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Organic farming and moderate tillage change the dominance and spatial structure of soil Collembola communities but have little effects on bulk abundance and species richness

Mikhail B. Potapov[1,*], Anna I. Bokova[1], Charlene Janion-Scheepers[2,3], Natalia A. Kuznetsova[1], Miryam S. Merk[4,*], Ksenia S. Panina[1], Anton M. Potapov[5, 6, 7] and Anna K. Saraeva[8]

[1] Moscow State Pedagogical University, Institute of Biology and Chemistry, Kibalchicha str. 6k3 129164 Moscow, Russia
[2] University of Cape Town, Department of Biological Sciences, Rondebosch, 7701, Private Bag x3, South Africa
[3] Iziko Museums of South Africa, PO Box 61, Cape Town, 8000, South Africa
[4] Chairs of Statistics and Econometrics, University of Goettingen, Humboldtallee 3, 37073 Göttingen, Germany
[5] Johann Friedrich Blumenbach Institute of Zoology and Anthropology, University of Göttingen, Untere Karspühle 2, 37073 Göttingen, Germany
[6] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstraße 4, 04103 Leipzig, Germany
[7] University of Leipzig, Puschstraße 4, 04103 Leipzig, Germany
[8] Forest Research Institute, Karelian Research Center, Russian Academy of Sciences, Petrozavodsk, 185910 Russia
* Corresponding authors: mpnk-abroad@yandex.ru, miryamsarah.merk@uni-goettingen.de

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Abstract

Organic farming technologies are increasingly being used to reduce environmental pollution and grow environmentally friendly products. An integrated approach to assessing the effectiveness of these technologies requires studying the reaction of various components of agroecosystems, including soil fauna. Collembola (springtails) are among the most abundant soil arthropods that regulate nutrient cycling in crop fields. However, the effects of different management types on Collembola communities are context-dependent, and spatial organization of these communities remains unexplored. Here, we studied winter wheat fields in European Russia using a large spatial sampling including 486 samples which were arranged in a nested fractal pattern and grouped into 18 meter plots across six agricultural fields. We compared fields with organic farming (no mineral fertilizer and pesticide applications, moderate tillage) with conventional farming ones. To account for spatial configuration of the sampling design, we applied generalized linear mixed-effects models. The organic farming with moderate tillage changed the structure of Collembola communities by reducing the effect of species over-domination. However, the total abundance and species richness of Collembola was only little and often non-significantly higher under organic than in under the conventional management type. The applied multiscale approach revealed larger spatial aggregations in Collembola communities in organic than in conventional management. Overall, we showed that the effect of organic farming technologies changes taxonomic and spatial structures of Collembola communities, rather their bulk characteristics, such as density and abundance. Functional consequences of these changes are yet to be discovered.

Keywords Spatial distribution | fractal design | abundance | species richness | dominance

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1. Introduction

Organic farming, in which the undesirable effects of chemical processing are minimized, is considered as a way to achieve sustainable agriculture (Hole 2005, Pretty 2008). This practice has become widespread in many countries around the world (Willer & Youssefi 2005, Baker et al 2007), where such fields cover from 2 to 70 % of agricultural land (Six et al. 2002). Disk tillage, shallow tillage, or no tillage (no-till), which all avoid deep tillage with soil turnover, is a complementary environmental technology preserving the natural soil structure, moisture, and soil biodiversity (Triplett & Dick 2008).

The maintenance of soil fertility is closely related to the state of soil biota (Altieri 1999, Lavelle et al. 2006), specifically by closely interacting communities of microorganisms and animals (Maeder et al. 2002). Through these interactions, soil fauna controls the cycles of organic and inorganic matter (Filser et al. 2016). Collembola, or springtails, are ubiquitous and diverse group of small (~1-mm long) soil arthropods, surviving in agroecosystems better than many other groups (Hopkin 1997, Potapov et al. 2020). They consume soil microorganisms that take part in decomposing of organic residues (Rusek 1998, Filser 2002). Collembola can regulate the number of phytopathogens; in particular, they reduce the *Fusarium* infection of wheat (Goncharov et al. 2020). Being a food themselves, Collembola maintain the diversity of a wide range of soil-dwelling predators (Bilde et al. 2000, Agusti et al. 2003). Springtails can compensate for the absence of other groups of soil fauna in agricultural fields by supporting various ecosystem functions (Potapov et al. 2020). This group reflects well the state of the soil environment under various types of anthropogenic pressure, including that in agroecosystems (Filser et al. 1995, Sousa et al. 2006).

Reducing the mechanical load on the soil by disk tillage usually has a positive effect on Collembola (House & Parmelee 1985, Alvarez et al. 2001, Demetrio et al. 2020). The influence of chemical treatments on the abundance of Collembola is generally negative (Paoletti et al. 1992, Culik et al. 2002, Filho et al. 2016) or neutral (Dekkers et al. 1994, Reddersen 1997, Czarnecki & Paprocki 1997), but rarely slightly positive (Ortiz et al. 2019). Microarthropod diversity tends to be higher with organic farming (see review: Bengtsson et al. 2005). All these effects, however, may also depend on the spatial scales of consideration. There is a predictable structure in the distribution and, accordingly, the activity of soil organisms on different spatial scales (Ettema & Wardle 2002, Dray et al., 2012). The importance of spatial approach, which is still poorly applied in agroecology, has been underlined when reviewing a large number of published data on the fauna of agroecosystems (Bengtsson et al. 2005). Some authors found regular clusters of springtails in agroecosystems on the centimeter and decimeter scales (Chernova 1982), as well as much larger clusters of hundreds of meters in size (Gao et al. 2014). Other authors indicated a slight variability in the distribution of springtails in agroecosystems in 50×50-m plots (Fromm et al. 1993). Until now, the spatial factor is hardly taken into account when studying the impact of agricultural technologies on soil animals. At the same time, the interest in the spatial heterogeneity of agroecosystems is in the focus of current precision agriculture (Finger et al. 2019).

The purpose of our study is to assess the impact of environment-friendly farming technologies on soil Collembola, taking into account the spatial scale factor. We set two main aims: (1) To estimate the differences in parameters of Collembola communities in winter wheat agroecosystems under organic farming and moderate (=disk) tillage in comparison to conventional technology; (2) To compare the spatial configuration of Collembola under the different field management types.

