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The effect of farming system and management practices on surface-dwelling soil macrofauna

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Abstract

Whereas contemporary agriculture reduces invertebrate diversity, organic farming is expected to minimize this negative influence. In this study, we compared communities of surface-dwelling soil macrofauna from the fields farmed conventionally and organically over the last 15 years in the crop rotation with winter oilseed rape and winter wheat. A statistically higher number of specimens were caught in the conventional treatment of both crops. Ground beetles (i.e. beetles of the family Carabidae) and spiders were the most abundant groups. While spiders preferred organically managed fields, carabids tended to prefer the conventional system, as carabid communities were affected by springtime mechanical soil interventions (harrowing and hoeing). These interventions were insignificant to spiders as they over-winter in field margins, spread very well by air and are able to re-colonize agroecosystems quickly. This reveals that organic farming does not necessarily support the development of populations and communities of soil fauna.

Key words: Araneae, Carabidae, conventional farming, farming management, organic farming, soil fauna.

Introduction

With its influence on the environment, intensive agriculture is considered to be one of the main drivers in the decline in invertebrate species richness and community composition (Tscharntke et al., 2012). Organic agriculture is a farming and food production system, which combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes (EC, 2007; Stockdale, Watson, 2009). This diversified farming system can also promote biocontrol services, e.g., by polyphagous predators such as Carabidae (Arus et al., 2012). Biodiversity and biocontrol services are affected also by landscape composition. The direct relationship between organic farming and landscape composition, especially the development of landscape elements, has not been proven unambiguously and organic farm cultural landscapes do not appear automatically as a by-product of the organic farming method (Levin, 2007). The results in Czech conditions, published by Dytrtová et al. (2016), showed differing trends in the studied locations, which do not depend on farm management alone but also on other factors, especially natural conditions in agricultural landscape.

Organic farming may offer benefits for a wide spectrum of taxa, but what influences these benefits is not well understood (Feber et al., 2015; Soderman et al., 2016). A simple comparison between organic and conventional farming does not reflect the diversity of practices that may exist within each farming system (Vasseur et al., 2013). Some conventional farmers may use techniques similar to organic farming even if they are not certified, whereas some organic farmers may use organic inputs and frequent, deep tillage, which are allowed by the specifications but are potentially lethal to arthropods (Thorbek, Bilde, 2004). The effect of agricultural practices can differ according to the model group of affected organism. While the greatest effect of agricultural system is on plants, a less consistent impact was noted on carabid beetles (Fuller et al., 2005) or spiders (Schneider et al., 2014). Other factors, e.g., less heterogeneous landscape, can suppress the effect of agricultural system (Roschewitz et al., 2005; Schneider et al., 2014).

Ground beetles and spiders could be good bioindicators of the condition of fields (Cardoso et al., 2013) as they play an important role in agroecosystems (Bruno, Cardinale, 2008). Most species are predators (Kromp, 1999; Holland et al., 2005), whereas some carabids are important seed predators and can effectively reduce weed density in fields. For example, ground beetles are usually more diverse and abundant within organically farmed areas (Bengtsson et al., 2005). Spider abundance generally increases with increasing habitat diversification within and around farm crops (Sunderland, Samu, 2000); other comparisons find little or no difference in ground

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beetle or spider species richness between organic and conventional fields (Fuller et al., 2005; Ekroos et al., 2010; Rahmann, 2011; Birkhofer et al., 2014). Both groups seem to be negatively affected not only by pesticide use (Riechert, 1998) but also by deep ploughing; on the other hand, reduced tillage systems (Kromp, 1999) as well as lower tillage frequency (Puech et al., 2014) can support their populations.

The current study looks at long-term operation of the organic farming system and compares this with practice and diversity in conventional farming. Using the example of soil invertebrates, with emphasis on carabids and spiders, the study focuses on identifying problematic management interventions, which influence their diversity.

Materials and methods

Study site. The research was carried out on experimental plots in Uhříněves (50°2′13.002″ N, 14°37′1.956″ E) at the Czech University of Life Sciences in Prague, Czech Republic. According to figures at the Czech Hydrometeorological Institute, the climate of the territory is moderately continental with an average temperature of 9.2°C and precipitation of 515 mm with a maximum between late spring and summer, and a minimum in winter. The soil type at the locality is *Haplic Luvisol* (WRB, 2014). Monitoring of agroecosystems in wheat was carried out over four years (2010–2014) and in oilseed rape over three years (2010–2013). These plots underwent a long-term comparative trial of organic and conventional farming, which began 15 years prior to the start of our monitoring. This means that, after such a long period, differences between the two agricultural approaches may be evident.

