Soil management system in hazelnut groves (*Corylus* sp.) versus the presence of ground beetles (Coleoptera: Carabidae)

Mariusz Nietupski[1*], *Agnieszka Kosewska*[1], *Bogumił Markuszewski*[2], *Wojciech Sądej*[1]

[1] University of Warmia and Mazury, Department of Phytopathology and Entomology, Prawocheńskiego 17, 10-722 Olsztyn, Poland
[2] University of Warmia and Mazury, Department of Horticulare, Prawocheńskiego 21, 10-722 Olsztyn, Poland

Received: August 11, 2014
Accepted: January 28, 2015

Abstract: Sustaining biodiversity as well as taking advantage of the natural environment's resistance are the key elements which should be considered when designing integrated plans for the protection of hazelnut groves. An effort has been made in this study to analyse the impact of different soil cultivation methods in hazelnut groves, on the species composition and number of individuals in carabid assemblages (Coleoptera: Carabidae). Another aim was to determine which method of inter-row soil management had the least negative effect on assemblages of these beetles. Because of the type of habitat, the xerothermic species characteristic for south-eastern Europe, i.e. *Calathus ambiguus*, *Poecilus lepidus*, *Harpalus calceatus*, and *H. griseus*, were the most numerous. The qualitative and quantitative analysis of the captured individuals implied that the optimal soil tillage system in young hazelnut groves is when soil is kept fallow with machines or chemicals, or when soil is covered with manure. The least favourable practice for the appearance of ground beetles of the Carabidae family is the use of polypropylene fabric, bark or sawdust, to cover soil.

Key words: ground beetle, hazelnut grove, inter-row soil tillage

Introduction

Hazelnut shrubs (*Corylus* sp.) are grown in many countries worldwide so that the nutritious, tasty nuts can be harvested. In 2010, the global yields of hazelnuts ranged around 900,000 tons (FAOSTAT 2012). Major producers are countries in the Black Sea basin. Most hazelnuts are produced in Turkey (66.6% of the world's production), Italy, Azerbaijan, Georgia, and in the United States. In Poland in 2010, hazelnut yields reach about 2,500 tons. A growing interest in this plant is mainly stimulated by the decreasing profitability of apple orchards compounded by the fact that apples are increasingly more difficult to sell. A hazelnut grove needs half the labour input compared to an apple orchard, and nuts – unlike apples – do not have to be stored in cool rooms (Gantner 2010).

Nowadays, growing hazelnuts is a matter of a trade-off between the volume and quality of yields which the farmer considers satisfying and the negative consequences caused by the application of fertilisers and pesticides. These assumptions are realised through the breeding progress, improved inter-row soil tillage technologies (weed control), and efforts made to use the resistance of the natural environment to minimize the gradation of pests which attack hazel shrubs. Weed control in hazelnut groves, especially young ones, is necessary to ensure a good supply of water and nutrients to hazelnut plants and facilitate the harvest of the nuts. Weed control is most often carried out using herbicides (glyphosate) and mechanical weeding. The high costs of agrochemicals as well as the risk of some weed species becoming resistant to herbicides encourage a search for new technologies to maintain inter-rows in hazelnut groves. Alternative treatments include growing grass swards and mowing, or covering the soil with various types of litter which prevents the growth of weeds (Mennan *et al*. 2006).

Sustaining biodiversity and using the resistance of nature, which to a large extent depends on predatory species, are the key components that should be included in integrated protection plans for this perennial crop (Santiveri *et al*. 2005; Scortichini *et al*. 2005). Ground beetles (Coleoptera, Carabidae) are a group of useful invertebrates, living numerously in the rural landscape. They are a predominantly predatory species. Their diet is composed of small invertebrates that often act as pests on cropped fields and horticultural farm fields (Kromp 1999; Oberholzer *et al*. 2003; Funayama 2011). Therefore, carabid beetles are considered an important component of integrated pest control methods. These beetles are regarded as important natural pest control agents (Kromp 1999). It should be pointed out, that Carabidae are sensitive to a range of crop production practices. It is very important to know how specified plant production systems affect ground beetle assemblages (Holland and Luff 2000; Twardowski *et al.* 2006). Carabidae also serve as bioindicators in studies designed to identify changes. These are changes which occur, for example, in an agricultural biocenosis in response to crop production factors and production intensity (Holland and Luff 2000).

*Corresponding address:
mariusz.nietupski@uwm.edu.pl

Areas overgrown with trees, like hazelnut groves, are the sites where numerous useful animal species find refuge, e.g. small mammals and predatory arthropods, including a large group of the ground beetles Carabidae (Testa and Zapparoli 1994; Klaa *et al*. 2005; Guidone *et al*. 2008). This is the reason why hazelnut groves are a valuable component of an agricultural landscape, dominated by monocultures of crops. Different inter-row soil tillage technologies in hazelnut groves may affect the presence of Carabidae, whose existence is closely related to the soil environment. The objective of this experiment was: 1 – to determine the species composition and abundance of Carabidae dwelling in a hazelnut grove in north-eastern Poland, 2 – to find out how the management methods used in the grove affect assemblages of ground beetles, 3 – to decide which of the inter-row soil tillage techniques had the least negative effect on the assemblages of these beetles.

Materials and Methods

Research area and design of experiment

The experiment was started in 2006, in the village called Tuszewo, located in northeastern Poland (UTM DE12). It was set up in a commercial hazelnut grove covering 1.5 ha. Trees of two varieties, Halle and Kataloński, were planted in single rows, at distances of 5 × 2 m (1,000 trees · · ha^{-1}), with rows running in a west-easterly direction. Trees were trimmed to grow low with a spindle-shaped crown. The sandy soil had a content of floatable particles equal to 5.7%. An area of 0.4 ha was set out for the experiment (0.06 ha for each treatment), in which different techniques were tested on the soil of the rows of trees. The techniques included: mechanical fallow – the control (C), herbicide fallow (HF), manure (M), bark (B), sawdust (SD), and black polypropylene fabric (F). In the control treatment, soil tillage consisted of mechanical weed removal with a soil cultivator to the depth of 5 cm. This treatment was repeated four times in a season (the first decade of May and June, half of July, and the third decade of August). In the herbicide fallow, weeds were controlled with a mixture of preparations: Roundup 360 SL (glyphosate) at a dose of 5 l · ha^{-1} and Chwastox 450 SL (2-methyl-4-chlorophenoxyacetic acid) at a dose of 1.5 l · ha^{-1}. The treatment was performed twice in a season: in the second decade of May and in the first decade of August each year. The tested types of soil cover were spread on the soil in spring 2006, before the plants began growing. A strip of soil 1.2 m wide between two rows of trees, was covered. Organic litter (manure, bark, sawdust) made a 10 cm thick layer. Bark and sawdust (fresh) originated from coniferous trees. Once the said litter had been spread on the soil, an additional dose of nitrogen (50% higher than the applied one) was sprayed. The soil between the rows of the hazelnut trees was kept as bare fallow using a soil cultivator and harrow.

