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Soil tillage and crop rotation differently affect biodiversity and species assemblage of ground beetles inhabiting winter wheat fields

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Abstract. This paper continues studies on ground beetles (Carabidae) in differently managed winter wheat (*Triticum aestivum*) fields in Latvia. The main task of those studies was to assess how different soil tillage regimes (ploughing and non-inverse tillage) and different pre-crops (winter wheat and spring rapeseed (*Brassica napus*) affect assemblage and biodiversity of ground beetles in winter wheat fields. The research was carried out in the Latvia University of Agriculture Research and Study Farm 'Pēterlauki' (56°30'39.38''N; 23°41'30.15''E) during vegetation season of 2013. The results were compared with the results of similar research carried out at the same place during 2012. Totally 57 ground beetle species were observed in studied fields in 2013. Total species assemblage varied between both consecutive vegetation seasons of the research, however these were minor differences not connected with studied agro-ecological factors. Dominance structure of ground beetle species was significantly different between both vegetation seasons – species which were dominant and subdominant in 2012 became subdominant and dominant one year later, accordingly. Annual effects of soil tillage regime and pre-crop on ground beetle dominance structure also were observed, however some differences were recognized between both vegetation seasons. In case, if weed control was successful, higher ground beetle biodiversity might be observed in ploughed fields pre-cropped with spring rapeseed. Otherwise, significantly higher ground beetle biodiversity may be observed in harrowed soil independently from the pre-crop.

Key words: Carabidae, *Triticum aestivum*, ploughing, non-inverse tillage, pre-crop, Latvia.

INTRODUCTION

Ground beetles (Carabidae) are well known inhabitants of almost all terrestrial habitats including different agrocenoses. From the economic point of view, those are beneficial insects consuming various pests and seeds of weeds in all field and horticultural crops (Holopainen & Helenius, 1992; Holland & Thomas, 1997; Cromar et al., 1999; Bohan et al., 2000; Arus et al., 2012; Renkema et al., 2012). There have been even attempts of mass culturing of some ground beetles to use them later as biological control agents in greenhouses and tunnels (Symondson, 1994). Overall, presence of diverse ground beetle species assemblage is a good indicator of successful integrated plant breeding in any agrocenosis. Since the integrated pest management (IPM) must be implemented in farms within EU, issues on more efficient use of natural enemies of pests became scientifically topical. As other invertebrates, also ground beetles are exposed to agricultural activities applied in crops. These insects are especially affected by soil tillage and crop rotations – factors which are mentioned as major components of the IPM. In the field crops, soil ploughing and crop rotation are mentioned as effective methods to reduce amount of pests, weeds and causal agents of plant diseases (Salt & Hollick, 1949; Brust & King, 1994; Dosdall et al., 1998; Bankina et al., 2013; Ruisi et al., 2015). On the contrary, non-inverse soil tillage or direct sowing and crop monocultures can dot the opposite effect. It is still unclear how significantly soil tillage and crop rotation affect ground beetles. Several authors had found out that more intensive soil tillage negatively affects ground beetle density, species richness and other parameters (Cárcamo, 1995; Thorbek & Bilde, 2004; Aviron et al., 2005; Cole et al., 2005; Hatten et al., 2007). However, other studies have opposite conclusions reporting that there is lesser activity density of ground beetles in the minimally tilled soil than in ploughed one (Hole et al., 2005). The third point of view is also available – different soil tillage regimes have not significantly different effect on ground beetles due to their migration abilities and breeding cycles adjusted to the tillage regime (Purvis & Fadl, 2002; Belaoussoff et al., 2003; Mason et al., 2006). Connections between ground beetles and crop rotation have been studied comparatively lesser than between beetles and the soil tillage, but mostly there is evidence that crop rotation positively affects ground beetles promoting higher activity density and diversity in the arable land (Brust & King, 1994; O'Rourke et al., 2008; Bourassa et al., 2010).

In Latvia, studies on ground beetles inhabiting winter wheat (*Triticum aestivum*) fields with different soil tillage intensities (ploughed and non-inverse) combined with different pre-crops (winter wheat, spring wheat, spring rapeseed) started in 2012. During this year, more than 60 ground beetle species were observed in the studied fields. Results of data analysis showed that ploughed soil promotes significantly higher activity density of small sized beetles (< 5 mm). Eight species – *Amara plebeja*, *Bembidion guttula*, *B. obtusum*, *Harpalus rufipes*, *Loricera pilicornis*, *Poecilus cupreus*, *Pterostichus melanarius* and *P. niger* – were the most frequent ones in the ground beetles' assemblage, but their proportion was not equal in the fields with all management types. For example, *B. guttula* and *L. pilicornis* over-dominated all other species in the ploughed and non-inverse tilled fields, respectively, but *A. plebeja* was 4–20 times more frequent in the non-inverse tilled fields pre-cropped with spring wheat than in other sample plots. Soil tillage combined with crop rotation also significantly affected biodiversity of ground beetles. Two management types of fields – ploughed soil and spring rapeseed (*Brassica napus*) as pre-crop (1) and non-inverse tilled soil and spring wheat as pre-crop (2) – promoted significantly higher biodiversity than other management types. Contrary, the lowest biodiversity of ground beetles was observed in the non-inverse tilled fields pre-cropped with spring rapeseed (Gailis & Turka, 2014a; Gailis & Turka, 2014b).

