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Effects of fertilizer and land-use type on soil properties and ground beetle communities

Wojciech SĄDEJ[1], Agnieszka KOSEWSKA[1], Wiera SĄDEJ[2], Mariusz NIETUPSKI[1]
[1]*Department of Phytopathology and Entomology, University of Warmia and Mazury, Olsztyn, Poland*
[2]*Department of Environmental Chemistry, University of Warmia and Mazury, Olsztyn, Poland*

Abstract

Among the most important factors influencing the properties of soil are the type of soil management and fertilization. Agronomic technologies, such as undifferentiated fertilization, or fallow and set-aside breaks have a significant, although not always positive effect on soil properties. They can stimulate humus degradation in soil, the leaching of nutrients and accumulation of weed seeds, pathogens and pests in soil. Being a very useful component of biocenoses, carabid fauna is a particularly valuable group of animals. They are very sensitive to changes in habitat quality and are therefore commonly used as environmental indicators. Because of their predatory polyphagous nutrition, they can be treated as an important component of natural environmental resistance. This paper discusses the species composition of Carabidae communities found on experimental plots maintained under identical, undifferentiated fertilization but managed differently. Relationships between selected physicochemical soil properties under long-term fertilization or soil fallowing and the composition of carabid communities were analyzed. Significantly more carabid individuals were found in the fallows compared to the experimental plots. The Shannon index indicated that treatments with a higher content of organic carbon and total nitrogen had a higher diversity. Carabidae preferred the treatments where the soil had lower pH. The most significant factor affecting assemblages of carabid beetles consisted in agronomic treatments, such as the type of soil management and fertilization. Thus, it can be concluded that the way the land is managed for agricultural purposes has a strong influence on shaping the epigeal fauna of Carabidae. We suggest that in the present experiment carabids preferred fallows, as beetles were not disturbed and could find more places to hide.

Key words: undifferentiated fertilization, fallow, soil macrofauna, Carabidae.

Introduction

Soil is an essential element of agriculture and the soil fauna, its intrinsic component, obviously affects its agricultural value (Tischler, 1955; Kromp, 1999; Nietupski *et al*., 2010; Gu *et al*., 2011; Santorufo *et al*., 2012; Keith *et al.*, 2012). Macrofauna can change soil properties, e.g. porosity, structure and aeration. It also contributes to the transfer of particular soil layers and enriches soil with various organic substances (Górny, 1968; Oprychałowa, 1994; Folgarait *et al*., 2003). Another important factor which determines soil properties is the soil tillage, cultivation and fertilization (Birkhofer *et al*., 2008a; Skłodowski, 2010). Over the recent years, two groups of farms in Poland have become more distinguishable. One comprises farms engaged in plant production, where mineral fertilization is applied. The other group of farms specializes in animal production and crops grown on these farms are more often nourished with natural fertilizers (liquid manure, farmyard manure). This division stems from the fact that Polish farmers tend to specialize in one type of production. At the same time, it is still common practice to lay fallow or set aside some of the farmland. Undifferentiated fertilization, simplified agronomic practice, fallowing or setting aside farmland, if lasting for many years, have a strong albeit not always positive effect on soil. The above factors can stimulate undesirable changes in soil, including the leaching of nutrients, mainly nitrogen, diminishing amounts or worse quality of humus, soil erosion, accumulation of weed seeds, pathogens and pests. Such negative consequences have been demonstrated in a three-year experiment conducted by Sądej *et al.* (2008), who found significant positive influence of the content of organic matter and total nitrogen in grey-brown podsolic soil on the density of pest macrofauna.