Experimental design. Within the crop rotation system on a 2-hectare experimental plots, we focused on the growth of winter rape (*Brassica napus* L.) and winter wheat (*Triticum aestivum* L.). In the conventional farming system both these crops were grown after a grain-legume mixture, while in the organic farming system the preceding crop was alfalfa. In individual years pitfall traps were set in each treatment within the experimental plot for late spring and summer. Soil samples were taken from each treatment twice a year. Both traps and soil samples were situated in the inner parts of experimental plots to avoid edge effect. The basic agro-technical methods in both crops were identical – a ploughing was used. The conventional treatment involved chemical input: in both crops readily soluble nitrogen in mineral fertilizer was applied in 2–3 applications amounting to 120–160 kg ha^{-1} N. A summary of interventions in both crops is shown in Table.

Table. Mechanical and agro-chemical interventions and their frequency in individual years in organically and conventionally cultivated crops

Study year	Organic treatment				Conventional treatment			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
				Winter oilseed rape				
Hoeing	2×	2×	2×	–	–	–	–	–
Herbicides	–	–	–	–	2×	3×	2×	–
Insecticides	–	–	–	–	2×	1×	1×	
Yield t ha^{-1}	2.83	3.39	3.01	–	5.49	5.03	5.54	–
				Winter wheat				
Harrowing	3×	3×	3×	4×	–	–	–	–
Herbicides	–	–	–	–	2×	1×	1×	2×
Insecticides	–	–	–	–	2×	2×	2×	2×
Fungicides	–	–	–	–	2×	2×	2×	2×
Yield t ha^{-1}	5.46	7.40	6.70	6.20	7.30	8.26	8.23	6.96

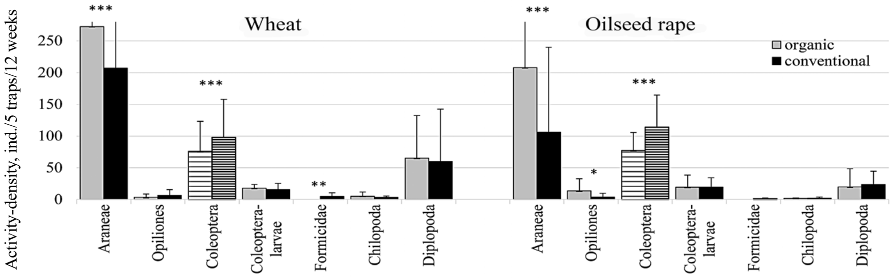
Winter oilseed rape: herbicides (g L^{-1}) metazachlor 400, clopyralid 267 and picloram 67; insecticides (g L^{-1}) chlorpyrifos 500 and cypermethrin 50; winter wheat: herbicides (g L^{-1}) fluroxypyr 333 and clopyralid 300; insecticides (g L^{-1}) chlorpyrifos 500, cypermethrin 50, thiacloprid 100 and deltamethrin 10; fungicides (g L^{-1}) tebuconazole 250 and metconazole 60

Fauna sampling and processing. Soil invertebrates were sampled each year in spring–summer by two methods: pitfall trapping of ground-dwelling invertebrates and heat-extraction of soil-dwelling invertebrates from soil samples. (1) Five pitfall traps (plastic cups 7 cm in diameter with metal covers, filled with a 4% water formaldehyde solution) were set up in each field from April–May of each year and were emptied twice a month until July. The catches for each year in each of the fields were analysed. Such data is known as activity-density, as the number of animals entering traps is dependent on both activity and density. (2) Five soil samples (area of each 1/30 m^2, 15 cm depth) were taken twice a year (May and July) in each treatment of field and crop using a metal soil sampler. Soil invertebrates were heat-extracted from samples in simple thermoextractors during the subsequent 14 days and abundance of soil dwelling animals of individual groups was calculated (Tuf, Tvardík, 2005).

