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THE MOST FREQUENT GROUND BEETLES (COLEOPTERA, CARABIDAE) ARE DIFFERENTLY AFFECTED BY MAIN SOIL TREATMENT AND CROP ROTATION IN WINTER WHEAT FIELDS

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Ground beetles (Carabidae) inhabiting arable land are popular group of insects for different studies, however there is lack of researches on their ecology in agro-ecosystems in Latvia. One objective of this article is to check how activity density of the most frequent ground beetle species is affected by different main soil treatment and different crop rotation schemes in winter wheat (*Triticum aestivum*) fields during vegetation season. The second objective of this study is to test following hypothesis: ground beetle species included in the same ecological group (body size, diet preference, breeding cycle) are differently affected by the main soil treatment and crop rotation. Field studies were carried out in Latvia University of Agriculture Research and Study Farm 'Pēterlauki' (56°30'39.38''N; 23°41'30.15''E) during vegetation seasons of 2012 and 2013. Ground beetles were collected with pitfall traps in sample plots sown with winter wheat with two different main soil treatments (ploughing and harrowing) and different pre-crops – spring wheat, winter wheat and spring rapeseed (*Brassica napus*) in 2012 and winter wheat and spring rapeseed in 2013. Studied agro-ecological factors affected activity density of ground beetles throughout growing season or at least during periods of their activity maximum. However, effect of the factors may be different between two consecutive growing seasons or it may be visible in one season, but unnoticeable in the second season. The hypothesis has been confirmed – species belonging to the same ecological group (body size, food preference or breeding cycle) differently react to the main soil treatment and/or crop rotation in winter wheat fields.

Key words: activity density, soil tillage, pre-crop, *Triticum aestivum*.

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INTRODUCTION

Ground beetles (Carabidae) inhabiting arable land are popular group of insects for different studies. In many researches, their abilities as natural enemies of pests were studied (Winder et al. 1994, Holland & Thomas 1997, Koval 1999, Bohan et al. 2000, Madsen et al. 2004, Schlein & Büchs 2006b, Haye et al. 2010, Thies et al. 2011, Arus et al. 2012, Renkema et al. 2012). These researches show that ground beetles have a big potential to be effective elements of integrated pest management (IPM), but implementation of IPM is mandatory in farms within EU, now. Other studies show how different agronomic activities affect ground beetles in various agro-ecosystems. Effect of comparably simple agro-ecological factors (e.g. soil tillage) as well as of very complex factors (e.g. farming systems) were discussed in these studies (Zangger et al. 1994, Cromar et al. 1999, Kikas & Luik 2004,Tamutis et al. 2004, Cole et al. 2005, Hole et al. 2005, Clough et al. 2007, Tamutis et al. 2007, Ward et al. 2011, Caballero-Lopez et al. 2012, Blubaugh & Caplan 2015). However, results of many studies are contradictious, thus knowledge on ecology of ground beetles is still incomplete, but it is important for successful implementation of IPM. Also in Latvia, there is comparably poor knowledge on ecology of ground beetles inhabiting arable land. Studies in this field have been done irregularly (Gailis & Turka 2013).

Diversity of species, species richness and activity density of ground beetles are main parameters used for ecological studies. In many cases, summarized activity density of all ground beetles or summarized activity density of ecological groups of ground beetles (body size, food preference, ability to fly, breeding cycle etc.) is analyzed (Cromar et al. 1999, Wamser et al. 2011, Gailis & Turka 2014a, Kosewska et al. 2014, Kosewska 2016). However, information about how agronomic activities affect particular species is fragmentary. Therefore, one objective of this article is to check how activity density of the most frequent ground beetle species is affected by different main soil treatment and different crop rotation schemes in winter wheat (*Triticum aestivum*) fields during vegetation season.

Main soil treatment (ploughing, harrowing, no-till regime etc.) may cause direct and indirect effect on ground beetles. In case of ploughing, direct effect is reduction of density of the beetles for 27% due to their death. Minimal tillage promotes more seeds of weeds on the soil surface, therefore this tillage regime causes opposed effect to ploughing – total density of ground beetles increases for 26% mainly due to sharp increase of density of *Amara* and other granivorous species. Direct effect of soil treatment disappears after 26 days (Thorbek & Bilde 2004). Indirect effect of the main soil treatment becomes apparent as presence or absence of different structures of habitat due to more or less intensive soil tillage regime. For instance, minimal tillage promotes straw mulch on the soil surface and more diverse vegetation of weeds within crop fields. These elements attract more saprophagous and phytophagous invertebrates, produce more diverse seeds of plants and create shelters for ground beetles. Therefore such parameters as activity density, species assemblage, biodiversity etc. of ground beetles change (Speight & Lawton 1976, Norris & Kogan 2000, Roger-Estrade et al. 2010, Diehl et al. 2012, Saska et al. 2014).

In our research, indirect effect of main soil treatment was discussed, because the research was performed during April – July, but the main soil treatment was executed in the August of previous year. Also pre-crop affects ground beetles indirectly. For instance, in winter wheat fields, different pre-crops may cause more or less dense vegetation of crop, but density of crop affects wide range of other environmental factors – soil moisture, soil coverage by canopy of plants, development of weed vegetation, diversity and density of attracted phytophagous invertebrates etc.; but all these environmental factors may affect ground beetle species.

The second objective of this study is to test following hypothesis: ground beetle species included in the same ecological group are differently affected by the main soil treatment and crop rotation. This hypothesis originated after checking out some studies on analysis of agro-ecological factors' effect on ecological groups of ground beetles e.g. small-sized and big-sized beetles, small zoophages, medium hemizoophages, spring breeders, autumn breeders etc. (Cromar et al. 1999, Wamser et al. 2011, Gailis & Turka 2014a, Kosewska et al. 2014, Kosewska 2016). However, each such ecological group consists of species having different needs in environment. For instance, *Bembidion lampros* and *B. properans* are mesophilous species and their activity density negatively correlates with ground coverage by canopy of plants (Wallin 1989, Guseva & Koval 2011). Contrary, two other species – *B. guttula* and *B. obtusum* – are hygrophilous species preferring shadier and moister conditions (Honek & Jarošik 2000). But all four species may be included in the group of small-sized beetles or small zoophages. Also division into ecological groups according to food preferences more likely is not certain because knowledge on diet of many ground beetle species is still insufficient (Kotze et al. 2011).

MATERIAL AND METHODS

Field studies were carried out during vegetation seasons of 2012 and 2013 in stationary trial place for researches on good agricultural practice for the most popular field crops. This trial place was created in 2009 and it belongs to the Latvia University of Agriculture Research and Study Farm 'Pēterlauki'. It is located 14 km south from Jelgava town near Poķi village (56°30'39.38''N; 23°41'30.15''E). Since the establishment, in this place, all agricultural activities (soil preparation, sowing of crops, usage of agrochemicals, crop harvesting etc.) were performed in accordance to conventional agricultural practice as in any usual field. This trial place consists of a grid of 24 sample plots (0.25 ha; 30 x 85 m) arranged into four columns and six rows (Fig. 1). Conventionally farmed arable land surrounded the grid. A strip (35 x 510 m) of circa 60 years old deciduous forest was located 30 m south, but the closest rural settlement – 120 m west from the study site. Strips of land (2.5 m wide) separated sample plots from each other and from near arable land. Strips separating columns of sample plots were not treated since the establishment of the trial place. Therefore, in these strips, stable perennial vegetation of wild herbaceous plants had been developed until beginning of our research. Contrary, land strips separating rows of sample plots were ploughed and loosened each year, and these activities promoted bare soil surface during the vegetation seasons.

The soil at this place is an Endogleyic Calcisol (GLu) with pH KCl 6.8 and low humus content – 20 g kg^{-1} (Dubova et al. 2013). Since 2009, the main soil treatments were conventional ploughing (0.22–0.23 m) with mouldboard plough and non-inverse tillage (0.10–0.11 m) with disc harrow for each 12 sample plots. These activities were performed in 29 August 2011 and in 10 August 2012 for the vegetation seasons of 2012 and 2013, accordingly. Other soil tillage activities were performed in accordance with the conventional agronomic practice as in any commercial field. In both years, six ploughed and six harrowed sample plots were sown with winter wheat (variety 'Zentos'), and these sample plots were used for this research. Other sample plots were sown with other field crops. After crop harvesting, straws and other plant remnants were left on the ground as fertilizer, but sample plots were fertilized with mineral fertilizers each year, as well. After monitoring, authorized fungicides, herbicides and retardants, but not insecticides were applied in the sample plots. In 2012, each two ploughed and each two harrowed winter wheat sample plots were pre-cropped with spring rapeseed (*Brassica napus*), spring wheat and winter wheat. In 2013, winter wheat was pre-crop in two ploughed and two harrowed sample plots, but spring rapeseed was pre-crop in four ploughed and four harrowed sample plots. Thus there were six and four combinations of both agro-ecological factors – soil tillage and pre-crop – represented in the studied sample plots in 2012 and 2013, accordingly (Fig. 1). In further text, abbreviations of management regimes of fields will be used:

HSR – harrowed soil and spring rapeseed as pre-crop;

PSR – ploughed soil and spring rapeseed as pre-crop;

HSW – harrowed soil and spring wheat as pre-crop;

PSW – ploughed soil and spring rapeseed as pre-crop;

HWW – harrowed soil and winter wheat as pre-crop;

PWW – ploughed soil and winter wheat as pre-crop.