The carabid fauna, in contrast, is a particularly valuable group of animals in a biocenosis. These beetles, mostly predators, contribute to the biological control of pests (Lövei and Sunderland, 1996; Kromp, 1999; Pałosz, 1999; Sunderland, 2002; Saska, 2007). Carabidae are frequently used for zooindication (Niemelä *et al*., 2000; Rainio and Niemelä, 2003; Skalski *et al*., 2011; Kotze *et al*., 2011) and the species composition of carabid fauna depends on several factors, including soil conditions (Szyszko, 1974; Pałosz, 1999; Holland and Luff, 2000). The fact that some species of ground beetles are sensitive to the factors associated with the type of soil management has been indicated by many authors (Andersen, 1999; Holland and Luff, 2000; Weibull *et al*., 2003; Shah *et al*., 2003; Birkhofer *et al*., 2008b; Jaworska and Gospodarek, 2009). The abundance of Carabidae is also affected by the soil treatments as well as the inter-row management in orchards (Cotes *et al*., 2009).

The purpose of the present experiment has been to determine the species composition and abundance of Carabidae populating the experimental plots, which received undifferentiated fertilization but were differently managed for agricultural purposes. Relationships between selected physicochemical properties of soil, formed under the influence of long-term fertilization or fallowing, and the composition of carabid assemblages have been examined.

Materials and methods

The location and design of the trials

The present research was based on a long–term static field experiment, set up in a random block design at the Research Station in Bałcyny (northern Poland – UTM DE23) in 1972. The field experiment has been conducted by the researchers from the Chair of Environmental Chemistry at the University of Warmia and Mazury in Olsztyn. It is located on grey-brown podsolic soil, developed on medium clay underlain by the light sand (Soil Taxonomy). The farmland covered by the experiment is used for growing crops in a 7-year rotation system, consisting of potato, spring barley, winter oilseed rape, winter wheat + winter rye aftercrop, maize, spring barley and winter wheat. The trials discussed in this paper began in the first year of the fifth rotation cycle and continued for 3 years on potato, spring barley and winter oilseed rape fields.

The objective has been to compare the effect of natural and mineral fertilizers. The natural fertilizers included farmyard manure (FYM) and bovine liquid manure (BLM), which was applied in two doses: I - balanced with FYM in the amount of total nitrogen introduced to soil (BLM I), and II - corresponding to FYM in the amount of organic carbon added to soil (BLM II). The rate of nitrogen in mineral fertilizers (NPK) was equal to the amount of this element introduced to soil with FYM or liquid manure dose I, whereas the fertilization with phosphorus and potassium was adjusted to the nutritional requirements of each of the crops. The rates of fertilizers were established every year, prior to their introduction to soil. The average annual rates of natural fertilizers are shown in figure 1. Figure 2, in turn, presents the average amounts of nutrients added to soil each year with the fertilizers applied over 33 years. The control (Control) was a treatment without any fertilization. The experiment was run in 6 replications, and the area of each plot for harvest was 52.5 m^2. Four out of the six replications were chosen for entomological investigations. Two other treatments consisted of fields kept fallow for eight (Fallow I) and twelve (Fallow II) years. The fallows were adjacent to the field experiment and the soil underneath belonged to the same soil classification class. The area of each fallow was approximately equal to the total area of four plots from a single treatment.

Chemical analyses of soil

Soil samples for chemical analyses were taken each year after the crop grown in that year had been harvested. The samples were collected from the 0-25 cm soil layer. Chemical analyses were carried out in the laboratory of the Chair of Environmental Chemistry of the UWM in Olsztyn. The following determinations were made: content of organic carbon by Tiurin method (Bednarek *et al.*, 2005), total nitrogen content by Kjeldahl method (Mroczkowski and Stuczyński, 2011), content of hydrogen and alkaline ions by Kappen method (Drozd *et al.*, 2002) and soil reaction by potentiometry. Having completed the chemical analyses, the following were computed: the ratio of organic carbon to total nitrogen (table 1), soil sorption capacity and base saturation of soil (table 2).

