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The diversity and structure of ground beetles (Coleoptera: Carabidae) assemblages in differently managed winter wheat fields

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Ground beetles (Carabidae) are significant elements of integrated pest management (IPM) as they are natural enemies of pests and weeds in any agro-ecosystem. This research is part of a larger study on ground beetles as bio-indicators in IPM in Latvia. The objective of this research was to find out how traditional and minimal soil tillage and different pre-crops – spring rapeseed (*Brassica napus*), spring wheat (*Triticum aestivum*), and winter wheat – affect the dominance structure and biodiversity of ground beetles in winter wheat fields. The research was carried out at the Latvia University of Agriculture Research and Study Farm 'Peterlauki' (56^{o}30'39.38"N; 23^{o}41'30.15"E) using 12 differently tilled and pre-cropped sample plots (0.3 ha) during 2012. Totally, 66 ground beetle species were recorded, eight of which – *Loricera pilicornis, Bembidion guttula, Bembidion obtusum, Poecilus cupreus, Harpalus rufipes, Pterostichus melanarius, Pterostichus niger*, and *Amara plebeja* – were dominants or subdominants in the sample plots with at least one type of management. The dominance structure of ground beetles was mostly affected by soil tillage, but biodiversity was affected by both agro-ecological factors simultaneously. In fields pre-cropped with spring rapeseed, the biodiversity of ground beetles positively correlated with intensiveness of soil tillage while, in fields pre-cropped with spring wheat, more intensive soil tillage led to lower biodiversity of ground beetles. In fields pre-cropped with winter wheat, biodiversity was not affected by soil tillage.

Key words: Carabidae, soil tillage, pre-crop, dominance structure, biodiversity, *Triticum aestivum*, Latvia

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INTRODUCTION

Many world-wide studies show that ground beetles (Carabidae) play a significant role as pest and weed predators in every agro-ecosystem. In cereals, different ground beetles significantly reduce the abundance of slugs, leaf beetles (Chrysomelidae), and aphids (Aphididae) (e.g. Sunderland & Vickerman 1980; Sotherton et al. 1984; Sunderland et al. 1987; Winder et al. 1994; Wiltshire & Hughes 2000; Lang 2003; Schmidt et al. 2003). Such ground beetle species as *Pterostichus melanarius, Poecilus cupreus,* and *Harpalus rufipes* are mentioned as important controllers of the Colorado beetle (*Leptinotarsa decemlineata*) in potato (*Solanum tuberosum*) fields (Koval 1999). Other studies show that *P. melanarius* also is a serious predator of the blueberry maggot (*Rhagoletis mendax*) in high bush blueberries (*Vaccinium corymbosum*) while *H. rufipes* and *P. cupreus* along with *Harpalus affinis* feed on the brassica-pod-midge (*Dasineura brassicae*) and pollen-beetle (*Meligethes* spp.) larvae in rapeseed (*Brassica napus*) fields (Schlein & Büchs 2006; Renkema et al. 2012). Recent studies of Arus et al. (2012) allow for the conclusion that large-sized ground beetles – *P. melanarius*, *Pterostichus niger*, *H. rufipes*, and *Carabus nemoralis* – can be significant reducers of populations of different raspberry pests, e.g. the raspberry beetle (*Byturus tomentosus*). Herbivorous and omnivorous ground beetles are weed predators. They reduce weed density up to 60-80% during one vegetation season (Ward et al. 2011). However, after soil tillage, herbivorous ground beetles along with other seed predators consume only 22-28% of weed seeds and sprouts in various crops (Cromar et al. 1999).

All examples mentioned above make ground beetles important elements of integrated pest management (IPM). IPM is the system of ecologically safe plant protection within conventionally farmed crops. According to this concept, agrotechnical, physical, genetical (less susceptible sorts), and biological pest-control mechanisms have priority over the chemical strategies (Kapitsa 2012). Here, ground beetles are components of IPM as well as bio-indicators. This is due to major agrotechnical elements of IPM, e.g. soil tillage, and other farming activities affecting not only populations of pests, weeds, and causal agents of plant diseases, but also populations of beneficial organisms, especially epigaeic ones, including ground beetles. The review of Gailis & Turka (2013) shows that ground beetles obviously reflect changes promoted by many farming activities – e.g. soil tillage, crop rotation, usage of fertilizers, insecticides and herbicides, etc. – within agro-ecosystems. But the reaction of ground beetles to farming activities is not the same in all cases, it may be site-, crop-, and even field-specific. This may be explained by the fact that each site and crop may have their own ecological and hence faunistic peculiarities. In addition, every field may have its own farming history, imposing long-term effects on ground beetles.

In Latvia, research on ground beetles of agroecosystems has been done infrequently, and most of the work comprised faunistic studies. However, some work was done on the effects of insecticides on ground-beetle abundance and assemblages in various crops (Gailis & Turka 2013). The objective of the present research is to find out how different soil-tillage methods and crop-rotation schemes affect the dominance structure and biodiversity of ground beetles in winter wheat (*Triticum aestivum*) fields. This is part of a large new study on ground beetles as bio-indicators in IPM in Latvia. Winter wheat was chosen as the model crop in this research, because conventional cultivation of it does not require local use of insecticides. Therefore, without the side effects brought about by chemicals, it allows for assessing the effects of soil tillage and crop rotation on ground beetles more precisely.