In the growing season of 2013, the research on the ground beetles inhabiting differently tilled and pre-cropped winter wheat fields had been continued in the same study place. Objectives of this research were to find out how soil tillage intensity and different pre-crops affected the species assemblage and biodiversity of ground beetles (1); to study whether similar management regime of fields causes equal effect to the species assemblage and biodiversity of ground beetles in two consecutive years (2); to discuss possible reasons of potential unequal between-years effects caused by both agro-ecological factors (3).

MATERIALS AND METHODS

Field studies were carried out during 2013 in stationary trial place created in 2009 for researches on good agricultural practice for the most popular field crops. This trial place belongs to the Latvia University of Agriculture Research and Study Farm 'Pēterlauki'. It is located near Poķi village 14 km south from Jelgava town (56°30'39.38''N; 23°41'30.15''E). Since the establishment, in this place, all agricultural activities, e.g., soil tillage, sowing of crops, usage of fertilizers and pesticides and crop harvesting were performed in accordance to conventional agricultural practice as in any usual field.

The trial place consists of a grid of 24 rectangular sample plots (0.25 ha; 30 x 85 m). The grid was surrounded by conventionally farmed arable land. A narrow 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. Stripes of land (2.5 m wide) separated sample plots from each other and from near crop fields. Vegetation of wild herbaceous plants covered those land stripes. 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. For the growing season of 2013, these activities were executed in 10 August 2012. Other soil tillage activities were performed in accordance with the conventional agronomic practice as in any commercial field.

Six ploughed and six harrowed sample plots were sown with winter wheat (variety 'Zentos') for the growing season of 2013, and these sample plots were used for this study. Other sample plots were sown with other field crops. 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 four combinations of both agro-ecological factors – soil tillage and pre-crop – represented in the studied sample plots (Fig. 1).

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.

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. Total weed density was evaluated twice in the season – in May 10 (seven days before the application of herbicides) and in July 8. Before the application of herbicides, weed density varied between nine and 60 plants m^{-2} in different sample plots, but harrowed plots were comparably weedier especially ones pre-cropped with winter wheat. Weed control was comparatively ineffective – weed density either decreased insignificantly or increased between both accountings. Especially significant increase of weed density occurred in harrowed sample plots pre-cropped with winter wheat. In these fields, 80–137 weeds m^{-2} were observed during the second accounting (Fig. 1).

H	P	P	H
No. 1 Winter wheat* (Winter wheat)** W.D.: 38/137	No. 2 Winter wheat (Winter wheat) W.D.: 60/66	No. 3 Winter rapeseed	No. 4 Spring rapeseed
No. 5 Spring rapeseed	No. 6 Winter rapeseed	No. 7 Winter wheat (Spring rapeseed) W.D.: 8/8	No. 8 Winter wheat (Spring rapeseed) W.D.: 33/32
No. 9 Winter wheat (Spring rapeseed) W.D.: 3/19	No. 10 Winter wheat (Spring rapeseed) W.D.: 7/8	No. 11 Winter rapeseed	No. 12 Spring rapeseed
No. 13 Winter wheat (Winter wheat) W.D.: 51/80	No. 14 Winter wheat (Winter wheat) W.D.: 22/12	No. 15 Winter rapeseed	No. 16 Winter rapeseed
No. 17 Winter rapeseed	No. 18 Winter rapeseed	No. 19 Winter wheat (Spring rapeseed) W.D.: 15/14	No. 20 Winter wheat (Spring rapeseed) W.D.: 40/39
No. 21 Winter wheat (Spring rapeseed) W.D.: 9/6	No. 22 Winter wheat (Spring rapeseed) W.D.: 19/14	No. 23 Winter rapeseed	No. 24 Winter rapeseed

Figure 1. Scheme of sample plots in stationary trial place in Study and Research Farm 'Pēterlauki'. (H – harrowed with disc harrow; P – ploughed; * – crop in 2013; ** – pre-crop; W.D. – weed density in 10 May 2013 / 8 July 2013; pre-crops and weed density values are showed only for winter wheat sample plots used for this research).

Transparent plastic glasses (vol. 200 ml, 65 mm opening diameter) were used as pitfall traps for collecting of ground beetles. The traps were half filled with 4–5% acetic acid solution with few drops of detergent. Ten traps were placed in cornerwise transect in each winter wheat sample plot, distance between traps were three meters. Exposition of traps started when first active ground beetles were observed in spring (23 April 2013), but ended few days before harvesting of winter wheat (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 were registered using Davis Vantage Pro2 weather station, which was located 100 m away from sample plots. The meteorological situation is showed in Fig. 2.

Species of ground beetles were identified after Freude et al. (2004), but Check-List of Latvian beetles (Telnov, 2004) was used for nomenclature. Species assemblages of ground beetles were expressed as the dominance structure calculated according to Engelmann (1978). 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%). The dominance structure was calculated for each of four studied winter wheat management types (the main soil tillage method in combination with the pre-crop). 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 throughout vegetation season. Biodiversity of ground beetles was assessed by calculating Simpson's index (D_s) for winter wheat fields with each management type:

$$D_s = \sum \frac{n_i\,(n_i - 1)}{N(N-1)} \qquad (1)$$

where: n_i – the number of individuals of the i^{th} species per trap; N – the total number of individuals per trap (Magurran, 2004).