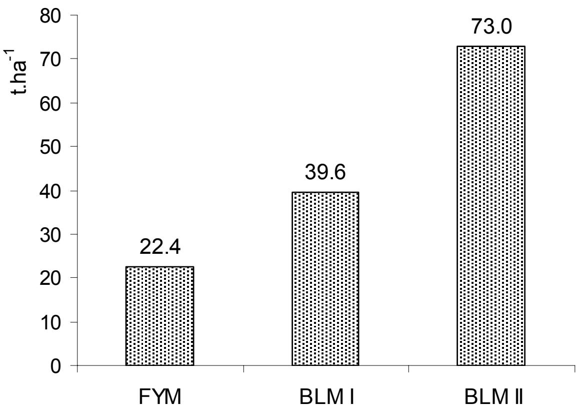

Figure 1. Rates of natural fertilizers applied during the long-term static experiment (annual means for 33 years).

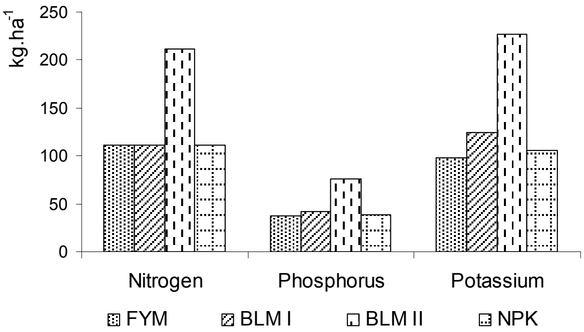

Figure 2. Amounts of nutrients introduced to soil with natural fertilizers (annual means for 33 years).

Soil sampling

In order to determine the composition of the fauna populating the tested plots and fallows, soil samples were taken six times at 3-week intervals from May to September each year. A cylinder measuring 160 mm in height and 95 mm in diameter was used for the sampling. On field, each soil sample was passed through a 10-mm-mesh sieve and, once brought to the laboratory, placed in Tullgren funnels for 7-8 days in order to obtain smaller insects using the dynamic method (Górny and Grűm, 1981). In total, 24 aggregate samples were taken annually from each experimental treatment. One sample consisted of the soil from 20 cylinders (5 cylinders from each plot - samples taken along the plot's diagonal). From both fallows, 20 single samples were taken once, 5 samples from each of the following locations: near the edge, near the middle and in the middle of the fallow field. Soil sampling with a soil cylinder is not a popular method for collecting samples of carabid fauna, but it was applied in this study because it is part of a larger project, in which all soil macrofauna is investigated. The best-known collection method used by carabidologists is pitfall trapping (Kotze *et al.*, 2011), but soil samples have also been, for example by Pfiffner and Luka (2000). The specimens of carabid beetles retrieved from soil samples were identified with the keys by Pawłowski (1974), Watała (1995) and Hůrka (1996).

Table 1. Content of organic carbon, total nitrogen and C:N ratio in soil (means for 3 years).

Parameter	Treatments*						
	1	2	3	4	5	6	7
pH in H_2O	6	5.9	5.8	6.2	5.5	6.6	6.2
C ($g \cdot kg^{-1}$ soil)	7.1	9.4	10.25	11.54	7.91	12.77	14.44
N ($g \cdot kg^{-1}$ soil)	0.6	0.73	0.85	0.87	0.71	1.15	1.3
C:N	11.9	12.9	12	13.4	11.1	11.6	11.4

* Treatments: 1. control, unfertilized; 2. liquid manure rate I (BLM I); 3. liquid manure rate II (BLM II); 4. FYM; 5. NPK; 6. eight-year fallow (Fallow I); 7. twelve-year fallow (Fallow II).

Table 2. Value of soil reaction and soil sorptive properties (means for 3 years).

No	Fertilization	pH in 1 mol KCl	Hydrolytic acidity (Hh) $mmol^{(+)} \cdot kg^{-1}$	Base exchange capacity (S) $mmol^{(+)} \cdot kg^{-1}$	Cation exchange capacity (T) $mmol^{(+)} \cdot kg^{-1}$	Base saturation of soils %
1	Control	5.00	20.2	40.0	60.2	66.4
2	BLM I	5.17	29.5	61.8	91.3	67.7
3	BLM II	5.02	29.8	75.8	105.6	71.8
4	FYM	5.45	27.6	83.8	111.4	73.5
5	NPK	4.50	42.8	44.7	87.5	51.1
6	Fallow I	5.78	28.7	77.9	106.6	73.1
7	Fallow II	5.44	26.7	74.2	100.9	73.5

Afterwards, they were analyzed in terms of their species composition and number of individuals. The following indices were used: the Shannon general species diversity index (H') and the Pielou index of evenness (J').