MATERIAL AND METHODS

During 2012, the research was carried out at the Latvia University of Agriculture Research and Study Farm 'Peterlauki' (56°30'39.38''N; 23°41'30.15''E) located near the village of Poki (14 km south of Jelgava). The soil at this site is an endogleyic calcisol (GLu) with pH 6.8 (KCl) and low humus content – 20 g kg^{-1} (Dubova et al. 2013). The research site was mostly surrounded by conventionally farmed arable land. A narrow strip of deciduous forest (35 x 510 m) was located 30 m south and the closest rural settlement 120 m west from the research site (Fig.1). Forest vegetation had evolved on the former arable land including orchards during last 60 years.

A stationary agronomic trial place consisting of 24 sample plots was used for the research. Ground beetles have been studied using pitfall traps in 12 sample plots (30 x 85 m each) covered with winter wheat (*Triticum aestivum*) vegetation (Fig.

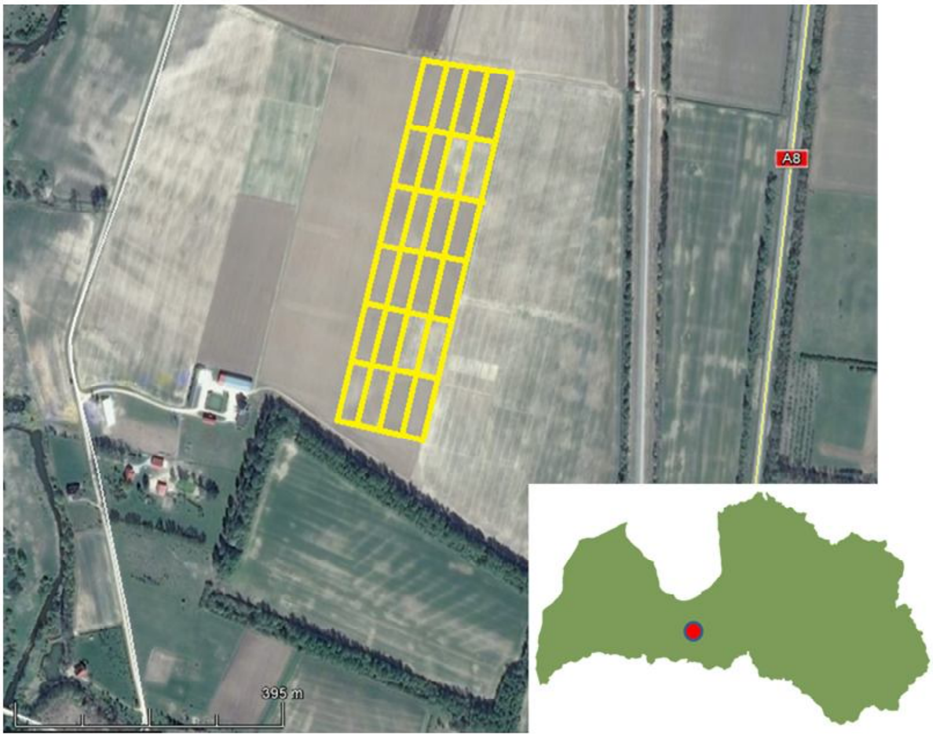

Figure 1. An orthoimage of the research site at the Latvia University of Agriculture Research and Study Farm 'Peterlauki' (picture taken from Google Earth). The yellow grid marks borders of sample plots.

2). Sample plots were separated from each other and from near crop fields by 2.5 m wide stripes of land covered with wild herbaceous plants. Since 2009, the soil in each six sample plots was tilled differently – traditionally or minimally. Hence, the main soil-treatment regimens for each six sample plots were conventional ploughing (0.22-0.23 m) with a mouldboard plough or shallow tillage (0.10-0.11 m) with a disc harrow. Winter wheat, spring wheat, and spring rapeseed (*Brassica napus*) were used as pre-crops in each two traditionally and two minimally tilled sample plots. Thus, the effects of six combinations including both agro-ecological factors – soil tillage and pre-crop – on ground beetles were studied.

Transparent plastic glasses with a volume of 200 ml and opening diameter of 65 mm half-filled with 4-5% acetic acid and a few drops of detergent were used as pitfall traps for collecting beetles. In each sample plot, 10 traps were placed in a 30 m long cornerwise transect. Exposition started on April 17, 2012, and ended on July 31, 2012 –

1	**2**	**3**	**4**
5	**6**	**7**	**8**
9	**10**	**11**	**12**
13	**14**	**15**	**16**
17	**18**	**19**	**20**
21	**22**	**23**	**24**
Sh	**P**	**P**	**Sh**

Figure 2. The grid of sample plots. Ground beetles were studied in sample plots 1-4 (pre-crop: spring wheat), 5, 6, 17, 18 (pre-crop: spring rapeseed) and 13-16 (pre-crop: winter wheat). (Abbreviations: Sh – shallow tilled soil, P – ploughed soil).

two days before cutting of the winter wheat. Traps were emptied and filled with fresh acetic acid every seven days.

