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ORIGINAL ARTICLE

The effect of hay mulching on soil temperature and the abundance and diversity of soil-dwelling arthropods in potato fields

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Key words. Potato field, soil-dwelling arthropods, hay mulch, soil temperature, soil sampler, soil pin trap

Abstract. The average soil temperature was significantly lower in plots covered with hay. Hay mulching, however, did not increase significantly the total number of soil micro-arthropods collected using a soil pin trap and a soil sampler. Significant increases in the number of individuals was recorded only for certain groups. 64% of all the arthropods collected using soil pin traps were collected in hay-covered plots and 36% in control plots. This increase was statistically significant for the orders Entomobryomorpha and Poduromorpha of the subclass Collembola and surface-dwelling (epigeic) Coleoptera. For the samples collected using the soil sampler, 57% of the specimens were collected from hay-covered plots and 43% from control plots. As for the pin traps this was reflected in differences in the numbers of the orders Entomobrhyomorpha and Poduromorpha of the subclass Collembola and Pauropoda, collected in the treated and control plots. We conclude that mulching affected the different arthropod groups differently.

INTRODUCTION

The significance of potato production

Worldwide 19–20 million hectares of potatoes (*Solanum tuberosum* L.) are cultivated with an average yield of around 16 t/ha. In Hungary, 30 thousand hectares of potatoes are planted with an average yield of 16–20 t/ha while the area is 41.1 and 40.7 thousand hectares in the USA and the Netherlands, respectively (Izsáki, 2005). The yield potential of potato is mainly determined by production technology and choosing the variety most suitable for the cultivation conditions (Sárközi, 2002). There are about 3000 varieties of potato worldwide and there were 43 varieties in Hungary in 2001 (Gólya, 2004). The yearly potato consumption is 50 – 60 kg per capita in Hungary (Sárközi, 2002).

The effects of mulching on the microclimate at the soil surface

Covering soil with plant cuttings reduces erosion, improves soil water management and provides a unique microclimate at the soil surface (Altieri & Nicholls, 2004). Overall soil moisture content increases (Yagioka et al., 2015) as a result of a covering of straw (Döring et al., 2005). The temperatures of soils covered with plant residues, such as weed cuttings or wheat straw, generally are lower (Yagioka et al., 2015; Zhang et al., 2009). However, the effects of mulching on soil temperature depend on several factors. Black polypropylene mulch textile is capable of increasing soil temperature, independent of altitude, whereas soils covered with grass cuttings have lower temperatures at low than at high altitudes (Dvořák et al., 2012); results suggest that the increase in temperature at the soil surface in areas covered with artificial mulch materials is independent of their colour (Ham et al., 1993). Mulching can also influence the occurrence and abundance of pest species (Altieri & Nicholls, 2004). For instance, the number of Colorado potato beetle larvae (*Leptinotarsa decemlineata* Say) decreased and yield increased significantly in potato plots mulched with grass cuttings (Dvořák et al., 2013). In addition, the number of tubers and their weight also increases, and the abundance of weeds is significantly reduced as a result of this treatment (Dvořák et al., 2012).

Springtails are sensitive to soil disturbance, therefore they are more abundant in uncultivated and mulched soils covered with rice chaff or grass cuttings than in regularly cultivated soils (Culik et al., 2002). The species richness and abundance, however, does not increase when straw is incorporated into the top soil layer during soil disturbance (Brennan et al., 2006). Some soil-dwelling organisms are particularly sensitive to soil disturbance. For example, soil cultivation greatly reduces the numbers of species and abundance of Symphyla (Menta et al., 2010). Collembola are quite sensitive to soil solarization, therefore mulching may provide more favourable conditions for light-sensitive soil-dwelling arthropods due to its light shielding effect (Gill & McSorley, 2010). Mulching may also have an effect on food chains. Certain soil fungi have become significantly more abundant in corn fields treated with white clover living mulch, which causes a significant increase in the abundance of mites and springtails (Nakamoto & Tsukamoto, 2006). Living mulch provides organic matter for soil microbes and enhances moisture conservation, shelter and provides a food source for the local mesofauna, including certain mites and springtails (Kaneda et al., 2012). In soils covered by sawdust there is an increase in the abundance of decomposer organisms, such as isopods, diplopods and soil-inhabiting Coleoptera (Wardle et al., 1999). Springtails and mites play an important role in the breakdown of dead organic matter (Dányi & Traser, 2007). However, wood chips and grape marc scattered among rows of vines reduces the abundance of Collembola, most likely due to the increase in diversity of predators in the covered areas (Addison et al., 2013). The variation in the species numbers of certain arthropods in soils covered by organic plant residues may also depend on the season (Thomson & Hoffman, 2007). Among the predatory arthropods occurring in potato plots, the numbers of centipedes are not increased significantly by mulching with organic materials, but their overall species and specimen numbers were originally low due to soil disturbance (Dudás et al., 2013).