Statistical analysis of the data

Similarities between the analyzed objects and communities of carabid beetles were illustrated by drawing up a dendrogram according to the TWINSPAN analysis (Hill and Milauer, 2005). While analyzing the data, the method of the canonical correlation analysis (CCA) was applied as it enabled us to evaluate changes in the assemblages dwelling on the experimental fields induced by environmental factors (content of C, N, C:N ratio, pH in H_2O and agrotechnical treatments). The statistical significance of canonical axes was determined with the Monte-Carlo test. The analysis was run with the computer software package Canoco v. 4.5 (Ter Braak and Milauer, 1998). The significance of differences between the means was determined using analysis of variance (ANOVA) at the level of significance $p < 0.05$ with the software package Statistica 9.0 Pl. In addition, Duncan's test, which combines means of similar values into ordered homogenous groups, was applied.

Results and discussion

In total, 161 specimens belonging to 32 species of Carabidae were collected (table 3). Statistically significant differences ($F = 6.55$; $p < 0.001$) were revealed between the number of carabid beetles on the 12-year fallow versus the fertilized and control treatments and between the eight–year fallow and all the other treatments. Duncan's test distinguished two homogenous groups (table 3). In terms of the number of captured Carabidae species, statistically significant differences ($F = 5.31$, $p = 0.008$) were found between the 12-year fallow and the treatments fertilized with liquid manure. The above can be attributed to the content of organic matter in soil (table 2). The soil organic matter content was positively related to carabid species numbers (Pfiffner and Luka, 2000). The application of organic manures may influence the beetles' capability of ovetwintering, burrowing and oviposition and the availability of prey (Holland and Luff, 2000). Soils that contain much organic carbon, which is the primary component of soil humus, are readily populated by a variety of soil organisms, including the pest macrofauna (Kowalska and Wierzbowski, 2002; Sądej *et al.*, 2007), whose subsequent developmental stages constitute a good food resource for predatory beetles, the object of the present study. Carabidae are typically polyphagous, having diverse diets (table 3). Many carabid beetles, both adults and soil-borne larvae, specialize in feeding on soil fauna (Hengeveld, 1980; Lövei and Sunderland, 1996; Holland and Luff, 2000; Brandmayr *et al.*, 2005).

Among the representatives of Carabidae captured during this research, the dominant group consisted of mesophilic, open-area ground beetles. Czechowski (1982) reports that, as agronomic practice intensify, the species typical of open spaces are replaced by groups of Carabidae characteristic for other types of habitats. The analyzed sites were dominated by such species as *Clivina fossor* (L.), *Harpalus rufipes* (De Geer), *Harpalus affinis* (Schrank) and *Poecilus cupreus* (L.). All of these species are able to adapt to unfavourable habitat conditions created under human pressure (Czechowski, 1982; Brandmayr, 1983; Aleksandrowicz, 2004). Statistically significant differences were observed in the diversity index (H') within the analyzed combinations ($F = 7.20$, $p = 0.001$). Cárcamo *et al.* (1995) noticed that carabid

Table 3. Species composition, number of specimens, biological features and biodiversity indices for the Carabidae communities on treatments.