Red dead-nettle (*Lamium purpureum*), wall speedwell (*Veronica arvensis*), cleavers (*Galium aparine*) and knotgrass (*Polygonum aviculare*) were the most common weeds in all studied sample plots, but loose silky-bent (*Apera spica-venti*) was very common in plots, especially in harrowed ones, were wheat was sown after wheat each year. In 2012, also rapeseed was abundant weed in winter wheat sample plots pre-cropped spring rapeseed, but such situation was not observed in 2013. Total weed density was evaluated twice in each study season – at the beginning of May (3 May 2012 and 10 May 2013) and at the beginning of July (9 July 2012 and 8 July 2013). The first accounting of weeds was done shortly before application of herbicides. In both vegetation seasons, non-inverse tilled sample plots were comparably weedier, especially those with both kinds of wheat as the pre-crop. However, weed control by using herbicides was more successful in 2012 than in 2013. In the first study year, herbicide application promoted significant decrease of weed density in all studied sample plots, but in the season of 2013, herbicide application was ineffective – weed density either decreased insignificantly or increased between both accountings (Fig. 1).

H	P	P	H
No. 1 (Spring wheat)* Winter wheat** Winter wheat*** W.D.^{1}: 104/35 W.D.^{2}: 38/137	**No. 2** (Spring wheat) Winter wheat Winter wheat W.D.: 48/4 W.D.: 60/66	**No. 3** (Spring wheat) Winter wheat Winter rapeseed W.D.: 97/5 W.D.: n/a	**No. 4** (Spring wheat) Winter wheat Spring rapeseed W.D.: 146/66 W.D.: n/a
No. 5 (Spring rapeseed) Winter wheat Spring rapeseed W.D.: 177/5 W.D.: n/a	**No. 6** (Spring rapeseed) Winter wheat Winter rapeseed W.D.: 33/2 W.D.: n/a	**No. 7** Spring rapeseed Winter wheat W.D.: n/a W.D.: 8/8	**No. 8** Spring rapeseed Winter wheat W.D.: n/a W.D.: 33/32
No. 9 Spring rapeseed Winter wheat W.D.: n/a W.D.: 3/19	**No. 10** Spring rapeseed Winter wheat W.D.: n/a W.D.: 7/8	**No. 11** Winter barley Winter rapeseed W.D.: n/a W.D.: n/a	**No. 12** Winter barley Spring rapeseed W.D.: n/a W.D.: n/a
No. 13 (Winter wheat) Winter wheat Winter wheat W.D.: 114/4 W.D.: 51/80	**No. 14** (Winter wheat) Winter wheat Winter wheat W.D.: 40/5 W.D.: 22/12	**No. 15** (Winter wheat) Winter wheat Winter rapeseed W.D.: 85/2 W.D.: n/a	**No. 16** (Winter wheat) Winter wheat Winter rapeseed W.D.: 95/13 W.D.: n/a
No. 17 (Spring rapeseed) Winter wheat Winter rapeseed W.D.: 159/6 W.D.: n/a	**No. 18** (Spring rapeseed) Winter wheat Winter rapeseed W.D.: 41/11 W.D.: n/a	**No. 19** Spring rapeseed Winter wheat W.D.: n/a W.D.: 15/14	**No. 20** Spring rapeseed Winter wheat W.D.: n/a W.D.: 40/39
No. 21 Spring rapeseed Winter wheat W.D.: n/a W.D.: 9/6	**No. 22** Spring rapeseed Winter wheat W.D.: n/a W.D.: 19/14	**No. 23** Winter barley Winter rapeseed W.D.: n/a W.D.: n/a	**No. 24** Winter barley Winter rapeseed W.D.: n/a W.D.: n/a

Fig. 1. Scheme of sample plots in Study and Research Farm 'Pēterlauki'. (H – harrowed with disc harrow; P – ploughed with mouldboard plough; *- crop in 2011 (pre-crop for 2012, it is shown only for sample plots sown with winter wheat in 2012); ** - crop in 2012; *** - crop in 2013; W.D.^{1} – weed density in 2012 (individuals m^{-2} in May 3/July 9); W.D.^{2} – weed density in 2013 (individuals m^{-2} in May 10/July 8); weed density values are showed only for winter wheat sample plots used for this research in both years; bolded vertical lines show stripes of land covered with perennial vegetation of wild herbaceous plants).

Transparent plastic glasses (vol. 200 ml, 65 mm opening diameter) were used as pitfall traps for collecting of ground beetles. Each trap was half filled with 4–5% acetic acid solution with few drops of detergent. In each winter wheat sample plot, ten traps were placed in cornerwise transect three meters apart from each other. In both years, exposition of traps started in spring when first active ground beetles were observed (17 April 2012 and 23 April 2013), but ended few days before harvesting of winter wheat (31 July 2012 and 30 July 2013). The traps were emptied and filled with fresh acid every seven days. During the same periods of time, precipitation and average air temperature (Fig. 2) were registered using Davis Vantage Pro2 weather station located 100 m away from sample plots.

Ground beetles were identified after Freude et al. (2004), but Check-List of Latvian beetles (Telnov 2004) was used for nomenclature. Information on ecological characteristics – average body size, breeding season, main feeding habits and habitat preferences – was taken from several papers (Sunderland 1975, Sotherton et al. 1984, Sunderland et al. 1987, Holopainen & Helenius 1992, Holland & Thomas 1997, Luff 1998, Mundy et al. 2000, Barševskis 2003, Schlein & Büchs 2006a, Honek et al.

2007, Matalin 2007, Desender et al. 2008, Haye et al. 2010, Aleksandrowicz 2014).

To determine the most frequent species, in every seven-day period of research, species dominance structure of ground beetles was calculated for each management type of studied fields (the main soil tillage + pre-crop). Scale of Engelmann (1978) was used for this purpose. This scale anticipates to classify species into five groups according to their proportion in the species assemblage: eudominants (40.0-100.0%), dominants (12.5-39.9%), subdominants (4.0-12.4%), recedents (1.3-3.9%) and subrecedents (<1.3%). Proportion of each particular species in each particular management type was calculated using total number of individuals of particular species and total number of all ground beetle individuals caught in all traps in every period of the research.

Analysis of variance (ANOVA) was used to determine which agro-ecological factor – main soil treatment or pre-crop – or which combination of both factors significantly affected activity density of all ground beetles and activity density of the most frequent species. In group of the most frequent species, all ground beetles reaching at least subdominant level in at least one seven-day period of the research were included. If ANOVA indicated statistically significant effect of pre-crop in 2012 or combination of both factors in both years, then Scheffé's *post-hoc* test was used to figure out which combination(s) significantly differ from the other ones. All those calculations were done using SPSS 17.0.

RESULTS

In studied winter wheat sample plots, species richness of ground beetles varied between 66 observed species in 2012 and 57 species in 2013. Total activity density of ground beetle individuals was noticeably higher in 2013 than one year earlier – 25,369 individuals were observed in 2012, but 60,024 individuals in 2013 despite one-week shorter study period. Full lists of observed species are already published (Gailis & Turka 2014b, Gailis et al. 2017). Counting both years together, eighteen species reached at least subdominant level in at least one seven-day period of the research (Table 1). The most part of these ground beetles were the most frequent species during both vegetation seasons, but some species were comparably frequent only in one year.