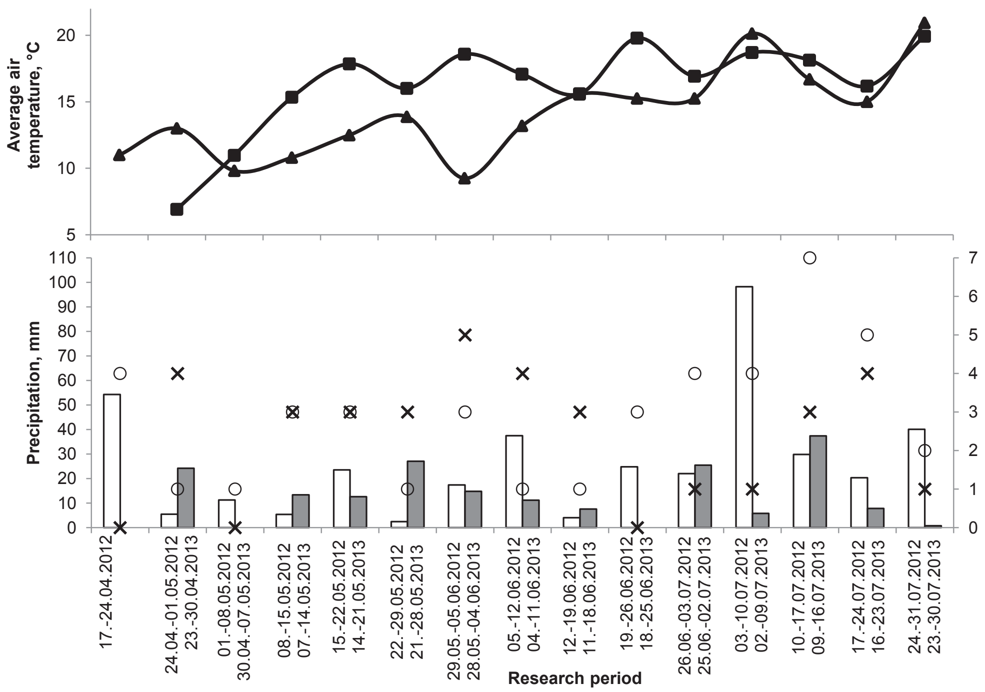

Figure 2. Meteorological conditions in studied winter wheat fields during vegetation season of 2013 and one year earlier (—▲— – air temperature in 2012; —■— – air temperature in 2013; □ – precipitation in 2012; ■ – precipitation in 2013; ○ – rainy days in 2012; × – rainy days in 2013).

In this paper, biodiversity of ground beetles is expressed as reciprocal Simpson's index ($1/D_s$). This value was calculated for each of 120 pitfall traps. Total number of ground beetle individuals collected throughout the vegetation season was used for the calculations. Interconnections among biodiversity and both agro-ecological factors were assessed calculating Spearman's rank correlation coefficients (r_s) with two-tailed significance test using SPSS 17.0. Correlation was calculated for six different variants: between the biodiversity and soil tillage independently from pre-crop (1), between the biodiversity and pre-crop independently form soil tillage (2), between biodiversity and pre-crop in harrowed soil (3), between biodiversity and pre-crop in ploughed soil (4), between biodiversity and soil tillage if pre-crop was winter wheat (5) and between biodiversity and soil tillage if the pre-crop was spring rapeseed (6). The strength of correlation was estimated after Green et al. (2000):

$|r_s|$ = 0.00-0.19 – very weak correlation;

$|r_s|$ = 0.20-0.39 – weak correlation;

$|r_s|$ = 0.40-0.59 – moderate correlation;

$|r_s|$ = 0.60-0.79 – strong correlation;

$|r_s|$ = 0.80-1.00 – very strong correlation.

RESULTS AND DISCUSSION

Composition of ground beetle species assemblage

In total, 60,024 ground beetles from 57 species were observed in studied winter wheat fields in 2013, but not all species were present in all sample plots. The number of species varied from 39 until 48 in differently managed fields (Table 1).

Table 1. List of ground beetles and number of their individuals caught in differently managed winter wheat fields during 2013. Species are grouped according to their habitat preferences after Barševskis (2003) and listed in descending order according to their frequency in each ecological group. (H – non-inverse tilled (harrowed) soil, P – ploughed soil; pre-crops: W.W. – winter wheat, S.R. – spring rapeseed. * – number of individuals caught in 20 traps; ** – number of individuals caught in 40 traps; Hab. – habitat preferences: G – generalists, species inhabiting open habitats and forests; Oh – open habitats; F – forests; x – xerophilous; m – mesophilous; h – hygrophilous)