Species	Abbrev.	Treatments						
		1	2	3	4	5	6	7
Amara apricaria (Paykull 1790) * S	A_apr	0	1	0	0	0	1	0
Amara bifrons (Gyllenhal 1810) * S	A_bifr	0	0	1	0	2	1	0
Amara communis (Panzer 1797) * S	A_com	0	0	1	0	1	1	0
Amara familiaris (Duftschmid 1812) * S	A_fami	0	0	0	0	0	4	0
Amara municipalis (Duftschmid 1812) * S	A_muni	0	0	0	0	0	1	1
Amara plebeja (Gyllenhal 1810) * S	A_pleb	0	0	0	0	0	0	1
Anchomenus dorsalis (Pontoppidan 1763) P S	Anch_dor	0	0	0	1	0	0	0
Anisodactylus binotatus (F. 1787) * S	Ani_bino	0	0	0	0	0	1	2
Asaphidion flavipes (L. 1761) P S	Asa_flavi	0	0	0	0	0	0	1
Badister bullatus (Schrank 1798) P S	Bad_bull	0	0	0	0	1	4	2
Badister lacertosus Sturm 1815 P S	Bad_lace	0	0	0	0	1	3	2
Bembidion lampros (Herbst 1784) P S	Be_lamp	0	0	0	0	1	0	3
Bembidion properans (Stephens 1828) P S	Be_pro	0	0	0	1	1	0	2
Bradycellus harpalinus (Audinet-Serville 1821) * W	Bra_harp	0	0	0	0	0	1	0
Calathus melanocephalus (L. 1758) P W	Cal_mela	0	0	0	0	1	1	0
Carabus granulatus L. 1758 P S	Ca_granu	0	0	0	2	0	2	1
Clivina fossor (L. 1758) P S	Cliv_fos	1	5	1	2	6	5	2
Dicheirotrichus rufithorax (Sahlberg 1827) * S	Dich_ruf	0	0	0	0	0	0	2
Dyschirius globosus Herbst 1784 P S	Dis_glo	0	0	0	0	0	0	4
Harpalus affinis (Schrank 1781) * S	H_affi	1	2	0	1	0	1	2
Harpalus rubripes (Duftschmid 1812) * S	H_rub	2	0	0	0	1	0	2
Harpalus rufipes (De Geer 1774) * W	H_ruf	0	0	0	4	1	8	10
Loricera pilicornis (F. 1775) P S	Lo_pil	0	0	1	0	0	0	0
Nebria brevicollis (F. 1792) P W	Ne_brevi	0	0	0	0	0	1	2
Ophonus rufibarbis (F. 1792) ** W	Oph_ruf	0	0	0	1	0	0	2
Panagaeus bipustulatus (F. 1775) P S	Pan_bipu	0	1	1	0	0	1	4
Poecilus cupreus (L. 1758) P S	Po_cupr	0	1	2	2	0	1	0
Poecilus versicolor (Sturm 1824) P S	Po_ver	0	1	0	0	0	0	0
Pterostichus melanarius (Illiger 1798) P W	Pt_mela	0	0	2	1	2	0	4
Pterostichus strenuus (Panzer 1797) P S	Pt_stre	0	0	0	0	1	8	4
Pterostichus vernalis (Panzer 1796) P S	Pt_ver	0	0	0	0	0	1	0
Syntomus truncatellus (L. 1761) P S	Syn_tru	0	0	0	1	1	0	0
Trechus quadristriatus (Schrank 1781) P W	Tre_qua	0	0	0	0	0	2	0
No of individuals		4^a	11^a	9^a	16^a	20^a	48^b	53^b
No of species		3^a	6^a	7^a	10^a	13^a	20^b	20^b
Standard deviation		0.58	1.16	1.73	0.58	5.03	8.66	5.51
Standard error		0.33	0.67	1.00	0.33	2.91	5.00	3.18
Shannon -Weaver H' Log Base 2,718		1.04	1.54	1.89	2.17	2.32	2.65	2.79
Pielou J'		0.95	0.86	0.97	0.94	0.90	0.89	0.93

Treatments: 1. control, unfertilized; 2. liquid manure rate I (BLM I); 3. liquid manure rate II (BLM II); 4. FYM; 5. NPK; 6. eight-year fallow (Fallow I); 7. twelve-year fallow (Fallow II); a, b - homogenous groups (Duncan's test), values in rows designated with the same letter do not differ statistically; * partly phytophagous, P zoophagous, ** pure seed feeder, S = summer larvae, W = winter larvae.