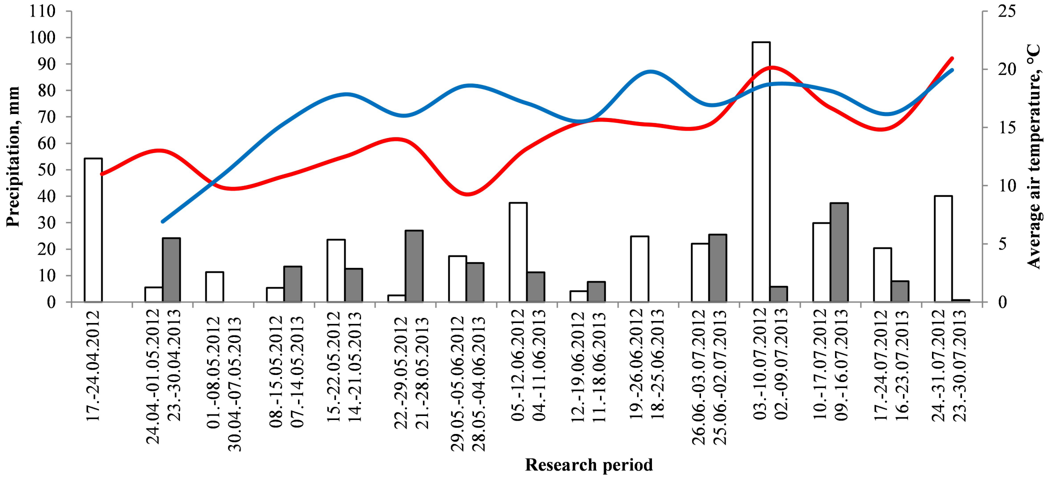

Fig. 2. Amount of precipitation and average air temperature in studied winter wheat fields during vegetation seasons of 2012 and 2013 (— – air temperature in 2012; — – air temperature in 2013; □ – precipitation in 2012; ■ – precipitation in 2013).

Table 1. List of the most frequent ground beetle species (in systematic order), their ecological characteristics and agro-ecological factors significantly affecting their presence in studied winter wheat fields in 2012 and 2013 (affecting factors: P – pre-crop; T – soil tillage; breeding season: aut. – autumn breeder, sum. – summer breeder, sp. – spring breeder; main feeding habits: z – zoophagous, h – hemizoophagous, g – granivorous; habitat preferences: G – generalists, species inhabiting open habitats and forests, Oh – open habitats, mx – meso-xerophilous, m – mesophilous, mh – meso-hygrophilous, h - hygrophilous).

Species	**Total individuals in 2012/2013**	**Affecting factor(s) in 2012/2013**	**Average body size, mm**	**Breeding season**	**Main feeding habit**	**Habitat pref.**
Nebria brevicollis (Fabricius, 1792)	388/236	P/P	11.5	aut.	z	G,m
Notiophilus aestuans Dejean, 1826	18/83	–/–	4.7	sum.	z	Oh,mx
Notiophilus germinyi Fauvel, 1863	63/14	–/–	4.3	aut.	z	G,mx
Loricera pilicornis (Fabricius, 1775)	5575/3014	T/T,P	7.0	sp.–sum.	z	G,h
Carabus cancellatus Illiger, 1798	76/131	–/P	24.5	sp.	z	G,m
Bembidion lampros (Herbst, 1784)	416/624	–/P	3.5	sp.	z	G,m
Bembidion properans (Stephens, 1828)	283/396	T/T	3.8	sp.	z	G,m
Bembidion guttula (Fabricius, 1792)	6237/4309	T/T,P	3.2	sp.	z	Oh,h
Bembidion obtusum Audinet-Serville, 1821	818/376	T/P	3.2	sp.	z	Oh,h
Trechus quadristriatus (Schrank, 1781)	210/1082	T,P/T,P	3.8	aut.	z	Oh,mx
Harpalus affinis (Schrank, 1781)	215/337	–/P	10.2	sp.–sum.	h	Oh,mx
Harpalus rufipes (DeGeer, 1774)	2817/19610	–/P	13.5	sum.–aut.	h	Oh,m
Acupalpus meridianus (Linnaeus, 1761)	50/31	–/–	3.7	sp.	h	Oh,h
Anchomenus dorsalis (Pontoppidan, 1763)	399/681	–/P	6.7	sp.	z	Oh,mh
Poecilus cupreus (Linnaeus, 1758)	3734/6183	T/P	11.0	sp.	z	Oh,m
Pterostichus melanarius (Illiger, 1798)	1202/9339	P/T,P	15.0	aut.	z	G,m
Pterostichus niger (Schaller, 1783)	1780/12519	T,P/P	18.0	aut.	z	G,m
Amara plebeja (Gyllenhal, 1810)	354/198	T,P/T,P	7.0	sp.	g	G,mh
All ground beetles	25369/60024	P/P	–	–	–	–

In both years, total activity density of ground beetles was relatively stable in the first part of study season, but sharply increased in the middle of summer. In 2012, starting from the beginning of study season until July, activity density fluctuated between circa five and 20 individuals per trap. Starting from July 10, the activity of ground beetles rapidly (2–2.5 times) increased reaching its maximum level in July 17. Then until the end of study season, it gradually decreased remaining significantly higher than before July 10. In 2013, activity density of ground beetles was noticeably higher comparing with previous year. In the end of April, activity density reached 20–25 individuals per trap in seven days. The parameter fluctuated and slightly increased until middle of June when it sharply increased in fields pre-cropped with spring rapeseed reaching circa 80 individuals pre trap in seven days. In fields pre-cropped with winter wheat, increase of the activity density was delayed for two weeks, and only in first days of July, activity density of ground beetles became more or less similar in all studied fields. Later in July, activity of ground beetles started to decrease – firstly in fields with wheat as pre-crop, following by other fields. But in the last seven days of study season (July 23–30), activity density of ground beetles sharply increased again. ANOVA indicated that only pre-crop significantly affected total activity density of ground beetles in both years, but main soil treatment did not have significant effect on ground beetles. In 2012, statistically significant effect was observed in nine sampling periods throughout the season, but stable connectedness was observed only during July when winter wheat as pre-crop promoted significantly lower, but spring wheat – significantly higher activity density of ground beetles. In previous sampling periods of the season, such noticeable connectedness between particular pre-crop and activity density of beetles was not observed. For example, spring wheat as pre-crop promoted significantly higher activity density in April 24, spring rapeseed – in May 8, winter wheat – in May 15, but in May 29, spring wheat promoted significantly lower activity density of ground beetles. Contrary, in whole study season of 2013, higher activity density of ground beetles was observed in fields pre-cropped with spring rapeseed than with winter wheat, and this effect was statistically significant in 11 sampling periods from 14 ones (Fig. 3).

According to results of ANOVA, activity density of three ground beetle species – *Notiophilus aestuans, N. germinyi* and *Acupalpus meridianus* – depended neither from main soil treatment nor from pre-crop in both seasons of research. However, this fact does not allow concluding that both agro-ecological factors were not affecting the species, at all. Total activity density of all three species was comparably low, and it might be the reason why calculations did not indicate dependence from the agro-ecological factors. Activity maximums of these species were observed during spring time when they appeared among the most frequent species as subdominants, however it happened only in one sampling period counting both years together.

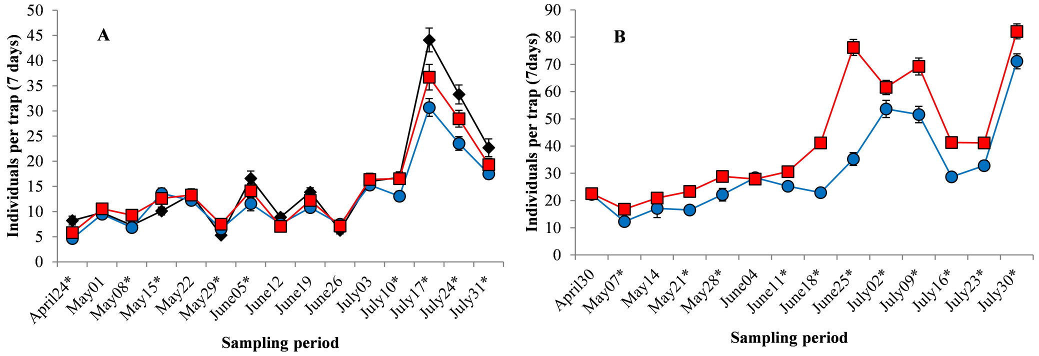

Fig. 3. Mean activity density of ground beetles in winter wheat fields with different pre-crops in 2012 (A) and 2013 (B) (pre-crops: —♦— – spring wheat, —●— – winter wheat, —■— – spring rapeseed; * – statistically significant ($p \leq 0.05$) effect of pre-crop).

Three species – *Bembidion lampros, B. properans* and *Poecilus cupreus* – reached their maximum activity density during the end of April and May in both years, however these species were permanently present in studied fields until the end of both seasons of research. In 2012, activity density of *B. lampros* almost did not depend from studied agro-ecological factors. Statistically significant effect by main soil treatment was observed only in two sampling periods, but it was not similar in both of them. One year later, activity density of *B. lampros* was noticeably higher in fields pre-cropped with spring rapeseed than in ones pre-cropped with winter wheat. This tendency was observed almost in all sampling periods, but in two periods in the beginning of study season, the tendency was statistically significant (Fig. 4). In both years, activity density of *B. properans* was affected by main soil treatment, but pre-crop did not cause noticeable effect on this species. However, tillage effect was opposite between both study seasons – in 2012, *B. properans* more preferred to inhabit ploughed fields, but a year later – harrowed ones (Fig. 5). Activity density of *P. cupreus* was significantly affected by main soil treatment in 2012, but pre-crop – in 2013. During the first study season, in first sampling periods, activity density of *P. cupreus* was similar in all sample plots, but starting from the middle of May, this species significantly preferred to inhabit harrowed fields comparing with ploughed ones. In 2013, pre-crop's effect was not equal during all study season. Until the beginning of June, significantly higher activity density of *P. cupreus* was observed in fields pre-cropped with spring rapeseed, but in last sampling periods of the season, this pre-crop promoted significantly lower activity density of the species than winter wheat as pre-crop (Fig. 6).

