.04.2016	24.04.2017
Herbicide: Sencor liquid (metribuzin) 0,55 $dm^3 \cdot ha^{-1}$	24.03.2015	–	–
Herbicide: Dispersion Afalon 450 SC (linuron) 1,5 $dm^3 \cdot ha^{-1}$	–	26.04.2016	–
Herbicide: Boxer 800 EC (prosulfocarb) 4,0 $dm^3 \cdot ha^{-1}$	–	–	27.04.2017
Herbicide: Select Super 120 EC (clethodim) 2,0 $dm^3 \cdot ha^{-1}$	–	–	19.05.2017
Herbicide: Corum 502,4 SL (bentazone and imazamox) 0,62 $dm^3 \cdot ha^{-1}$	–	19.05.2016	25.05.2017, 9.06.2017
Soybean harvest	12.09.2015	13.09.2016	29.09.2017*

*late harvest due to delayed sowing

Agrotechnical conditions

The soybean (*Glycine max* (L.) Merr.) variety used in the experiment was Merlin. The plants were cultivated on clay-loam soil. The forecrop was winter wheat. The wheat was harvested each year during the first ten days of August using a combine harvester with a mounted straw chopper (Table 2). Harvest residues were introduced into the soil using a grubber, followed by pre-harvest ploughing (November 10–20). In 2015 and 2016, soil levelling was carried out using a cultivating aggregate (spring cultivator + spring shaft). In the spring pre-sowing fertilization was applied in doses ($kg \cdot ha^{-1}$): 60 P_2O_5, 120 K_2O and 30 N. Soybeans were sown from April 20 to 30 with the use of a field seed drill. The sowing depth was 3–4 cm. Pre-emergence herbicide treatments were applied to reduce the occurrence of dicotyledonous weeds (active substance – linuron 450 $g \cdot l^{-1}$) at a dose of 1.5 $dm^3 \cdot ha^{-1}$. Chemical treatment against dicotyledonous weeds and some monocotyledons was performed on May 19 with benzonates and mazamox at a dose of 1.25 $dm^3 \cdot ha^{-1}$ combined with an adjuvant containing methyl oleate and fatty alcohol (Dash HC) at a dose of 0.6 $dm^3 \cdot ha^{-1}$. Neither insecticides nor fungicides were used throughout this experiment. The soybean were usually harvested at full maturity in the dormancy phase (BBCH 99) with a field plot harvester in the middle of September.

Sampling and identification of ground beetles

Ground beetles were collected using pitfall traps. Sixteen traps were used, with one trap in the middle part of each of the four plots (replicates) in each of the four treatments. Traps were emptied once a week from the beginning of the emergence of soybean (May 11–31) until full maturity of the soybeans (September 10–20). One trap consisted of a transparent 0.5 liter plastic container (9 cm diameter, and height 14.2 cm). Each trap was located in the middle of plots, placed into the ground with the top of the trap at the soil surface. Each container was filled 1/3rd with ethylene glycol (100% concentration), which caused the death and preservation of the collected arthropods. The traps were additionally secured with a plastic roof placed over the container, which protected them from falling leaves and rain. The collected specimens of beetles were counted and identified to the species level mainly using the Hůrka identification key (Hůrka 1996).

Data analysis

Statistical analyses were carried out separately for each of the 3 years of research, both for the total number of individuals and the number of selected species of ground beetles. The significance of differences was examined in the Statistica program, version 13.2. The GLM (general linear model) model was used for analysis. The data from all years of the study had unnominal distribution (Shapiro-Wilk test). The p-value in the tests was lower than 0.05, thus the hypothesis of normality was rejected. The explanatory variables were treatments (A – 15/50, B – 15/90, C – 30/50, D – 30/90), date (16 dates in 2015, 15 in 2016, and 11 in 2017) and the interaction between date and treatment ($p \leq 0.05$).

The species response of ground beetles in relation to the tested treatments is shown in redundancy analysis (RDA) graphs (Canoco, version 4.5) separately for each year of research. The treatment was included as the environmental factor. The occurrence of the four most abundant species (*P. rufipes*, *H. affinis*, *C. fuscipes* and *P. melanarius*), which accounted for more than 77% of the whole Carabidae community, was used for further analysis.

Results

Total abundance

A total of 10,919 ground beetles were caught during all years of the experiment (Table 3). The largest number of beetles was collected in 2016 – 3,791 individuals, fewer in 2015 – 3,661, and the least of all in 2017 – 3,467. The number of ground beetles did not differ significantly between experimental treatments (effect of treatment, $F = 0.2044$; $p = 0.89$), or in the case of interaction between treatment and date ($F = 1.2555$; $p = 0.30$). In all years of the study a significant influence of the date on the occurrence of the ground beetles was noticed. In 2015, the highest number of beetles (1,183 individuals) was found in treatment D (30 cm row spacing and 90 seeds per m^2) (1,183 individuals), the least in treatment C (30 cm row spacing and 50 seeds per m^2) (736 individuals). In 2016, the highest number of beetles was found in treatments B (15 cm row spacing and 90 seeds per m^2) (1,092 individuals) and A (15 cm row spacing and 50 seeds per m^2) (1,062 individuals). In 2017, the highest number of beetles was found in treatment A – 1,080 individuals, the least in treatment B –761 individuals.