The purpose of this research was to investigate the effect of hay mulching on the temperature of the top soil layer (1–20 cm) and on various groups of soil-dwelling micro-arthropods. We also wanted to examine and compare the efficiency of two methods of determining abundance and estimating species diversity; traditional soil samplers and novel soil pin traps.

MATERIALS AND METHODS

Study site

The study was conducted in potato plots located in highland and domestic garden environments in a town called Hidegkút (Veszprém County, Western Hungary) (47°00´20.6˝N, 17°83´05.9˝E) near a mixed community forest, *Quercetum robori-cerris* (Bartha et al., 1995). The variety of potato (*Solanum tuberosum* L.) planted was "Sárpo Mira". The size of the area studied was 168 m^2, including tramlines, and was divided into 12 plots of 3 × 4 m. The number of treatments was 2 (hay-mulched and control plots) with 6 replicates of each. After the beginning of shoot growth, the treated potato plots were covered with a 10 cm thick layer of natural meadow hay coming from an area adjacent to the experimental site. Hay was previously dried and stored in an indoor area before it was used in the field. The potatoes were planted in early May in 2014 and 2015, and were harvested at the end of autumn in both years. Potato was planted at the experimental site in previous years. The experimental area was surrounded by a *Convolvulo-Agropyretum repentis* (Kovács, 1995) association. Dominant plant species were perennial weeds, such as *Convolvulus arvensis* L., and grasses, such as *Agropyron repens* L. The soil in the area is brown forest soil. The soil pH varied between 7–8 (slightly alkaline), salt concentration (EC 2.5 mS/cm) was low under 0.02% and soil was strongly calcareous ($CaCO_3$% = 23,4%). The saturation percentage (54 SP) indicated clay loam soil types at the study site (Gavlak et al., 2003). The soil sample depth was 0–8 cm.

Data collection and sorting of soil-dwelling arthropods

We installed soil pin traps, called EDAPHOLOG probes (Dombos, 2016), in each plot. The Edapholog System, including probes, was developed for the automated detection and collection of soil-dwelling arthropods and measurement of soil temperature in the upper 10–20 cm of soil (Dombos, 2016). Soil pin traps were installed randomly in the upper soil layer following Gedeon et al. (2012). Built-in thermometers provided hourly data on soil temperature (Dombos & Bánszegi, 2013). This device collects soil-dwelling micro-arthropods from the top 20 cm layer of soil into a 50 ml tube filled with 30 ml of 98% ethanol, and simultaneously measures soil temperature at this depth. In addition to this method of collection, two soil samples per plot (24 samples altogether) were collected at random from the top 8 cm layer of soil using a soil sampler. The height and diameter of the soil sampling cylinders were 8 cm, and each sample had a volume of 402 cm^3. Soil pin traps were installed on 22.vi.2015 and were collected from control potato plots on 08.x.2015. The collection tubes of the instruments were changed once during the study period, on 01.viii.2015. Soil sampling using soil samplers took place on two occasions: on 30.x.2014 and 09.x.2015. The soil-dwelling arthropods were extracted from the collected samples using a Tullgren funnel. The funnels of the apparatus were equipped with sample holders of 19 × 19 × 6 cm in dimension at the upper opening; the length of the funnel was 30 cm. Due to the desiccation of the samples, the animals move from the funnel into the collecting vessel. Samples collected from the same plots were combined and placed in the same Tullgren funnel, and the arthropods were collected in 120 ml vessels. 60 ml of 70% ethanol was added to the vessels, and the liquid that evaporated was replaced regularly. The soil samples were left in the apparatus for 14 days to achieve complete desiccation, and allow sufficient time for the arthropods to escape from the drying soil. Arthropods in each ethanol sample were sorted under a stereomicroscope and then stored in 70% ethanol for later use. We only classified the arthropods to the order or family level.

Data analysis

For the comparison of abundance of specimens recorded in treated and control areas, the Mann-Whitney U test was applied (Newcombe, 2006). The software SPSS 20 and Shannon's diversity index were used (Kautz et al., 2006). For both methods, the Shannon indices calculated for the treated and control areas were compared using Paired Sample T-tests. Normality assumptions were tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). We found that normality was not violated in either method (soil pin trap: sig = 0.929; soil sampler: sig = 0.22). In the case of the samples collected using the soil sampler, as only one sample was collected each year, the data for the two years were pooled (Table 2, Fig. 2). For the comparison of the average daily soil temperatures in mulched and control plots, the related samples Wilcoxon signed rank test (Siegel, 1956) was used.