Statistical analysis. The abundance and activity-density of soil invertebrates from plots of the same crop, but differing in management, were compared using the χ^2 test comparing the difference between the two ratios. Quantitative data of activity-density patterns of individual species from pitfall traps was evaluated by the programme *Canoco* for *Windows*, version 4.5 (ter Braak, Šmilauer, 1998). The effect of different forms of management on the distribution of ground beetles and spiders was evaluated by unimodal principal component analysis (PCA), and the best model was selected using Monte-Carlo permutation tests. The form of management (organic *vs* conventional) and crop (wheat *vs* oilseed rape) were used as environmental variables, whereas the year of sampling was used as a co-variable. Species of ground beetles and spiders of which overall catch exceeded 10 individuals were used as species variables.

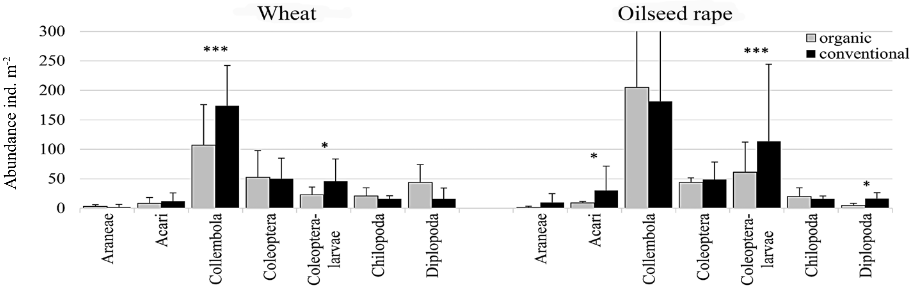
Results

When evaluating the results obtained, we focused on the selected groups of soil fauna in conventional and organic farming systems. Numbers of individuals in both systems and both crops (winter wheat and winter rape) are summarized in Figures 1 and 2. Total abundance as well as total activity-density is significantly higher on sites with conventional management in both wheat ($p \leq 0.001$ and $p \leq 0.05$, respectively) and rape ($p \leq 0.001$) crops. Beetles and spiders are among the most active-dense animals in both crops, therefore these model groups at species level were studied. Although beetles are more active-dense in conventionally managed crops (similar to ants in wheat crops), the spiders prefer sites with organic management in both crops, similar to harvestmen in rape crops (Fig. 1). On the other hand, conventional sites of both wheat and rape are preferred by soil-dwelling animals, where abundance in soil samples is significantly higher for larvae of beetles as well as for springtails (in wheat only) or mites and millipedes (in rape only) (Fig. 2).



Note. The number of trapped beetles (Coleoptera) was reduced ten times for lucidity and is highlighted by hatching; significant differences between plots with different management are highlighted by asterisks: * – $p \leq 0.05$, ** – $p \leq 0.01$ and *** – $p \leq 0.001$.

Figure 1. Comparison of mean year activity-density of soil surface active animals on wheat and oilseed rape sites managed organically and conventionally



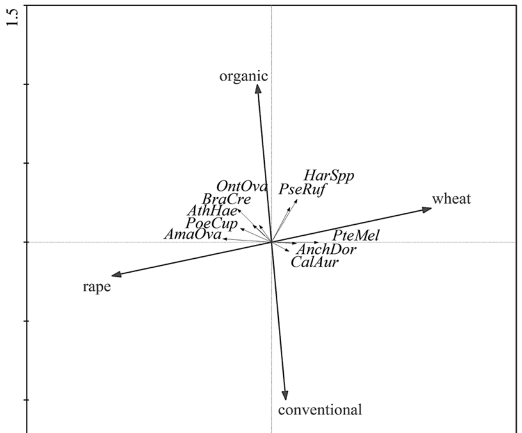
Note. Significant differences between abundance on plots with different management are highlighted by asterisks: * – $p \leq 0.05$, ** – $p \leq 0.01$ and *** – $p \leq 0.001$.