Among the ground beetles collected during the 3 years of the experiment, 53 species were identified (Table 4). Most species were found in treatment A – 42 species. Less diversity was noted in treatment C – 38 species and D – 40 species. The smallest variety was characterized by treatment B. In 2015, significantly more species occurred in treatment A than in other treatments ($F = 6.0718$; $p = 0.001$).

Redundancy analysis (RDA) of ground beetles depending on the tested treatment

In 2015, the first RDA axis explained 91% of the variance, while the second axis explained 7.4% of the variance (Fig. 1). The treatment which had the greatest impact on the carabids was D, associated with the occurrence of species reaching high numbers (*P. rufipes*, *Calathus melanocephalus*, *P. cupreus*). Combination C was associated with the occurrence of species *Cicindela germanica*, *Amara aulica*, *Notiophilus aquaticus*, *Calathus erratus*). Treatments B and A showed similar effects on the beetle community. That means that row spacing was a factor of greater importance than the number of sown seeds. The species associated with those combinations were: *Harpalus tardus*, *Dolichus halensis* and *Ophonus azureus*.

In 2016, the first RDA axis explained 82.1% of the variance, while the second axis explained 16.9% of the variance (Fig. 2). On opposite sides of the first RDA axis species related to different row spacing have been arranged. Species: *Harpalus affinis*, *Microlestes minutulus*, *N. aquaticus* preferred spacing of 30 cm wide, while narrower spacing (15 cm) was preferred by: *P. cupreus*, *Bembidion lampros*, *Trechus quadristriatus*. On the opposite sides of the second ordinate axis

Table 3. Total number of individuals and species number of ground beetles

Treatment	A*	B	C	D	All treatments	Effect of treatment (*F*, *p*, *df*)	Effect of date (*F*, *p*, *df*)	Effect treatment** data (*F*, *p*, *df*)
2015								
Number of individuals	899	843	736	1,183	3,661	0.2044; 0.89, 3	22.8037; **0.000013**; 15	1.2555; 0.30; 45
Species number	26 a	23	22b	24	40	6.0718; 0.001; 3	0.0001; 0.99; 15	3.1801; **0.02**; 45
2016								
Number of individuals	1,062	1,092	821	816	3,791	0.0366; 0.99; 3	18.6028; **0.00007**; 14	0.20392; 0.89; 32
Species number	30	26	32	26	47	0.4656; 0.71; 3	2.419; 0.12; 14	0.5432; 0.60; 32
2017								
Number of individuals	1,080	761	774	852	3,467	0.1681; 0.92;3	11.7738; **0.001**; 10	0.5069; 0.68; 30
Species number	25	25	24	26	40	1.0307; 0.38; 3	8.6275; **0.004**; 10	0.1839; 0.91, 30
Total in 3 years								
Number of individuals					10,919			
Species number					53			

*code see Table 1
**GLM analysis results (general linear model)
The values which show significant effects ($p \leq 0.05$) are marked in bold
Different lower case letters in rows indicate significant differences between treatments ($p \leq 0.05$, GLM)

Table 4. The abundance of the most numerous beetle species during the three years of the study

Species	A*		B		C		D		Total
	No.	%	No.	%	No.	%	No.	%	
2015									
Pseudoophonus rufipes	342	38.0	334	39.6	352	47.8	491	41.5	1,519
Harpalus affinis	181	20.1	157	18.6	144	19.6	217	18.3	699
Calathus fuscipes	176	19.6	163	19.3	119	16.2	227	19.2	735
Pterostichus melanarius	81	9.0	93	11	57	7.7	83	7.0	314
2016									
Pseudoophonus rufipes	689	64.8	629	57.6	490	59.7	472	57.8	2,280
Harpalus affinis	81	7.6	77	7.1	99	12.1	75	9.2	332
Calathus fuscipes	18	1.7	13	1.2	14	1.7	14	1.7	59
Pterostichus melanarius	11	1.0	17	1.6	15	1.8	16	2.0	59
2017									
Pseudoophonus rufipes	422	39.1	250	32.9	276	35.6	310	36.4	1,258
Harpalus affinis	93	8.6	81	10.6	100	12.9	64	7.5	338
Calathus fuscipes	94	8.7	56	10.6	76	9.8	120	14.1	346
Pterostichus melanarius	65	6.0	54	7.1	41	5.3	68	8.0	228

*experimental treatments (see Table 1)