2. Material and methods

Research area. The work was carried out near Mosalsk town in Kaluga Region, which is located in the central European part of Russia, in the humid continental climate (average annual temperature +6.3°C, average annual precipitation 668 mm; http://www.pogodaiklimat.ru) and in the broadleaved forest zone. The landscape is a mosaic of forests of different ages and agricultural lands (fields, meadows, and pastures), occupying about 60 % of the territory of Kaluga region (Aldoshin et al. 2015). The soil type was Haplic Phaeosem Aric, Arenic (WRB 2014), sandy loam (Goncharov et al. 2020). Fields on which mineral fertilizers and pesticides were not used for 11 years were studied in the vicinity of Mosalsk on the territory of the 'Savinskaya Niva' farm, which is the part of the 'EkoNiva-APK', the latter is one of the leading agricultural holdings of organic farming in Russia. For comparison, the fields with the conventional farming were investigated on the territory of the 'Zhivoy Istochnik' agro-tourist enterprise.

Management types and fields. Three treatments of winter wheat fields were selected to assess the effect of tillage: ODISK (Organic farming and Disk tillage) - without chemical treatment, i.e., mineral fertilizers and pesticides and without deep tillage but only with 5–10 cm disk tillage; OTILL (Organic farming and Tillage) - without chemical treatment but with tillage (20 cm with soil layer turnover); CONV (Conventional farming) –

with chemical treatment and deep tillage. There was no treatment where chemical treatment was combined with disk tillage. The treatments ODISK - OTILL - CONV - form a series of increasing impact on the agroecosystem. Each treatment was studied on two different fields, with 3 meter-plots per field. Plots within a field were 10 meters apart, the fields were between 3 and 15 km from each other (Fig. 1). Winter wheat was preceded mainly by perennial grasses. The history of the fields is given in Table S3. No chemical treatments were applied to fields A-D since 2011. Mineral fertilizers were applied annually to fields E and F: ammonium phosphate (150 kg/ha) and potassium chloride (150 kg/ha), and the herbicide Secator Turbo: 25 g/L iodosulfuron methyl sodium, 100 g/L amidosulfuron, 250 g/L mephenpyr diethyl (antidote) at 100 ml/ha. Insecticides and fungicides were not applied.

Agrochemical characteristics were estimated after the cores the Collembola had been extracted from. 9 cores from each 25-cm plots were mixed and homogenizated together resulting in 54 samples. Total organic content and humus was measured by CHNS/O-analyzer 2400 Series II (Perkin Elmer, USA), pH of the soil - by pH-device HI-2211-02 (Hanna Instruments, Germany), hygroscopic moisture and ash content according to Vorobyova (1998). Fraction content was measured by Laser analyzer LS-13320 Beckman Couter, according to classification of Kachinsky (1965). Fraction content was very similar between fields and meter plots, the average values are given in Table S2. The weight of every core before and after extraction (drying) was measured, the moisture content of samples was high and similar in all fields (see the Sampling design part). Organic matter content % in the fields A, B, C, D, E, F was 1.57 ± 0.15, 1.41 ± 0.13, 1.79 ± 0.04, 2.04 ± 0.16, 2.02 ± 0.16, 2.23 ± 0.13 (Mean ± 1 SD), respectively. Characteristics of the meter plots are given in Table S1.

Weather conditions. Soil samples to extract Collembola were collected on 24-26 July 2019. The

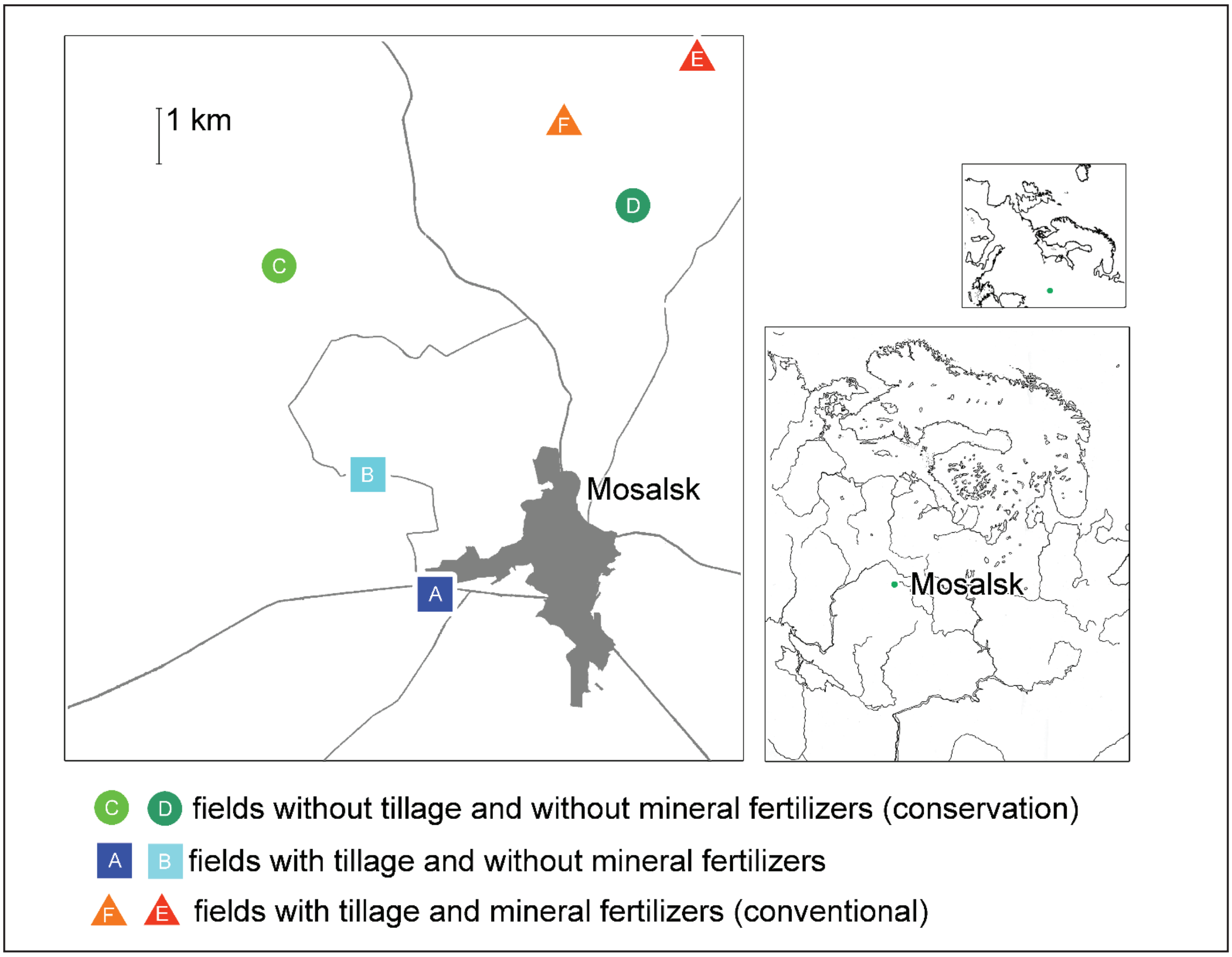

Figure 1. Location of the fields studied with different treatments: ODISK (Organic farming and Disking - C and D circles), OTILL (Organic farming and Tillage - A and Bsquares), and CONV (Conventional farming - E and F triangles). Coordinates of locations: A: N 54.482 E 34.928, B: N 54.496 E 34.933, C: N 54.543 E 34.880, D: N 54.555 E 34.996, E: N 54.585 E 35.0187, F: N 54.570 E 34.974. The altitude was from 175 to 234 m above sea level depending on the field.