Carabid sampling

Carabids were captured in two seasons in the years 2007 and 2008. In 2007, traps were placed in holes in the soil on 21 April and removed on 8 December. The traps were exposed for 210 days. In the following year, Carabidae were sampled for 196 days, from 5 May to 8 November. Epigeic species of ground beetles were caught using modified Barber soil traps, which is a widespread technique in such studies (Kotze *et al*. 2011). The traps were filled to a third of their capacity with ethylene glycol. A few droplets of detergent were added to the ethylene glycol to lower the surface tension. Plastic containers 130 mm high and 90 mm in diameter, with a capacity of 500 ml, served as traps. The traps were placed in the ground so that the upper edge of each container was level with the surface of the ground. A little roof was installed above each trap to prevent excess rainfall flowing into the jar, diluting the solution and causing the traps to overflow. Six traps in a row between the trees, set 10 m from one another, were placed on each of the six experimental plots. The traps were emptied every 14 days, when the conserving mixture was supplemented and the beetles found in the traps were put into containers with 75% ethanol.

Data analysis

The collected material was species identified with the key by Hůrka (1996), using the terminology proposed by Aleksandrowicz (2004). The captured Carabidae individuals were then analysed with respect to the species composition, abundance, and dominance structure. The following dominance classes were distinguished: eudominants (> 10% of individuals in a assemblage), dominants (5.1–10%), subdominants (2.1–5%), recedents (1.1–2%), and subrecedents (< 1%) (Górny and Grüm 1981). The expected species number in all treatments was estimated using the Jackknife estimation technique of species richness (Zahl 1977). The randomisation of samples was achieved using statistical software EstimateS v. 9.1.0 (Colwell 2005). The ecological specification of the captured beetles was made according to their feeding demands (Szoo – small zoophages, Mzoo – medium zoophages, Lzoo – large zoophages, Hzoo – hemizoophages, Phy – phytophages), habitat requirements (OA – open area, Eu – eurytopic, Ri – ripicolous, F – forest), preferred humidity (Xe – xerophilic, Mxe – mesoxerophilic, M – mesophilic, Mhy – mesohygrophilic), and type of development (A – autumn breeders, S – spring breeders), and was referred for this purpose to Larsson (1939), Sharova (1974), Thiele (1977), Lindroth (1985, 1986), and Aleksandrowicz (2004). When analysing the results, the following indices were used: the Shannon species diversity index (H’) and the Pielou evenness index (J’). Similarities between the carabid assemblages in the analysed hazelnut grove variants were assessed using cumulative hierarchical clustering with the Bray-Curtis similarity measure. Differences between the means were assessed with a single factor analysis of variance (ANOVA). The achieved means from treatments (for tested indices) were set in homogenous groups using the Tukey’s test (HSD) of significance ($p < 0.05$). Each homogenous group, which gathered means with no statistical differences between one another, was assigned an identical letter: a, b, c, etc. Groups of means assigned different letters were statistically significantly different.

The evaluation of dependences between the presence of specific ecological groups of Carabidae and the soil maintenance technique on a hazelnut grove was accomplished with ordination techniques (Ter Braak and Smilauer 1998). The principal component analysis (PCA) was applied because the distribution of the analysed data was linear. All statistical computations and their graphic presentation were completed with the aid of Statistica 8.0 and Canoco 4.51 software.

Results and Discussion

In total, 9,154 individuals of Carabidae, representing 61 species, which corresponds to around 25% of the species identified in northeastern Poland, were captured during our two-year-long experiment (Aleksandrowicz *et al*. 2003) (Table 1). The hazelnut grove, compared to other similar habitats in this part of Poland (e.g. apple orchards, willow groves, groups of trees between fields) was characterized by a higher level of species richness and number of captured carabid individuals (Kosewska *et al*. 2010; Nietupski 2012). However, the actual species richness of a carabid assemblage in a given grove may depend on the wildlife diversity of adjacent habitats (Deuschle and Glück 2008). The dynamics of Carabidae captures in 2007, is illustrated in figure 1, which shows two peaks of activity (spring and autumn), characteristic for populations of ground beetles in this part of Europe (Larsson 1939). The carabid beetles were active until the first decade of December (no snow cover) on the control plot (*Amara ingenua*, *Asaphidion flavipes*, *Calathus melanocephalus*, and *Trechus quadristriatus*) and on soil covered with fabric (*Bembidion femoratum*, *C. ambiguus*, and *C. melanocephalus*). Beetle activity in these treatments was most probably prolonged because of the better thermal conditions and because food was still available (Jaskuła and Soszyńska--Maj 2011). The vernal peak activity in 2008 was less evident, but also occurred earlier than in the preceding year.

The species richness of the Carabidae assemblages from the examined treatments, was submitted for analysis based on the rarefaction method. This method enables one to determine the expected value according to the distribution of samples. Samples are randomised and, based on their randomisation, cumulative curves for the analysed parameter are drawn. The course of the rarefaction curves indicated that the highest number of expected species was confirmed for the treatments HF, C, M, and SD, fluctuating within the range of 58 species. When the soil in the rows of trees was covered with bark or fabric, the number of expected species fell to about 40 (Fig. 2). In all the tested treatments, during the two years of the experiment, the most numerous species was *C. ambiguus*, classified as an eudominant and contributing between 29.7 and 54.5% to the analysed assemblage (Table 1). This species is characteristic for open and dry areas, for example cropped fields on sandy soils (Lindroth 1986). Another eudominant species was *C. fuscipes*. It is an eurytopic, open-area species. It was numerous in the manure treatment because it prefers soil richer in organic matter (Lindroth 1986). Besides, manure creates the type of habitat where this extremely predatory beetle is more likely to find prey. The group of dominants was composed of seven species characteristic for open and dry areas (except *Harpalus rufipes*, which is mesophilic). The species *C. cinctus*, appeared in all the variants and was the only dominant species in the HF treatment, while in the B and SD variants, *C. cinctus* was accompanied by *H. griseus*. In the variants where soil was covered with M, these two species were joined by *H. rufipes*, while in the variant with F, they co-occurred with dominant *H. calceatus* and *H. smaragdinus*. Besides *C. cinctus*, the group of dominants in the control treatment, consisted of *Broscus cephalotes* and *Poecilus lepidus*, species frequently met on cropped fields (Hůrka 1996; Irmler 2003; Kosewska *et al*. 2011). The examined assemblage of carabids comprised a large group of species, both among dominant and recedent groups, which originate from the steppes of southeastern Europe (Aleksandrowicz 2011). These xerothermic species are typical of the continental climate. In Poland, these species usually dwell in fields on sandy soils. The species *C. ambiguus*, *P. punctulatus*, *P. lepidus*, *H. calceatus*, and *H. griseus* identified in the hazelnut grove, are examples (Tischler 1971).