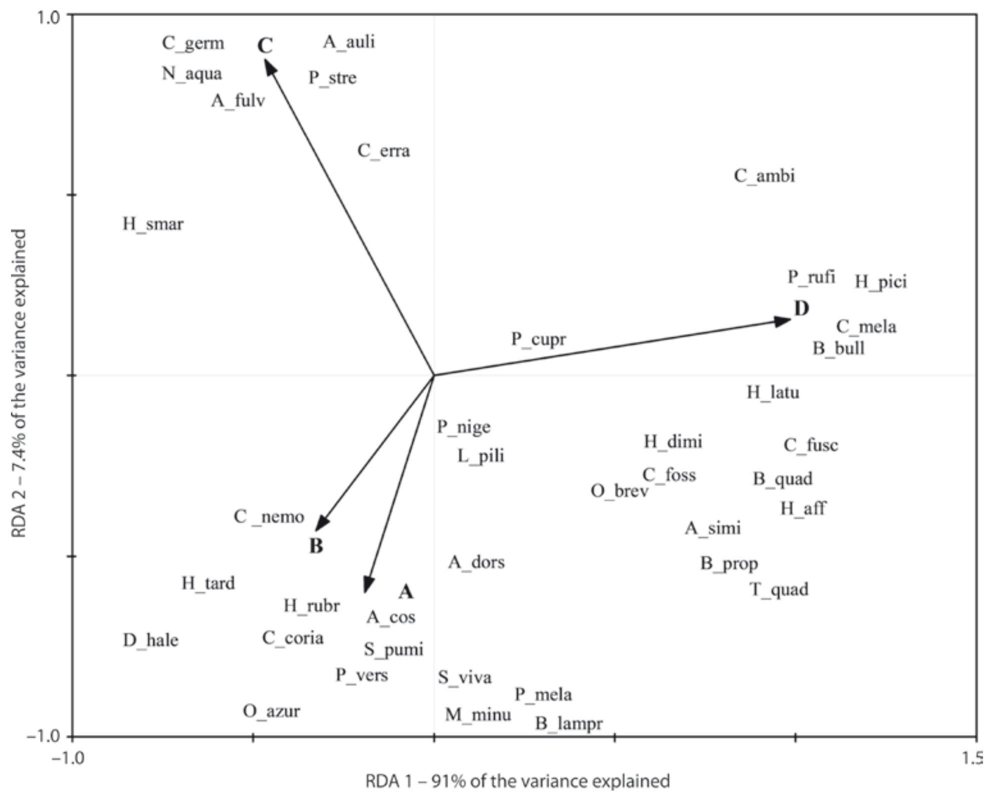

Fig. 1. The RDA biplot of the ground beetle community depended on experimental treatments in 2015
A_dors – *Anchomenus dorsalis*; A_auli – *Amara aulica*; A_cos – *Amara consularis*; A_fulv – *Amara fulva*; A_simi – *Amara similata*; B_bull – *Badister bullatus*; B_lampr – *Bembidion lampros;* B_quad – *Bembidion quadrimaculatum*; B_prop – *Bembidion properans*; C_ambi – *Calathus ambiguus*; C_erra – *Calathus erratus*; C_fusc – *Calathus fuscipes*; C_mela – *Calathus melanocephalus*; C_coria – *Carabus coriaceus*; C_nemo – *Carabus nemoralis*; C_germ – *Cicindela germanica*; C_foss – *Clivina fossor*; D_hale – *Dolichus halensis*; H_affi – *Harpalus affinis*; H_dimi – *Harpalus dimidiatus*; H_pici – *Harpalus picipennis*; H_rubr – *Harpalus rubripes*; H_smar – *Harpalus smaragdinus*; L_pili – *Loricera pilicornis*; M_minu – *Microlestes minutulus*; N_aqua – *Notiophiluss aquaticus;* O_azur – *Ophonus azureus*; O_brev – *Ophonus brevicollis*; P_cupr – *Poecilus cupreus;* P_vers – *Poecilus versicolor*; P_rufi – *Pseudoofonus rufipes*; P_mela – *Pterostichus melanarius;* P_nige – *Pterostichus niger*; P_stre – *Pterostichus strenuus*; S_pumi – *Stomis pumicatus*; S_viva – *Synuchus vivalis;* T_quad – *Trechus quadristriatus*