Figure 2. Comparison of mean year abundance of heat extracted soil-dwelling animals on wheat and oilseed rape sites managed organically and conventionally

Carabid beetles in different crops and farming systems. When interpreting the results (via PCA analysis) of beetle species trapped in different crops and farming systems, it is apparent that the crop species is more significant (in terms of species difference) than the farming system used (Fig. 3). Irrespective of crop preference, the most dominant species *Pterostichus melanarius* is more active on conventionally managed plots (both crops: $p \leq 0.001$). The same significant pattern is visible on rape sites for *Anchomenus dorsalis* and *Poecilus cupreus* (both: $p \leq 0.001$), whereas *Brachinus crepitans* predominates on organically managed rape plots ($p \leq 0.001$). On the other hand, on wheat plots *P. cupreus* along with *Pseudoophonus rufipes* and *Amara ovata* prefer plots under organic management ($p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$, respectively). Other species show no significant difference in activity pattern between plots under different management.

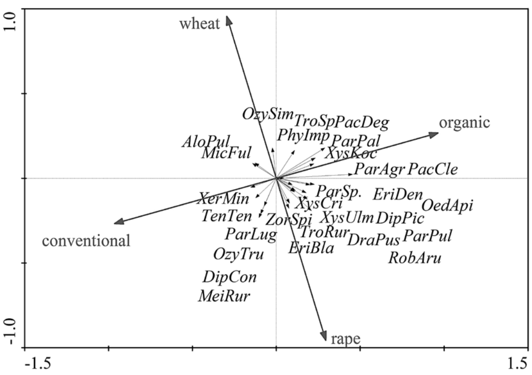
Spiders in different crops and farming systems. In contrast to carabids, PCA analysis of spider species found in different crops and farming systems shows not only the influence of crop species but also the impact of the farming system used (Fig. 4).

Irrespective of crop preference, the most active-dense species *Oedothorax apicatus* was, in terms of rape crops, more numerous on sites under organic management ($p \leq 0.001$). The same significant pattern was visible on sites of both crops for *Pachygnatha degeeri* and *Pardosa agrestis* ($p \leq 0.001$, *P. degeeri* on rape plots – $p \leq 0.05$). This preference was significant also for *Drassyllus pusillus* on wheat sites and *Erigone atra* on



Note. AmaOva – Amara ovata, AnchDor – Anchomenus dorsalis, AthHae – Athous haemorrhoidalis, BraCre – Brachinus crepitans, CalAur – Calosoma auropunctatum, HarSpp – Harpalus spp., *OntOva – Onthophagus ovatus, PoeCup – Poecilus cupreus, PseRuf – Pseudoophonus rufipes, PteMel – Pterostichus melanarius*; environmental variables with significant contribution to model are highlighted in larger typeface; the first axis describes 55.9%, while the whole model describes 65.7% of variability in species distribution.

Figure 3. Principal component analysis (PCA) of beetle species found in different crops and farming systems



Note. AloPul – Alopecosa pulverulenta, *DipPic – Diplocephalus picinus*, *DipCon – Diplostyla concolor*, *DraPus – Drassyllus pusillus*, *EriBla – Erigone atra*, *EriDen – Erigone dentipalpis*, *MeiRur – Meioneta rurestris*, *MicFul – Micaria fulgens*, *OedApi – Oedothorax apicatus*, *OzySim – Ozyptila simplex*, *OzyTru – Ozyptila trux*, *PacCle – Pachygnatha clercki*, *PacDeg – Pachygnatha degeneri*, *ParAgr – Pardosa agrestis*, *ParLug – Pardosa lugubris*, *ParPal – Pardosa palustris*, *ParPul – Pardosa pullata*, *ParSp. – Pardosa* sp., *PhyImp – Phylloneta impressa*, *RobAru – Robertus arundineti*, *TenTen – Tenuiphantes tenuis*, *TroRur – Trochosa ruricola*, *TroSp. – Trochosa* sp., *XerMin – Xerolycosa miniata*, *XysCri – Xysticus cristatus*, *XysKoc – Xysticus kochi*, *XysUlm – Xysticus ulmi*, *ZorSpi – Zora spinimana*; all environmental variables have significant contribution to model; the first axis describes 42.3%, while the whole model describes 57.7% of variability in species distribution.

Figure 4. Principal component analysis (PCA) of spider species found in different crops and farming systems

rape sites (both $p \leq 0.001$), whereas *E. atra* predominated on conventionally managed wheat plots ($p \leq 0.001$). Another species with a slight significant preference for conventionally managed plots was *Pardosa pullata* on plots of rape ($p \leq 0.05$). Other species showed no significant difference in activity pattern between plots under different management.