Species of ground beetles were identified according to Freude et al. (2004); the checklist of Latvian beetles by Telnov (2004) was used for nomenclature. The dominance structure of ground beetles was calculated according to Engelmann (1978). This scale divides species into five groups according to the frequency of their appearance in the coenosis: 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 biodiversity of ground beetles was assessed by calculating Simpson's index (D) with n_i = number of individuals of the i^{th} species per trap, and N = total number of individuals per trap (Magurran 2004). In this paper, the biodiversity of ground beetles is expressed as the reciprocal Simpson's index (1/D). Relationships between the biodiversity and both agro-ecological factors were assessed calculating Spearman's rank correlation coefficient (r_s) with a two-tailed significance test using SPSS 17.0. Correlation strength was estimated according to 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

Overall, 25,369 ground beetles from 66 species were recorded (Table 1). No species were eudominant, but two species – *Loricera pilicornis* and *Bembidion guttula* – were dominant in all sample plots. Independently of pre-crop, *L. pilicornis* was the most dominant species on shallow tilled soil and *B. guttula* on ploughed soil. Six other species – *Bembidion obtusum*, *Poecilus cupreus*, *Harpalus rufipes*, *Pterostichus melanarius*, *Pterostichus niger*, and *Amara plebeja* – were dominant or subdominant in the sample plots with at least one type of management. The percentage of *H. rufipes* and *P. melanarius* was affected by pre-crop only. Accordingly, *H. rufipes* was the dominant species in sample plots where winter wheat was the pre-crop, but subdominant in other sample plots. In contrast, *P. melanarius* was subdominant in sample plots where cereals were pre-crops, but recedent or even subrecedent if spring rapeseed was used as the pre-crop. The percentage of *P. cupreus*, *P. niger*, *B. obtusum*, and *A. plebeja* was determined by the combination of both agro-ecological factors. *B. obtusum* and *A. plebeja* were subdominant on ploughed soil with spring rapeseed as pre-crop as well as shallow tilled soil with spring wheat as pre-crop. In other sample plots, percentages of these two species were noticeably lower – they were recedent or subrecedent. *P. niger* was recedent on shallow tilled soil with winter wheat as pre-crop, but subdominant in other sample plots. Finally, *P. cupreus* was the dominant species in all sample plots except for those with ploughed soil and spring wheat as the pre-crop (Fig. 3). All other species recorded, even *Bembidion lampros* and *Bembidion properans*, which are usually very abundant on arable land, were recedent or subrecedent in all sample plots. Noticeably lower percentages of small-sized *Bembidion* species corresponded with the presence of comparably dense straw aggregations lying on the shallow tilled soil surface (Fig. 4 A). The surface of ploughed soil was almost strawless (Fig. 4 B) and the percentage of small-sized ground beetles was higher (Fig. 3).

When analysing the soil tillage independently of pre-crops, there was no significant difference in the biodiversity of ground beetles between ploughed and shallow tilled winter wheat fields (Fig. 5 A). On the contrary, analysing pre-cropping independently of soil tillage, a gradient of ground-beetle biodiversity existed. As a pre-crop, spring wheat promoted significantly higher biodiversity of ground beetles than spring rapeseed or winter wheat. In this case, there was a weak negative correlation between biodiversity and pre-crop (Fig. 5 B). More explicit differences of ground-beetle biodiversity was seen when soil tillage and pre-cropping were jointly analysed (Figure 6). In shallow tilled sample plots, the highest biodiversity was observed where spring wheat was used as pre-crop, but it significantly

Table 1. The list of species of ground beetles in alphabetic order and their abundance recorded in differently tilled and pre-cropped winter wheat fields (Sh – shallow tilled soil, P – ploughed soil, WW – winter wheat as pre-crop, SW – spring wheat as pre-crop, SR – spring rapeseed as pre-crop).