Five species – *Nebria brevicollis, Carabus cancellatus, Bembidion guttula, B. obtusum* and

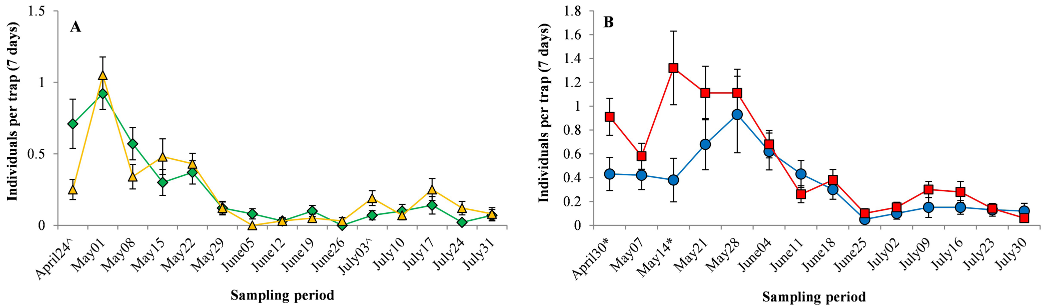

Fig. 4. Mean activity density of *Bembidion lampros* in winter wheat fields with different main soil treatments in 2012 (A) and different pre-crops in 2013 (B) (main soil treatments: —◆— – harrowing, —▲— – ploughing; pre-crops: —●— – winter wheat, —■— – spring rapeseed; ^ - statistically significant ($p \leq 0.05$) effect of main soil treatment, * – statistically significant ($p \leq 0.05$) effect of pre-crop).

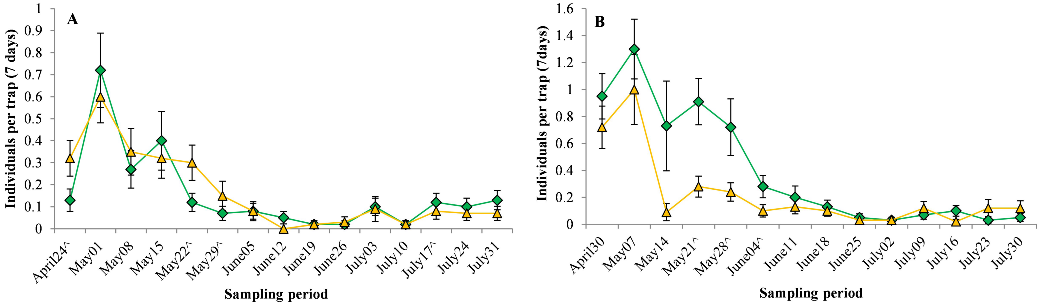

Fig. 5. Mean activity density of *Bembidion properans* in winter wheat fields with different main soil treatments in 2012 (A) and 2013 (B) (main soil treatments: —◆— – harrowing, —▲— – ploughing; ^ - statistically significant ($p \leq 0.05$) effect of main soil treatment).

Anchomenus dorsalis – reached their maximum activity density in the beginning of summer (last days of May, but mainly in June). In both years, *N. brevicollis* was observed starting from the second decade of May, and its activity density was significantly affected by pre-crop. In 2012, during the maximum activity period, this species preferred fields pre-cropped with spring rapeseed than other ones, however statistically significant effect was observed only in two sampling periods. One more statistically significant interconnection was observed in the last sampling period (July 31) when *N. brevicollis* was significantly more abundant in fields pre-cropped with spring wheat than in any other field. In 2013, interconnection between pre-crop and activity density of *N. brevicollis* was much more visible. In fields pre-cropped with spring rapeseed, activity density of the species was 4–10 times higher and its presence was two times longer than in fields pre-cropped with winter wheat (Fig. 7). Also *C. cancellatus* and *A. dorsalis* were affected by pre-crop, but this connectedness appeared only in 2013 when almost in all sampling periods, spring rapeseed as pre-crop promoted higher activity density of these species than winter wheat as pre-crop (Fig. 8). In sampling periods of 2012, activity density of *C. cancellatus* was too low to calculate interconnections between the agro-ecological factors and abundance of this species in winter wheat fields. Contrary, *A. dorsalis* was more abundant, but its activity density was comparably equal in all fields. Phenology of *B. guttula* differed between years. In 2012, this species had one shorter activity maximum in the end of April and comparably long activity maximum period during June and first part of July. In this year, activity density of *B.* guttula was affected by main soil treatment – the species was more abundant in ploughed soil

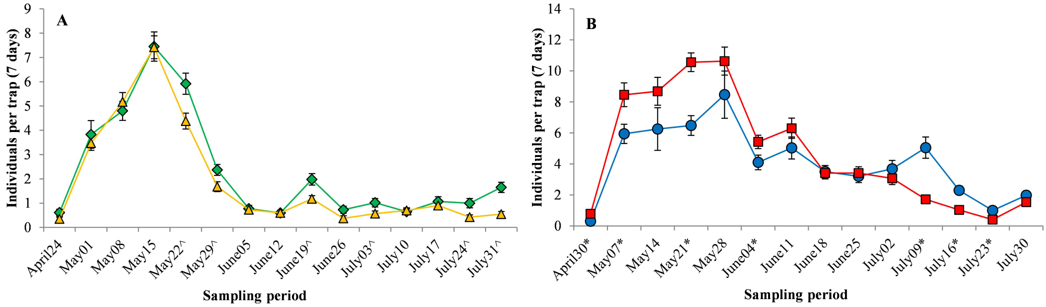

Fig. 6. Mean activity density of *Poecilus cupreus* in winter wheat fields with different main soil treatments in 2012 (A) and different pre-crops in 2013 (B) (main soil treatments: —♦— – harrowing, —▲— – ploughing; pre-crops: —●— – winter wheat, —■— – spring rapeseed; ^ - statistically significant ($p \leq 0.05$) effect of main soil treatment, * – statistically significant ($p \leq 0.05$) effect of pre-crop).

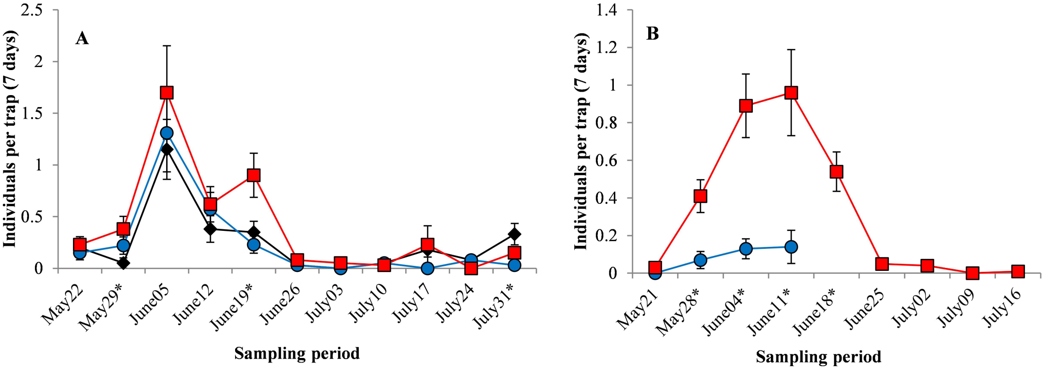

Fig. 7. Mean activity density of *Nebria brevicollis* in winter wheat fields with different pre-crops in 2012 (A) and 2013 (B) (pre-crops: —♦— – spring wheat, —●— – winter wheat, —■— – spring rapeseed; * – statistically significant ($p \leq 0.05$) effect of pre-crop).

than in harrowed one. This interconnection was statistically significant during both maximum periods. A year later, only one activity maximum was observed in the end of April when activity density of *B. guttula* was circa four times higher than during the rest of study season. During this maximum period, similarly with 2012, ploughed soil promoted significantly higher activity density of the species than harrowed soil. However, until the middle of June, neither main soil treatment nor pre-crop significantly affected this species, but in the last third of study season, pre-crop affected activity density of *B. guttula* – noticeably higher activity density was observed in fields pre-cropped with spring rapeseed than fields pre-cropped with winter wheat (Fig. 9). Also phenology of *B. obtusum* was not similar in both years of research. In 2012, this species had one maximum period from middle of May until middle of June. In this season, *B. obtusum* was noticeably (significantly during maximum period) more abundant in ploughed fields than in harrowed ones, but pre-crop did not affected activity density of this species. In 2013, three maximum periods were observed: in the end of April when the highest activity density was observed (1), in the end of May and beginning of June when activity density was twice lower than in the first maximum period (2), during the second half of July when activity density was twice lower than in the second maximum period (3). During the second year of research, only pre-crop significantly affected presence of *B. obtusum* in winter wheat fields. Higher activity density was observed in fields pre-cropped with spring rapeseed, and this interconnection was significant during all three maximum periods (Fig. 10).