The number of caught Carabidae individuals was significantly ($p < 0.01$) different between the treatments (Table 2). Most specimens of the investigated carabid species during the two years of the experiment, were captured from the C and HF. These species were also quite numerous in the variant with M. The smallest number of ground beetles was caught in the variant with B in 2007, and F in 2008. Differences in numbers of caught individuals in both years of the investigations can be explained by the 'spreading of risk' hypothesis, which assumes that there is a sub-population whose abundance is varied in time and space, which gives the whole species a better chance to survive (Den Boer 1968; Schwerk *et al*. 2006). A good indicator which enables us to compare numbers of captured individuals in different habitats is catchability, which expresses the average number of caught individuals into a single trap in 24 h (individuals/trap/day). The assessed value of catchability varied during the two years of observations, reaching the highest values for the HF, C, and M treatments and being the lowest on the B and F treatments. Cotes *et al*. (2009) demonstrated that when inter-row soil in olive groves was kept fallow, the number of ground arthropods caught into pitfall traps increased. A similar relationship was found in our experiment, namely most Carabidae individuals were captured in the control and herbicide fallow variants. This can be explained by the fact that beetles move more easily on bare ground. Other reasons could be the higher abundance and better access to food. The latter factor could have also stimulated the higher number of Carabidae in the variant with manure, which is colonised by many species of invertebrates and attracts species from other trophic groups (Garratt *et al*. 2011). A higher content of organic carbon, characteristic for manure treated soils, is positively correlated with a higher species richness of epigeic Carabidae (Sądej *et al*. 2012). The low values of the catchability index, relative to the years of the research, determined in the variants with bark and fabric may have been due to the low availability of food for zoophages and hemizoophages.

Table 1. Species composition and dominance among Carabidae species captured in analyzed treatments in a hazelnut grove