average temperature during the period from 1 to 31 of July 2019 was 15.9°C and the total rainfall was 75 mm. Compared to the average values for July over the past 10 years, in 2019 the temperature was lower (18.5°C), and almost the same amount of precipitation (74 mm) fell (http://www.pogodaiklimat.ru/history). The average moisture content of samples in fields A, B, C, D, E and F was 19.3 ± 0.1, 20.2 ± 0.3, 23.6 ± 0.2, 20.3 ± 0.2, 20.9 ± 0.2, and 21.2 ± 0.1 % (Mean ± 1 SE), respectively.

Sampling design. Sampling followed a multiscale approach with fractal design to balance sampling effort and statistical power in studying biodiversity and spatial heterogeneity (Marsh & Ewers 2013). This scheme has been applied to study the distribution of individuals in a population (Saraeva et al. 2015) and to study the diversity structure of the Collembola across temperate forests (Kuznetsova & Saraeva 2018). In each field, a visually homogeneous area of 10x10 m was selected. Samples 8 cm^2 in area and 20 cm deep were taken at the corners of equilateral triangles of different sizes, with sides ranging from 7 cm to 10 m, which were arranged in a nested fractal pattern. To our knowledge, the fractal-nest multiscale approach has never been applied to study Collembola in agroecosystems. Collembola were extracted from soil to ~70 % alcohol by using Berlese funnels. We did not apply artificial heating, the completeness of the extraction was indicated by the complete drying of a sample (5-7 days).

Identifications. Specimens were mounted using Hoyer's medium on permanent microscope slides and identified under a Zeiss Axio Lab.A1 microscope. The species were identified using available keys (Fjellberg 1998, 2007, Schneider & D'Haese 2013). Georeferenced data on species abundances were placed in the international Global Biodiversity Information Facility (GBIF) in the 'sampling event dataset' format (Kuznetsova et al. 2021). A total of 6,906 specimens representing 32 species of Collembola were processed.

Data analysis. Considered fractal design included 3 'management types', each with 2 nested 'fields', each with 81 samples, grouped in tryads on three spatially-hierarchical levels: 'meter plots' (distance was 10 meters between meter plots, 27 samples each), '25-centimeter plots' (distance was 1 m between them, 9 samples each), and '7-centimeter plots' (distance was 25 cm between them, 3 samples (i.e. soil cores) each; Fig. 2). Three basic indicators of Collembola communities were calculated for each 8 cm^2 sample and analysed: total abundance, number of species and degree of dominance (Berger-Parker index, i.e. the proportion of the most abundant species).

We first tested the effect of management type on abundance, number of species and Berger-Parker index of Collembola communities in the samples. To account for spatial configuration of the sampling design, we applied generalized linear mixed-effects models (the *lme4* and *glmmTMB* packages) with management type (OTILL, ODISK, CONV) and soil moisture (also estimated in each soil core) as the fixed factors and three spatially-hierarchical levels as random effects. Three models differing in random effects were built initially: (1) with meter plots nested in fields; (2) with 25-centimeter plots nested in meter plots nested in fields; (3) with 7-centimeter plots nested in 25-centimeter plots nested in meter plots nested in fields. These three models were compared using *anova* and the model with the lowest AIC and BIC values

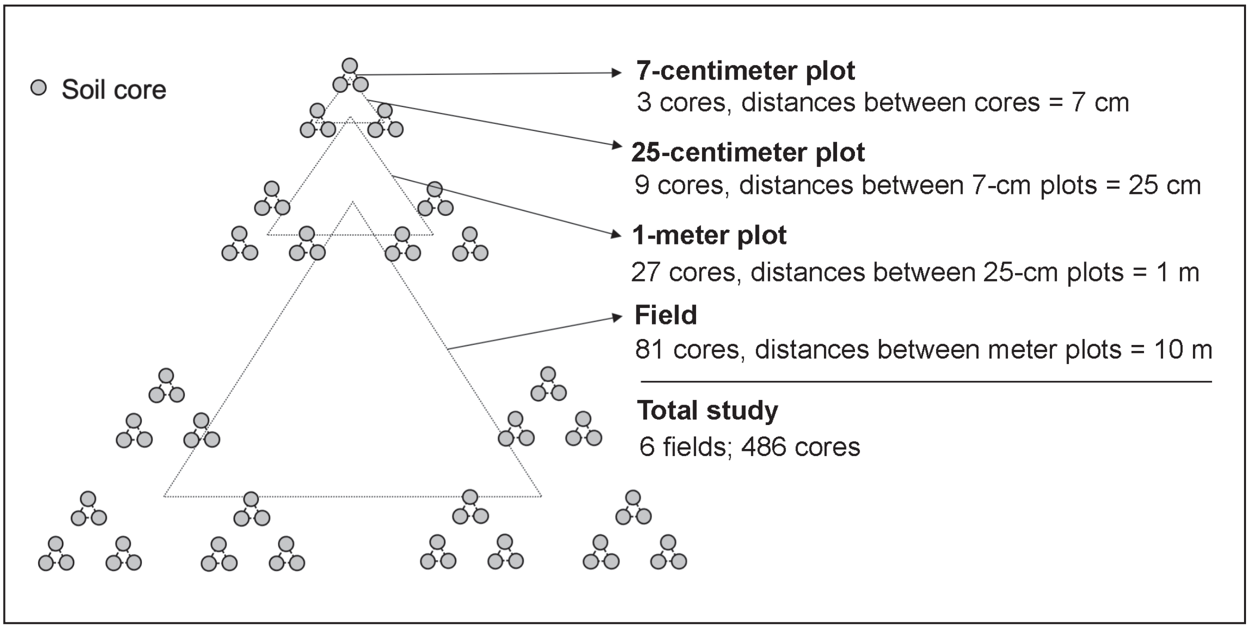

Figure 2. Spatially nested hierarchical sampling design. In total, 486 samples were collected from 6 fields across 3 management types.

was selected. In case of discrepancy, AIC was used for decision. After visually inspecting the data distributions, we fitted negative binomial distribution for abundances, generalized Poisson distribution for the number of species, and Gaussian distribution for the Berger-Parker index. Confidence Intervals (95 %CIs) and p-values were computed using the Wald approximation (the *sjPlot* package). To test the robustness of the results, we also tested models with alternative data distributions (Poisson versus negative binomial) and algorithms (*lme4* versus *glmmTMB* package). Due to similar results, these models are not presented in the results. The interaction between soil moisture and management type was not significant and not included in the final models.