RESULTS

64% of the 7241 arthropod specimens collected using soil pin traps were collected in hay-covered plots and 36% in control plots. A total of 8321 arthropods were collected using the soil samplers. 57% of these animals were collected from mulched plots and 43% from control plots. There

Table 1. Effect mulching potato fields at Hidegkút in 2015 with hay had on soil-dwelling Arthropods determined by using soil pin traps. Data indicate the average number of individuals collected ± standard error per sample for each taxon. * Indicates a significant difference between the treated and control plots (p < 0.05).

	Mulched	Unmulched	p value
Acari	136.8 ± 21.7	156.8 ± 45.5	1
Araneae, 5 mm <	0.7 ± 0.3	0.7 ± 0.5	0.818
Araneae, 5 mm >	1.0 ± 0.6	1.2 ± 0.8	1
Blattaria	0.2 ± 0.2	0.0 ± 0.0	0.699
Chilopoda 5 mm <	1.0 ± 0.5	1.0 ± 0.6	1
Chilopoda 5 mm >	0.0 ± 0.0	0.3 ± 0.3	0.699
Cicada larvae	0.0 ± 0.0	0.0 ± 0.0	1
Coleoptera, epigeic	37.2 ± 5.2	18.8 ± 4.7	0.026*
Coleoptera, euedaphic	0.0 ± 0.0	0.0 ± 0.0	1
Collembola / Entomobriomorpha	457.2 ± 112.1	172.0 ± 42.2	0.026*
Collembola / Poduromorpha	12.2 ± 6.9	0.7 ± 0.3	0.004*
Collembola / Symphypleona	19.7 ± 8.8	10.3 ± 9.0	0.132
Dermaptera	0.0 ± 0.0	0.0 ± 0.0	1
Diplopoda 5 mm <	0.3 ± 0.2	0.8 ± 0.5	0.589
Diplopoda 5 mm >	0.0 ± 0.0	0.2 ± 0.2	0.699
Diplura	0.8 ± 0.3	0.8 ± 0.3	1
Diptera imago	12.2 ± 5.3	8.7 ± 3.3	0.699
Diptera larvae	13.0 ± 6.3	5.0 ± 2.7	0.24
Formicidae	19.7 ± 12.7	12.8 ± 3.3	0.699
Hemiptera, not Cicada larvae	0.2 ± 0.2	0.5 ± 0.3	0.589
Hymenoptera, not Formicidae	1.5 ± 0.4	3.2 ± 1.4	0.699
Isopoda	58.7 ± 23.5	37.7 ± 15.8	0.589
Opiliones	0.0 ± 0.0	0.0 ± 0.0	1
Orthoptera	0.0 ± 0.0	0.2 ± 0.2	0.699
Other holometabol imago	0.0 ± 0.0	0.0 ± 0.0	1
Other holometabol larvae	0.3 ± 0.3	0.2 ± 0.2	1
Palpigradi	0.0 ± 0.0	0.0 ± 0.0	1
Pauropoda	0.2 ± 0.2	0.0 ± 0.0	0.699
Protura	0.0 ± 0.0	0.0 ± 0.0	1
Pseudoscorpiones	0.8 ± 0.3	1.2 ± 0.5	0.818
Psocoptera	0.0 ± 0.0	0.0 ± 0.0	1
Symphyla	0.0 ± 0.0	0.0 ± 0.0	1
Thysanoptera	0.2 ± 0.2	0.2 ± 0.2	1
Zygentomata	0.0 ± 0.0	0.0 ± 0.0	1

Table 2. Effect of mulching on soil-dwelling Arthropods in potato fields at Hidegkút between 2014–2015 determined from samples collected using soil samplers. Data indicate the average number of individuals collected ± standard error per sample for each taxon. * Indicates a significant difference between treated and control plots (p < 0.05).