Species	Treatments											
	C		HF		M		B		SD		F	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Amara aenea (De Geer, 1744)	0.1	2.3	–	2.7	0.4	1.4	–	0.4	0.4	1.1	0.6	2.6
A. apricaria (Paykull, 1790)	–	–	0.2	0.1	–	0.1	–	–	–	0.1	–	0.2
A. bifrons (Gyllenhal, 1810)	1.8	1.0	3.1	0.6	4.5	3.2	0.3	0.4	0.9	0.8	3.2	1.7
A. brunnea (Gyllenhal, 1810)		–	–	–	–	–	–	–	–	0.1	–	–
A. communis (Panzer, 1797)	0.3	0.1	–	–	0.2	0.1	–	–	–	–	–	0.2
A. consularis (Duftschmid, 1812)	1.1	0.7	4.2	0.7	2.3	1.8	1.0	1.3	2.1	1.6	1.9	3.3
A. convexior Stephens, 1828	–	–	0.2	–	–	–	–	–	–	–	–	–
A. eurinota (Panzer, 1797)	0.1	0.4	–	0.4	0.2	–	–	0.1	–	0.2	–	–
A. familiaris (Duftschmid, 1812)	0.1	0.8	–	2.5	0.4	0.8	–	1.1	–	2.5	–	1.7
A. fulva (Degeer, 1774)	0.7	–	0.2	0.1	0.2	0.3	–	0.2	0.9	0.1	0.4	–
A. ingenua (Duftschmid, 1812)	0.3	–	0.3	0.1	–	–	–	–	–	0.2	0.2	–
A. majuscula (Chaudoir, 1850)	–	–	0.2	–	–	–	–	–	–	–	–	–
A. municipalis (Duftschmid, 1812)	–	–	–	0.1	–	0.1		–	–	–	–	–
A. ovata (Fabricius, 1792)	–	–	0.2	–	–	0.1	–	–	–	–	–	–
A. plebeja (Gyllenhal, 1810)	0.4	0.4	–	0.5	–	0.8	–	0.4	0.2	0.4	–	–
A. similata (Gyllenhal, 1810)	–	1.1	0.2	0.6	–	3.6	–	0.3	0.2	0.4	0.4	1.0
A. spreta Dejean, 1831	0.8	1.5	0.5	1.6	0.4	3.0	0.3	1.8	0.4	2.0	0.6	4.0
Anchomenus dorsalis (Pontoppidan, 1763)	–	–	0.2	–	0.2	–	–	–	–	–	0.2	–
*Asaphidion flavipes (*Linnaeus, 1761)	0.3	–	–	–	–	–	–	0.1	–	–	–	–
Bembidion femoratum (Sturm, 1825)	–	–	–	–	–	–	–	–	–	–	0.4	–
B. lampros (Herbst, 1784)	0.8	0.1	0.7	0.4	0.2	0.1	–	–	0.2	–	0.4	–
B. properans (Stephens, 1828)	1.4	0.2	1.3	0.3	0.2	–	–	–	0.4	0.1	–	0.2
B. quadrimaculatum (Linnaeus, 1761)	0.1	0.2	0.2	–	–	0.2	–	–	0.4	0.1	0.2	–
Broscus cephalotes (Linnaeus, 1758)	6.8	4.0	2.9	3.1	0.7	1.3	1.3	1.6	1.7	4.1	1.9	2.6
Calathus ambiguus (Paykull, 1790)	43.2	39.3	36.3	45.8	31.4	26.4	54.5	41.8	38.9	42.3	29.7	39.2
C. cinctus (Motschulsky, 1850)	3.1	10.0	2.9	7.2	2.3	8.0	2.2	7.6	6.6	7.3	5.4	8.7
C. erratus (Sahlberg, 1827)	1.7	0.8	2.5	1.2	2.2	0.5	1.0	0.9	3.0	1.8	1.5	0.3
C. fuscipes Goeze, 1777	8.9	21.2	17.2	15.8	21.4	27.9	15.7	25.8	7.5	12.5	10.8	10.8
C. melanocephalus (Linnaeus, 1758)	2.1	0.5	2.1	0.2	3.2	2.0	1.9	1.1	3.0	0.5	4.3	0.5
C. micropterus (Duftschmid, 1812)	0.1	–	–	–	–	–	0.3	–	0.2	–	–	–
Carabus auratus Linnaeus, 1761	0.1	0.1	0.3	–	0.4	–	–	–	–	–	0.2	–
C. cancellatus Illiger, 1798	–	–	0.3	–	0.2	0.1	0.6	–	0.2	0.1	–	–
C. hortensis Linnaeus, 1758	–	–	0.2	–	–	–	–	–	–	–	–	–
C. nemoralis O.F.Muller, 1764	–	–	–	–	–	–	–	0.1	–	–	–	–
Cicindela hybriba Linnaeus, 1758	1.1	0.2	1.1	–	0.9	–	–	–	4.1	0.5	1.9	0.2
Clivina collaris (Herbst,1784)		0.1	–	–	–	–	–	–	–	–	–	–
C. fossor (Linnaeus, 1758)	0.3	0.1	0.8	0.1	–	0.2	–	–	0.2	0.2	–	0.2
Curtonotus aulicus (Panzer, 1797)	0.3	0.1	–	–	0.2	–	0.6	–	0.2	–	–	0.2
Dolichus halensis (Schaller, 1783)	0.1	0.1	0.3	0.1	–	0.1	–	0.3	–	0.1	–	–
Dyschirius globosus (Herbst, 1784)	–	–	–	–	–	0.2	–	–	–	–	–	–
Harpalus affinis (Schrank, 1781)	1.4	1.7	2.6	3.3	1.6	0.7	0.3	0.1	0.6	0.8	1.1	0.7
H. calceatus (Duftschmid,1812)	0.8	0.2	0.7	0.1	1.1	1.6	1.6	0.4	4.5	1.7	9.7	6.8
H. griseus (Duftschmid, 1812)	4.4	0.5	3.3	0.5	7.0	3.8	5.1	0.8	8.5	3.3	6.2	3.7
H. picipennis (Duftschmid, 1812)	–	–	–	–	–	–	–	–	–	0.1	–	–
H. rubripes (Duftschmid, 1812)	–	–	–	0.1	–	–	0.6	–	–	–	–	–
H. rufipes (De Geer, 1744)	4.1	2.1	4.4	2.3	6.5	2.4	3.5	3.1	3.8	2.8	2.8	0.9
H. signaticornis (Duftschmid, 1812)	0.8	1.5	1.1	0.6	1.3	1.6	1.3	0.9	3.2	4.8	4.5	1.7
H. smaragdinus (Duftschmid, 1812)	4.8	1.5	2.8	0.4	1.4	0.5	2.2	0.5	4.5	1.4	5.8	1.7
H. tardus (Panzer, 1797)	0.6	0.4	0.3	0.1	3.6	1.4	1.3	1.1	0.6	0.8	0.4	1.0
Masoreus wetterhallii (Gyllenhal, 1813)	0.1	–	–	–	–	0.1	–	–	0.2	0.2	–	–
Microlestes minutulus (Goeze, 1777)	0.3	0.1	0.7	–	1.1	–	1.0	–	–	–	0.6	–
M. maurus (Sturm, 1827)	–	0.2		0.1	–	–	–	0.1	–	0.1	–	–
Notiophilus aquaticus (Linnaeus, 1758)	0.4	–	0.5	–	–	0.1	0.3	–	0.9	–	–	–
Poecilus cupreus (Linnaeus, 1758)	0.6	0.1	0.8	0.1	0.4	0.2	–	0.3	0.2	0.4	–	–
P. lepidus (Leske, 1758)	1.0	5.3	1.5	4.3	1.1	2.0	1.0	2.4	0.2	2.0	0.9	2.8
P. punctulatus (Schaller, 1783)	–	0.2	0.2	1.9	–	–	–	–	–	0.1	–	–
P. versicolor (Sturm, 1824)	0.6	–	0.2	1.4	1.6	1.6	1.6	4.1	0.2	1.0	0.9	2.1
Pterostihus melanarius (Illiger, 1798)	0.3	0.3	0.8	0.4	0.9	1.0	0.3	0.8	–	0.2	–	–
Syntomus foveatus (Fourcroy, 1758)	1.0	0.7	–	0.1	0.2	0.4	–	0.2	–	0.4	0.6	0.5
S. trancatellus (Linnaeus, 1761)	–	–	–	–	0.2	0.1	–	–	–	–	0.2	–
Trechus quadristriatus (Schrank, 1781)	2.3	0.4	1.8	0.4	0.4	0.5	–	0.2	0.6	0.4	1.7	0.2
Number of individuals	708	1101	612	1387	557	1109	312	1033	468	830	465	572
	1809		1999		1666		1345		1298		1037	
Number of species	42	39	41	38	36	40	25	32	34	41	32	29
	46		49		47		38		45		38	

C – control; HF – herbicide fallow; M – manure; B – bark; SD – sawdust; F – black polypropylene fabric

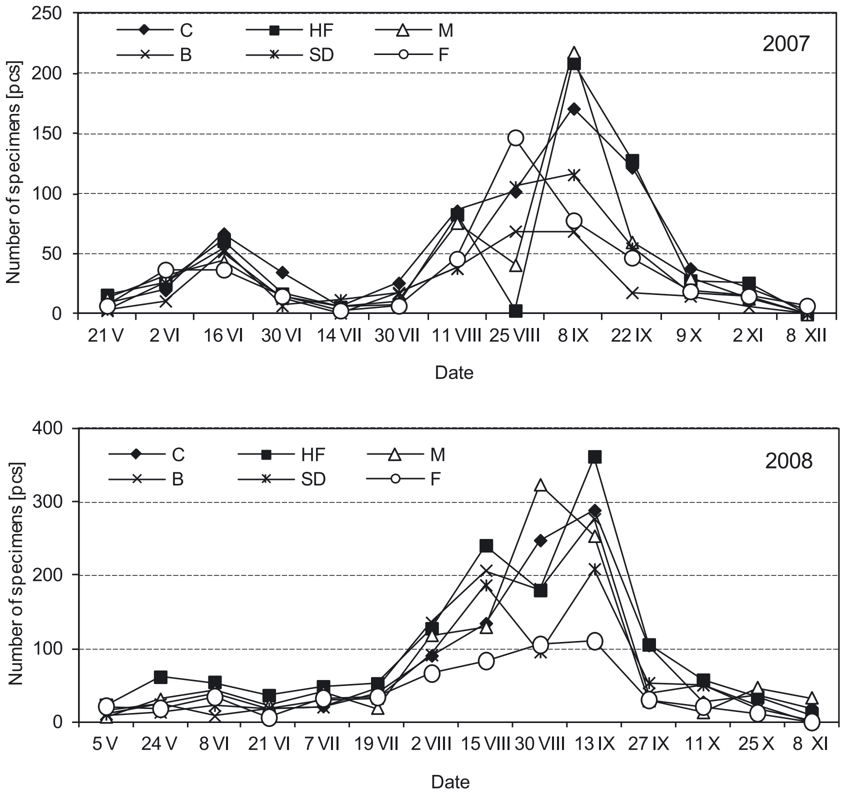

Fig. 1. Dynamics of catches of Carabidae from the analysed combinations in a hazelnut grove (2007–2008): C – control; B – bark; HF – herbicide fallow; SD – sawdust; M – manure; F – black polypropylene fabric