No.	**Species**	**Sh, WW**	**P, WW**	**Sh, SW**	**P, SW**	**Sh, SR**	**P, SR**
1	*Acupalpus meridianus* (Linnaeus, 1761)	6	4	19	11	5	5
2	*Agonum gracilipes* (Duftschmid, 1812)	-	-	-	-	-	1
3	*Agonum sexpunctatum* (Linnaeus, 1758)	-	-	-	-	1	-
4	*Amara aenea* (DeGeer, 1774)	3	3	1	2	-	3
5	*Amara apricaria* (Paykull, 1790)	2	1	2	3	1	2
6	*Amara aulica* (Panzer, 1796)	-	-	-	-	-	1
7	*Amara communis* (Panzer, 1797)	2	3	2	-	1	-
8	*Amara convexior* Stephens, 1828	1	3	1	1	1	1
9	*Amara eurynota* (Panzer, 1796)	1	-	-	-	3	1
10	*Amara familiaris* (Duftschmid, 1812)	-	-	-	-	-	1
11	*Amara fulva* (O.F.Müller, 1776)	2	3	-	-	-	3
12	*Amara nitida* Sturm, 1825	11	4	4	3	5	2
13	*Amara ovata* (Fabricius, 1792)	2	3	3	1	6	2
14	*Amara plebeja* (Gyllenhal, 1810)	12	12	245	56	13	16
15	*Amara similata* (Gyllenhal, 1810)	7	6	5	5	9	8
16	*Amara spreta* Dejean, 1831	2	-	-	-	1	1
17	*Anchomenus dorsalis* (Pontoppidan, 1763)	72	86	79	44	64	54
18	*Asaphidion flavipes* (Linnaeus, 1761)	2	3	1	3	5	5
19	*Badister bullatus* (Schrank, 1798)	-	1	-	-	-	-
20	*Badister dorsiger* (Duftschmid, 1812)	1	2	-	3	-	-
21	*Bembidion guttula* (Fabricius, 1792)	799	1165	995	1376	768	1100
22	*Bembidion lampros* (Herbst, 1784)	70	43	81	74	55	93
23	*Bembidion mannerheimii* C.R.Sahlberg, 1827	2	8	6	5	5	8
24	*Bembidion obtusum* Audinet-Serville, 1821	59	148	128	173	93	217
25	*Bembidion properans* (Stephens, 1828)	37	25	49	42	48	82
26	*Bembidion quadrimaculatum* (Linnaeus, 1761)	12	9	10	4	6	12
27	*Blemus discus* (Fabricius, 1792)	6	3	16	7	2	-
28	*Calathus ambiguus* (Paykull, 1790)	4	1	2	-	1	3
29	*Calathus fuscipes* (Goeze, 1777)	-	1	3	1	1	1
30	*Carabus arcensis* (Herbst, 1784)	-	-	-	-	-	1
31	*Carabus cancellatus* Illiger, 1798	26	14	6	9	8	13
32	*Carabus granulatus* Linnaeus, 1758	1	1	-	-	5	1
33	*Carabus nemoralis* O.F.Müller, 1764	1	-	-	-	1	-
34	*Chlaenius nitidulus* (Schrank, 1781)	-	2	2	4	3	-
35	*Clivina fossor* (Linnaeus, 1758)	19	23	22	16	5	11
36	*Demetrias monostigma* Samouelle, 1819	-	1	-	-	-	-
37	*Dolichus halensis* (Schaller, 1783)	-	-	3	-	1	1
38	*Dyschirius aeneus* (Dejean, 1825)	-	-	1	-	-	-
39	*Dyschirius politus* (Dejean, 1825)	-	-	-	1	-	-
40	*Harpalus affinis* (Schrank, 1781)	29	29	49	49	21	38
41	*Harpalus luteicornis* (Duftschmid, 1812)	1	-	2	3	1	-
42	*Harpalus rufipes* (DeGeer, 1774)	501	475	445	437	467	492
43	*Harpalus signaticornis* (Duftschmid, 1812)	1	4	-	-	4	5
44	*Harpalus tardus* (Panzer, 1796)	2	-	-	-	1	1
45	*Loricera pilicornis* (Fabricius, 1775)	938	653	1048	797	1195	944
46	*Microlestes maurus* (Sturm, 1827)	-	-	1	-	-	1
47	*Nebria brevicollis* (Fabricius, 1792)	78	27	78	31	56	118
48	*Notiophilus aestuans* Dejean, 1826	3	-	-	3	9	3
49	*Notiophilus aquaticus* (Linnaeus, 1758)	3	-	2	-	2	3

Table 1. The list of species of ground beetles in alphabetic order and their abundance recorded in differently tilled and pre-cropped winter wheat fields (Sh – shallow tilled soil, P – ploughed soil, WW – winter wheat as pre-crop, SW – spring wheat as pre-crop, SR – spring rapeseed as pre-crop). *(Continuation)*

50	*Notiophilus germinyi* Fauvel, 1863	13	6	23	9	4	8
51	*Notiophilus palustris* (Duftschmid, 1812)	10	6	20	10	8	5
52	*Platynus assimilis* (Paykull, 1790)	-	-	-	1	-	-
53	*Poecilus cupreus* (Linnaeus, 1758)	690	563	617	520	726	618
54	*Poecilus versicolor* (Sturm, 1824)	10	5	17	6	16	8
55	*Pterostichus diligens* (Sturm, 1824)	-	-	1	1	-	1
56	*Pterostichus macer* (Marsham, 1802)	-	1	6	9	1	-
57	*Pterostichus melanarius* (Illiger, 1798)	161	208	422	279	46	86
58	*Pterostichus niger* (Schaller, 1783)	135	218	314	406	246	461
59	*Pterostichus nigrita* (Paykull, 1790)	1	-	1	-	-	1
60	*Pterostichus oblongopunctatus* (Fabricius, 1787)	1	-	-	1	-	-
61	*Pterostichus strenuus* (Panzer, 1796)	9	3	5	4	3	3
62	*Pterostichus vernalis* (Panzer, 1796)	23	14	47	17	7	5
63	*Stenolophus mixtus* (Herbst, 1784)	-	-	1	-	-	-
64	*Stomis pumicatus* (Panzer, 1796)	1	2	-	-	-	-
65	*Synuchus vivalis* (Illiger, 1798)	1	1	1	-	-	-
66	*Trechus quadristriatus* (Schrank, 1781)	20	30	10	22	31	97
	Total species	49	45	46	42	47	49
	Total individuals	3793	3823	4796	4449	3961	4547

decreased in fields where winter wheat and spring rapeseed were pre-crops. The relationship between biodiversity and pre-cropping in shallow tilled fields was strongly negative. In ploughed fields, spring rapeseed as pre-crop promoted the highest biodiversity, followed by spring wheat and winter wheat. Here, pre-crops did not promote differences of ground-beetle biodiversity as significantly as in shallow tilled fields (Figure 6). Soil tillage did not cause differences of ground-beetle biodiversity in sample plots where winter wheat was used as pre-crop, but it did with the other two pre-crops. In fields where spring wheat was used as pre-crop, there was a moderately negative correlation between the biodiversity and the intensiveness of soil tillage ($r_s = -0.42$; $p = 0{,}006$) – soil ploughing led to lower biodiversity of ground beetles than shallow tillage. On the contrary, more intensive soil tillage promoted an increase of groung-beetle biodiversity in fields where spring rapeseed was pre-crop ($r_s = 0.66$; $p < 0.001$).