Fig. 2. The RDA biplot of the ground beetle community depended on experimental treatments in 2016
A_dors – *Anchomenus dorsalis*; A_aene – *Amara aenea*; A_cons – *Amara consularis*; A_eury – *Amara eurynota*; A_fulv – *Amara fulva*; A_simi – *Amara similata*; A_bino – *Anisodactylus binotatus*; B_lamp – *Bembidion lampros*; B_quad – *Bembidion quadrimaculatum*; B_prop – *Bembidion properans*; B_harp – *Bradycellus harpalinus*; B_ceph – *Broscus cephalotes*; C_ambi – *Calathus ambiguus*; C_erra – *Calathus erratus*; C_fusc – *Calathus fuscipes*; C_cant – *Carabus cancellatus*; C_gran – *Carabus granulatus*; C_foss – *Clivina fossor*; D_hale – *Dolichus halensis*; H_affi – *Harpalus affinis*; H_dimi – *Harpalus dimidiatus*; H_dist – *Harpalus distinguendus*; H_froe – *Harpalus froelichii*; H_latu – *Harpalus latus*; H_lute – *Harpalus luteicornis*; H_rubr – *Harpalus rubripes*; H_smar – *Harpalus smaragdinus*; H_tard – *Harpalus tardus*; L_pili – *Loricera pilicornis*; M_minu – *Microlestes minutulus*; N_aqua – *Notiophilus aquaticus*; O_azur – *Ophonus azureus*; O_brev – *Ophonus brevicollis*; P_assi – *Platynus assimilis*; P_cupr – *Poecilus cupreus*; P_versi – *Poecilus versicolor*; P_rufi – *Pseudoophonus rufipes*; P_mela – *Pterostichus melanarius*; P_nige – *Pterostichus niger*; P_sten – *Pterostichus strenuus*; Pt_vern – *Pterostichus vernalis*; S_pumi – *Stomis pumicatus*; S_viva – *Synuchus vivalis*; T_quad – *Trechus quadristriatus*; Z_tene – *Zabrus tenebrioide*

there were species that preferred treatments with different sowing density. Lower seeding was preferred by: *Amara eurynota*, *Calathus ambiguus* and *Harpalus dimidiatus*, while sowing of 50 seeds per meter was preferred by: *Synuchus vivalis*, *Harpalus smaragdinus* and *Ophonus brevicollis*.

In 2017, the 1st RDA axis explained 80.2% of the variance, while the 2nd explained 13.1% of the variance (Fig. 3). The A treatment had the greatest influence on the Carabidae community. It was associated with the following species: *P. cupreus*, *Bembidion properans*, *Loricera pilicornis*. The vectors of treatments D and B were on opposite sides of the second ordinate axis. The D treatment was associated with the occurrence of *B. lampros*, *Stomis pumicatus*, *Harpalus latus*, and B with *Amara familiaris*, *Carabus nemoralis*, *Amara consularis*.