Table 2. Mean number of individuals and species, catchability and indices describing ground beetles assemblages in hazelnut plantation (2007–2008) (mean of six traps)

Indices	Years	Treatments					
		C	HF	M	B	SD	F
Mean number of individuals	2007	118.0±11.3 c	102.0±1.5 bc	92.8±5.0 bc	52.0±3.6 a	78.0±1.1 ab	77.5±12.2 ab
		$p < 0.01$					
	2008	183.5±36.5 bc	231.2±1.4 c	184.8±11.6 bc	172.2±4.3 bc	138.3±6.3 ab	95.3±22.9 a
		$p < 0.01$					
Mean number of species	2007	24.2±1.1 c	24.2±0.8 c	21.3±0.5 bc	13.5±1.6 a	19.5±0.9 b	20.8±12.2 bc
		$p < 0.01$					
	2008	23.5±2.6	25.5±2.1	27.0±1.8	22.3±2.2	25.3±2.6	19.3±2.0
		ns					
Shannon H’ (log n)	2007	2.3±0.04 b	2.4 ± 0.06 b	2.3 ± 0.03 b	1.7±0.11a	2.3±0.04 b	2.4±0.04 b
		$p < 0.01$					
	2008	2.0±0.07 ab	2.1±0.07 ab	2.4±0.06 c	1.9±0.08 a	2.3±0.08 bc	2.2±0.10 b
		$p < 0.01$					
Pielou (J’)	2007	0.72±0.01 b	0.74±0.01 bc	0.76±0.01 bcd	0.65±0.02 a	0.77±0.01 cd	0.80±0.01 d
		$p < 0.01$					
	2008	0.65±0.01	0.64±0.02 a	0.73±0.01 bc	0.62±0.01 a	0.70±0.01 b	0.75±0.01 c
		$p < 0.01$					
Catchability (individuals/trap/day)	2007	0.56±0.05 c	0.48±0.01 bc	0.44±0.02 bc	0.25±0.02 a	0.37±0.01 ab	0.37±0.06 ab
		$p < 0.01$					
	2008	0.94±0.19 bc	1.18±0.01 c	0.94±0.06 bc	0.88±0.02 b	0.71± 0.03 ab	0.49±0.12 a
		$p < 0.01$					

ns – non-significant differences; standard error of the mean (±SEM)

a, b, c, etc. – means followed by the same letter within each column not significantly different at $p < 0.05$

C – control; B – bark; HF – herbicide fallow; SD – sawdust; M – manure; F – black polypropylene fabric

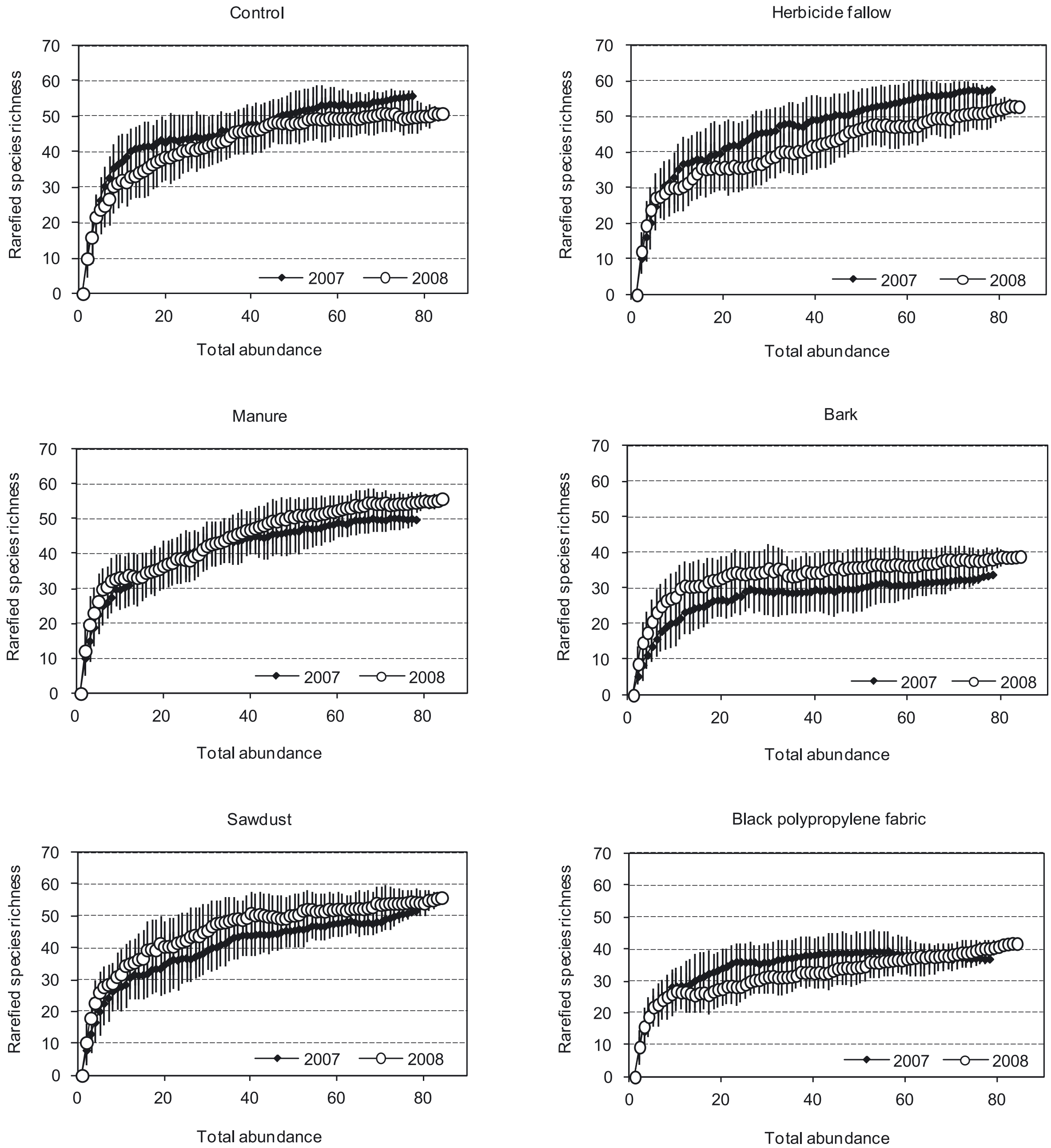

Fig. 2. Expected number of carabid species caught in testing combinations at a hazelnut grove using the Jackknife estimator (±SD) of species richness