Further, we compared spatial configuration of Collembola communities among the three management types by dividing the dataset to corresponding subsets (OTILL, ODISK, CONV). We constructed the same models as above, but without the management type

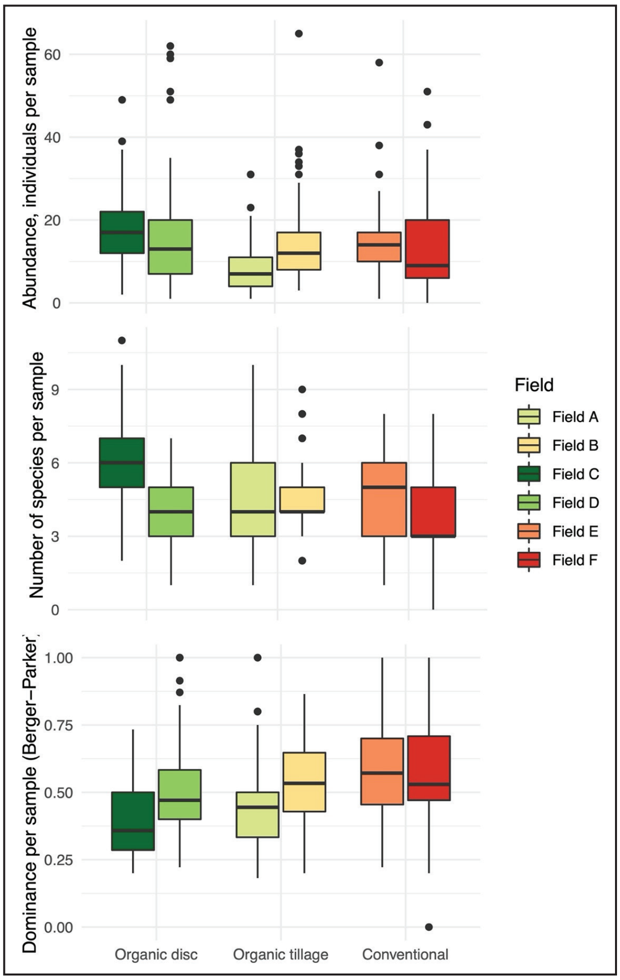

Figure 3. Abundance, number of species and Berger-Parker index in samples in different management types and fields. Colors show fields. Boxplots show data distribution (n = 81 per field), horizontal lines represent the medians.

factor and using always the same random effects for comparison. Random effect sizes (Tau parameters) were extracted from the models and used to compare different scales (meter-plots, 25-centimeter plots, 7-centimeter plots) in shaping abundance, number of species and Berger-Parker index of Collembola communities in the samples.

2. Results

General remarks. A total of 32 species of Collembola were found. *Protaphorura armata* s.str. (Tullberg), *Parisotoma notabilis* (Schaeffer), and *Sphaeridia pumilis* (Krausbauer), totalled 62 % of abundance and were the most abundant species (Kuznetsova et al. 2021). Under different management types (ODISK, OTILL, CONV) the total number of species found was 29, 28, and 27 and the total abundance of Collembola was 21.4 ± 4.8, 14.4 ± 4.5, 17.4 ± 3.3 ths ind. m^{-2} (Mean ± 1 SD), respectively (Table S4).

Abundance. Abundance of Collembola was the highest in the organic disk management (17.1 ± 11.4 ind. $core^{-1}$); the difference was statistically significant against the organic tillage (11.6 ± 8.7 ind. $core^{-1}$; beta -0.35, CI [-0.63, -0.07], p = 0.016), but not against the conventional management type (13.9 ± 9.7 ind. $core^{-1}$; beta -0.18, CI [-0.45, 0.09], p = 0.189; Fig. 3). The effect of Humidity was statistically marginally significant and positive (beta = 0.03, CI [-0.0003, 0.07], p = 0.070). The model's total explanatory power was moderate (conditional R^2 = 0.29) and the part related to the management type and humidity effects (marginal R^2) was of 0.08.

Number of species. Number of species was also the highest in the organic disk management (5.2 ± 1.9 spp. $sample^{-1}$), however, the differences to the organic tillage (4.4 ± 1.8 spp. $sample^{-1}$; beta -0.11, CI [-0.34, 0.12], p = 0.341), and the conventional management type (4.1 ± 1.6 spp. $sample^{-1}$; beta -0.21, 95 % CI [-0.44, 0.02], p = 0.071) were not, or marginally significant (Fig. 3). The effect of Humidity was statistically non-significant and positive (beta = 0.01, CI [-0.0009, 0.03], p = 0.269). The model's total explanatory power was moderate (conditional R^2 = 0.23) and the part related to the management type and humidity effects (marginal R^2) was of 0.06.

Berger-Parker index. Berger-Parker index (proportional abundance of the first dominant species) was the lowest in the organic disk management type (45 ± 17 %), the difference to the organic tillage was statistically non-significant (49 ± 17 %; beta 0.04, CI [-0.05, 0.12], p = 0.384), the difference to the conventional management type was statistically significant (58 ± 19 %; beta 0.12, CI [0.04, 0.21], p = 0.003; Fig. 3). The effect of Humidity was statistically non-significant (beta -0.002, CI [-0.13, 0.08], p = 0.669). The model's total explanatory power was moderate (conditional $R^2 = 0.23$) and the part related to the management type and humidity effects (marginal R^2) was of 0.08.

3. Spatial configuration

For the conventional management type, the variation of abundance, number of species and dominance occurred mainly at the middle and small scales (i.e., at the 25-centimeter and 7-centimeter plots), while large scales (meter plots) were less relevant (Fig. 4). In both organic management types, abundance varied at the 25-centimeter plots, but also at larger scales. In contrast to the conventional management type, number of species and dominance in both organic management types varied mainly at the meter-plot scale; in the organic tillage management type number of species varied also at the 25-centimeter scale.