In addition, there were some interconnections between the biodiversity and the balance of ground-beetle dominance structures. The highest biodiversity was observed in sample plots with the most balanced dominance structure – ploughed sample plots with spring rapeseed as pre-crop and shallow tilled sample plots with spring wheat as pre-crop. In these fields, the abundances of ground-beetle species decreased gradually from the most dominant species towards the least dominant ones (Fig. 3 C, F). On the contrary, in sample plots with lower biodiversity, the abundances of ground-beetle species decreased more unevenly. In ploughed soil pre-cropped with both cereals and in shallow tilled soil pre-cropped with spring rapeseed, the most abundant species noticeably dominated over one to three other species, which in turn significantly dominated over all other species recorded in these sample plots (Fig. 3 B, D, E). However, in shallow tilled soil pre-cropped with winter wheat, four species noticeably dominated over all other species while their own abundances decreased very evenly (Fig. 3 A).

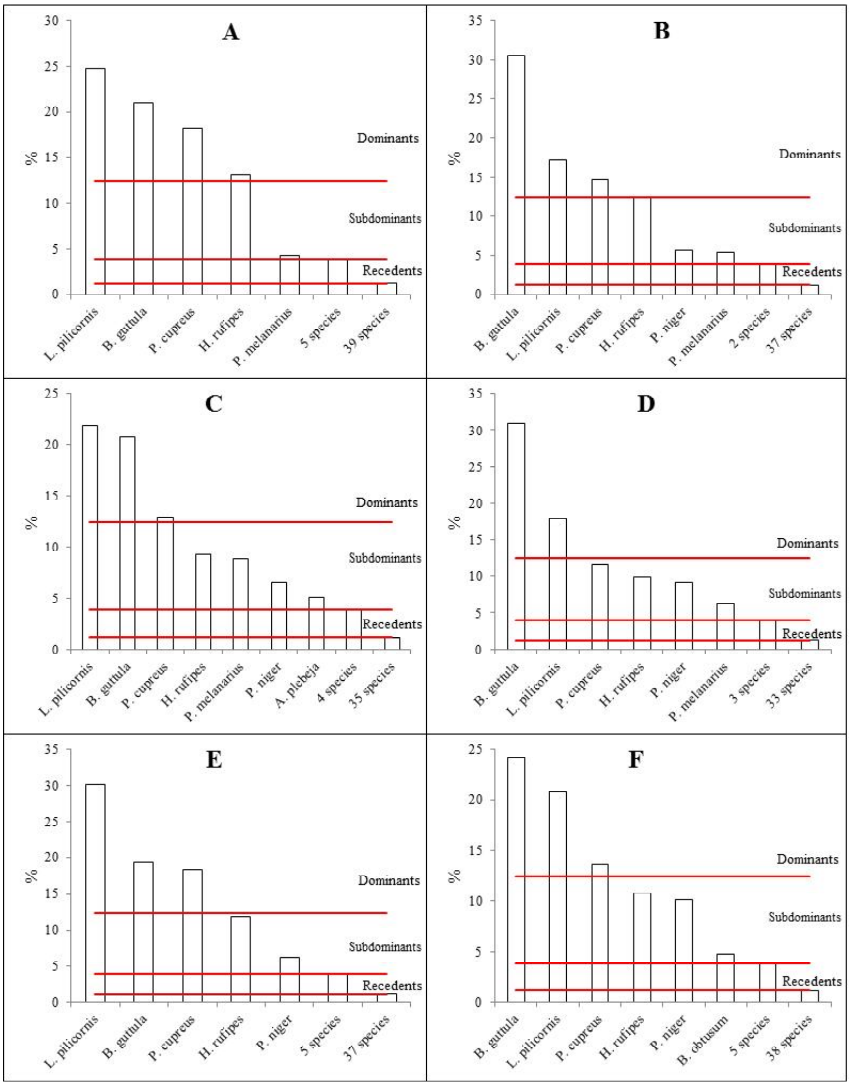

Figure 3. The dominance structure of ground beetles in differently tilled and pre-cropped winter wheat fields (A – shallow tilled soil, winter wheat as pre-crop; B - ploughed soil, winter wheat as pre-crop; C - shallow tilled soil, spring wheat as pre-crop; D - ploughed soil, spring wheat as pre-crop; E - shallow tilled soil, spring rapeseed as pre-crop; F - ploughed soil, spring rapeseed as pre-crop).