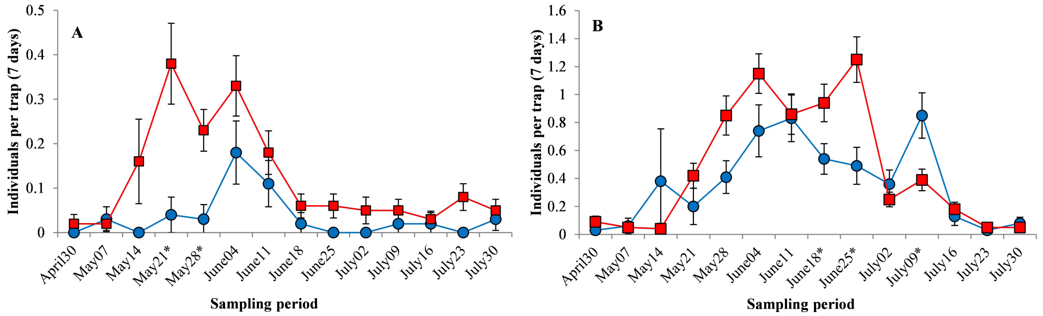

Fig. 8. Mean activity density of *Carabus cancellatus* (A) and *Anchomenus dorsalis* (B) in differently pre-cropped winter wheat fields in 2013 (pre-crops: —●— – winter wheat, —■— – spring rapeseed; * – statistically significant ($p \leq 0.05$) effect of pre-crop).

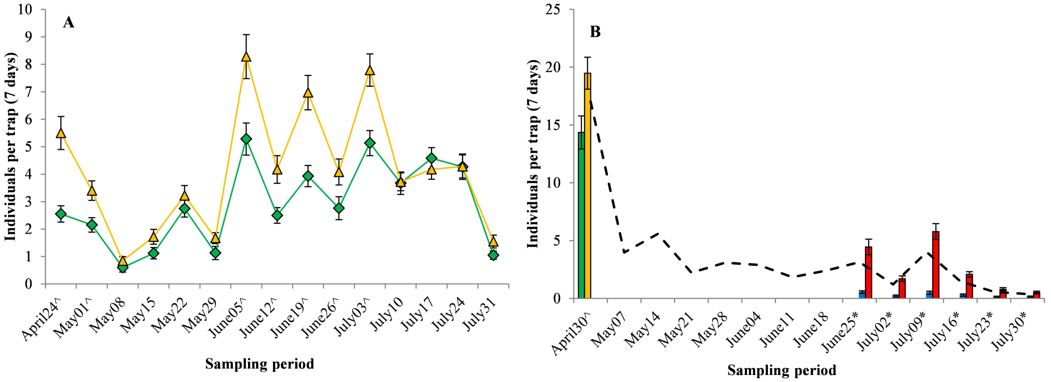

Fig. 9. Mean activity density of *Bembidion guttula* in winter wheat fields with different main soil treatments in 2012 (A) and different main soil treatments and pre-crops in 2013 (B) (- - - – mean activity density; main soil treatments: —◆— and 🟩 – harrowing, —▲— and 🟨 – ploughing; pre-crops: 🟦 – winter wheat, 🟥 – spring rapeseed; ^ - statistically significant ($p \leq 0.05$) effect of main soil treatment, * – statistically significant ($p \leq 0.05$) effect of pre-crop).

Maximum activity density of six species – *Trechus quadristriatus, Harpalus affinis, H. rufipes, Pterostichus melanarius, P. niger* and *Amara plebeja* – was observed during the middle of summer (last decade of June, but mainly July). Activity density of *T. quadristriatus* was significantly affected by both agro-ecological factors in both years. In 2012, in studied sample plots, this species became noticeably active starting from June 19 when its activity density was not affected by the factors. But seven days later, effect of main soil treatment was observed – significantly higher activity density was observed in ploughed soil. After one more seven-day period, also pre-crop began to affect activity density of *T. quadristriatus*. In three sampling periods (July 3, July 17 and July 24), soil ploughing and spring rapeseed as pre-crop promoted significantly higher activity density than soil harrowing and other pre-crops. However in these sampling periods, unambiguous superiority of PSR combination was not observed. Results of Scheffé's test showed that PSR promoted significantly higher activity density over other combination excepting HSR in July 3, over all other combinations in July 17 and over other combinations excepting PWW in July 24. In 2013, *T. quadristriatus* was noticeably present in studied fields during all season of research. One short activity maximum appeared in the first sampling period, but main maximum was observed during the second half of June and beginning of July. Also in that year, both agro-ecological factors affected activity density of the species, but significant combination of factors occurred only once – in April 30, PSR promoted higher activity density than other combinations. Later in the season, during the period of main activity maximum, at first, *T. quadristriatus* was significantly affected by

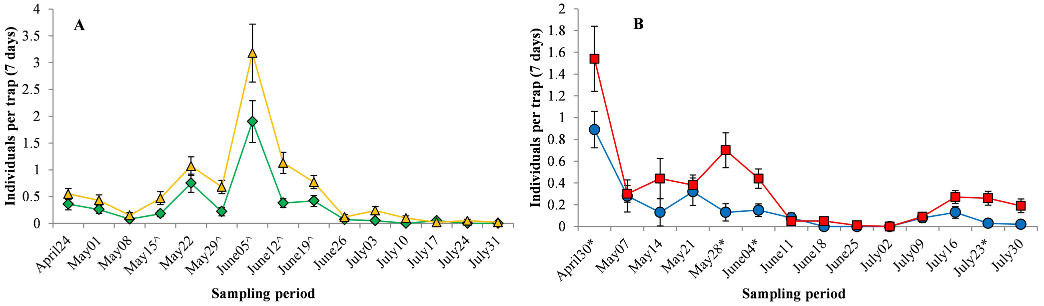

Fig. 10. Mean activity density of *Bembidion obtusum* in winter wheat fields with different main soil treatments in 2012 (A) and different pre-crops in 2013 (B) (main soil treatments: —◆— – harrowing, —▲— – ploughing; pre-crops: —●— – winter wheat, —■— – spring rapeseed; ^ - statistically significant ($p \leq 0.05$) effect of main soil treatment, * – statistically significant ($p \leq 0.05$) effect of pre-crop).

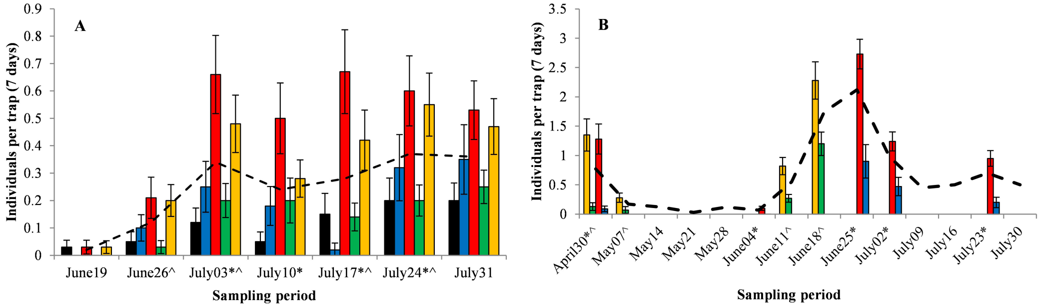

Fig. 11. Mean activity density of *Trechus quadristriatus* in winter wheat fields with different main soil treatments and pre-crops in 2012 (A) and 2013 (B) (main soil treatments: 🟩 – harrowing, 🟨 – ploughing; pre-crops: ■ – spring wheat, 🟦 – winter wheat, 🟥 – spring rapeseed; ^ – statistically significant ($p \leq 0.05$) effect of main soil treatment, * – statistically significant ($p \leq 0.05$) effect of pre-crop).