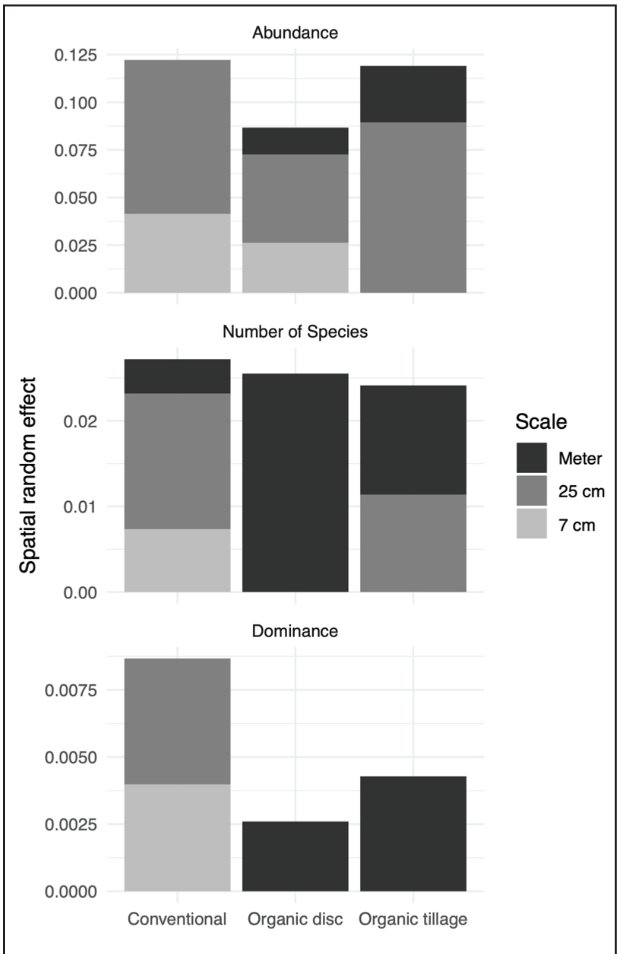

Figure 4. Spatial random effects explaining abundance, number of species and Berger-Parker index in samples in different management types. Grayscale palette shows scales (meters, 25cm-plots, 7-cm plots). Barplots show Tau parameter of the (spatial) random effects; mixed-effects models were run in each management type separately.

4. Discussion

Influence of management type on the abundance of springtails. In conventional farming, the application of mineral fertilizers has both negative and positive effects on soil fauna. Soil contamination with associated pollutants (Giller et al. 1998) and decreased soil biodiversity (Alvarez et al. 2001) are examples of the negative consequences; stimulation of the microbiota by the nutrient addition (Greenslade et al. 2010) and obvious grow of crop productivity are examples of the positive consequences. A published study showed no clear effect of herbicides, applied under conventional management on Collembola abundance, in comparison with organic agriculture (House et al. 1987). Insecticides can shift the community composition of Collembola by reducing the abundance of several species thereby favouring a few other species (Endlweber et al. 2006). In our case, Collembola abundance also did not significantly decrease in the fields of conventional farming compared with those of organic farming. Apparently, this was due to the counterbalancing of positive and negative impacts of mineral fertilizers on soil Collembola.

In our organic fields (ODISC and OTILL), mineral fertilizers were not used for more than 10 years. No chemical fertilizers combined with moderate tillage farming may have a negative effect on the number of springtails. The lack on nutrients, which conventionally are introduced with mineral fertilizers can be the main reason, since these nutrients are critical for increasing the yield and for stimulating the soil microbiota, the latter being the main food base for springtails. However, the absence of chemical fertilizers combined with disk tillage contributes to better conservation of nutrients in the soil and, accordingly, to preservation of soil biota resources (Bedoussac et al. 2015), reflected in a higher abundance of springtails as was also shown in our study. Regard must be paid to the effects of organic farming taking a long time to affect soil springtails. Three years appear to be an insufficient period for obvious changes in the Collembola community (Schrader et al. 2006). Our study suggests that these effects may still not be evident after 10 years.

Influence of management type on the species richness of springtails. Despite general trend of higher Collembola species richness under organic managements, no clear differences in the species richness of springtail communities were observed in our study. Similar numbers of species were mostly due to similar species lists under different management types (Kuznetsova et al. 2021). Apparently, the studied conventional management of wheat crops do not lead to complete extermination of species. This may be explained by adaptation of recorded species to life in agricultural fields, and generally higher resistance of Collembola, in comparison to many other soil animal groups, to ecosystem disturbance. However, some authors reported on differences in the species composition of springtails between different agricultural management types (Culik et al. 2002, Santos et al. 2018), suggesting that these effects are context-specific.

Influence of the field management type on the Berger-Parker index of springtails. High values of the dominance index are a common characteristic of harsh natural as well as disturbed habitats (Magurran 1992). Over-dominance, when the relative abundance of a single species exceeds 40 % of the total abundance, is common in Collembola communities of agricultural fields (Schrader et al. 2006). In our case, the dominance index was 45–58 % at a half of the studied fields. Increasing of the Berger-Parker index in the series ODISK—OTILL—CONV is significant and is the clearest effect we recorded in our study. Thus, we confirm that increase in management intensity (nutrient input and perturbation) lead to over-dominance in Collembola communities. This can serve as a sensitive indicator of soil disturbance (Kuznetsova 2009) and may have implications for stability of the system (Magurran 1992).

Influence of soil moisture content. Several authors found a positive correlation between the number of springtails and soil moisture content in agroecosystems (Choi et al. 2006, Schultz et al. 2006, Kardol et al. 2011). In our study, humidity had overall weak effect on the abundance of Collembola, and no effect on other parameters. We speculate that this was due to the overall high soil moisture (19.3–21.2 %) in our study sites at the sampling time (rainy July of 2019). Such favorable conditions may lead to more homogeneous distribution of Collembola communities in space.

Spatial configuration of Collembola under different field management types. The spatial distribution of individuals depends on both the external factors (alternating microsites with more and less suitable habitat conditions), and on the biological peculiarities of species (for example, reproduction, molting, protection against predators), as well as different rates of dispersion, stochastic events, and presence of interactions with other organisms/species (Vellend et al. 2010). This causes the formation of aggregations of different scale and mosaic distribution of Collembola in their habitats, repeatedly recorded on the scales from several centimeters to hundreds of meters (Gao et al. 2014, Saraeva et al. 2015, Widenfalk et al 2016).