The computed values of the H′ and J′ index in both years were the lowest for the beetle assemblage inhabiting the plot covered with B (Table 2). The lowest values of the H′ index were determined in 2007 for the assemblages of ground beetles in the HF and F variants, and in 2008 – for the assemblage in the M treatment. The Shannon index is higher with an increasing number of species in each analysed sample, and when the shares of identified species in a sample are more even. The species richness of Carabidae is higher in fields using the organic farming regime, where fewer agronomic and chemical treatments are applied (Carcamo *et al*. 1995; Kromp 1999; Hummel *et al*. 2002). Our results show that keeping the inter-row soil fallow with mechanical (C) or chemical (HF) methods did not negatively affect the number of captured Carabidae species, which is confirmed by the values of H′ and J′ indices.

Dendrograms of similarities between Carabidae assemblages were different, respectively, for the year of the study (Fig. 3). The strongest similarity to the carabid assemblage found in the control treatment in 2007 was identified for the assemblages from the herbicide fallow and manure treatments. In 2008, the assemblages dwelling in the bark and herbicide fallow variants were most similar to the control. The high species richness and counts of captured Carabidae individuals on mechanical and herbicide fallow imply that keeping the ground free from plants in a hazelnut grove, encourages the presence of ground beetles. This observation contradicts the results obtained in apple orchards, which suggest that there is a negative effect of herbicide applications on epigeic carabid beetles (Minarro and Dapena 2003; Nietupski 2012). Some adverse influences of herbicides on Carabidae assemblages may occur at the moment of the herbicide application. The curve illustrating the dynam-

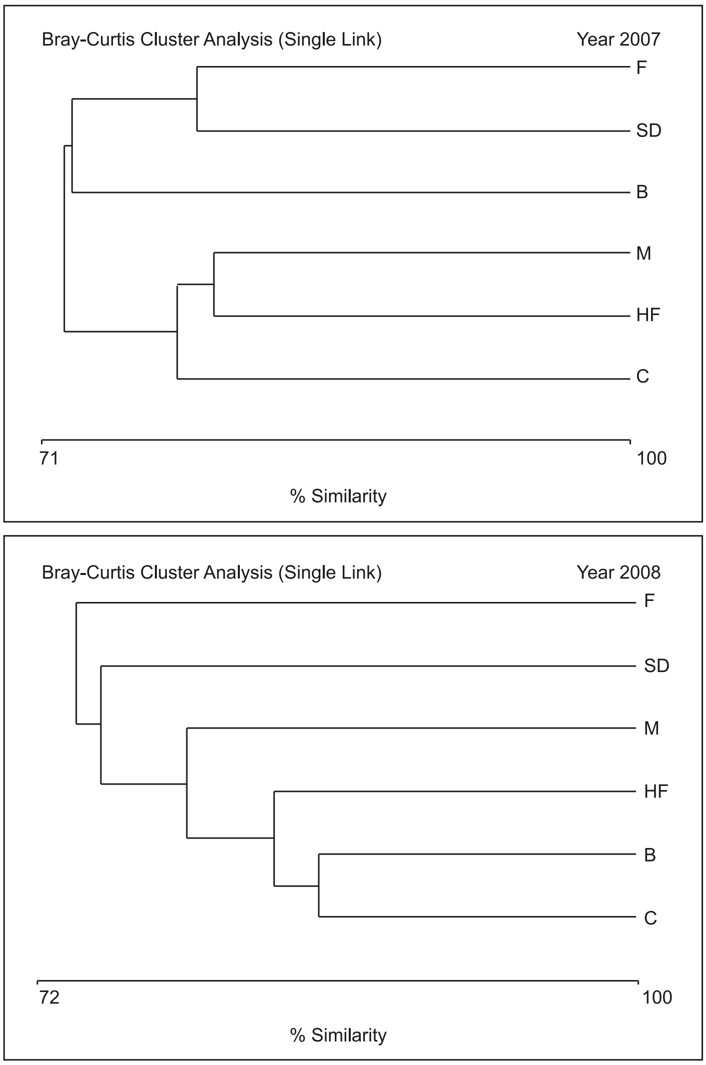

Fig. 3. Dendrograms of similarities between Carabidae communities from the analysed combinations in a hazelnut grove (2007–2008): C – control; B – bark; HF – herbicide fallow; SD – sawdust; M – manure; F – black polypropylene fabric

ics of the captures of the ground beetles falls radically on a day when herbicide is sprayed but on the following observation dates, the curve reaches high values (Fig. 1). This trend may indicate that an application of herbicide repels beetles from the area subjected to the treatment for a few days. The following year, there was no such decline in the number of caught ground beetles during the herbicide application. The lack of an unambiguously negative influence of herbicides may stem from the fact that dominant ground beetles in the analysed area were predatory species and hemizoophages, while typical phytophages were far less numerous.

The PCA shows that in 2007, the control and manure variants were located near the 1st ordination axis (Fig. 4). It was also found that a group of medium zoophages and open area species best fit to this axis. These ecological groups were distinguished by the presence of specific species, such as *C. ambiguus*, *C. fuscipes*, *B. cephalotes*, *C. cinctus*, and *P. lepidus*. In the herbicide fallow variant, large zoophages (including *B. cephalotes*) and hemizoophages were characteristic representatives of the carabids. In both years, it was possible to notice some correlation between the placement of traps on the control treatment and the capture of Carabidae which belong to small zoophages. This dependence was also noticed by Purvis and Curry (1984) during their observations on sugar beet farm fields in England. The incorporation of manure to soil as fertiliser most probably has a beneficial effect on ground beetles. The addition of manure raises the content of soil organic matter, improves soil structure, raises its moisture content, and enhances the availability of food supplies to predators (Holland and Luff 2000). On the other hand, as manure is rather expensive to buy and apply to the soil, this soil management practice is rarely used in hazelnut groves. Our analysis of the PCA's diagrams (2007–2008), in relation to the distribution of the samples along the ordination axes, suggests that the Carabidae assemblages caught in the B variant are not positively correlated with the presence of any of the distinguished ecological groups. The soil surface covered with bark or fabric is a rather extreme habitat for epigeic carabid beetles. The presence of fresh, not yet decomposed bark can make the soil more acid and create suitable conditions for the reproduction and multiplication of small rodents (Billeaud and Zajicek 1989; Schmid *et al*. 2004). In turn, black polypropylene fabric can make it more difficult for beetles to gain access to