main soil treatment – species preferred ploughed fields more than harrowed ones. After two such sampling periods, pre-crop became only affecting factor – species preferred fields pre-cropped with spring rapeseed more than ones pre-cropped with winter wheat (Fig. 11). Both *Harpalus* species showed dependence from one agro-ecological factor (pre-crop) only in 2013 despite they were comparably frequent also in 2012. Dependence of *H. rufipes* from pre-crop was ambiguous also in 2013. During the May and in the end of July, there were some sampling periods when species preferred fields pre-cropped with winter wheat. Contrary, in the middle of June, when the species started to reach its activity maximum, spring rapeseed as pre-crop promoted significantly higher activity density than winter wheat. *H. affinis* interaction with pre-crop was more visible. This species was significantly more frequent in fields pre-cropped with winter wheat starting from June until the end of study season (Fig. 12). In both years, *P. melanarius* was present in sample plots all-season long, but its activity density became noticeable starting from June. In 2012, this species was affected by pre-crop, but effect of main soil treatment was insignificant. Starting from June 19, *P. melanarius* preferred fields pre-cropped with spring wheat, but avoided fields pre-cropped with spring rapeseed. In fields pre-cropped with winter wheat, in almost all sampling periods, activity density of the species was significantly lower than in fields pre-cropped with spring wheat, but significantly higher than in fields pre-cropped with spring rapeseed. In 2013, *P. melanarius* was affected by main soil treatment (significantly more individuals in harrowed soil), but effect of pre-crop was not as clear as in 2012. Starting from June 11, significantly higher activity density was observed in fields pre-cropped with spring rapeseed, but

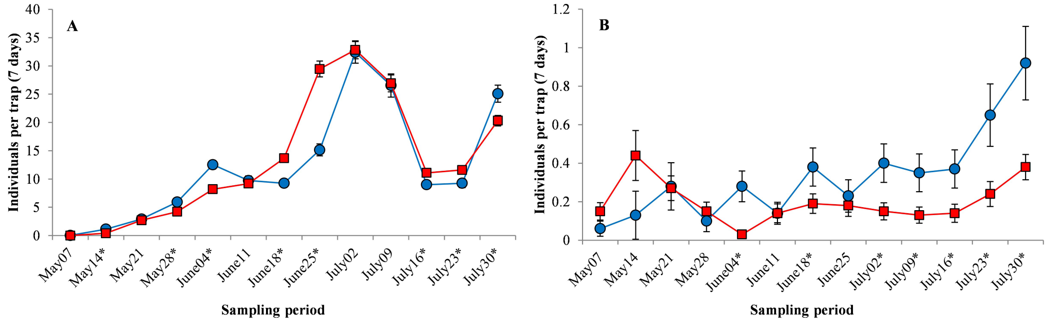

Fig. 12. Mean activity density of *Harpalus rufipes* (A) and *H. affinis* (B) in differently pre-cropped winter wheat fields in 2013 (pre-crops: —●— – winter wheat, —■— – spring rapeseed; * – statistically significant (p ≤ 0.05) effect of pre-crop).

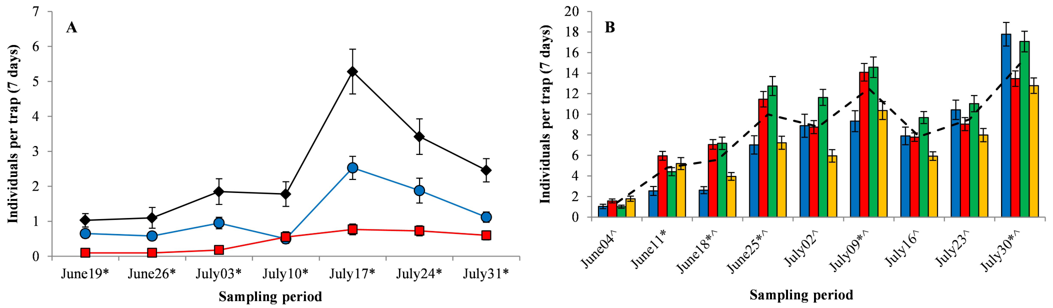

Fig. 13. Mean activity density of *Pterostichus melanarius* in winter wheat fields with different pre-crops in 2012 (A) and different pre-crops and main soil treatments in 2013 (B) (- - - – mean activity density; pre-crops: —♦— – spring wheat, —●— and 🟦 – winter wheat, —■— and 🟥 – spring rapeseed; main soil treatments: 🟩 – harrowing, 🟨 – ploughing; * – statistically significant (p ≤ 0.05) effect of pre-crop; ^ – statistically significant (p ≤ 0.05) effect of main soil treatment).

this state lasted until the middle of July when *P. melanarius* gradually started to prefer fields pre-cropped with winter wheat (Fig. 13). *P. niger* also was affected by both agro-ecological factors, but effect of main soil treatment was visible only in the first year of research. In 2012, the activity density of the species started to depend from factors starting from the middle of June. Until the end of the season, winter wheat as pre-crop promoted significantly lower activity density than other pre-crops having not significant difference between them. *P. niger* preferred ploughed soil more than harrowed one, as well, however significant effect of one or more combinations of both agro-ecological factors did not appear. In 2013, effect of pre-crop was evident and similar with 2012 – significantly lower activity density was observed in fields pre-cropped with winter wheat. Contrary, effect of main soil treatment was not so visible than in 2012 – significant effect was observed only in two sampling periods (June 18 and July 9) when *P. niger* noticeably preferred ploughed soil (Fig. 14). Activity density of *A. plebeja* was dependent from combination of both agro-ecological factors in both seasons of research. This species was present in sample plots starting from May, but became frequent during July reaching maximum of activity. In 2012, *A. plebeja* significantly preferred HSW fields, but HWW fields promoted the highest activity density one year later (Fig. 15).

Loricera pilicornis was only species with varying activity cycle between both seasons of research. In 2012, this species was comparably frequent during all study season and it had one sharp activity maximum in the middle of July. In the beginning of study season of 2013, activity density of *L. pilicornis* was very low, but it quickly increased during May. As a result,

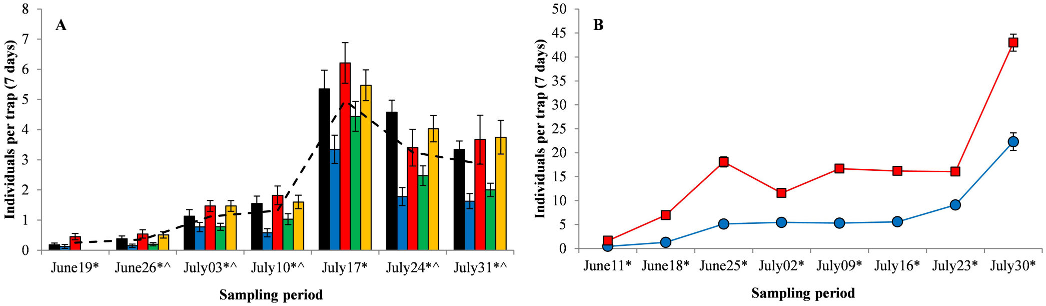

Fig. 14. Mean activity density of *Pterostichus niger* in winter wheat fields with different pre-crops and main soil treatments in 2012 (A) and different pre-crops in 2013 (B) (- - - – mean activity density; pre-crops: ■ – spring wheat, —●— and 🟦 – winter wheat, —■— and 🟥 – spring rapeseed; main soil treatments: 🟩 – harrowing, 🟨 – ploughing; * – statistically significant ($p \leq 0.05$) effect of pre-crop; ^ – statistically significant ($p \leq 0.05$) effect of main soil treatment).

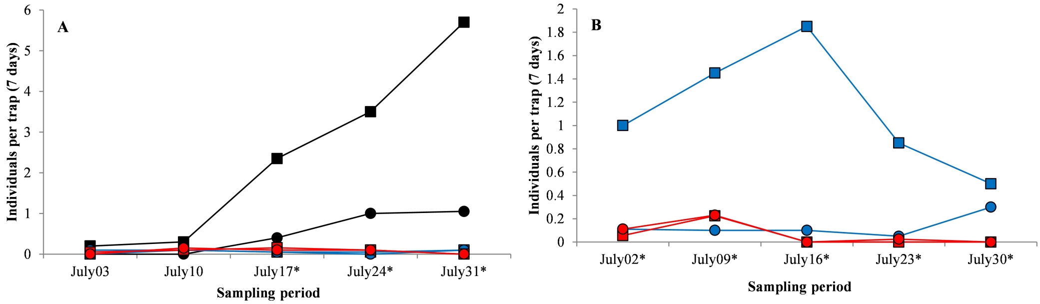

Fig. 15. Mean activity density of *Amara plebeja* in differently tilled and pre-cropped winter wheat fields in 2012 (A) and 2013 (B) (management regime of fields (main soil treatment + pre-crop): —■— – harrowed + spring wheat, —●— – ploughing + spring wheat, —■— – harrowing + winter wheat, —●— – ploughing + winter wheat, —■— – harrowing + spring rapeseed, —●— – ploughing + spring rapeseed; * – statistically significant ($p \leq 0.05$) effect of management regime).

activity maximum of the species lasted from the middle of May until the middle of June, but in July, activity density was comparably low. In the first season of research, activity density of *L. pilicornis* depended only from main soil treatment. All-season long, harrowed fields were more suitable for the species and activity density was significantly higher in harrowed fields than in ploughed ones almost in all sampling periods. In 2013, *L. pilicornis* depended from both agro-ecological factors, but it did not happen synchronously. In first two thirds of the second study season, activity density was affected by pre-crop – significantly more specimens were observed in fields pre-cropped with spring rapeseed. Effect of main soil treatment became significant only in the end of June and it was similar as in 2012 – higher activity density of the species was observed in harrowed fields. In the end-part of the season, effect of pre-crop was not significant anymore (Fig. 16).