Abundance and, to a lesser extent, other two parameters varied mainly at the 25 centimeter-plot scale in our fields (Fig.4), suggesting that local community processes in Collembola may act predominantly at this spatial scale. However, the spatial configuration was clearly different under different management types. Both organic management types were characterized by higher (at 1 meter-plots) spatial-grain mosaic of the abundance and diversity of Collembola. Such high level mosaic was not formed in the fields under the conventional management type, indicating more simple spatial configuration (i.e. at finer spatial scales). Such a simplification possibly affects also functional spatial matrix of these agroecosystems, but its general consequences remains unexplored. Modern methods of precision farming in agriculture require taking into account the spatial variation of soil properties (Finger et al. 2019). Perhaps the spatial distribution of soil fauna is also important to take into account in precision farming due to its role in nutrition of plants (Endlweber & Scheu 2007). Our study suggests that spatial grain of community parameter variation can serve as another potential indicator of soil ecosystem disturbance. This hypothesis, however, needs to be tested in various environmental settings.

5. Conclusions

Our study is among the first ones, testing the effects of organic agriculture on soil biodiversity and its spatial distribution aspects. We showed that the variation of Collembola abundance, species richness and dominance under different management types of wheat crop is relatively weak. The response of the Berger-Parker dominance index was the most informative: the organic farming with moderate tillage balances the structure of Collembola communities, reducing the effect of species over-domination. The response of the total abundance of Collembola was moderate, while the sample-scale species richness was nearly the same across all fields. The applied multiscale approach revealed the clear difference in the spatial configuration of Collembola communities between the two types of the organic farming and the conventional management. Large scale spatial mosaic was present in the former, but absent in the latter. The relationship between the taxonomic (i.e. dominance) and spatial structure of Collembola communities and soil ecosystem functioning is attractive avenue for future research.

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7. References

Agusti, N., S. P. Shayler, J. D. Harwood, I. P. Vaughan, K. D. Sunderland & W. O. C. Symondson (2003): Collembola as alternative prey sustaining spiders in arable ecosystems: prey detection within predators using molecular markers. – Molecular Ecology **12**(12): 3467–3475.

Aldoshin, S. S., E. N. Gorbacheva, S. G. Myshliakov & A. S. Skachkova (2015): Space monitoring of agricultural lands of Kaluga Region. – Geoprofi **4**: 10–14. [in Russian].

Altieri, M. A. (1999): The ecological role of biodiversity in agroecosystems. – Agriculture, Ecosystems & Environment **74**: 19–31.

Alvarez, T., G. K. Frampton & D. Goulson (2001): Epigeic Collembola in winter wheat under organic, integrated and conventional farm management regimes – Agriculture, Ecosystems & Environment: **83**(1–2): 95–110.

Baker, C. J., K. E. Saxton, W. R. Ritchie, W. C. T. Chamen, D. C. Reicosky, F. Ribeiro, S. E. Justice & P. R. Hobbs (2007): No-tillage seeding in conservation agriculture, 2nd edition. Edited by Baker, C. J. & K. E. Saxton. – Food and Agriculture Organization of the United Nations: 326 pp.

Bedoussac, L., E.-P. Journet, H. Hauggaard-Nielsen, C. Naudin, G. Corre-Hellou, E. S. Jensen, L. Prieur & E. Justes (2015): Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review – Agronomy for Sustainable Development **35**: 911–935.

Bengtsson, J., J. Ahnström & A.-C.Weibull (2005): The effects of organic agriculture on biodiversity and abundance: a meta-analysis. – Journal of Applied Ecology **42** (2): 261–269.

Bilde, T., J. A. Axelsen & S. Toft (2000): The value of Collembola from agricultural soils as food for a generalist predator. – Journal of applied ecology **37**(4): 672-683.

Chernova, N. M. (1982): Distribution of microarthropods in arable lands. – In: Antropogennoye Vozdeystviye na Faunu Pochv. – Moscow: 3–10. [in Russian].

Choi, W. I., D. L. Moorhead, D. A. Neher & M. I. Ryoo (2006): A modeling study of soil temperature and moisture effects on population dynamics of Paronychiurus kimi (Collembola: Onychiuridae). – Biology and Fertility of Soils **43**(1): 69–75.

Culik, M.P., J. L. Souza & J. A.Ventura (2002): Biodiversity of Collembola in tropical agricultural environments of Espírito Santo, Brazil. – Applied Soil Ecology **21**: 49–58.

Czarnecki, A. J. & R. Paprocki (1997): An attempt to characterize complex properties of agroecosystems based on soil fauna, soil properties and farming system in the north of Poland. – Biological Agriculture & Horticulture **15**(1–4): 11–23.

Dekkers, T. B. M., P. A. Werff & P. A. M. Amelsvoort (1994): Soil Collembola and Acari related to farming systems and crop rotations in organic farming. – Acta Zoologica Fennica **195**: 28–31.

Demetrio, W., O. Assis, C. C. Niva, M. L. C. Bartz, L. Paes, G. Cardoso, S. Ferreira, E. Santos, M. Marzagao, H. Nadolny et al. (2020): Comparison of soil invertebrate communities in organic and conventional production systems in Southern Brazil. – Soil Organisms **92**(2): 143–157.

Dray, S., R. Pelissier, P. Couteron, M.-J. Fortin, P. Legendre, P. R. Peres-Neto, E. Bellier, R. Bivand, F. G. Blanchet, M. Cáceres et al. (2012): Community ecology in the age of multivariate multiscale spatial analysis. – Ecological Monographs **82**(3): 257–275.

Ettema, C. H. & D. A. Wardle (2002): Spatial soil ecology. – Trends in ecology & evolution **17**(4): 177–183.

Endlweber, K., M. Schädler & S. Scheu (2006): Effects of foliar and soil insecticide applications on the collembolan community of an early set-aside arable field. – Applied Soil Ecology **31**(1-2): 136-146.

Endlweber, K. & S. Scheu (2007): Interactions between mycorrhizal fungi and Collembola: effects on root structure of competing plant species. – Biology and Fertility of Soils **43**: 741–749.

Filho, L. C. I. O., O. K. Filho, D. Baretta, C. A. S. Tanaka & J. P. Sousa (2016): Collembola Community Structure as a Tool to Assess Land Use Effects on Soil Quality. – Revista Brasileira de Ciência do Solo **40**: 1–18.

Filser, J. (2002): The role of Collembola in carbon and nitrogen cycling in soil: Proceedings of the Xth international Colloquium on Apterygota, České Budějovice 2000: Apterygota at the beginning of the third millennium. – Pedobiologia **46**(3–4): 234–245.

Filser, J., H. Fromm, R. E. Nagel & K. Winter (1995): Effects of previous intensive agricultural management on microorganisms and the biodiversity of soil fauna. – Plant and Soil **170**(1): 123–129.