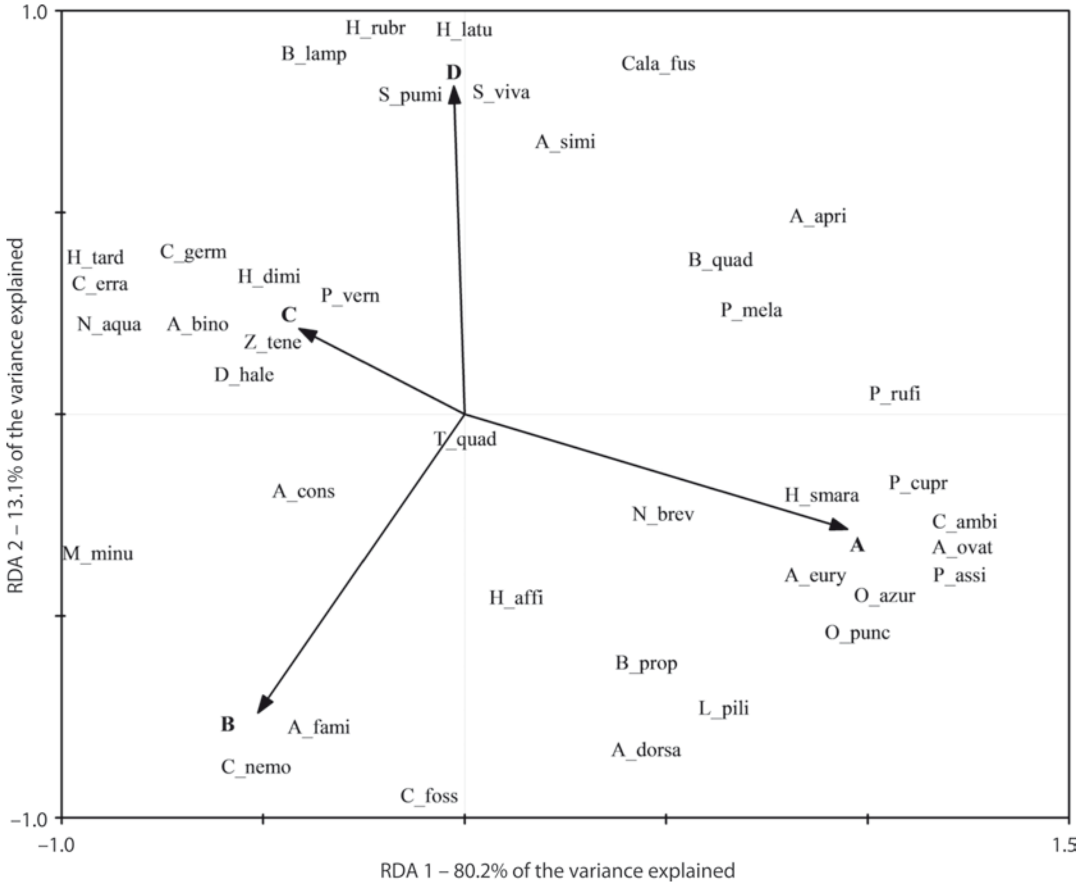

Fig. 3. The RDA biplot of the ground beetle community depended on experimental treatments in 2017
A_dors – *Anchomenus dorsalis*; A_apri – *Amara apricaria*; A_cons – *Amara consularis*; A_eury – *Amara eurynota*; A_fami – *Amara familiaris*; A_ovat – *Amara ovata*; A_simi – *Amara similata*; A_bino – *Anisodactylus binotatus*; B_lamp – *Bembidion lampros*; B_quad – *Bembidion quadrimaculatum*; B_prop – *Bembidion properans*; C_ambi – *Calathus ambiguus*; C_erra – *Calathus erratus*; Cala_fus – *Calathus fuscipes*; C_nemo – *Carabus nemoralis*; C_germ – *Cicindela germanica*; C_foss – *Clivina fossor*; D_hale – *Dolichus halensis*; H_affi – *Harpalus affinis*; H_dimi – *Harpalus dimidiatus*; H_rubr – *Harpalus rubripes*; H_smara – *Harpalus smaragdinus*; H_tard – *Harpalus tardus*; L_pili – *Loricera pilicornis*; N_aqua – *Notiophilus aquaticus*; O_azur – *Ophonus azureus*; O_punc – *Ophonus puncticollis*; P_assi – *Platynus assimilis*; P_cupr – *Poecilus cupreus*; P_rufi – *Pseudoophonus rufipes*; P_mela – *Pterostichus melanarius*; P_vern – *Pterostichus vernalis*; S_pumi – *Stomis pumicatus*; S_viva – *Synuchus vivalis*; T_quad – *Trechus quadristriatus*; Z_tene – *Zabrus tenebrioides*

Analysis of the number of selected species

During the 3 years of the study the most abundant species were *P. rufipes*, *H. affinis*, *C. fuscipes* and *P. melanarius* (Table 4). In different years they accounted together for 61.2 to 91.3% of the whole population in particular treatments. There were no distinct differences in the abundance of the most abundant species between experimental treatments (Table 4).

Discussion

In agroecosystems ground beetles are a crucial link as natural enemies of herbivorous invertebrates (Kromp 1999; Lang *et al.* 1999; Lee and Edwards 2011). Furthermore, numerous studies have shown that some carabid species occurring in crop fields effectively limit the number of weeds by eating their seeds (Honek *et al.* 2003; Kulkarini *et al.* 2015). Due to their connection with the soil environment, they are often used as indicators of this crucial element of the ecosystem (Cameron and Leather 2012; Rusch *et al.* 2013). The impact of different agricultural systems and crops on ground beetles is relatively well investigated (Twardowski *et al.* 2012; Nijak *et al.* 2013; Gailis *et al.* 2017). However, there is a lack of information about ground beetles and other beneficial insects in the soybean crop, which is relatively new in Poland. In our research we examined the impact of soybean plant density (row spacing and seed number) on the abundance of ground beetles and species composition. Plant density impacts the shape of agrocenosis and, consequently, insect diversity and number. In this study plant density had a significant impact on species diversity, but only in one year of the study. In 2015, significantly more species appeared in treatment A (15 cm row spacing and 50 seeds per m^2) in comparison to treatment C

(30 cm row spacing and 50 seeds per m^2). At the same time, no effects were observed in the case of total abundance and numbers of the most abundant species. Baker and Dunning (1975) found that the density of a sugar beet crop differentially affected the number of the most abundant species of ground beetles. The experiment of Honêk and Jarošik (2000) showed that carabids prefer shaded positions until the density of the crop is partial or low. At the same time, the abundance of ground beetles was different, depending on the type of crop. In an earlier experiment Honêk stated that in the case of cereals, significantly more ground beetles were caught in stands with lower plant density. These differences concerned both the number and the species diversity of caught beetles (Honêk 1988). The density of plants has a direct impact on the microclimate of the crop. A greater density of plants results in increased shading, as well as lower temperatures at the soil surface, and higher humidity (Monteiro *et al*. 2006; Murányi 2015).