DISCUSSION

In general, seasonal activity of ground beetles corresponded with their life cycles, thus activity of spring breeders – *Bembidion* species and *P. cupreus* – was the highest in the first part of both growing seasons, but summer-autumn breeders – *H. rufipes, P. melanarius, P niger* – reached maximum of their activity density during the second part of both study seasons. Also *N. brevicollis* is autumn breeding species, but it has also one activity peak during May/June when individuals of new generation emerge. In temperate zone, polyvariant breeding cycles have been developed for many species (Matalin 1997, Matalin 1998, Matalin 2007, Matalin 2008, Matalin 2014). For example, populations of two frequent species – *H. rufipes* and *P. melanarius* – mainly consist of individuals breeding in summer or autumn, but part of population may overwinter and breed in spring. It was noticeable also in our study when the main activity of *H. rufipes* and *P. melanarius* was observed during the middle of summer, but little activity peaks were observed also in the middle of May of 2012 and 2013, accordingly. Noticeable between-year differences of activity density of each species may be connected with significantly different meteorological conditions, success of weed control and other environmental factors discussed already (Gailis et al. 2017).

A. plebeja was only species affected by combination of studied agro-ecological factors in both growing seasons. It was frequent in HSW fields in 2012 and in HWW fields in 2013, but comparably rare in other sample plots. These management types promoted noticeably denser vegetation of weeds than other combinations of main soil treatment and pre-crop in each year of study, accordingly (Fig. 1). Primarily *A. plebeja* is granivorous species consuming seeds of different plants, but it may also attack aphids and other

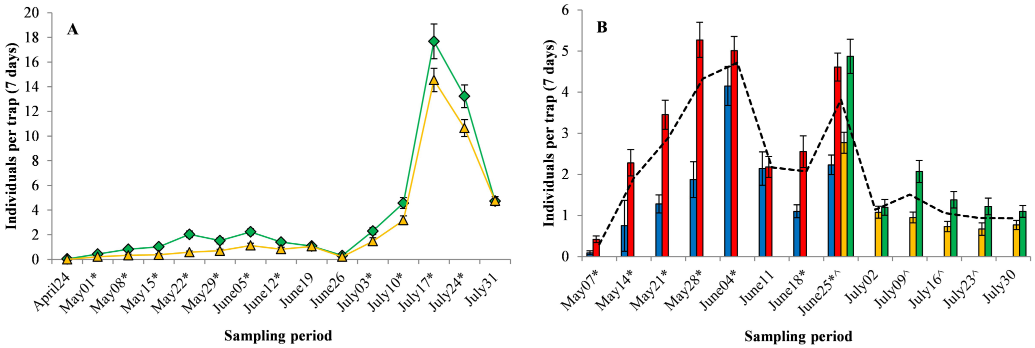

Fig. 16. Mean activity density of *Loricera pilicornis* in winter wheat fields with different main soil treatments in 2012 (A) and different pre-crops and main soil treatments in 2013 (B) (- - - – mean activity density; pre-crops: 🟦 – winter wheat, 🟥 – spring rapeseed; main soil treatments: —♦— and 🟩 – harrowing, —▲— and 🟨 – ploughing; * – statistically significant ($p \leq 0.05$) effect of pre-crop; ^ – statistically significant ($p \leq 0.05$) effect of main soil treatment).

invertebrates (Holopainen & Helenius 1992, Lundgren 2009). Therefore in our study, habitat preference of *A. plebeja* may be explained with its diet preference.

Habitat preference of *L. pilicornis* also may be explained with feeding habit of this species which mostly preferred harrowed soil, but in the first part of growing season of 2013, was more abundant in fields pre-cropped with rapeseed than with wheat. *L. pilicornis* is well known predator of springtails (Collembola), but density of them increase in habitats containing more decaying organic material on soil surface (Idinger & Kromp 1997). In cereal fields, such conditions are promoted by non-inverse soil tillage and also by rapeseed as pre-crop because straw biomass of rapeseed is bigger than one of wheat (Boehmel et al. 2008).

T. quadristriatus prefers shaded soil, therefore this species is more abundant in fields covered by dense canopy of crop than in cenoses with sparse vegetation (Mitchell 1963, Honek & Jarošik 2000). The species also prefers ploughed soil than minimally tilled soil (Holland & Luff 2000). In our research, occurrence of *T. quadristriatus* in studied sample plots may be explained with those factors. In fields pre-cropped with rapeseed, soil is more shaded due to denser vegetation of winter wheat. But soil ploughing promotes bare soil surface without straw mulch mentioned as disturbing factor for small-sized ground beetles to move and to notice a prey (Roger-Estrade et al. 2010).

In our research, activity density of *N. brevicollis* did not depend on main soil treatment, but pre-crop. However, this species is mentioned as one preferring ploughed soil instead of minimally tilled soil (Holland & Luff 2000). Purvis & Fadl (2002) reported that *N. brevicollis* prefers fields cultivated in autumn for sowing of winter crops, but tries to avoid fields cultivated in spring. So far, in Latvia, this species was more known as inhabitant of forest and parks (Barševskis 2003), but it allows to conclude that *N. brevicollis* prefers shady habitats. It may explain why the species was significantly more abundant in our sample plots pre-cropped with spring rapeseed than in ones pre-cropped with both types of wheat. As it was mentioned already, canopy of winter wheat is denser in fields pre-cropped with rapeseed than in fields pre-cropped with wheat.

In general, *Carabus* species often are reported as sensitive against intensive soil tillage (e.g. Holland & Luff 2000, Skłodowski 2014), however *C. cancellatus* do not depend on main soil treatment in agricultural land (Holland & Luff 2000). It agrees also with results of our research – activity density of *C. cancellatus* was not affected by the main soil treatment, but by pre-crop in the second study season. This species prefers to inhabit agro-ecosystems with dense canopy of crop and without patches of bare soil (Honek & Jarošik 2000). Therefore, higher activity density in sample plots pre-cropped with spring rapeseed is logical. More likely, in season of 2012, statistically significant dependence from pre-crop was not observed due to low general activity density of the species.

B. lampros is photophilic species preferring habitats with gaps in canopy of vegetation and bare soil. Thus, activity density of this species is significantly higher in arable land than in natural or semi-natural perennial grassland habitats (Wallin 1989). Within crop fields, activity density of the species negatively correlates with ground cover promoted by canopy of plants (Mitchell 1963, Honek & Jarošik 2000, Guseva & Koval 2011). *B. lampros* is not affected by the main soil treatment in arable land – the species is equally abundant in ploughed and minimally tilled soil (Holland & Luff 2000). Also in our research, effect of the main soil treatment was not observed, but higher activity density in fields pre-cropped with spring rapeseed is not explainable yet, besides it was evident only in the second season of the research.

Ecological features of *B. properans* are similar with those of *B. lampros*. This species prefers habitats with bare soil surface, and its activity density negatively correlates with soil shading promoted by crop canopy (Guseva & Koval 2011). *B. properans* is more abundant in cereal fields comparing with perennial grassland habitats located next to the crop fields (Hatvani et al. 2001). Results of our research are not explainable, yet. So far, effect of main soil treatment was not reported as affecting factor for the species. Besides, in each season of the research, *B. properans* preferred fields with different main soil treatment. Perhaps, more or less shaded surface of soil is not the main factor affecting activity density of the species in arable land. Schröter & Irmler (2013) found out that *B. properans* prefers to inhabit agrocenoses under organic farming system instead of conventional farming system. Farming system is ecologically complex thing and it means that activity density of *B. properans* may be affected by combination of different ecological factors.

B. guttula prefers ploughed soil instead of minimally tilled one (Holland & Luff 2000). It was also visible in our research during whole season of 2012 and in the beginning of season of 2013, but during the biggest part of the second study season, effect of the main soil treatment disappeared, but effect of pre-crop became significant. Results of studies on ecology of *B. guttula* are contradictory. Cole et al. (2005) reported that species prefers arable land instead of intensively cultivated and semi-natural grassland habitats. Contrary, Kinnunen & Tiainen (1999) found out that *B. guttula* prefers green set-asides, minimally inhabits barley, but is almost absent from potato, sugar beet, oat and black set-aside agrocenoses. Results of another research show that the species prefers fields sown with field beans, it is lesser abundant in cereals and grasslands, but seldom in vegetable agrocenoses (Eyre et al. 2012). *B. guttula* is hygrophilous species, therefore in real time, it may prefer habitat promoting suitable moisture conditions. In wheat fields, suitable moisture may be promoted both by soil ploughing and by crop rotation instead of non-inverse tillage and wheat monoculture. In both cases, crop vegetation is denser promoting moister microclimate, therefore agrocenosis is more suitable for the species.