Filser, J., J. H. Faber, A. V. Tiunov, L. Brussaard, J. Frouz, G. D. Deyn, A. V. Uvarov, M. P. Berg, P. Lavelle, M. Loreau et al. (2016): Soil fauna: key to new carbon models. – Soil **2**(4): 565–582.

Finger, R., S. M. Swinton, N. El Benni & A. Walter (2019): Precision farming at the nexus of agricultural production and the environment. – Annual Review of Resource Economics **11**(1): 313–335.

Fjellberg, A. (1998): The Collembola of Fennoscandia and Denmark. Part 1: Poduromorpha. Fauna Entomologica Scandinavica. – Brill Academic, Leiden.

Fjellberg, A. (2007): The Collembola of Fennoscandia and Denmark. Part II: Entomobryomorpha and Symphypleona. Fauna Entomologica Scandinavica. – Brill Academic, Leiden.

Fromm, H., K. Winter, J. Filser, R. Hantschel & F. Beese (1993): The influence of soil type and cultivation system on the spatial distributions of the soil fauna and microorganisms and their interactions. – Geoderma **60**(1-4): 109–118.

Gao, M., D. Liu, D. Wu & X. Zhang (2014): Spatial autocorrelation of aboveground and belowground mite communities in farmland of the Sanjiang Plain. – Acta Pedologica Sinica **51**(6): 1342–1350.

Giller, K. E., E. Witter & S. P. Mcgrath (1998): Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review. – Soil biology and biochemistry **30**(10-11): 1389–1414.

Goncharov, A. A., T. I. Chernov, N. A. Kuznetsova, I. P. Taranets, A. K. Tkhakakhova & M. I. Kartashov (2020): Springtails *Parisotoma notabilis* (Collembola: Isotomidae) indicate favourable conditions for *Fusarium* species in arable soil: an experimental study in a winter wheat field. – In: Bagirov, R., Yu. Maximova, E. Subbotina, M. Shcherbakov & A. Simakova (eds): Conceptual and applied aspects of scientific research and education in the field of invertebrate zoology: collection of articles V International conference. – Tomsk October 26–28. – Tomsk, Tomsk State University Press: 55–58.

Greenslade, P. J., I. A. Reid & I. J. Packer (2010): Herbicides have negligible effects on ants and springtails in an Australian wheat field. – Soil Biology and Biochemistry **42**: 1172–1175.

Hole, D. G., A. J. Perkins, J. D. Wilson, I. H. Alexander, P. V. Grice & A. D. Evans (2005): Does organic farming benefit biodiversity. – Biological Conservation **122**: 113–130.

Hopkin, S. P. (1997): Biology of the springtails (Insecta: Collembola). – Oxford University Press, Oxford, New York, Tokyo: 330 pp.

House, J. & R. W. Parmelee (1985): Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. – Soil and Tillage Research **5** (4): 351–360.

House, G. J., A. D. Worsham, T. J. Sheets & R. E. Stinner (1987): Herbicide effects on soil arthropod dynamics and wheat straw decomposition in a North Carolina no-tillage agroecosystem. – Biology and fertility of soils **4**(3): 109–114.

Kachinsky, N. A. (1965): Soil physics. Moscow: Publ. House High School. 321 pp. [in Russian].

Kardol, P., W. N. Reynolds, R. J. Norby & A. T. Classen (2011): Climate change effects on soil microarthropod abundance and community structure. – Applied Soil Ecology **47**(1): 37–44.

Kuznetsova, N. A. (2009): Communities in extreme natural and anthropogenic conditions: a case study of collembolan taxocoenoses. – In: Golovatch S. I., O. L. Makarova, A. B. Babenko & L. D. Penev (eds): Species and Communities in Extreme Environments. – Pensoft Publishers & KMK Scientific Press, Sofia-Moscow: 441–458.

Kuznetsova, N. A. & A. K. Saraeva (2018): Beta-diversity partitioning approach in soil zoology: A case of Collembola in pine forests. – Geoderma **332**: 142–152.

Kuznetsova N. A., M. B. Potapov, K. S. Panina, M. D. Antipova & A. I. Bokova (2021): Collembola of winter wheat fields in the Kaluga Region: conservation treatment versus conventional one. Version 1.6. Moscow Pedagogical State University (MPGU). Sampling event dataset [https://doi.org/10.15468/rv6g98].

Lavelle, P., T. Decaëns, M. Aubert, S. Barot, M. Blouin, F. Bureau, P. Margerie, P. Mora & J.-P. Rossi (2006): Soil invertebrates and ecosystem services. – European Journal of Soil Biology **42**: 3–15.

Maeder, P., A. Fliessbach, D. Dubois, L. Gunst, P. Fried & U. Niggli (2002): Soil Fertility and Biodiversity in Organic Farming. – Science **296**: 1694–1697.

Magurran, A. (1991): Ecological diversity and its measurement. London etc.: Chapmen a. Hall, 179 pp.

Marsh, C. J. & R. M. Ewers (2013): A fractal-based sampling design for ecological surveys quantifying β-diversity. – Methods in Ecology and Evolution **4**(1): 63–72.

Ortiz, D. C., M. A. B. Santos, L. C. I. Oliveira Filho, P. N. Pompeo, J. C. Niemeyer, O. K. Filho, C. Riviera, D. M. Baretta, J. A. Sampietro & D. Baretta (2019): Diversity of springtails (Collembola) in agricultural and forest systems in Southern Santa Catarina. – Biota Neotropica **19**(3): 1–9.

Paoletti, M. G., D. Pimentel, B. R. Stinner & D. Stinner (1992): Agroecosystem biodiversity: matching production and conservation biology. – Agriculture, Ecosystems & Environment **40**(1–4): 3–23.

Potapov, A., B. C. Bellini, S. L. Chown, L. Deharveng, F. Janssens, L. Kováč, N. Kuznetsova, J.-F. Ponge, M. Potapov, P. Querner, D. Russell, X. Sun, F. Zhang & M. P. Berg (2020): Towards a global synthesis of Collembola knowledge – challenges and potential solutions. – Soil Organisms **92**(3): 161–188.

Pretty, J. (2008): Agricultural sustainability: concepts, principles and evidence. – Philosophical Transactions of the Royal Society B: Biological Sciences **363**(1491): 447–465.

Reddersen, J. (1997): The arthropod fauna of organic versus conventional cereal fields in Denmark. – Biological Agriculture & Horticulture **15**(1–4): 61–71.

Rusek, J. (1998): Biodiversity of Collembola and their functional role in the ecosystem. – Biodiversity & Conservation **7**(9): 1207–1219.