Species	H.* W.W.	H.** S.R.	P.* W.W.	P.** S.R.	Hab.
Pterostichus niger (Schaller, 1783)	1,019	4,999	1,170	5,331	G, h
Pterostichus melanarius (Illiger, 1798)	1,824	3,540	892	3,083	G, h
Poecilus cupreus (Linnaeus, 1758)	877	2,160	992	2,154	G, m
Loricera pilicornis (Fabricius, 1775)	375	1,317	306	1,016	G, h
Trechus quadristriatus (Schrank, 1781)	36	348	138	560	G, m
Bembidion lampros (Herbst, 1784)	94	261	66	203	G, m
Bembidion properans (Stephens, 1828)	88	161	34	113	G, h
Clivina fossor (Linnaeus, 1758)	22	77	40	59	G, h
Amara plebeja (Gyllenhal, 1810)	120	30	19	29	G, x
Blemus discus (Fabricius, 1792)	15	38	25	60	G, h
Carabus cancellatus Illiger, 1798	10	70	8	43	G, m
Bembidion quadrimaculatum (Linnaeus, 1761)	10	28	22	27	G, m
Amara similata (Gyllenhal, 1810)	9	17	3	16	G, m
Acupalpus meridianus (Linnaeus, 1761)	7	11	2	11	G, h
Poecilus versicolor (Sturm, 1824)	6	3	4	14	G, m
Notiophilus palustris (Duftschmid, 1812)	9	7	5	7	G, h
Notiophilus aquaticus (Linnaeus, 1758)	5	6	6	7	G, h
Notiophilus germinyi Fauvel, 1863	6	4	2	2	G, h
Badister sodalis (Duftschmid, 1812)	6	-	6	4	G, h
Amara ovata (Fabricius, 1792)	3	6	1	5	G, m
Carabus granulatus Linnaeus, 1758	-	7	-	3	G, h
Carabus nemoralis O.F.Müller, 1764	-	6	-	3	G, m

Table 1 (continued)

Amara aenea (DeGeer, 1774)	1	3	3	1	G, m
Amara familiaris (Duftschmid, 1812)	-	1	-	5	G, m
Amara nitida Sturm, 1825	-	5	-	1	G, m
Badister bullatus (Schrank, 1798)	-	-	-	2	G, m
Patrobus atrorufus (Ström, 1768)	-	-	-	1	G, h
Pterostichus nigrita (Paykull, 1790)	-	1	-	-	G, h
Harpalus rufipes (DeGeer, 1774)	3,020	6,452	3,169	6,969	Oh, x
Bembidion guttula (Fabricius, 1792)	680	1,379	677	1,573	Oh, h
Anchomenus dorsalis (Pontoppidan, 1763)	98	237	81	265	Oh, m
Bembidion obtusum Audinet-Serville, 1821	37	180	36	123	Oh, x
Harpalus affinis (Schrank, 1781)	66	79	95	97	Oh, x
Notiophilus aestuans Dejean, 1826	12	30	6	35	Oh, x
Asaphidion flavipes (Linnaeus, 1761)	3	9	4	9	Oh, x
Pterostichus macer (Marsham, 1802)	3	6	9	7	Oh, m
Chlaenius nitidulus (Schrank, 1781)	1	6	1	10	Oh, h
Amara eurynota (Panzer, 1796)	5	3	-	4	Oh, x
Calathus ambiguus (Paykull, 1790)	1	4	3	4	Oh, m
Calathus fuscipes (Goeze, 1777)	2	4	1	3	Oh, m
Amara littorea Thomson, 1857	3	3	1	-	Oh, x
Amara apricaria (Paykull, 1790)	5	-	2	-	Oh, m
Harpalus calceatus (Duftschmid, 1812)	-	-	-	6	Oh, x
Synuchus vivalis (Illiger, 1798)	-	2	-	3	Oh, m
Harpalus distinguendus (Duftschmid, 1812)	-	1	-	2	Oh, x
Microlestes minutulus (Goeze, 1777)	1	-	2	-	Oh, x
Cylindera germanica (Linnaeus, 1758)	-	-	1	-	Oh, m
Anisodactylus signatus (Panzer, 1796)	-	-	-	1	Oh, h
Harpalus signaticornis (Duftschmid, 1812)	-	1	-	-	Oh, m
Microlestes maurus (Sturm, 1827)	-	-	1	-	Oh, x
Agonum gracilipes (Duftschmid, 1812)	-	-	1	-	Oh, h
Nebria brevicollis (Fabricius, 1792)	4	159	8	65	F, m
Pterostichus vernalis (Panzer, 1796)	15	46	4	17	F, h
Platynus assimilis (Paykull, 1790)	-	7	1	4	F, h
Pterostichus oblongopunctatus (Fabricius, 1787)	-	4	-	2	F, m
Leistus piceus Frölich, 1799	1	-	-	-	F, h
Stomis pumicatus (Panzer, 1796)	-	-	-	1	F, m
Total species	39	45	41	48	
Total individuals	8,499	21,718	7,847	21,960	
Average individuals per trap	425	543	392	549	

Overall in 2013, general species richness in studied fields was similar to the species richness observed in other studies in cereals in Latvia and elsewhere in Europe. For instance, 41 ground beetle species were observed in wheat fields in Eastern Latvia (Bukejs & Balalaikins, 2008). In general, all observed ground beetles are creating typical species assemblage inhabiting arable land. Almost all species mentioned in Table 1 are reported as more or less common faunistic elements of different agrocenoses and other open habitats across the Europe (Basedow et al., 1976; Hellenius et al., 2001; Purvis et al., 2001; Irmler, 2003; Tamutis et al., 2007; Bukejs et al., 2009; Kosewska et al., 2014; Kazlauskeitė et al., 2015).

In studied winter wheat fields, general composition of species assemblage differed between vegetation season of 2013 and one year earlier. Sixteen species observed in 2012 (Gailis & Turka, 2014b) were not present in the studied winter wheat fields during 2013, and seven species observed in 2013 were not established in the fields one year earlier (Table 2). Overall, this should be considered as an unimportant difference of species assemblage that was not caused by studied agro-ecological factors. All species observed in just one vegetation season were subrecedents and represented by only few individuals in the species assemblage. Mostly, infrequent species with low population density are observed in certain area due to their migration fortuities, therefore one species, observed in 2012, can avoid pit-fall traps one year later. For example, *Dolichus halensis* was observed in studied sample plots in 2012, but not in next year. However, in 2013, this species was observed at the edge of arable field located circa 50 meters apart from studied sample plots (Gailis & Turka, 2014b; Telnov et al., 2016).