	Mulched	Unmulched	p value
Acari	266.1 ± 77.9	240.1 ± 54.6	0.932
Araneae, 5 mm <	0.0 ± 0.0	0.1 ± 0.1	0.755
Araneae, 5 mm >	0.0 ± 0.0	0.0 ± 0.0	1
Blattaria	0.0 ± 0.0	0.0 ± 0.0	1
Chilopoda 5 mm <	0.8 ± 0.4	0.7 ± 0.4	0.799
Chilopoda 5 mm >	0.2 ± 0.1	0.0 ± 0.0	0.514
Cicada larvae	0.1 ± 0.1	0.0 ± 0.0	0.755
Coleoptera, epigeic	5.2 ± 1.0	5.9 ± 1.0	0.755
Coleoptera, euedaphic	0.4 ± 0.3	0.0 ± 0.0	0.319
Collembola / Entomobriomorpha	65.2 ± 13.7	11.4 ± 2.0	< 0.001*
Collembola / Poduromorpha	18.5 ± 5.3	11.8 ± 7.0	0.028*
Collembola / Symphypleona	3.5 ± 1.1	4.1 ± 2.1	0.887
Dermaptera	0.0 ± 0.0	0.0 ± 0.0	1
Diplopoda 5 mm <	0.7 ± 0.4	0.3 ± 0.2	0.671
Diplopoda 5 mm >	0.1 ± 0.1	0.0 ± 0.0	0.755
Diplura	0.6 ± 0.2	0.1 ± 0.1	0.16
Diptera imago	0.2 ± 0.1	0.1 ± 0.1	0.755
Diptera larvae	1.1 ± 0.3	1.3 ± 0.7	0.551
Formicidae	0.8 ± 0.5	6.1 ± 5.0	0.319
Hemiptera, not Cicada larvae	0.3 ± 0.2	2.8 ± 2.7	0.799
Hymenoptera, not Formicidae	0.0 ± 0.0	0.1 ± 0.1	0.755
Isopoda	0.0 ± 0.0	0.0 ± 0.0	1
Opiliones	0.0 ± 0.0	0.0 ± 0.0	1
Orthoptera	0.0 ± 0.0	0.0 ± 0.0	1
Other holometabol imago	0.0 ± 0.0	0.0 ± 0.0	1
Other holometabol larvae	0.0 ± 0.0	0.0 ± 0.0	1
Palpigradi	0.0 ± 0.0	0.0 ± 0.0	1
Pauropoda	21.0 ± 4.0	9.3 ± 3.6	0.033*
Protura	0.1 ± 0.1	0.0 ± 0.0	0.755
Pseudoscorpiones	5.4 ± 2.3	1.8 ± 0.8	0.378
Psocoptera	0.4 ± 0.2	0.5 ± 0.2	0.755
Symphyla	3.9 ± 1.1	2.4 ± 0.7	0.319
Thysanoptera	0.0 ± 0.0	0.3 ± 0.1	0.319
Zygentomata	0.0 ± 0.0	0.0 ± 0.0	1

were no significant difference between the treated and untreated plots in terms of the total number of soil-dwelling arthropods collected by either the soil pin traps ($p = 0.132$) or soil samplers ($p = 0.671$). However, hay mulching caused a significant difference in the numbers of specimen of the following arthropod groups collected by the soil pin traps: the orders Entomobryomorpha and Poduromorpha of the subclass Collembola and epigeic Coleoptera (living above the soil surface) (Table 1). There were also no significant differences in the abundances recorded in treated and untreated plots in the case of samples collected using soil samplers ($p = 0.671$). There were significant differences in the numbers of specimens of the orders Entomobryomorpha and Poduromorpha of the subclass Collembola, and Pauropoda collected from treated and control plots using soil samplers (Table 2).

The diversity of arthropod groups collected varied depending on the treatment: based on the results of the soil pin traps (Fig. 1), there is no significant difference between the diversities recorded in the treated and untreated plots ($p = 0.819$), whereas based on the data obtained using the soil sampler (Fig. 2), there was a greater diversity in the treated plots ($p = 0.032$).

On the basis of the soil temperatures measured by soil pin traps, the average daily soil temperature in hay mulched plots was lower than that in control plots (Fig. 3). The mulching, in particular, reduces the maximum temperatures rather than evenly reducing the average temperature. The average difference between the average daily soil temperatures in treated and control plots was 1.155°C; the mean daily temperature of treated plots was significantly lower ($p < 0.001$).