diversity was higher where agronomic inputs were reduced, especially among autumn species with winter larvae, which are highly sensitive to tillage and further agricultural practices. The highest values of the Shannon index H' were recorded for the samples taken from the fallows, where they reached 2.65 (eight-year fallow) and 2.79 (twelve-year fallow) (table 3). These are quite high values of the H' index, but close to the ones determined by other authors who investigated similar habitats. Huruk (2002), who studied one-year crop plantations, reported the values of H' within the range of 2.39 - 3.10. Kosewska *et al.* (2009), who investigated the factors which affected carabids dwelling on cereal crop fields, noted the values of H' equal 1.77 on a wheat field and 2.27 on a triticale field. The Shannon index has higher values when a community is more speciose and when the abundance of individuals is more evenly distributed among species. The diversity index in our study was also related to the organic carbon content, reaction and sorption properties of soil. The value of H' was higher for the plots richer in organic matter and nutrients, with a higher pH value. Beside the fallow fields, the treatments fertilized with NPK and FYM were quite conspicuous as the value of the Shannon index calculated for those plots was 2.32 and 2.17, respectively. Zhang *et al*. (1997) noticed no difference for *H. rufipes* between fields treated with organic and inorganic fertilizer. In the present study, the result of our calculations of this index for the eight-year fallow was somewhat blurred (table 3) by the frequent appearance of the forest, hygrophilous species *Pterostichus strenuus* (Panzer), which most probably migrated in search for food from some trees near the fallow field, undisturbed by man.

The similarities and differences between the analyzed treatments and communities of Carabidae are presented in the form of a dendrogram (figure 3). The first division is where two branches are distinctly separated, such as the fallow and the cultivated fields, and the differentiating species is *Amara municipalis* (Duftschmid). The second division distinguishes between the control treatment and the one fertilized with liquid manure in a dose providing the same amount of total nitrogen as FYM. The species *Pterostichus melanarius* (Illiger) was identified as the characteristic element of the fauna dwelling on these two plots. The dendrogram shows very clearly how all the other assemblages of Carabidae are shaped depending on what fields they populate. The observations could indicate that habitats with similar concentrations of organic carbon, total nitrogen and values of the sorptive complex (table 2) form distinct groups, thereby implying the important role of these soil properties on the presence of carabid beetles. However, the authors did not study the effect of other important factors which influence the formation of Carabidae communities. The species composition of carabid beetles communities depends on many factors, including the way the soil is managed for agricultural production and types of crops, pesticide application, microclimatic changes etc. (Thiele, 1977; Holland and Luff, 2000; Scheu, 2001; Shah *et al*., 2003; Holland and Reynolds, 2003; Aviron *et al*., 2005; Birkhofer *et al*., 2008b; Flohre *et al*., 2011).

In order to illustrate changes which occurred in the Carabidae assemblages on the analyzed fields, as affected by various factors, the canonical correspondence analysis (CCA) method was applied. The Monte Carlo test that followed demonstrated the statistical significance for all canonical axes (p = 0.018) (table 4). The diagram of the CCA analysis shows that agronomic treatments, which were correlated with ordination axis I, proved to be statistically significant in terms of the changes induced on the carabid communities (figure 4).

The fertilized treatments also appeared on the right-hand side of the ordination diagram. The presence of the following species was correlated with these variables: *Anchomenus dorsalis* (Pontoppidan), *Syntomus truncatellus* (L.), *Poecilus versicolor* (Sturm), *Loricera pilicornis* (F.), *H. affinis*, *P. cupreus*, *C. fossor*. The content of organic carbon and total nitrogen in soil as well as soil pH were negatively correlated with the above variables. In turn, the organic C content and total N in soil