Table 2. List of ground beetle species observed in studied winter wheat fields during only one vegetation season

Species observed in 2012 only	Species observed in 2013 only
Carabus arcensis (Herbst, 1784)	*Leistus piceus* Frölich, 1799
Dyschirius aeneus (Dejean, 1825)	*Cylindera germanica* (Linnaeus, 1758)
Dyschirius politus (Dejean, 1825)	*Patrobus atrorufus* (Ström, 1768)
Harpalus luteicornis (Duftschmid, 1812)	*Anisodactylus signatus* (Panzer, 1796)
Harpalus tardus (Panzer, 1796)	*Harpalus distinguendus* (Duftschmid, 1812)
Stenolophus mixtus (Herbst, 1784)	*Amara littorea* Thomson, 1857
Demetrias monostigma Samouelle, 1819	
Agonum sexpunctatum (Linnaeus, 1758)	
Pterostichus diligens (Sturm, 1824)	
Pterostichus strenuus (Panzer, 1796)	
Dolichus halensis (Schaller, 1783)	
Amara communis (Panzer, 1797)	
Amara convexior Stephens, 1828	
Amara spreta Dejean, 1831	
Amara fulva (O.F. Müller, 1776)	
Amara aulica (Panzer, 1796)	

One revision also must be done for the list of ground beetles observed in studied winter wheat fields in 2012 (Gailis & Turka, 2014b). Three misidentifications of species were recognized after repeated checking of ground beetle material collected in 2012. Firstly, all *Badister sodalis* specimens were incorrectly identified as *Badister dorsiger*. Secondly, one *Microlestes minutulus* individual was incorrectly identified as *Microlestes maurus*, thus both *Microlestes* species were observed in studied sample plots. Thirdly, some untypical *Bembidion guttula* specimens were misidentified as *Bembidion mannerheimii*. All these misidentifications are acknowledged as minor mistakes, because both *Microlestes* species and *B. sodalis* were subrecedents, and only 34 *B. guttula* individuals from in total 6,237 ones (circa 0.5%) were incorrectly identified as *B. mannerheimii*.

Species dominance structure in differently managed winter wheat fields

In 2013, five species – *Harpalus rufipes*, *Pterostichus niger*, *P. melanarius*, *Poecilus cupreus* and *Bembidion guttula* – were the most frequent species in all studied winter wheat fields. One more species – *Loricera pilicornis* – joined the group of subdominant species in all fields except those with ploughed soil and winter wheat as pre-crop (Fig. 3). *H. rufipes* noticeably over dominated all other species, especially in previously mentioned fields with ploughed soil and winter wheat as pre-crop, where *H. rufipes* reached eudominant status.

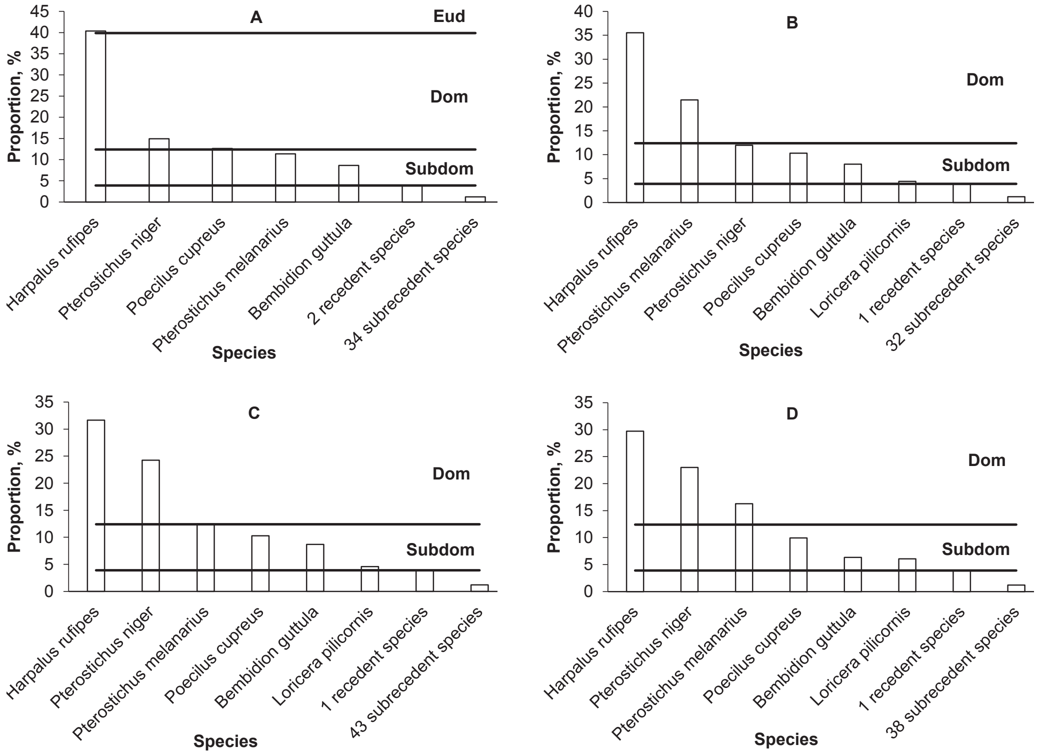

Figure 3. Dominance structure of ground beetles in differently managed winter wheat fields in the season of 2013 (A – ploughed soil, winter wheat as pre-crop; B – harrowed soil, winter wheat as pre-crop; C – ploughed soil, spring rapeseed as pre-crop; D – harrowed soil, spring rapeseed as pre-crop; Eud – eudominants, Dom – dominants, Subdom - subdominants).