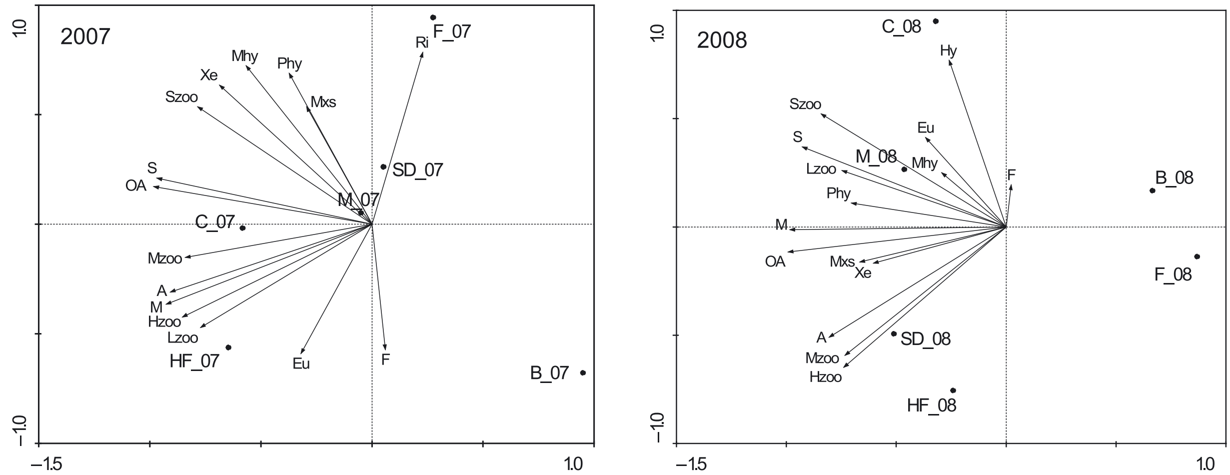

Fig. 4. The PCA diagram presenting variability of ecological groups of Carabidae depending on the soil cultivation method in the subsequent years of research (abbreviations given in the section on Materials and Methods, see page 27)

food, which they find on the ground. Besides, by absorbing solar radiation, black fabric contributed to the elevating of the temperature near the soil surface, which may repel beetles active during the daytime.

Conclusions

The analysed hazelnut grove is a habitat characterised by a high richness of species and abundance of beetles which belong to the family of Carabidae. Because of the characteristics of the hazel grove (age, type of soil), xerothermic species typical of southeastern Europe, i.e. *C. ambiguus*, *P. lepidus*, *H. calceatus*, and *H. griseus*, were amply represented in the examined assemblages. In a young hazelnut groves, the best way to manage soil in order to control weeds is by keeping the soil fallow through either mechanical or chemical treatments. This type of soil cultivation has a positive effect on the species richness and counts of epigeic Carabidae, especially the ones which are classified as large and medium zoophages. Soil cover made from black polypropylene fabric, bark or sawdust is less friendly towards ground beetles.

References

Aleksandrowicz O., Gawroński R., Browarski B. 2003. New species of carabid beetles (Coleoptera: Carabidae) from North-East Poland. Baltic Journal of Coleopterology 3 (2): 153–156.

Aleksandrowicz O.R. 2004. Biegaczowate (Carabidae). [Graund beetles (Carabidae)]. p. 28–42. In: „Fauna Polski – charakterystyka i wykaz gatunków". [Polish fauna – characteristic and species specification] (W. Bogdanowicz, E. Chudzicka, I. Pilipiuk, E. Skibińska, eds.). Muzeum i Instytut Zoologii Polskiej Akademii Nauk, Warszawa, Poland, 580 pp.

Aleksandrowicz O. 2011. Recent records of steppe species in Belarus, first indications of a steppe species invasion? ZooKeys 100: 475–485.

Billeaud L.A., Zajicek J.M. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content and growth of *Ligustrum japonicum*. Journal of Environmental Horticulture 7 (4): 155–157.

Cárcamo H.A., Niemelä J., Spence J.R. 1995. Farming and ground beetles: effects of agronomic practice on populations and community structure. The Canadian Entomologist 127 (1): 123–140.

Colwell R.K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples, ver. 9.1.0. http://purl.oclc.org/estimates [Accessed: January 27, 2015].

Cotes B., Castro J., Cardenas M., Campos M. 2009. Responses of epigeal beetles to the removal of weed cover crops in organic olive orchards. Bulletin of Insectology 62 (1): 47–52.

Den Boer P.J. 1968. Spreading of risk and stabilization of animal numbers. Acta Biotheoretica 18 (1–4): 165–194.

Deuschle J., Glück E. 2008. Similarity of ground beetle communities of extensively managed orchards depending on management regimes. Bulletin of Insectology 61 (1): 73–80.

FAOSTAT 2012. Food and Agriculture Organization data. http://faostat3.fao.org/download/Q/QC/E [Accessed: January 27, 2015].

Funayama K. 2011. Influence of pest control pressure on occurrence of ground beetles (Coleoptera: Carabidae) in apple orchards. Applied Entomology and Zoology 46 (1): 103–110.

Gantner M. 2010. Aktualne problemy występujące w uprawach małoobszarowych na przykładzie leszczyny. [Current problems in minor crops on hazelnut example]. Progress of Plant Protection/Postępy w Ochronie Roślin 50 (4): 1583–1591. (in Polish with English summary)

Garratt M.P.D., Wright D.J., Leather S.R. 2011. The effects of farming system and fertilizers on pests and natural enemies: A synthesis of current research. Agriculture, Ecosystems and Environment 141 (1–2): 261–270.

Górny M., Grüm L. 1981. Metody stosowane w zoologii gleby. [Methods using in soil zoology]. PWN, Warszawa, Poland, 483 pp. (in Polish)

Guidone L., Loru L., Marras P.M., Fios X., Pantaleoni R.A., Tavella L. 2008. Predatory bugs in hazelnut orchards of Piedmont and Sardinia (Italy). Bulletin of Insectology 61 (1): 207–208.