DISCUSSION

The characteristics of soil affect the occurrence and frequency of soil insects. Decomposing organisms, such as Podorumorpha springtails, are abundant in crops growing in soils with a high carbon and nitrogen content. In crop cultures where ryegrass is used as green weight the abundance of herbivorous Symphypleona increases (Crotty et

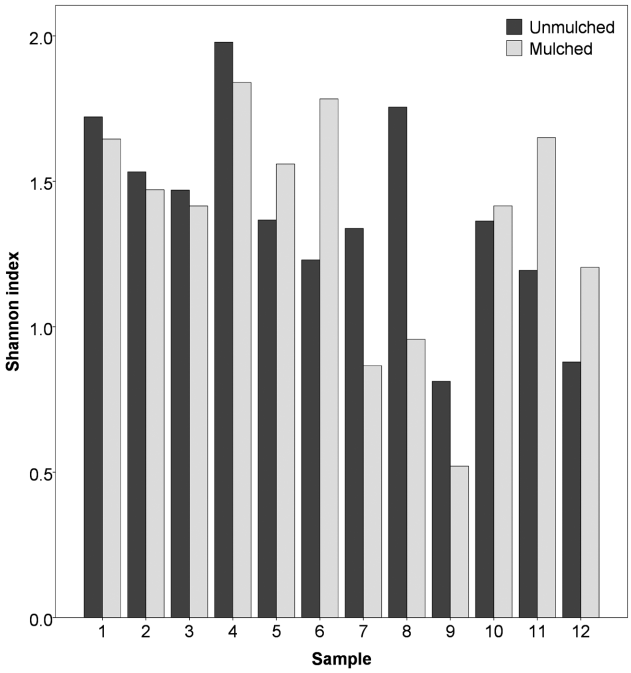

Fig. 1. Shannon diversity indices for each of the samples collected using soil pin traps.

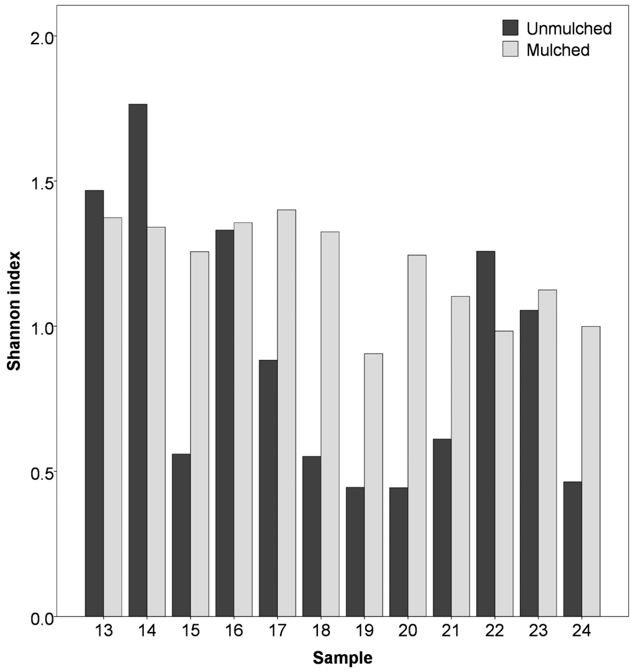

Fig. 2. Shannon diversity indices for each of the samples collected using soil samplers.

al., 2015). As a result of mulching with compost, decomposing and predatory soil-dwelling arthropods proliferate but herbivores do not (Mathews et al., 2002). Among the arthropods collected using soil pin traps, Collembola were the most abundant (4032 individuals), especially the Entomobryomorpha (3775 individuals); followed by Acari (1762 individuals). However, in the case of samples collected using soil samplers this ratio was reversed, with the Acari the most abundant (6072 individuals), followed by Collembola (1373 individuals); but within this subclass, Entomobryomorpha were again the most abundant (919 individuals). Different sampling methods resulted in different ratios of arthropod groups. The advantage of soil pin traps was that they continuously collect soil arthropods. Among soil-dwelling arthropods in English fields, Collembola are the most abundant, with the next most abundant group, mites, not far behind; the abundance of both these arthropods is approximately 10,000 individuals/m^2 (Dunger, 1983). Despite the relatively high numbers collected, we could not detect a significant difference between the mite populations in treated and untreated plots (Tables 1, 2). Mulching the soil surface with plant cuttings has no significant effect on the numbers of armoured mites, however, it results in an increase in the numbers of predatory mites and springtails (Wang et al., 2011). In the case of the application some organic mulches (wheat straw, bark and wood chips, dried municipal sludge) there is an increase in the abundance soil microfauna, and as a result of more fungi, there are more fungal-grazing pygmephorid and tarsonemid mites and Collembolans (Whitford et al., 1989). As a result mulching our potato plots with hay, the abundance of the orders Entomobryomorpha and Poduromorpha of the subclass Collembola increased significantly but not that of Acari (Tables 1, 2). Collembola also feed on plant-pathogenic fungi (Hopkin, 1997), therefore, they benefit agriculture. Various organic mulches may affect the abundance of different soil-dwelling arthropod groups in diverse ways; pine bark mulch has a more positive effect on fly larvae inhabiting the soil surface presumably due to its slower decomposition (Gill et al., 2011). There was no significant increase in the numbers of flies recorded following mulching with hay in this study (Tables 1, 2). Abundance of Coleoptera increases as a result of mulching with cowpea cuttings (Gill & McSorley, 2012a). Based on the results of the soil pin traps, the abundance of epigeic Coleoptera (living above the soil surface) was also increased by hay mulching in this study. Other sampling methods, such as Berlese funnels, differ in their efficiency for sorting soil Arthropods. For example, Berlese funnels can only process small amounts of litter (Gill et al., 2010) and the