In fields with all management types, ground beetle dominance structure observed in the growing season of 2013 noticeably differed from one observed a year earlier. In 2012, *Bembidion guttula* and *Loricera pilicornis* over-dominated other species, but the proportion of *H. rufipes*, *P. cupreus* and both *Pterostichus* was significantly smaller. However, all these species reached dominant or subdominant level in species assemblage in almost all studied winter wheat fields. Two more species – *Bembidion obtusum* and *Amara plebeja* – were among subdominant ground beetles in some fields in 2012, as well (Gailis & Turka, 2014b). In 2013, these species were comparably frequent, but their proportion did not reach at least subdominant level in the fields with any type of management.

Such significant changes of species dominance structure may be explained by noticeably changed activity density of the most frequent species. The activity density of *L. pilicornis*, *B. guttula* and other *Bembidion* species significantly decreased in the studied winter wheat fields in the 2013 comparing with the 2012, and it happened despite more than twice-bigger total density of ground beetles in the growing season of 2013. On the contrary, activity density of other commonest species such as *H. rufipes*, *P. melanarius*, *P. niger* and *P. cupreus* significantly increased in 2013. Between the years, fluctuations of ground beetle populations are common occurrence (Irmler, 2007). It could be explained by several ecological factors, e.g. weather and variation of reproduction cycle which also may depend on climatic conditions. Meteorological situation was significantly different in both years of the research. The growing season of 2012 was cooler and rainier than the season of 2013 (Fig. 2). Irmler (2007) found out that the activity density of *P. niger* and *H. rufipes* negatively correlates with the amount of precipitation, but some *Bembidion species* (e.g. *B. lampros*) increase their activity density if the weather is rainier. *P. cupreus* and some *Harpalus* species activity density correlates with the environmental temperature – temperature increase by 1ºC promotes the increase of beetle's activity density for 6–7 percentage points (Honěk, 1997). Meteorological conditions also can significantly affect presence of food resources for the ground beetles. For example, more precipitation (as it was in 2012) can enhance abundance of springtails (Collembola) by almost 50% (Wu et al., 2014). These soil arthropods are primary food source for *L. pilicornis*, but they are also used as the secondary food by *Bembidion* species (Mundy et al., 2000). *P. niger* and *P. melanarius* are species with varying reproduction cycle. Typically, they are autumn-breeding univoltine species, but their reproduction cycle may become biennial due to unsuitable environmental conditions for individual development (Matalin, 2006; Irmler, 2007; Trushitsyna & Matalin, 2016). Higher population density of those species may be expected in the year after comparably cool summers, and it was observed also in our study. Overall, facts mentioned above explain why the dominance structure of ground beetles was so noticeably different in each vegetation season.

In 2013, proportions of some dominant and subdominant species were noticeably affected by studied agro-ecological factors. In some cases, these effects were similar as in 2012, but in other cases, these effects differed between the years. In 2013, proportion of *P. melanarius* was noticeably bigger in harrowed soil than in ploughed soil. Independently from the pre-crop, *P. melanarius* reached dominant status in harrowed fields while in ploughed soil, this species was subdominant (Fig. 3). This fact disagrees with results of some other researches reporting that *P. melanarius* more often is affected by pre-crop, but not by soil tillage in arable land. It usually prefers agrocenoses without or with minimal crop rotation (Lövei, 1984; Lübke-Al Husein, 2000). It was also evident in our previous research performed in 2012, when *P. melanarius* was significantly less abundant and its proportion was significantly smaller in the fields pre-cropped with spring rapeseed than in fields pre-cropped with winter and spring wheat, but its proportion was not noticeably affected by soil tillage regime (Gailis & Turka, 2014b).

The proportion of *P. niger* was mainly affected by pre-crop in 2013. In the fields pre-cropped with spring rapeseed, the proportion of *P. niger* exceeded 23%, and the species was convincingly dominant. In fields pre-cropped with winter wheat, *P. niger* was comparably less frequent – in ploughed soil, it reached dominant level (proportion 14.9%), but in harrowed soil, *P.niger* was subdominant (proportion less than 12%)

(Fig. 3). Similarly with the season of 2013, also in 2012, *P. niger* was significantly less abundant and its proportion was smaller in fields pre-cropped with winter wheat than in fields with other pre-crops (Gailis & Turka, 2014b). Explanation is not clear for this fact, yet.

Soil tillage regime and pre-crop did not noticeably affect proportion of *B. guttula* in 2013. This species reached subdominant status in all studied winter wheat fields (Fig. 3). In 2012, *B. guttula* was significantly more abundant and more dominant in ploughed fields than in harrowed ones. That connectedness was explained with bare soil surface (without straw aggregations) which is more suitable for small-sized ground beetles to move and to notice a prey (Gailis & Turka, 2014b). In Europe, studies on relationships between other *Bembidion* species and soil tillage intensity are done, but those results also are inconsistent. For example, in one study, *B. obtusum* is reported as the species which equally prefer ploughed and minimally tilled agrocenoses (Holland & Luff, 2000), but results of other study show that this species may be significantly more frequent in minimally tilled soil than in ploughed one (Holland & Reynolds, 2003). It means that soil tillage intensity may be significant affecting factor for *Bembidion* species (also for *B. guttula*) inhabiting arable land, but not always.