Holland J.M., Luff M.L. 2000. The effects of agricultural practices on Carabidae in temperate agroecosystems. Integrated Pest Management Reviews 5 (2): 109–129.

Hummel R.L., Walgenbach J.F., Hoyt G.D., Kennedy G.G. 2002. Effects of vegetable production system on epigeal arthropod populations. Agriculture, Ecosystems and Environment 93 (1–3): 177–188.

Hůrka K. 1996. Carabidae of the Czech and Slovak Republics. Illustrated key. Kabournek – Zlin, Czech Republic, 565 pp.

Irmler U. 2003. The spatial and temporal pattern of carabid beetles on arable fields in northern Germany (Schleswig-Holstein) and their value as ecological indicators. Agriculture, Ecosystems and Environment 98 (1–3): 141–151.

Jaskuła R., Szoszyńska-Maj A. 2011. What do we know about winter active ground beetles (Coleoptera, Carabidae) in Central and Northern Europe? ZooKeys 100: 517–532.

Klaa K., Mill P.J., Incoll L.D. 2005. Distribution of small mammals in a silvoarable agroforestry system in Northern England. Agroforestry System 63 (2): 101–110.

Kosewska A., Nietupski M., Laszczak-Dawid A., Ciepielewska D. 2010. Biegaczowate (Col., Carabidae) zasiedlające uprawy wierzby krzewiastej w okolicach Olsztyna. [Ground beetles (Coleoptera: Carabidae) inhabiting shrub willow plantations]. Progress in Plant Protection/Postępy w Ochronie Roślin 50 (3): 1504–1510. (in Polish with English summary)

Kosewska A., Nietupski M., Laszczak-Dawid A., Ciepielewska D. 2011. Naziemna fauna biegaczowatych (Col., Carabidae) występująca w uprawach rzepaku ozimego. [Assemblages of epigeic carabid beetles (Col., Carabidae) in winter oilseed rape plantations]. Progress in Plant Protection/Postępy w Ochronie Roślin 51 (2): 763–770. (in Polish with English summary)

Kotze J.D., Brandmayr P., Casale A., Dauffy-Richard E., Dekoninck W., Koivula M.J., Lövei G.L., Mossakowski D., Noordijk J., Paarmann W., Pizzolotto R., Saska P., Schwerk A., Serrano J., Szyszko J., Taboada A., Turin H., Venn S., Vermeulen R., Zetto T. 2011. Forty years of carabid beetle research in Europe – from taxonomy, biology, ecology and population studies to bioindication, habitat assessment and conservation. ZooKeys 100: 55–148.

Kromp B. 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agriculture, Ecosystems and Environment 74 (1–3): 187–228.

Larsson S.G. 1939. Entwicklungstypen und Entwicklungszeiten der dänischen Carabiden. [Development types and development time of the Danish Carabidae]. Entomologische Meddelelser 20: 270–560.

Lindroth C.H. 1985. The Carabidae (Coleoptera) of Fennoscandia and Denmark. Fauna Entomolgica Scandinavica 15 (1): 1–225.

Lindroth C.H. 1986. The Carabidae (Coleoptera) of Fennoscandia and Denmark. Fauna Entomolgica Scandinavica 15 (2): 226–497.

Mennan H., Ngouajiob M., Isik D., Kaya E. 2006. Effects of alternative management systems on weed populations in hazelnut (*Corylus avellana* L.). Crop Protection 25 (8): 835–841.

Minarro M., Dapena E. 2003. Effects of groundcover management on ground beetles (Coleoptera: Carabidae) in an apple orchard. Applied of Soil Ecology 23 (2): 111–117.

Nietupski M. 2012. Naziemne biegaczowate (Coleoptera: Carabidae) występujące w sadach jabłoniowych objętych różnymi systemami produkcji. [Ground beetles (Col., Carabidae) occurring in apple orchards under different production systems.] Progress of Plant Protection/Postępy w Ochronie Roślin 52 (2): 360–365. (in Polish with English summary)

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 (1): 81–85.

Purvis G., Curry J.P. 1984. The influence of weeds and farmyard manure on the activity of Carabidae and other ground-dwelling arthropods in a sugar beet crop. Journal of Applied Ecology 21 (1): 271–283.

Santiveri C., Ibanez R., Aymami A., Mateu J., Nubiola N., Palau R., Ribe E., Agusti J.A. 2005. Hazelnut plant protection groups in Catalonia: cultural practices improvement and new management in hazelnut. p. 331–332. In: Proceedings of the VI-th International Congress on Hazelnut, 14–18 June 2004, Tarragona-Reus, Spain, 672 pp.

Sądej W., Kosewska A., Sądej W., Nietupski M. 2012. Effects of fertilizer and land-use type on soil properties and ground beetle communities. Bulletin of Insectology 65 (2): 239–246.

Schmid A., Weibel F., Allemannn P., Santini D. 2004. Sandwich system: A new method for the management of in-row strips in orchards without herbicides. Erwerbs-Obstbau 46: 87–94.

Schwerk A., Sałek P., Duszczyk M., Abs M., Szyszko J. 2006. Variability of Carabidae in time and space in open areas. Entomologica Fennica 17 (3): 258–268.

Scortichini M., Avanzato D., Me G., Valentini N., Tavella L., Pantaleoni R.A., Fiori M., Chiorri M., Belisario A., Loreti S., Pilotti M. 2005. A national project on organic hazelnut production in Italy. p. 327–330. In: Proceedings of the VI-th International Congress on Hazelnut, 14–18 June 2004, Tarragona-Reus, Spain, 672 pp.

Sharova I.H. 1974. Zhiznennye formy imago zhuzhelits (Coleoptera, Carabidae). Zoologitcheskoy Zhurnal 53 (5): 692–709. (in Russian)

Ter Braak C.J.F., Smilauer P. 1998. CANOCO Reference Manual and User's Guide to Canoco for Windows. Microcomputer Power, Ithaca, USA.

Testa G. Zapparoli M. 1994. First data on soil arthropoda communities of hazel-groves in central Italy. Acta Horticulturae 351: 631–637.

Thiele H.U. 1977. Carabid Beetles in Their Environments. Springer Verlag, Berlin, Germany, 369 pp.

Tischler W. 1971. Agroekologia. [Agroecology]. PWRiL, Warszawa, Poland, 487 pp. (in Polish)

Twardowski J.P., Hurej M., Jaworska T. 2006. An effect of strip-management on carabid beetles (Col., Carabidae) in sugar beet crop. Journal of Plant Protection Research 46 (1): 61–71.

Zahl S. 1977. Jackknifing an index of diversity. Ecology 58 (4): 907–913.