Discussion

Over a four-year period, the effect of organic and conventional agriculture on soil invertebrates was studied in winter wheat and winter oilseed rape fields. Plots under organic agriculture did not support greater abundance of soil invertebrates at all. Conventionally managed plots were more favourable for ground beetles (cf. Rana et al., 2010), whereas organically managed plots supported abundance of spiders.

It can be quite difficult to actually determine the influence of different farming systems, as the abundance of arthropods varied considerably within each farming system, sometimes more than between organic and conventional farming. Many factors such as soil characteristics, plant diversity within fields, soil tillage and non-crop habitat in the surrounding environment affect ground beetles, and this could explain the variable results (Holland, Luff, 2000). Change may even occur in the course of time, due to changes in farming systems (Rusch et al., 2013). Puech et al. (2014) suggest that farmers can implement strategies that enhance populations of natural enemies within crops, regardless of whether the farms have received organic certification. These authors also show that there is enough flexibility in the strategies of both farming systems to enhance natural enemy populations. They found that the different responses, which we also found for ladybirds, carabid beetles and parasitoids, emphasized the need to account for a large spectrum of groups of species when studying the effects of farming practices on communities of natural enemies of crop pests and biological control. In research by Diekötter et al. (2010) ground beetle activity as well as diversity was neither affected by management type nor landscape composition spider activity but not diversity, tended to be affected by landscape composition showing higher activity in conventional management than organic management. Predaceous carabid species may benefit from increased availability of potential herbivore prey in highly productive conventionally managed wheat fields and may later shift to organic fields, as they offer ample seeds and prey due to their diversity of arable weeds (Rivers et al., 2018).

It is not easy to judge the effect of organic and conventional agriculture on biodiversity, even due to the fact that conventional systems often involve elements of organic farming and *vice versa* (Thorbek, Bilde, 2004). There are often considerable differences between organic and conventional agriculture in particular conditions, which does not only mean the use of pesticides but also the way the soil is tilled. In some cases these interventions can be quite a harmful factor in terms of biodiversity of soil fauna (Silva et al., 2018). These authors state that physical disturbance (e.g., ploughing) is a key factor affecting biotic activity and species diversity in agroecosystems. A ground beetle, predator of crop pests *Pterostichus melanarius*, can be significantly more numerous in minimum tillage than frequent tillage conditions. Small carabids (as *Anchomenus dorsalis*) can, according to references, be even more abundant in frequent tillage conditions (Kennedy et al., 2013), as these fields are characterised by less competition from larger species. The systems examined in our study also differed in mechanical intervention, where organically farmed land was tilled intensively (Table), i.e. using hoeing and harrowing to eliminate weeds. For each crop, spraying with pesticides, often in early spring when most species are wintering in the soil, seemed to have relatively less impact (e.g., on dominant *P. melanarius* populations) than tillage. Similarly Legrand et al. (2011) reported that under both organic and conventional management, intensive deep tillage during the reproduction period resulted in rapid population extinction of *P. melanarius* despite the presence of grass margins. Our results agree with this conclusion that the spread of *P. melanarius* larvae due to farming practices was the key to species presence in crop fields. Compared with harrowing, hoeing is a more intensive and deeper intervention to the soil environment. This finding can be taken as a general recommendation for the timing of mechanical interventions, either as early as possible (while respecting other circumstances) or later, when carabids are in the imago stage (if this does not destroy the crop). Organic management could be less effective as it requires repeated soil tillage to compensate for the lack of herbicide use.

In research by Doring and Kromp (2003) *Amara* species were more active in organic crops; we confirmed this result in wheat plots only. As *A. ovata* feeds on plant seeds, the high activity of this species in oilseed rape could indicate a preference for crops other than cereals (Eyre et al., 2013) due to highly selective herbicides in wheat fields. The activity of *Brachinus crepitans* followed the activity of *Amara*, as its larvae parasitize on *Amara* pupae.

In the case of spiders, a reduction in mechanical disturbance of soil increased diversity (Thorbek, Bilde, 2004), whereas direct destruction of spiders (mainly larger species) or their prey, or negative effects on habitat heterogeneity, were the most likely reasons for reduced abundance. In our study abundance of *Pardosa agrestis* was higher on organically farmed fields, despite mechanical disturbance. Mechanical management was carried out in autumn and spring, during this period this species was juvenile (smaller body size) and mechanical disturbance had a lesser impact on it.