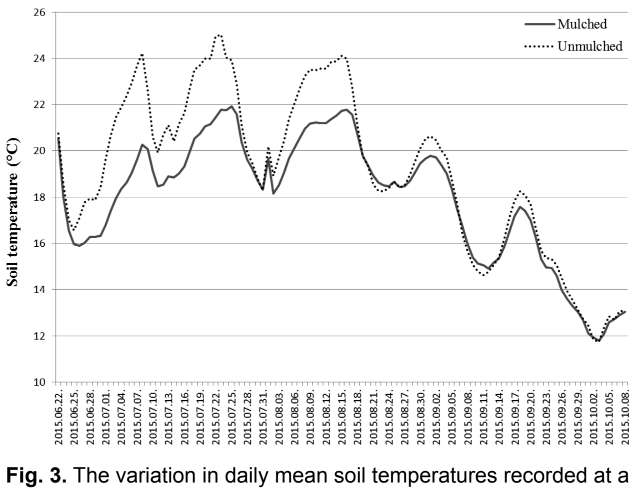

Fig. 3. The variation in daily mean soil temperatures recorded at a depth of 20 cm in the soil during a fallow period from 22.vi.2015 to 8.x.2015, in treated and control potato plots at Hidegkút.

number of taxa collected by this method is lower than by other sampling methods (Gill & McSorley, 2012b). There were no differences in taxa collected by the two sampling methods used in this study (Tables 1, 2). The variations in the temperature at the soil surface can be substantial both spatially and temporally. The majority of the soil-dwelling animals can tolerate occasional major changes in soil temperature, but generally are very sensitive to higher temperatures (Dunger, 1983). Therefore, we assume that lower soil temperatures in mulched plots may also have contributed to the increase in the numbers of individuals of some groups of soil-dwelling micro-arthropods in these plots. Soil solarisation using plastic mulch can be used to control weeds (Gill et al., 2009).

CONCLUSIONS

With the exception of certain groups, hay mulching did not result in a widespread and significant increase in the numbers of soil-dwelling micro-arthropods. There were marked differences in the numbers of certain groups collected associated with both the treatment and method of sampling. The efficiency the sampling techniques used differed, therefore depending on the method of collection, statistically detectable increases in the numbers was only recorded for: Entomobryomorpha and Poduromorpha of the subclass Collembola, Pauropoda and epigeic Coleoptera (living above the soil surface). In terms of diversity of arthropod groups, differences between treated and untreated plots were only detected in the samples collected using a soil sampler, which revealed a greater diversity in the treated plots. Consequently, further studies are needed to verify this finding using other methods. On the other hand, the effect of mulching on epigeic groups was only detected using soil pin traps. A detectable reduction in the average soil temperature was recorded in the potato plots that were mulched with hay. Based on the analysis of the samples collected using the two methods described above, it is assumed that soil pin traps are not suitable for sampling certain groups of soil-inhabiting organisms such as Symphyla, Pauropoda and Psocoptera. Our results indicate that hay mulching in potato fields results in an increase in the activity of soil-dwelling micro-arthropods, consequently it is recommended as a preferable management practice.

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REFERENCES

Addison P., Baauw A.H. & Groenewald G.A. 2013: An initial investigation of the effects of mulch layers on soil-dwelling Arthropod assemblages in vineyards. — *Sth Afr. J. Enol. Viticult.* **34**: 266–271.

Altieri M.A. & Nicholls C.I. 2004: *Biodiversity and Pest Management in Agroecosystems. 2nd ed*. The Haworth Press, New York, 236 pp.

Bartha D., Kevey B., Morcschhauser T. & Pócs T. 1995: Hazai erdőtársulásaink. [Forest communities of Hungary.] In Szmorad F. & Timár G. (eds): *Tilia. Vol. 1. Növénytársulástani és -ökológiai tanulmányok*. [*Plant Associations and Ecology.*] Institute of Botany, University of Forestry and Wood Sciences, Sopron, pp. 8–16 [in Hungarian].