DISCUSSION

Five of the most dominant species – *L. pilicornis, P. cupreus, P. niger, P. melanarius,* and *H. rufipes* – are well-known eurytopic species often abundant in different crops (e.g. Basedow et al. 1976; Jones 1976; Barsevskis 2003; Bukejs et al. 2009; Holland et al. 2009). Also, *A. plebeja* may be found in different crops – Bukejs et al. (2009) report this species from different agrocoenoses except for those on sandy soil in the eastern part of Latvia. However, Eyre et al. (2008) conclude that *A. plebeja* prefers cereal compared to vegetable, bean, or grass/clover agrocoenoses. It seems that there are two major environmental conditions determining the presence of *A. plebeja* on arable land – heavy soil and closeness of deciduous forest. Van Huizen (1977) reports that deciduous forest is a hibernation habitat for *A. plebeja* and, therefore, that this species migrates flying from the forest to open habitats in spring and back to the forest in autumn. Thus, at our study site,

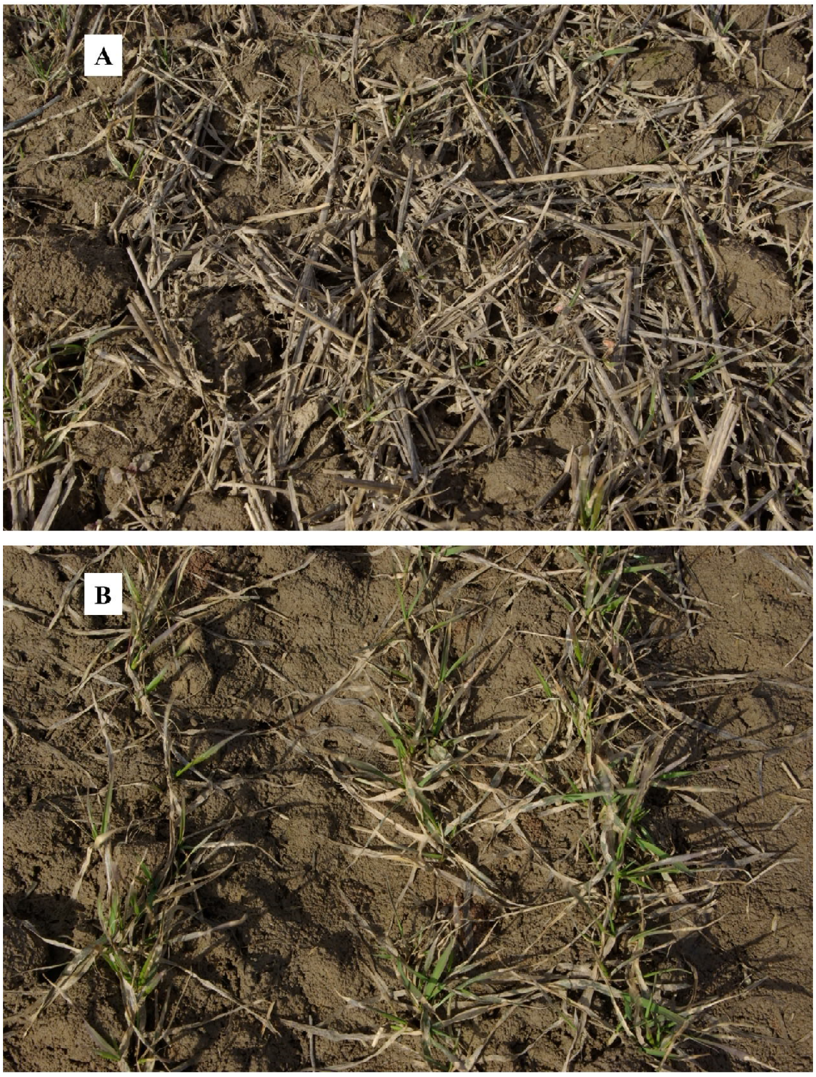

Figure 4. Shallow tilled (A) and ploughed (B) winter wheat fields in the middle of April (photo: J.Gailis).

both environmental conditions – clay soil and a close patch of forest – are suitable for the occurrence of *A. plebeja.* Abundance of *B. guttula* and *B. obtusum* in our study site was quite unexpected. According to Barsevskis (2003), *B. guttula* may be found in moist open habitats, e.g. moist meadows, pastures, river banks, and also agrocoenoses, but *B. obtusum* usually occurs in dry, sandy habitats such as dunes and beaches. Thus, the question is why both species are abundant on clay soil in the same site? Tolonen (1995) mentions *B. guttula* as an abundant generalist aphid predator in cereal crops, but Eyre et al. (2008) as well as Bukejs et al. (2009) report that this species may be found in various agrocoenoses. In Europe, *B. obtusum* is reported as abundant species in cereal crops (e.g. Jones 1976; Fournier & Loreau 2001; Holland et al. 2009) and also in lucerne (Steenberg et al. 1995). In Latvia, however, there are only few localities known for this species (Barsevskis 2003), and it was never found in agrocoenoses. Right now, it can be considered that the most likely reason for this situation is the lack of research but not the environmental conditions of our country.