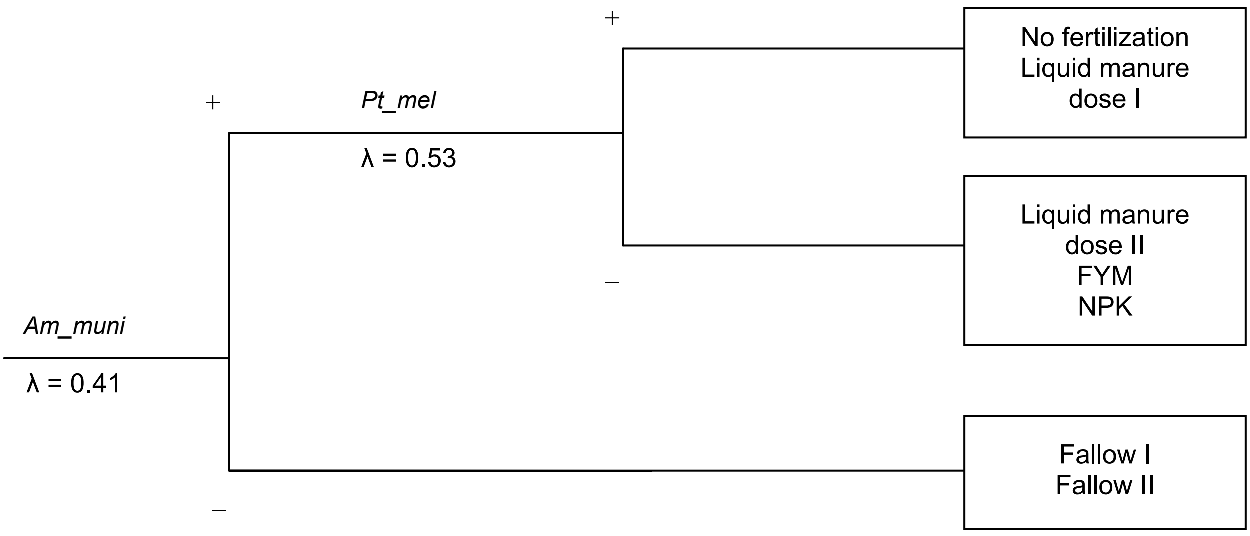

Figure 3. The dendrogram acc. to TWINSPAN classification for the treatments and the assemblages of ground beetles on the analyzed treatments. For each division, own values (λ) and characteristic species (*Pt_mel* – *Pterostichus melanarius*; *Am_muni* – *Amara municipalis*) are given.

Table 4. Results of the Monte Carlo test for the CCA diagram canonical axes.

Test of the significance of 1st canonical axis: own values = 0.348		
F-ratio	=	0.300
P-value	=	0.3500
Test of the significance of all axes = 1.297		
F-ratio	=	1.245
P-value	=	0.0180