Brennan A., Fortune T. & Bolger T. 2006: Collembola abundances and assemblage structures in conventionally tilled and conservation tillage arable systems. — *Pedobiologia* **50**: 135–145.

Crotty F.V., Fychan R., Scullion J., Sanderson R. & Marley C.L. 2015: Assessing the impact of agricultural forage crops on soil biodiversity and abundance. — *Soil Biol. Biochem.* **91**: 119–126.

Culik M.P., de Souza J.L. & Ventura J.A. 2002: Biodiversity of Collembola in tropical agricultural environments of Espírito Santo, Brazil. — *Appl. Soil Ecol.* **21**: 49–58.

Dányi L. & Traser G. 2007: Magyarország ugróvillásai. [Springtails of Hungary.] In Forró L. (ed.): *A Kárpát-medence állatvilágának a kialakulása*. [*The Origin of the Fauna of the Carpathian Basin.*] Magyar Természettudományi Múzeum, Budapest, pp. 21–29 [in Hungarian].

Dombos M. (ed.) 2016: *MEDAPHON*. URL: http://www.medaphon.hu/ (last accessed 8 May 2016).

Dombos M. & Bánszegi O. 2013: EDAPHOLOG: a new sensor-system to in-situ, on-line monitoring of soil mezofauna. In: *5. Ecozoology Symposium, 22th March 2013.* Institute of Ecology and Botany in Hungarian Academy of Sciences Institute, Vácrátót. URL: http://www.ecology.hu/abstractok/szuszi_2013.pdf (last accessed 26 April 2016).

Döring T.F., Brandt M., Hess J.H., Finckh M.R. & Saucke H. 2005: Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. — *Field Crops Res.* **94**: 238–249.

Dudás P., Ambrus G., Piltz M. & Tóth F. 2013: Analysis of centipede (Chilopoda) assemblages by pitfall trapping of mulched and non-mulched potato plots using leaf litter. — *Állatt. Közl.* **98**: 47–56 [in Hungarian, English abstr.].

Dunger W. 1983: *Tiere im Boden*. Amandus Ziemsen, Wittenberg Lutherstadt, 280 pp.

Dvořák P., Tomášek J., Kuchtová P., Hamouz K., Hajšlová J. & Schulzová V. 2012: Effect of mulching materials on potato production in different soil-climatic conditions. — *Roman. Agric. Res.* **29**: 201–209.

Dvořák P., Kuchtová P. & Tomášek J. 2013: Response of surface mulching of potato (*Solanum tuberosum*) on SPAD value, Colorado potato beetle and tuber yield. — *Int. J. Agric. Biol.* **15**: 798–800.

Gavlak R., Horneck D., Miller R.O. & Kotuby-Amacher J. 2003: *Soil, Plant, and Water Reference Methods for the Western Region. 3rd ed.* WCC-103 Publication, Corvallis. URL: http://www.naptprogram.org/files/napt/western-states-method-manual-2005.pdf (last accessed 15 March 2016).

Gedeon C., Bánszegi O., Hambek T. & Dombos M. 2012: Edapholog®: an automatized system for monitoring numerical abundance and body size distribution of soil mesofauna. In Sensei N. (ed.): *Proceedings of the Workshop S04.06-P Current Issues and Applications of Soil Monitoring at EUROSOIL 2012, 2.7.–6.7.2012, Bari, Italy*. URL: http://rps.entecra.it/pages/PageData/allegati/FinalProgramme200612.pdf (last accessed 15 March 2016).

Gill H.K. & McSorley R. 2010: Effect of integrating soil solarization and organic mulching on the soil surface insect community. — *Fla Entomol.* **93**: 308–309.

Gill H.K. & McSorley R. 2012a: Effects of different organic mulches on the soil surface arthropod community and weeds in snapdragon. — *Int. J. Pest Manag.* **58**: 33–40.

Gill H.K. & McSorley R. 2012b: Methods for sampling soil surface arthropods in bush beans: Which one is the best? — *Proc. Fla State Hortic. Soc.* **125**: 192–195.

Gill H.K., MsSorley R. & Treadwell D.D. 2009: Comparative performance of different plastic films for soil solarization and weed suppression. — *HortTechnology* **19**: 769–774.

Gill H.K., McSorley R. & Buss L. 2010: The insect community on the soil surface. — *University of Florida IFAS Extension ENY-859*. URL: http://edis.ifas.ufl.edu/in876 (last accessed 26 April 2016).