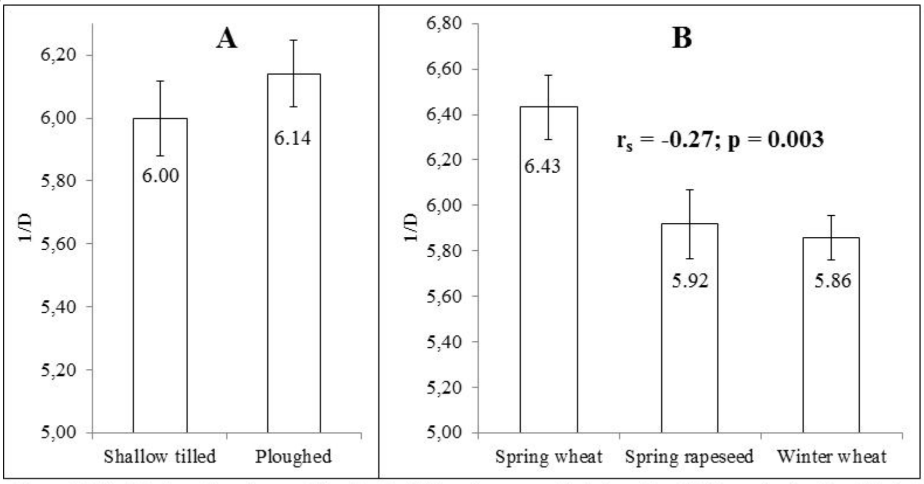

Figure 5. The biodiversity of ground beetles in differently managed winter wheat fields analysing the effect of soil tillage (A) and pre-crops (B) independently of each other.

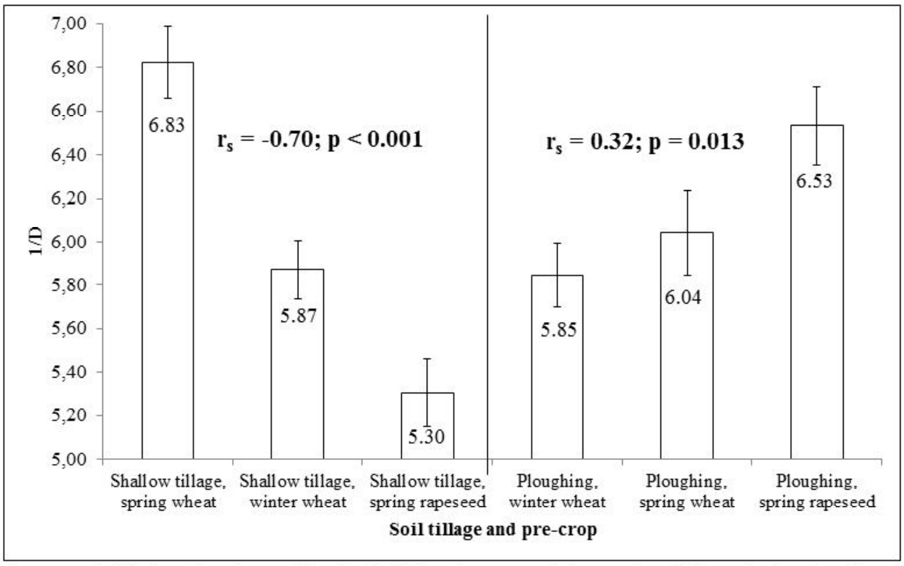

Figure 6. The biodiversity of ground beetles in differently managed winter wheat fields analysing the effect of soil tillage together with pre-crops.

In ploughed fields, the higher percentage of small-sized *B. guttula* and *B. obtusum* corresponds with the results of earlier research of Gailis & Turka (2014), showing significantly higher activity density of small-sized ground beetles (body size d” 5 mm) in ploughed winter wheat fields than in shallow tilled ones. This can be explained by two factors: Firstly, soil tillage is causing direct mortality of ground beetles while large-sized ground beetles are more sensitive to it. Different studies in agrocoenoses and afforested fallows show that intensiveness of soil tillage has a significant negative relationship with the body size and mean individual biomass of ground beetles (e.g. Holland & Luff 2000; Cole et al. 2005; Sklodowski 2014). Secondly, straw aggregations lying on the surface of shallow tilled soil are affecting the presence of small-sized ground beetles. On the one hand, straw aggregations make the soil surface more heterogeneous and create structures suitable for ground-beetle shelters. On the other hand, straw lying on the soil surface is more likely an obstacle for small-sized ground beetles when moving around and noticing prey. Similarly, Cole et al. (2005) conclude that small-sized visually hunting ground beetles prefer intensively tilled agrocoenoses over less intensively tilled ones due to the patchiness of vegetation and bare soil surface promoted by ploughing. The biomass of rapeseed straws is almost twice as large as the biomass of wheat straws in fields of the same size, and rapeseed straws are also larger than wheat straws. All these conditions explain why the abundance and dominance of *B. guttula* and other small-sized species was lower in shallow tilled fields than in ploughed ones and why spring rapeseed as a pre-crop led to noticeably lower abundance of small-sized ground beetles than cereals as pre-crops on shallow tilled soil. Likewise, decaying straws also affected the abundance and dominance of *L. pilicornis*. Decaying organic material may attract saprophagous springtails (Collembola), which are the main food resource for *L. pilicornis* (Sunderland 1975). As a result, this species was significantly more abundant in shallow tilled sample plots.