In 2013, the proportion of *L. pilicornis* had a tendency to be bigger in fields promoting more decaying plant material on the surface of soil and in the upper layer of soil. This species was subdominant in all fields except those with ploughed soil and winter wheat as the pre-crop (Fig. 3). This fact was more evident in the vegetation season of 2012 when *L. pilicornis* was the most dominating species in all harrowed fields, but the second most abundant species in ploughed fields independently from the pre-crop (Gailis & Turka, 2014b). *L. pilicornis* mostly feeds on springtails (Collembola) which are saprophagous elements of epigeic fauna. Intensive soil tillage, e.g. ploughing, significantly reduces abundance of springtails in ecosystem (Sousa et al., 2004; Brennan et al., 2006) causing lesser abundance of their predators.

Biodiversity of ground beetles in differently managed winter wheat fields

In 2013, in cases when both agro-ecological factors – soil tillage intensity and pre-crop – were considered independently from each other, weak, but statistically significant correlations were observed between them and ground beetle biodiversity. They showed tendency that soil harrowing and spring rapeseed as the pre-crop promoted higher biodiversity of ground beetles if comparing with soil ploughing and winter wheat as the pre-crop, accordingly (Fig. 4).

Combined effect of both agro-ecological factors was more noticeable, but not in all cases. In ploughed soil, moderate correlation was observed between ground beetle biodiversity and pre-crop – spring rapeseed promoted significantly higher biodiversity than winter wheat. In harrowed soil, pre-crop did not significantly affect ground beetle biodiversity; however, it was higher in the fields pre-cropped with rapeseed (Fig. 4).

Moderate negative correlation was observed between biodiversity and soil tillage intensity in the fields pre-cropped with the winter wheat. In these fields, harrowed soil promoted significantly higher biodiversity of ground beetles than ploughed soil. In fields pre-cropped with spring rapeseed, soil tillage intensity did not significantly affect biodiversity, however non-inverse soil tillage had a tendency to promote higher biodiversity than soil ploughing (Fig. 4).

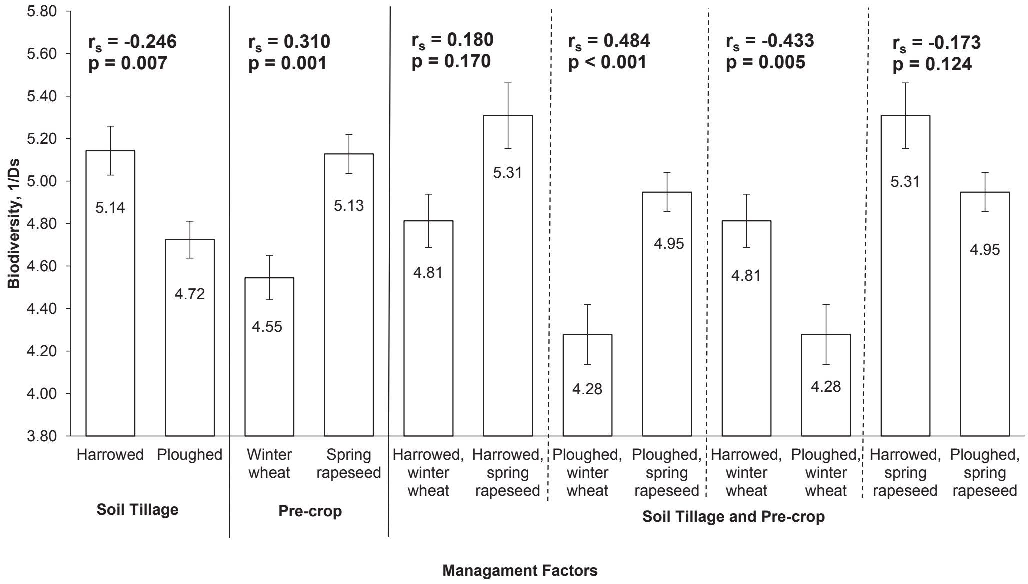

Figure 4. Ground beetle biodiversity's dependence from the soil tillage regime and pre-crop in winter wheat fields in 2013.

Similarly with the species dominance structure, also connectednesses between biodiversity of ground beetles and studied agro-ecological factors were noticeably different between the 2013 and previous season. In 2012, biodiversity mostly positively correlated with the intensity of soil tillage – harrowed soil promoted higher ground beetle biodiversity only in the fields pre-cropped with spring wheat, but in other fields (pre-crops: winter wheat and spring rapeseed), biodiversity was higher in ploughed soil. In harrowed soil, spring rapeseed as the pre-crop promoted significantly lower biodiversity than the wheat as the pre-crop. But in ploughed soil, the highest biodiversity was observed in the fields pre-cropped with the rapeseed (Gailis & Turka, 2014b), and this was the only analogous case in both years.