By analyzing the species diversity and the number of carabids in the experimental treatments (RDA biplots) it can be noticed that the occurrence of individual species is related to their habitat preferences. For example, *B. properans* preferred stands with the A treatment, while *N. aquaticus* preferred stands with the C treatment. It is worth mentioning that the listed species are rather rare in the whole population. Considering this, RDA plots showed some minor effects of plant density only on selected species. This is consistent with our hypothesis, that the effect of plant arrangement might be more specific. Honêk and Jarošik (2000) found that species *B. lampros, N. aquaticus* and *Bembidion quadrimaculatum,* in all the years of their experiment, preferred a treatment without plant cover, while treatments with high shading were more frequently chosen by *Anchomenus dorsalis*, *Bembidion obtusum*, and *Carabus cancellatus*. Trefas and van Lenteren (2008) found that *P. melanarius* females are more likely to choose shaded and moist places for laying eggs. In our studies this species was also the most numerous in treatments with highest density (treatment D – 30 cm row spacing and 90 seeds per m^2).

In our study the most abundant species (which accounted for more than 76% of the community) were: *P. rufipes*, *H. affinis*, *C. fuscipes* and *P. melanarius* (Table 4). No distinct differences were found when comparing experimental treatments (Table 4). These species are relatively common in other agricultural experiments. Hurej and Twardowski (2006) found high numbers of *P. rufipes* and *H. affinis* in a mixed crop of yellow lupin and spring triticale, while Kosewska (2018) found high numbers of *P. rufipes* and *P. melanarius* in large scale cereal cultivation.

Conclusions

In conclusion, plant density had no significant effect on the abundance of ground beetles. Only minor differences were found considering species richness, which was higher in the lower row spacing. Plant density affected only less abundant species (*B. properans*, *M. minutulus*, *T. quadristriatus* and *L. pilicornis*), whose abundance was related to particular treatments. The most abundant species in soybean (in all treatments) were *P. rufipes*, *H. affinis*, *C. fuscipes* and *P. melanarius*. The abundance of listed species did not differ significantly between treatments.

Carabidae are important predators in the agricultural landscape. Their high number and species diversity might directly decrease the abundance of pests in many crops, including soybean. Therefore, it is important to create suitable conditions for these insects, which is consistent with integrated plant protection and sustainable agriculture.

In the future we hope to continue this project with a study on predatory insects in soybean crops and their prey.

Acknowledgements

We are grateful to Mrs. Kamila Twardowska and Joanna Magiera-Dulewicz from the Department of Plant Protection, Wroclaw University of Environmental and Life Sciences as well as Emilia Wiciejowska for their input with sample collection and laboratory work.

References

Akinkunmi O., Akintoye H., Umeh V., AdeOluwa O. 2012. Influence of spacing on the feeding activities of major pests of sunflower and their associated damage. Agriculture and Biology Journal of North America 3 (6): 233–236. DOI: 10.5251/abjna.2012.3.6.233.236

Baker A., Dunning R. 1975. Some effects of soil type and crop density on the activity and abundance of the epigeic fauna, particularly Carabidae, in sugar-beet fields. Journal of Applied Ecology 12: 809–818.

Błaszkiewicz M., Schwerk A. 2013. Carabid beetle (Coleoptera: Carabidae) diversity in agricultural and post-agricultural areas in relation to the surrounding habitats. Baltic Journal of Coleopterology 13 (1): 15–26.

Boros L., Wawer A. 2016. The next stage of dissemination and expansion of soybean cultivation in Polish conditions. Agro Serwis 3: 47–52.

Cameron K., Leather S. 2012. How good are carabid beetles (Coleoptera, Carabidae) as indicators of invertebrate abundance and order richness? Biodiversity and Conservation 21: 763–779. DOI: https://doi.org/10.1007/s10531-011-0215-9

Carrillo R., Alarcón R., Neira M. 2007. The effects of carabid beetles (Coleoptera: Carabidae) on the arthropod fauna of wheat fields in Chile. Revista de Biología Tropical 55 (1): 101–111. DOI: 10.15517/rbt.v55i1.6060

COBORU. 2018. Research Centre of Cultivar Testing (COBORU), Varieties admitted to the Polish National List. Available on: http://www.coboru.pl/English/Rejestr_eng/odm_w_rej_eng.aspx?kodgatunku=SOS

Czerniakowski Z., Olbrycht T. 2004. Różnorodność gatunkowa biegaczowatych (Col. Carabidae) w wybranych biotopach południowo-wschodniej Polski. Progress in Plant Protection 44 (1): 2–27.

Domański P., Osiecka A., Stuczyńska E. 2017. Wyniki porejestrowych doświadczeń odmianowych – Bobowate grubonasienne. Centralny Ośrodek Badania Odmian Roślin Uprawnych 132: 5–43.