The abundance and dominance of three more species – *P. niger, P. melanarius,* and *A. plebeja* – depended on both agro-ecological factors. The abundance and dominance of *P. niger* was noticeably lower on shallow tilled soil pre-cropped with winter wheat, which may be explained as a coincidence, because the dominance of *P. niger* (3.5%) in these sample plots was just a little below subdominance. The scarceness of *P. melanarius* in sample plots pre-cropped with spring rapeseed can hardly be explained, because this species is reported to be one of the most abundant ground-beetle species in rapeseed fields (e.g. Haye et al. 2010). Significantly higher abundance and dominance of *A. plebeja* was expected in shallow tilled sample plots, because this species is a granivore of various plants (Lundgren 2009), and non-inverse soil tillage promotes weed biodiversity on arable land. As a consequence, the abundance of granivorous ground beetles, especially *Amara* spp., increases (Holland & Luff 2000; Thorbek & Bilde 2004). However, this does not explain why the abundance of *A. plebeja* was significantly higher in shallow tilled sample plots pre-cropped with spring wheat than in other shallow tilled fields. This issue on *A. plebeja* and also *P. melanarius* remains open for future studies.

It is likely that the high biodiversity and balanced dominance structure of ground beetles was promoted by two environmental conditions in ploughed sample plots pre-cropped with spring rapeseed. Firstly, its strawless soil attracts more small-sized beetles. Secondly, wheat vegetation with rapeseed as pre-crop is thicker and lusher and therefore provides more shelter and also food resources suitable for ground beetles by attracting more aphids and other phytophagous invertebrates. As a result, the biodiversity is higher. In shallow tilled fields pre-cropped with spring wheat, high biodiversity may be explained by a more noticeable density of weeds throughout the vegetation season. Weed vegetation fosters higher biodiversity of ground beetles in different crops (Diehl et al. 2012), and thus, in our case, weeds in shallow tilled fields pre-cropped with spring wheat play a similar role as thicker wheat vegetation in ploughed fields pre-cropped with spring rapeseed. Wheat straws are thinner and less dense, thus they are not such severe obstacles for small-sized ground beetles. Consequently, there was also high biodiversity of ground beetles in shallow tilled fields pre-cropped with spring wheat. The only fact left to consider is that the higher weed density in these sample plots is probably not the rule. Thus, in shallow tilled fields pre-cropped with spring wheat, the biodiversity and balance of dominance structure of ground beetles may be different under conditions which do not promote unusually high density of weeds.

It seems that rapeseed straws on the soil surface exerted a greater negative effect on the biodiversity of ground beetles than the thicker winter wheat vegetation could compensate via promotion of extra shelter and food resources in shallow tilled fields pre-cropped with spring rapeseed. As a result, these fields were the most unsuitable for the occurrence of ground beetles. In sample plots pre-cropped with winter wheat, the biodiversity of ground beetles did actually not differ depending on the soil treatment, which caused differences between dominance structures only. Biodiversity was observed to be just a little higher in ploughed sample plots pre-cropped with spring wheat, but the difference was not statistically significant. It seems that, on ploughed soil, both types of wheat as pre-crops provide similar environmental conditions, and these conditions are less suitable for ground beetles than those in ploughed fields pre-cropped with spring rapeseed. This is due to the less thick and lush vegetation of winter wheat in fields pre-cropped with spring and winter wheat.

Many authors report that different soil-treatment regimens do not cause significant differences of ground beetle biodiversity in various crops (e.g. Belaoussoff et al. 2003; Mason et al. 2006; Twardowski 2006). Now it is evident that soil tillage may significantly affect ground-beetle biodiversity in winter wheat, but this effect depends on the pre-crop. Different soil-treatment methods cause significant differences of ground-beetle biodiversity in winter wheat fields pre-cropped with spring rapeseed while the relationship between the intensiveness of soil tillage and increase of the biodiversity is statistically strong. In contrast, biodiversity is not affected by soil tillage in fields pre-cropped with winter wheat. However, the impact of soil treatment on ground-beetle biodiversity is still uncertain in winter wheat fields pre-cropped with spring wheat. In this case, more studies are needed.

CONCLUSIONS

Overall, 66 ground-beetle species were recorded in differently tilled and pre-cropped winter wheat fields during 2012.

No species were eudominant, but eight species – *Loricera pilicornis*, *Bembidion guttula*, *Bembidion obtusum*, *Poecilus cupreus*, *Harpalus rufipes*, *Pterostichus melanarius*, *Pterostichus niger*, and *Amara plebeja* – were dominant or subdominant in the sample plots with at least one type of management.

Soil tillage noticeably affected the dominance structure of ground beetles – small-sized ground beetles (body size d” 5 mm) were more dominant in ploughed soil while medium- and large-sized ground beetles (body size e” 5 mm) dominated in shallow tilled soil.

Ploughed soil with spring rapeseed as pre-crop and shallow tilled soil with spring wheat as pre-crop promoted the highest biodiversity and the most balanced dominance structure of ground beetles in winter wheat fields. The lowest biodiversity was observed in shallow tilled sample plots pre-cropped with spring rapeseed.

Soil tillage significantly affected the biodiversity of ground beetles in winter wheat fields pre-cropped with spring rapeseed but not with winter wheat. It is possible that soil tillage also affects biodiversity in fields pre-cropped with spring wheat, but this must be proven by further studies.

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