More spider specimens were found on organically farmed plots, which were confirmed by several studies, e.g., Batáry et al. (2012) and Feber et al. (2015). Organically farmed crops are usually less dense and occasionally disturbed by mechanical intervention against weeds. Locations which are light and disturbed suit light-dependent spider species, proven by the higher abundance of the dominant species, *Oedothorax apicatus* and *P. agrestis*, in organic oilseed rape. These spiders are effective in controlling pests. The lower spider density in oilseed rape is testified by a much lower yield than in the conventional treatment (Table).

High species richness of weeds in fields can increase spider diversity, because more host plants increase the amount of prey for spiders (Batáry et al., 2012). The conventional system using pesticides have an indirect impact on spiders – decrease abundance and quality of prey. In wheat, the *P. agrestis* species was more abundant in the organic system, which enables easier movement for actively hunting wolf spiders (both *Pardosa* and *Trochosa* species). On the other hand, increased abundance of small spider species (particularly Linyphiidae) in a conventional agriculture system should be due to better and faster colonisation by ballooning (Feber et al., 2015). These small spiders were less affected by the use of pesticides than by mechanical disturbance of soil in organic farming. Higher abundance of millipedes in conventional oilseed rape can correspond with higher humidity and amount of organic litter. Millipedes are hygrophilous and detritovorous, the presence of dead organic matter is an important factor affecting the number of millipedes (Berg, Hemerik, 2004).

Conclusions

1. Carabid populations were negatively affected by mechanical disturbances of soil on the plots of organic wheat, as documented from the 1st year of evaluation, when, due to a warm winter, farmers carried out these interventions sooner with no effect on carabids. By contrast, in the 4th year of evaluation, following deep snow cover, the soil surface was harrowed four times (compared with only three times in previous years) with negative effect on carabid communities. Mechanical interventions may not be a problem for spiders as they over-winter in field margins and surrounding grassy sites.

2. It seems evident that individual taxa of the same ecological group – soil-dwelling fauna in this case – respond differently to the effects of long-term organic farming. Rejecting some conventional technologies and replacing these with an organic system can result in an uncontaminated harvest, but on the other hand, it can negatively affect some animal species. When considering individual interventions within the system, its biological and ecological context must be taken into account. In terms of agroecosystems, this means applied ecology or ecology of food systems. Properly targeted management, with regard to the requirements of individual species, can be more important than the choice of a farming system. A credible evaluation of all positive and negative effects should be carried out before choosing the best farming system.

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Ūkininkavimo sistemų ir žemės dirbimo būdų įtaka dirvožemio paviršiaus makrofaunai

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Santrauka

Nors dėl šiuolaikinio žemės ūkio veiklos bestuburių gyvūnų įvairovė mažėja, tikimasi, kad šią neigiamą įtaką sumažins ekologinis ūkininkavimas. Tyrimo metu palygintos dirvos paviršiuje gyvenančios makrofaunos bendruomenės laukuose, kuriuose pastaruosius 15 metų buvo taikyta tradicinė ir ekologinė žemdirbystė sėjomainoje su žieminiais rapsais ir žieminiais kviečiais. Iš esmės didesnis kiekis makrofaunos individų buvo nustatytas abiejų kultūrų laukuose taikant tradicinę žemdirbystę. Gausiausias grupes sudarė žemės (Carabidae (žygių) šeimos) vabalai ir vorai. Vorų daugiau nustatyta ekologiniuose laukuose, žygių – augalus auginant tradiciškai, kur jie buvo veikiami pavasarinio mechaninio žemės dirbimo (akėjimo ir purenimo). Šios priemonės nebuvo reikšmingos voram, nes jie peržiemoja laukų pakraščiuose, labai gerai plinta oru ir geba greitai iš naujo kolonizuoti agroekosistemas. Tai rodo, kad ekologinis ūkininkavimas nebūtinai palaiko dirvožemio faunos populiacijų ir bendruomenių vystymąsi.

Reikšminiai žodžiai: agrotechnika, Araneae, Carabidae, dirvožemio fauna, ekologinis ūkininkavimas, tradicinis ūkininkavimas.