In general, direct connection between ground beetle biodiversity and soil tillage intensity is still unclear (Holland & Luff, 2000; Roger-Estrade et al., 2010). Many studies show that intensive soil tillage and loosening simplifies species assemblage and reduces biodiversity of ground beetles due to the negative effect to different trophic and body size groups of the beetles. Soil ploughing can reduce population density or fully eliminate *Carabus* and other big-sized ground beetles from the ecosystem (Cárcamo, 1995; Aviron et al., 2005; Cole et al., 2005; Hatten et al., 2007; Skłodowski, 2014). On the contrary, other studies report that soil ploughing and non-inverse tillage have similar influence on ground beetle biodiversity in arable land (Booij & Noorlander, 1992; Andersen, 2003; Belaoussoff et al., 2003; Mason et al., 2006; Twardowski, 2006; Lalonde et al., 2012), or that soil ploughing is more favourable for ground beetles than the reduced tillage (Hole et al., 2005). There are also papers available showing that soil tillage intensity can be affecting factor for some trophic groups of ground beetles. For example, Kosewska et al. (2014) found out that omnivorous species are negatively affected by soil ploughing, but carnivorous species (all body size groups) do not react to different soil tillage intensity. Other study reports that soil ploughing reduced (27%), but non-inverse soil tillage significantly promoted (26%) ground beetle density in arable fields (Thorbek & Bilde, 2004).

More likely, in the harrowed soil, bigger biodiversity of ground beetles can be explained by denser and more diverse weed vegetation that was observed in all harrowed sample plots during 2013, but only in sample plots pre-cropped with spring wheat in 2012. In the arable land, presence of weeds enhances biodiversity of plants, but vegetation that is more diverse enhances biodiversity of invertebrates including ground beetles. Presence of weeds also creates thicker vegetation compensating thin vegetation of wheat promoted by long-term non-inverse soil tillage. Weeds provide more various shelters and additional food resources – attracted phytophagous invertebrates for carnivorous ground beetles and seeds and seedlings for herbivorous ground beetles (Cromar et al., 1999; Norris & Kogan, 2000; Pfiffner & Luka, 2003; Hole et al., 2005; Diehl et al., 2012; Saska et al., 2014). In our sample plots, herbicides were used during the growing season of 2013 just as one year previously. However, weed control was comparably effective only in 2012, when noticeable weed vegetation remained only in harrowed sample plots pre-cropped with spring wheat. During the growing season of 2013, weed density did not significantly decrease or even increased after herbicide application in harrowed sample plots (Fig. 1). Perhaps this is the main reason why higher biodiversity of ground beetles was observed in harrowed soil (all pre-crops) in 2013, but mostly in ploughed soil – in 2012 (excepting fields pre-cropped with spring wheat).

There is one more issue that is complicated. In the season of 2013, biodiversity of ground beetles overall was noticeably lower than one year earlier. The highest biodiversity was observed in harrowed fields pre-cropped with spring rapeseed, but contrary situation was observed in the growing season of 2012, when this combination of soil tillage and pre-crop promoted the lowest biodiversity of ground beetles (Gailis & Turka, 2014b). However, this management regime was the single one promoting similar biodiversity of ground beetles in both study seasons, while in the fields with other management regimes, biodiversity noticeably decreased in the 2013 comparing with previous year. This decrease may be explained with less balanced species assemblages in the greatest part of studied winter wheat fields in the second study year. More suitable environmental conditions for *H. rufipes*, *P. niger* and *P. melanarius* and less suitable conditions for *L. pilicornis*, *Bembidion* and other species promoted a noticeable dominance of one or two species over the other ones in 2013. In the harrowed fields pre-cropped with rapeseed, environmental circumstances enabled *P. melanarius* to increase its proportion until dominant level in 2013, while in 2012 this species was significantly less frequent in the fields with such type of management (Gailis & Turka, 2014b). This factor maintained mainly similarly balanced species assemblage and also similar biodiversity of ground beetles in these fields in both study seasons. Partly such differences of ground beetle species' proportions may be explained by significantly different climatic conditions between study seasons. As it was discussed previously, air temperature and precipitation influence ground beetle breeding cycles, presence of their prey in the agro-ecosystem and possibly other still unknown environmental factors differently affecting densities of various ground beetle populations and also biodiversity. However, our study is still too short to do valid conclusions about environmental factors causing differences of assemblages and biodiversity of ground beetles inhabiting winter wheat fields located at the same place and having the similar management regime in different years.

CONCLUSIONS

In winter wheat fields located at the same place, ground beetle species assemblage may vary between two consecutive vegetation seasons. However, these are minor differences connected with migration fortuities of subrecedent species, but not with studied agro-ecological factors – soil tillage and crop rotation.

Ground beetle species dominance structure may be significantly different in the same winter wheat fields during consecutive years. Species dominating in the first vegetation season may become subdominant in the second season. And contrary –former subdominants may reach dominant or eudominant state during the second season.

Different soil tillage regimes and different crop rotation schemes are affecting the dominance structure of ground beetles inhabiting winter wheat fields. However, this effect may be different between two years and is still unclear. More likely, both studied agro-ecological factors are combining themselves with other environmental factors, and those combinations differently affect proportion of different ground beetle species in the species assemblage.

Soil tillage regimes and different pre-crops may significantly affect ground beetle biodiversity in winter wheat fields. However, the effect of those factors may depend on other agro-ecological factors, e.g., efficiency of herbicide application. If weed control was successful, then ploughed soil in combination with spring rapeseed as pre-crop promotes significantly higher biodiversity than harrowed soil and wheat as pre-crop. Otherwise, significantly higher ground beetle biodiversity is observed in harrowed soil independently from the pre-crop.

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