European Commission. 2019 European Commission, Oilseeds and Protein Crops Market Situation. 2019. Available on: https://circabc.europa.eu/sd/a/215a681a-5f50-4a4b-a953-e8fc6336819c/oilseeds-market%20situation.pdf

Fischer C., Schlinkert H., Ludwig M., Holzschuh A., Gallé R., Tscharntke T., Batàry P. 2013. The impact of hedge-forest connectivity and microhabitat conditions on spider and carabid beetle assemblages in agricultural landscapes. Journal of Insects Conservation 17: 1027–1038. DOI: 10.1007/s10841-013-9586-4

FAOSTAT. 2017. Food and Agriculture Organization of the United Nations. Top 10 Country Production of Soybeans. Available on: www.fao.org/faostat/en/#rankings/countries

Fox T., Landis D., Cardoso F., Difonzo C. 2005. Impact of predation on establishment of the soybean aphid, Aphis glycines in soybean, *Glycine max*. BioControl 50 (4): 545–563. DOI: 10.1007/s10526-004-6592-1

Gailis J., Turka I., Ansumane M. 2017. The most frequent ground beetles (Coleoptera, Carabidae) are differently affected by main soil treatment and crop rotation in winter wheat fields. Acta Biologica Universitatis Daugavpiliensis 17 (1): 29–52.

Getanjaly Rai V., Sharma P., Kushwaha R. 2015. Beneficial insects and their value to agriculture. Research Journal of Agriculture and Forestry Sciences 3 (5): 25–30.

Ghahari H., Kesdek M., Samin N., Ostovan H., Havaskary M., Imani S. 2009. Ground beetles (Coleoptera: Carabidae) of Iranian cotton fields and surrounding grasslands. Munis Entomology & Zoology Journal 4 (2): 436–450.

Hartman G., West E., Herman T. 2011. Crops that feed the World 2. Soybean – worldwide production, use, and constraints caused by pathogens and pests. Food Security 3: 5–17. DOI: http://dx.doi.org/10.1007/s12571-010-0108-x

Honêk A. 1988. The effect of crop density and microclimate on pitfall trap catches of Carabidae, Staphylinidae (Coleoptera) and Lycosidae (Araneae) in cereal fields. Pedobiologia 32: 233–242.

Honêk A., Jarošik V. 2000. The role of crop density, seed and aphid presence in diversification of field communities of Carabidae (Coleoptera). European Journal of Entomology 97: 517–525. DOI: 10.14411/eje.2000.080

Honêk A., Martinkova Z., Jarošik V. 2003. Ground beetles (Carabidae) as seed predators. European Journal of Entomology 100 (4): 531–544. DOI: 10.14411/eje.2003.081

Hlivko J., Rypstra A. 2003. Spiders reduce herbivory: nonlethal effects of spiders on the consumption of soybean leaves by beetle pests. Annals of the Entomological Society of America 96 (6): 914–919. DOI: https://doi.org/10.1603/0013-8746(2003)096

Hummel J., Dosdall L., Clayton G., Harker K., O'Donovan J. 2012. Ground beetle (Coleoptera: Carabidae) diversity, activity density, and community structure in a diversified agroecosystem. Environmental Entomology 41 (1): 72–80. DOI: 10.1603/EN11072

Hurej M., Twardowski J. 2006. The influence of yellow lupin intercropped with spring triticale on predatory carabid beetles (Coleoptera: Carabidae). European Journal of Entomology 103 (1): 259–261. DOI: 10.14411/eje.2006.031

Hůrka K. 1996. Carabidae of the Czech and Slovak Republics. Kabourek, Zlin, Czech Republic, 565 pp.

Kosewska A. 2018. Comparison of ground beetle (Coleoptera, Carabidae) assemblages in tillage and no-tillage cultivation of cereals crop. Progress in Plant Protection 58 (1): 40–48. DOI: 10.14199/ppp-2018-005

Kosewska A., Nietupski M., Nijak K., Skalski T. 2016. Effect of plant protection on assemblages of ground beetles (Coleoptera, Carabidae) in pea (*Pisum* L.) and lupine (*Lupinus* L.) crops. Periodicum Biologorum 118 (3): 213–222. DOI: 10.18054/pb.2016.118.3.391

Kromp B. 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agriculure, Ecosystems and Environment 74: 187–228. DOI: https://doi.org/10.1016/S0167-8809(99)00037-7

Kulkarini S., Dosdall L., Willenborg C. 2015. The role of ground beetles (Coleoptera: Carabidae) in weed seed consumption: a review. Weed Science 63: 355–376. DOI: https://doi.org/10.1614/WS-D-14-00067.1

Lang A., Filser J., Henschel J. 1999. Predation by ground beetles and wolf spiders on herbivorous insects in a maize crop. Agriculture, Ecosystems and Environment 72: 189–199. DOI: https://doi.org/10.1016/S0167-8809(98)00186-8

Lee J., Edwards D. 2011. Impact of predatory carabids on below- and above-ground pests and yield in strawberry. BioControl 57: 515–522. DOI: 10.1007/s10526-011-9425-z

Leslie T., Biddinger D., Rohr J., Hulting A., Mortensen D., Fleischer S. 2013. Examining shifts in Carabidae assemblages across a forest-agriculture ecotone. Environmental Entomology 43 (1): 18–28. DOI: 10.1603/EN13099

Lövei G. 2008. Ecology and conservation biology of ground beetles (Coleoptera: Carabidae) in an age of increasing human dominance. Magyar Tudományos Akadémia 5–22. DOI: http://real-d.mtak.hu/id/eprint/121

Masuda T., Goldsmith P. 2009. World soybean production: area harvested, yield, and long-term projections. International Food and Agribusiness Management Review 12: 143–163.