Main soil treatment does not affect activity density of *B. obtusum*. This species is equally abundant in ploughed and minimally tilled agrocenoses (Holland & Luff 2000). It agrees with results of our research in the second season, but do not agrees with the results in the first season when the species was significantly more frequent in ploughed fields than harrowed ones. *B. obtusum* is hygrophilous species demanding comparably moist environmental conditions. Therefore, in arable land, the species is more frequent in dense vegetation, but its activity density decreases if the soil is not completely covered by canopy of plants (Honek & Jarošik 2000). Some correlations are observed also in grasslands – activity density of *B. obtusum* positively correlates with soil moisture and biomass of plants (Byers et al. 2000). Therefore, results of our research seem to be logical, because both soil ploughing and spring rapeseed as pre-crop promotes denser vegetation of wheat and moister soil, consequently. Reasons why the species was affected by another agro-ecological factor in each season are still unclear.

Main soil treatment and soil cultivation regime are not affecting factors for *A. dorsalis*, but it prefers fields sowed with cereals during several years in a row (Holland & Luff 2000, Purvis & Fadl 2002). *A. dorsalis* is meso-hygrophilous species, therefore it usually prefers habitats with covered soil by canopy of plants (Honek & Jarošek 2000). In our research, the species was not affected by main soil treatment, but spring rapeseed as pre-crop positively affected activity density of *A. dorsalis*, however this effect was observed only during the second season of the study – in 2013. During the first study season, weather was comparably cool and rainy promoting equal microclimatic conditions in all sample plots. Perhaps, this is the main reason why pre-crop did not affect activity density of *A. dorsalis* during study season of 2012.

H. affinis prefers minimally tilled soil more than ploughed one (Holland & Luff 2000), however it was not observed in our research. This was only species preferring winter wheat monocultures; perhaps it also may be explained with its ecological properties. Contrary to *A. dorsalis, H. affinis* is meso-xerophilous species, therefore in 2013, its activity density was significantly higher in winter wheat monocultures which promote thin vegetation and more dry soil conditions. But in 2012, the species was not affected by pre-crop due to comparably rainy weather promoting equal humidity in all sample plots. Although, this theory do not agrees with research of Honek & Jarošik (2000). They found out that *H. affinis* prefer dense vegetation within winter wheat fields, but comparably sparse vegetation and patches of bare ground within winter rapeseed fields.

In general, *H. rufipes* is affected by soil tillage. Activity density of this species is significantly higher in no-till agrocenoses than in ploughed and non-inverse tilled ones (Lalonde et al. 2012). However, main soil treatment is not affecting factor for *H. rufipes*. This eurytopic species is equally abundant in ploughed and minimally tilled agro-ecosystems (Holland & Luff 2000). Also crop rotation does not significantly affect abundance of *H. rufipes* in arable land (Lalonde et al. 2012). In our study, main soil treatment did not affect activity density of the species. Whereas, effect of pre-crop in 2013 was ambiguous – periods when one pre-crop promoted higher activity density alternated with periods when the other pre-crop promoted significantly higher activity density of the species.

P. cupreus prefers minimally tilled soil instead of ploughed one (Holland & Luff 2000) and it was also observed during the first season of our research. In winter cereals, activity density of the species is not affected by pre-crop (Marrec et al. 2015) and it does not react to changes of density of crop (Honek & Jarošik 2000). Several studies report that *P. cupreus* is more abundant in organic agro-ecosystems comparing with conventional ones (Purtauf et al. 2005, Schröter & Irmler 2013, Kazlauskaitė et al. 2015). For the present, there is lack of information to explain why the species was significantly affected by pre-crop during the second season of our study.

Information about interactions between soil tillage regime and *P. melanarius* is contradictious. Some papers report that the species prefers green set-asides and no-till fields instead of tilled soil (Kinnunen & Tiainen 1999, Lalonde et al. 2012). Contrary, Purvis & Fadl (2002) observed higher activity density of *P. melanarius* in autumn-cultivated soil than in uncultivated fields. Whereas, Holland & Luff (2000) reports that the species is equally abundant in ploughed and minimally tilled fields. Also our research does not give clear explanation which main soil treatment is more suitable for *P. melanarius*. Only during one study season, activity density of the species was affected by the main soil treatment when *P. melanarius* was significantly more abundant in harrowed soil. Also interactions between the species and crop rotation are still unclear. Löwei (1984) reported that *P. melanarius* is conservative species preferring agrocenoses without sharp crop rotation. It agrees with the first season of our research when activity density of the species was significantly lower in fields pre-cropped with spring rapeseed than in ones pre-cropped with both types of wheat. However, results of our research were contrary in the second season, but it implicitly agrees with study of Honek & Jarošik (2000) who found out that activity density of *P. melanarius* correlates with density of vegetation and land cover by crop. Vegetation in winter wheat fields pre-cropped with rapeseed is significantly denser than vegetation in wheat monocultures. However, also in this case, opposite results of studies are available. Byers et al. (2000) did not find any correlation between activity density of *P. melanarius* and soil moisture, grazing intensity and biomass of plants in pastures. Actually, it means that there was no correlation between activity density of the species and land coverage by the plants.

In arable land, *P. niger* prefers fallows and cereal fields, but tries to avoid from black set-asides (Kinnunen & Tiainen 1999, Kinnunen et al. 2001). The species is more abundant spring crops than in winter crops and in minimally tilled soil than in ploughed soil (Holland & Luff 2000). In reforested clear cuttings, *P. niger* quickly colonizes deeply ploughed areas due to quicker growth of young trees which promote land coverage (Skłodowski 2014). Brygadyrenko (2006) observed that the species is abundant in meso-hygrophilic habitats, but in dryer and moister environment, its activity density is significantly lower. These facts explain results of our study when *P. niger* avoided to inhabit monocultures of winter wheat (during both seasons) and preferred ploughed soil instead of harrowed one (during the second season). As it was mentioned above, ploughed soil and crop rotation promote denser vegetation of winter wheat and moister environment within the field, as a result.

The hypothesis of our research is proved true – ground beetles which may be included in the same ecological group according to their body size, diet preference or breeding cycle are differently affected by main soil treatment and crop rotation in winter wheat fields. For instance, small-sized spring breeding zoophages *Bembidion* spp. differently reacted to studied agro-ecological factors. Similar situation was observed with large-sized autumn breeding zoophages – *P. melanarius* and *P. niger* – and with hemizoophages *H. affinis* and *H. rufipes*. Data used in this paper were used also in other study when effect of the same agro-ecological factors on body size groups of ground beetles were analysed (Gailis & Turka 2014a). At that time, small-sized ground beetles significantly preferred ploughed fields, but medium and large-sized ground beetles were more abundant in harrowed fields, but pre-crop did not significantly affect summarized activity density of the beetles from these ecological groups. More likely, 'ecological group' reacts to environmental factor equally as one or few the most dominant species do, but less abundant species from the same 'ecological group' do not have possibilities to impact tendency of the whole group even if their reaction is antipodal to the same factor.

CONCLUSIONS

In winter wheat fields, studied agro-ecological factors – main soil treatment and crop rotation – affected activity density of ground beetles throughout growing season or at least during periods of their activity maximum. However, effect of the factors may be different between two consecutive growing seasons or it may be visible in one season, but unnoticeable in the second season.

Activity density of *Notiophilus aestuans, N. germinyi* and *Acupalpus meridianus* did not react to studied agro-ecological factors due to too low activity density of the species. Other species were affected indirectly. Interactions between their activity density and the agro-ecological factors may be explained differently. *Amara plebeja* and *Loricera pilicornis* were more abundant in fields with management regimes which may promote more food resources for them. *N. brevicollis, C. cancellatus, B. guttula, B. obtusum, T. quadristriatus, A. dorsalis* and *P. niger* were more abundant in fields with management regimes promoting denser crop canopy thus shadier and moister ground. *H. affinis* was more abundant in fields with management regime promoting thinner crop canopy thus more open ground patches and dryer conditions. Also activity density of *B. lampros, B. properans, H. rufipes, P. cupreus* and *P. melanarius* depended from the factors, but it is unclear, yet; therefore studies should be continued.

The hypothesis has been confirmed – species belonging to the same ecological group (body size, food preference or breeding cycle) differently react to the main soil treatment and/or crop rotation in winter wheat fields.

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