Santos, M. A. B., L. C. Iunes, O. Filho, P. N. Pompeo, D. C. Ortiz, A. L. Mafra, O. K. Filho & D. Baretta (2018): Morphological diversity of springtails in land use systems. – Revista Brasileira de Ciência do Solo: 1–19.

Saraeva, A. K., M. B. Potapov & N. A. Kuznetsova (2015): Different-scale distribution of collembola in homogenous ground vegetation: Stability of parameters in space and time. – Entomological Review **95**(6): 699–714.

Schneider, C. & C. A. D'Haese (2013): Morphological and molecular insights on Megalothorax: the largest Neelipleona genus revisited (Collembola). – Invertebrate Systematics **27**(3): 317–364.

Schrader, S., J. Kiehne, T.-H. Anderson, H.-M. Paulsen & G. Rahmann (2006): Development of Collembolans after conversion towards organic farming. – Aspects of Applied Biology **79**: 181–185.

Schultz, B. J., J. R. Lensing & D. H. Wise (2006): Effects of altered precipitation and wolf spiders on the density and activity of forest-floor Collembola. – Pedobiologia **50**(1): 43–50.

Six, J., C. Feller, K. Denef, S. Ogle, J. C. de Moraes Sa & A. Albrecht (2002): Soil organic matter, biota and aggregation in temperate and tropical soils-Effects of no-tillage. – Agronomie **22**(7-8): 755–775.

Sousa J. P., T. Bolger, M. M. Gama, T. Lukkari, J.-F. Ponge, C. Simon, G. Traser, A. J. Vanbergen, A. Brennan, F. Dub et al. (2006): Changes in Collembola richness and diversity along a gradient of land-use intensity: a pan European study. – Pedobiologia **50**(2): 147–156.

Triplett, G. B. & W. A. Dick (2008): No-tillage crop production: a revolution in agriculture! – Celebrate the Centennial [A Supplement to Agronomy Journal]: 154–165.

Vellend, M. (2010): Conceptual Synthesis in Community Ecology. – The Quarterly Review of Biology **85**: 183–206.

Vorobyova, L. A. (1998): Chemical analysis of soils: Textbook. – Moscow University Press, 272 pp. [in Russian].

Willer, H. & M. Youssefi (2005): The World of Organic Agriculture. Statistics and Emerging Trends 2005. – International Federation of Organic Agriculture Movements (IFOAM), Bonn Germany, 7th, revised edition, slightly abridged version: 189 pp.

Widenfalk, L. A., A. Malmströma, M. P. Berg, & J. Bengtsson (2016): Small-scale Collembola community composition in a pine forest soil – overdispersion in functional traits indicates the importance of species interactions. – Soil Biology and Biochemistry **103**: 52–62 [http://dx.doi.org/10.1016/j.soilbio.2016.08.006].

World Reference Base for Soil Resources (2014) International soil classification system for naming soils and creating legends for soil maps. – World Soil Resources Reports No. update 2015. 106 FAO, Rome. IUSS Working Group WRB: 203 pp.

Supplementary materials

Table S1. Soil chemistry of the meter plots studied

Meter plots	pH KCl	TOMC, %	Ash, %
A1	6.2	1.6	97.6
A2	5.9	1.7	97.4
A3	5.8	1.4	95.7
B1	6.0	1.5	97.7
B2	5.9	1.5	97.4
B3	5.8	1.3	97.9
C1	4.9	1.8	97.0
C2	5.1	1.8	97.1
C3	4.9	1.8	97.3
D1	6.9	1.9	97.1
D2	6.8	2.0	96.8
D3	6.6	2.2	96.8
E1	5.2	2.1	96.5
E2	5.4	2.1	96.2
E3	5.4	1.8	96.9
F1	6.3	2.1	96.8
F2	5.6	2.3	96.2
F3	5.9	2.3	96.5

Ash – ash content, dry weight, %; **TOMC** – total organic matter content, %; **A, B, C, D, E, F** – fields (see Fig.1);
A1, A2, A3 etc. – meter-plots in a field.

Table S2. Average fraction content of the fields studied

Diameter of fraction, mm	1-0.5	0.5-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001
% (Mean ± 1 SD)	1.6 ± 1,5	4.6 ± 3.3	41.7 ± 5.0	38.4 ± 6.1	6.2 ± 1.1	5.3 ± 1.0	2.2 ± 0.3

Each average value calculated by 9 samples with 3 samples from each B, C, and E fields.

Table S3. Previous use of the fields studied

Name of field	Type of farmland	Crop, 2013	Crop, 2014	Crop, 2015	Crop, 2016	Crop, 2017	Culture, 2018	Culture, 2019	Culture, 2020
A	x	x	oat + clover	red clover + timothy clover	red clover+timothy perennial	herbaceous grasses	Perennial herbaceous grasses (legumes)	Winter wheat	Oats with litter (red fodder clover)
B		clover + timothy	oat	buckwheat	red clover + festulolium м	red clover +Festulolium	red clover +Festulolium	winter wheat	littered oats (mul. grasses)
C	arable land		fallow	fallow, forest	fallow, shrubbery	fallow	fallow	Winter wheat	Bedded oats (red forage) clover)
D	arable land	fallow	fallow	fallow	fallow	fallow	Buckwheat for green manure	Winter wheat	Peas
E						Perennial herbaceous forbs	Perennial herbaceous grass	Winter wheat	Peas
F						Perennial herbaceous grass	Perennial herbaceous grass	Winter wheat	Oats

Table S4. Collembola communities in fields with different management type options (ODISK, OTILL, CONV), taking into account the scale of consideration. A1, A2, A3 etc.: meter plots markings.

Scale	Abundance, ths. ind/m^2	Number of species	Berger-Parker Index, %
Management type			
OTILL	14.5	28	39.3
ODISK	21.4	29	20.4
CONV	17.4	27	32.1
Field			
OTILL A, B	11.0, 17.9	23, 23	21.5, 52.5
ODISK C, D	22.4, 20.4	26, 21	35.8, 28.2
CONV E, F	17.8, 17.0	20, 21	50.2, 52.2
Meter			
A1, A2, A3	10.0, 11.3, 11.9	16, 17, 21	0.26, 0.38, 0.18
B1, B2, B3	13.4, 19.9, 20.2	14, 16, 19	0.41, 0.53, 0.60
C1, C2, C3	26.0, 20.9, 20.3	17, 20, 21	0.40, 0.28, 0.39
D1, D2, D3	26.6, 21.2, 13.4	12, 14, 17	0.46, 0.34, 0.40
E1, E2, E3	22.9, 14.6, 16.0	15, 15, 15	0.26, 0.38, 0.18
F1, F2, F3	14.0, 18.8, 18.2	14, 16, 16	0.41, 0.53, 0.60