Monteiro J., Sentelhas P., Chiavegato E. 2006. Microclimate and ramulosis occurrence in a cotton crop under three plant population densities in Southern Brazil. AgriScientia 23 (2): 45–53.

Murányi E. 2015. Effect of plant density and row spacing on maize (*Zea mays* L.) grain yield in different crop year. Journal of Agricultural and Environmental Sciences 2 (1): 57–63. DOI: 10.18380/SZIE.COLUM.2015.1.57

Musser F., Catchot A., Davis J., Herbert D., Leonard B., Lorenz G., Reed T., Reisig D., Stewart S. 2011. 2016 soybean insects losses in the southern US. Midsouth Entomologist 5: 11–22.

Nijak K., Kosewska A., Kordan B. 2013. Comparison of carabid beetles (Col., Carabidae) assemblages in integrated and organic potato management. Progress in Plant Protection 53 (1): 64–69. DOI: http://dx.doi.org/10.14199/ppp-2013-118

Oberholzer F., Escher N., Frank T. 2003. The potential of carabid beetles (Coleoptera) to reduce slug damage to oilseed rape in the laboratory. European Journal of Entomology 100: 81–85. DOI: 10.14411/eje.2003.016

Pretorius R., Hein G., Blankenship E., Purrington F., Bradshaw J. 2017. Response of *Pemphigus betae* (Hemiptera: Aphididae) and Beneficial Epigeal Arthropod Communities to Sugarbeet Plant Density and Seed-Applied Insecticide in Western Nebraska. Environmental Entomology 46 (1): 107–117. DOI: 10.1093/ee/nvw157

Rainio J., Niemelä J. 2003. Ground beetles (Coleoptera: Carabidae) as bioindicators. Biodiversity and Conservation 12: 487–506. DOI: 10.1023/A:1022412617568

Renkema J., Cutler G., Blanchard D., Hammermeister A. 2014. Using ground beetles (Coleoptera: Carabidae) to control slugs (Gastropoda: Pulmonata) in salad greens in the laboratory and greenhouse. The Canadian Entomologist 146 (5): 567–578. DOI: https://doi.org/10.4039/tce.2014.8

Rusch A., Bommarco R., Chiverton P., Öberg S., Wallin H., Wiktelius S., Eckbom B. *2013.* Response of ground beetle (Coleoptera, Carabidae) communities to changes in agricultural policies in Sweden over two decades. Agriculture, Ecosystem and Environment 176: 63–69. DOI: https://doi.org/10.1016/j.agee.2013.05.014

Saska P. 2007. Diversity of carabids (Coleoptera: Carabidae) within two Dutch cereal fields and their boundaries. Baltic Journal of Coleopterology 7 (1): 37–50.

Śpiewak I. 2017. Publikacje Wyników Doświadczeń PDO – Soja. Centralny Ośrodek Badania Roślin Uprawnych: 1–11.

Trefas H., van Lenteren J. 2008. Egg-laying-site preferences of *Pterostichus melanarius* in mono- and intercrops. Bulletin of Insectology 61 (2): 225–231.

Twardowski J. 2010. Wpływ uproszczeń w uprawie roli pod pszenicę ozimą na zgrupowania stawonogów epigeicznych i glebowych. Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu: 7–141. (in Polish)

Twardowski J., Bereś P., Hurej M., Klukowski Z., Dąbrowski Z., Sowa S., Warzecha R. 2012. The quantitative changes of ground beetles (Col., Carabidae) in bt and conventional maize crop in southern Poland. Journal of Plant Protection Research 52 (4): 404–409. DOI: https://doi.org/10.2478/v10045-012-0066-8

Twardowski J., Pastuszko K., Hurej M., Gruss I. 2017. Effect of different management practices on ground beetle (Coleoptera: Carabidae) assemblages of uphill grasslands. Polish Journal of Ecology 65 (3): 400–409. DOI: https://doi.org/10.3161/15052249PJE2017.65.3.007

Tyczewska A., Gracz J., Twardowski T., Małyska A. 2014. Soybean is the future of Polish agriculture? Nauka 4: 121–138.

Voronin A., Chamakov L. 2015. Distribution of ground beetles (Coleoptera, Carabidae) from different ecological groups in the forest-meadow ecotone. Russian Journal of Ecology 46 (6): 589–591. DOI: 10.1134/S1067413615060235