Gill H.K., McSorley R. & Branham M. 2011: Effect of organic mulches on soil surface insects and other arthropods. — *Fla Entomol.* **94**: 226–232.

Gólya E. 2004: Korai burgonya. [Early potato.] In Hodossi S., Kovács A. & Terbe I. (eds): *Zöldségtermesztés szabadföldön.* [*Cultivation of Vegetables in Open Fields.*] Mezőgazda, Budapest, pp. 159–165 [in Hungarian].

Ham J.M., Kluitenberg G.J. & Lamont W.J. 1993: Optical properties of plastic mulches affect the field temperature regime. — *J. Am. Soc. Hortic. Sci.* **118**: 188–193.

Hopkin S.P. 1997: *Biology of the Springtails (Insecta: Collembola)*. Oxford University Press, New York, 231 pp.

Izsáki Z. 2005: Gyökér- és gumós növények. [Root and tuber crops.] In Antal J. (ed.): *Növénytermesztéstan 2*. [*Plant Production 2*.] Mezőgazda, Budapest, pp. 7–102 [in Hungarian].

Kaneda S., Miura S., Yamashita N., Ohigashi K., Yamasaki S., Murakami T. & Urashima Y. 2012: Significance of litter layer in enhancing mesofaunal abundance and microbial biomass nitrogen in sweet corn-white clover living mulch systems. — *Soil Sci. Plant Nutr.* **58**: 424–434.

Kautz T., López-Fando C. & Ellmer F. 2006: Abundance and biodiversity of soil microarthropods as influenced by different types of organic manure in a long-term field experiment in Central Spain. — *Appl. Soil Ecol.* **33**: 278–285.

Kovács J.A. 1995: Lágyszárú növénytársulásaink rendszertani áttekintése. [Taxonomic studies on the herbaceous associations of Hungary.] In Szmorad F. & Timár G. (eds): *Tilia. Vol. 1. Növénytársulástani és -ökológiai tanulmányok*. [*Plant Associations and Ecology.*] Institute of Botany, University of Forestry and Wood Sciences, Sopron, pp. 86–145 [in Hungarian].

Mathews C.R., Bottrell D.G. & Brown M.W. 2002: A comparison of conventional and alternative understory management practices for apple production: multi-trophic effects. — *Appl. Soil Ecol.* **21**: 221–231.

Menta C., Leoni A., Tarasconi K. & Affani P. 2010: Does compost use affect microarthropod soil communities? — *Fresenius Environ. Bull.* **19**: 2303–2311.

Nakamoto T. & Tsukamoto M. 2006: Abundance and activity of soil organisms in fields of maize grown with a white clover living mulch. — *Agric. Ecosyst. Environ.* **115**: 34–42.

Newcombe R.G. 2006: Confidence intervals for an effect size measure based on the Mann-Whitney statistic. Part 2: Asymptotic methods and evaluation. — *Statist. Medicine* **25**: 559–573.

Sárközi F. 2002: *Amit a vetőburgonyáról tudni kell*. [*What Should You Know about Planting Potatoes.*] Agroinform, Budapest, 104 pp [in Hungarian].

Shapiro S.S. & Wilk M.B. 1965: An analysis of variance test for normality (complete samples). — *Biometrika* **52**: 591–611.

Siegel S. 1956: *Non-parametric Statistics for the Behavioral Sciences*. McGraw-Hill, New York, pp. 75–83.

Thomson L.J. & Hoffman A.A. 2007: Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macro invertebrates in vineyards. — *Agric. Forest Entomol.* **9**: 173–179.

Yagioka A., Komatsuzaki M., Kaneko N. & Ueno H. 2015: Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching. — *Agric. Ecosyst. Environ.* **200**: 42–53.

Wang K.-H., Hooks C.R.R. & Marahatta S.P. 2011: Can using a strip-tilled cover cropping system followed by surface mulch practice enhance organisms higher up in the soil food web hierarchy? — *Appl. Soil Ecol.* **49**: 107–117.

Wardle D.A., Nicholson K.S., Bonner K.I. & Yeates G.W. 1999: Effects of agricultural intensifcation on soil-associated Arthropod population dynamics, community structure, diversity and temporal variability over a seven-year period. — *Soil Biol. Biochem.* **31**: 1691–1706.

Whitford W.G., Aldon E.F., Freckman D.W., Steinberger Y. & Parker L.W. 1989: Effects of organic amendments on soil biota on a degraded rangeland. — *J. Range Manag.* **42**: 56–60.

Zhang S., Lövdahl L., Grip H., Tong Y., Yang X. & Wang Q. 2009: Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. — *Soil Tillage Res.* **102**: 78–86.

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