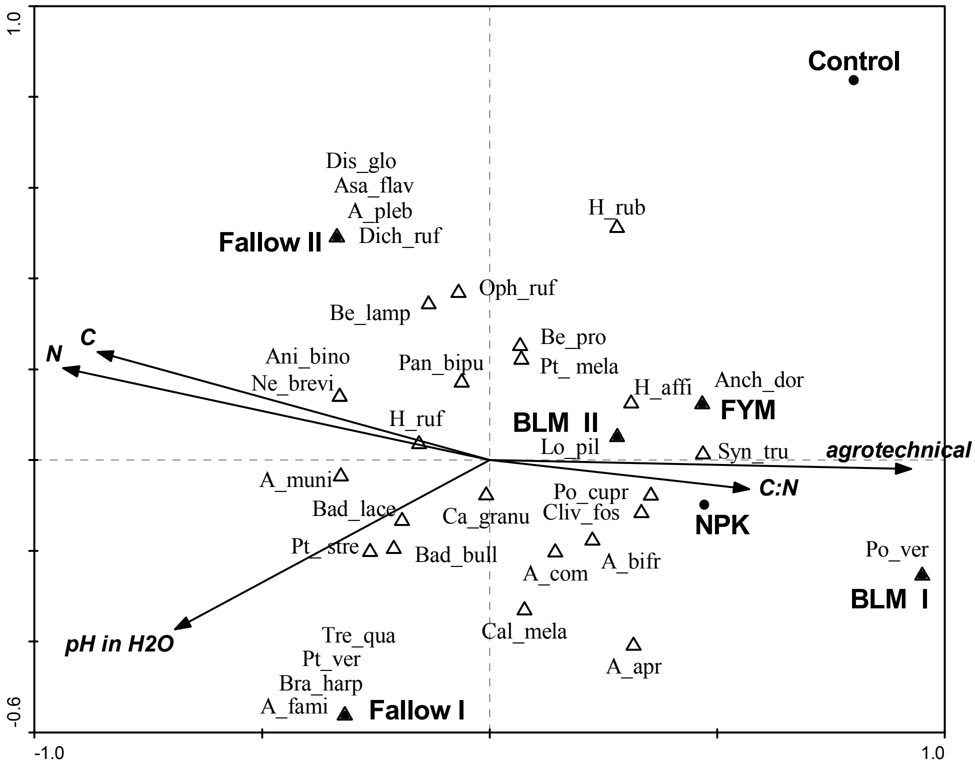

Figure 4. The ordination diagram of the canonical correlation analysis (CCA) for assemblages of Carabidae on the analyzed treatments (Species abbreviations are given in table 3, environmental variables (arrows) and names of treatments see in methods).

were positively correlated with the presence of *Anisodactylus binotatus* (F.) and *Nebria brevicollis* (F.), whereas the occurrence of *Badister lacertosus* Sturm, *Badister bullatus* (Schrank) and *P. strenuus* was positively correlated with the soil reaction. Kuperman (1996) reports that high soil pH is closely connected with the abundance and richness of carabid populations. Nietupski *et al*. (2010) found out that a decreasing pH gradient of mucky, peat-muck and peat soil was correlated with a decrease in the number of Carabidae specimens only slightly sensitive to changing moisture conditions (mesophilic ones), which were being replaced by hygrophilic species. In contrast, an increasingly acid reaction of soil stimulated a rise in the number of zoophytophagous beetles at the expense of predatory individuals. The effect of soil pH on the biodiversity of ground beetles assemblages has been confirmed by the results of our tests concerning the fallow fields. The second canonical axis was found to correspond with the analyzed fallows. However, it is quite evident that the two fallows were populated by two distinctly different communities, with different characteristic species. Thus, it is possible to indicate that long-term land fallowing creates a chance for the development of different ground beetles. On the eight-year fallow field, they included: *Bradycellus harpalinus* (Audinet-Serville), *Trechus quadristriatus* (Schrank), *Pterostichus vernalis* (Panzer) and *Amara familiaris* (Duftschmid). The species which were positively correlated with the twelve-year fallow fields were *Dischirius globosus* (Herbst), *Dicheirotrichus rufithorax* (Sahlberg), *Amara plebeja* (Gyllenhal) and *Asaphidion flavipes* (L.).

Conclusions

The type of land management has a considerable impact on Carabidae. In the agricultural biocenosis, these beetles prefer fallow farmland, which was evidenced by the highest number of carabid individuals and species found on the two fallow fields we examined. In this study, it has also been demonstrated that the treatments with a higher organic carbon and total nitrogen content are characterized by a higher species diversity of Carabidae. The dendrogram of similarities indicates that separate communities of ground beetles tend to be shaped depending on the land management types. Another significant factor that affected communities of ground beetles consisted in fertilization management.

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Authors' addresses: Wojciech SĄDEJ (corresponding author, wojciech.sadej@uwm.edu.pl), Agnieszka KOSEWSKA, Mariusz NIETUPSKI, Department of Phytopathology and Entomology, Prawocheńskiego 17, 10-722 Olsztyn, Poland; Wiera SĄDEJ, Department of Environmental Chemistry, Plac Łódzki 4, 10-727 Olsztyn, Poland.

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