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The amount of mulch increases the abundance, and its composition the species diversity of springtails in crop rotation on chernozem soils

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Abstract

Mulching is widely used in agriculture to improve soil structure and agrochemical parameters. This is especially true for agroecosystems of steppe chernozems with strong wind erosion and occasional drought. The effect of mulch introduction to the springtail communities was studied in a multi-year field experiment using different mulch quantities (0 tons/ha, 4 tons/ha, 8 tons/ha, 12 tons/ha and 16 tons/ha) and composition (pea and wheat plant residues). No-till technology was applied in a six-field crop rotation (peas — winter wheat— sunflower— winter wheat — corn— winter wheat). Collembola or springtails, playing a significant role in soil formation, were set as a model group for assessing the state of soil animals. Both the general characteristics of the springtail community and the response of individual species to the introduction of plant residues were studied. Their total abundance was correlated positively with an increase in the amount of plant residues of any composition, while no significant changes in species richness (number of species) were noted. Species diversity, assessed by the Shannon-Weaver index, significantly differed when plant residues of different compositions were introduced, while the amount of mulch did not affect this indicator. Different groups of springtail life forms reacted differently to the composition and amount of mulch. The number of springtails increased mainly due to hemiedaphic springtail species, both when plant residues of peas and wheat were introduced. Certain springtail species increased in abundance to the maximum (*P. notabilis*) and minimum (*S. elegans*, *S. niger*, *C. succinea*) amount of plant residues, while other species were associated with the composition of the mulch (*D. tigrina*, *S. pumilis*, *P. alba*) were identified. These results show that mulch management has pronounced impacts on springtail communities, which can inform management practices to improve the functioning of sustainable soil ecosystems in the future.

Keywords Agroecosystems | Collembola | plant residues | field experiment | steppe zone

1. Introduction

Many studies have shown that traditional agriculture leads to soil depletion, reduced fertility, disruption of its structure, and reduction of soil biota (Lal 2015, Bender et al. 2016, Plaas et al. 2019). The negative effects of conventional agriculture are partly minimized by applying no-till technology (Frey et al. 1999, Barrios 2007), which has become widespread in a number of Western European countries, the USA, Argentina, Australia, Paraguay, South Africa, India, and Brazil (Baker & Saxton 2007). In the latter, for example, crop fields with no-till technology occupy from 30 to 70 % of all agricultural areas (Six et al. 2002). The overall effect of this technology is obvious when combined with the preservation of crop residues (mulching) on the soil

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surface (Hobbs 2007, Singh & Rengel 2007, Pittelkow et al. 2015, Knapp & van der Heijden 2018, Kassam et al. 2019).

Conventional tillage results in dry soils, while no-till technology and mulching reduce water loss in the soil. In addition, the conservation of crop residues reduces both wind and water erosion and increases soil infiltration (Groen & Woods 2008, Basche et al. 2016). The reduction of temperature variability in the soil is another significant advantage of this technology, especially in areas with a large daily temperature fluctuation (Dabney et al. 2001). Conventional tillage destroys the natural structure of the soil, which negatively impacts the soil porosity, despite increasing soil aeration (Mordhorst et al. 2014). No-till technology with mulching minimizes the destruction of soil structure which increases organic matter stock (Hobbs 2007) and nitrogen fixation in the soil (Siczek & Lipiec 2011). Soil fertility depends highly on soil biodiversity, of which microarthropods make up a significant portion. Microarthropods are involved in organic matter decomposition and nutrient cycling (Wall & Nielsen 2012, Conti 2015, Gagnarli et al. 2021). Generally, tillage reduces the species and genetic diversity of microarthropods, causing the loss of a number of functional groups (Vandermeer et al. 1998).

Springtails are a large group of microarthropods in agroecosystems (Cluzeau et al. 2012). They contribute greatly to litter decomposition by stimulating microbial activity (Chahartaghi et al. 2005, Schneider et al. 2012). Moreover, springtails are often central to soil food chains, as they are not only consumers of microorganisms (Turnbull & Lindo 2015, Thakur & Geisen 2019), but are also prey to such predators as centipedes, spiders, and predatory mites (Turnbull & Lindo 2015, Yin et al. 2019). Because of their high sensitivity to environmental changes, springtails are often used as indicators to assess environmental degradation and soil quality (Gardi & Parisi 2002, Hågvar & Klanderud 2009).

The springtail community has been shown to respond inconsistently to the preservation of plant residues on the soil surface. In general, the abundance of springtails increases in fields with mulching (Culik et al. 2002, Wang et al. 2011), although both species richness and diversity do not always depend directly on the presence of mulch (Buchholz et al. 2017, Jiang et al. 2021). Some authors explain such response of the springtail community by the influence of climatic conditions (Thomson & Hoffman 2007). Only a few studies are known that have studied the response of springtails in agroecosystems to different amounts of plant residues (Jiang et al. 2021) and their composition (Badejo et al. 1995). These studies are important for determining the optimal amount of mulch and its composition in the fields.

In our study, springtail communities in chernozem soils in agroecosystems were studied using no-till technology and mulching in crop rotation. The study aims to assess the response of the springtail community to the introduction of different amounts of plant residues in a field experiment for chernozem soils for the first time.

2. Materials and Methods

2.1 Study area characteristics and weather conditions

The study area is located in the south of the European part of Russia, in the Stavropol Krai (45°07′48″ N 42°01′39″ E, Shpakovsky District, Stavropol Krai). The average air temperature in winter is -1.6°C, in summer, +21.5°C. The average annual rainfall is 767 mm. The humidity coefficient (HC), reflecting the balance between precipitation and evaporation, is 0.27–0.31, which indicates a lack of moisture. According to long-term observations, April, May and June are characterized by abundant moisture, dry periods here are usually observed in July, and very dry periods in August. However, it is noted that dry and very dry periods may continue throughout the entire growing season. The probability of dry years (HC < 0.15) varies from 1 to 9 % (Kulintsev et al. 2013).

2.2 Experiment design

The experiment was launched in July 2020 as a six-field crop rotation, where peas, winter wheat, sunflower, winter wheat, corn and winter wheat replace each other. This experiment is based on fields with no-till and with the removal or preservation of plant residues. Detailed crop cultivation technology in the experiment is given in Tab. S1. According to the experimental design, stubble residues of the previous crop (peas in 2021, wheat in 2022) were manually placed on the plots in the amount of 0, 4, 8, 12 and 16 tons/ha. Mulch was applied in August of 2020 and 2021. The crop residues collected from these fields were used as mulch. The experiment was replicated three times, and the plot area used was 168 (11.2 × 15.0) m^2 (Fig. 1). The study was carried out over two years. Sampling was done on April 28, 2021 and April 27, 2022. Our study began one year after the start of the experiment in order to assess the response of the springtail community to the introduction or removal of plant residues. The average monthly air temperature in April was +9.7°C and +11.9°C with a total precipitation of 71 mm and 25 mm in 2021 and 2022, respectively. In the spring of 2021, samples were taken from plots with 0, 8, and 16 tons/ha to describe the overall pattern of the mulch effect on the springtail community. A clear response of springtails to ≥ 8 tons/ha of mulch was found; therefore, in the spring of 2022, samples were taken from all experimental plots (0, 4, 8, 12, and 16 tons/ha) to assess threshold effects. Samples (50 cm^2 area, 15 cm depth) were taken at the beginning and at the end of each plot in 2021; and at the beginning, middle and end of each plot in 2022. A total of 63 samples were collected over the two years of the study (Fig. 1).

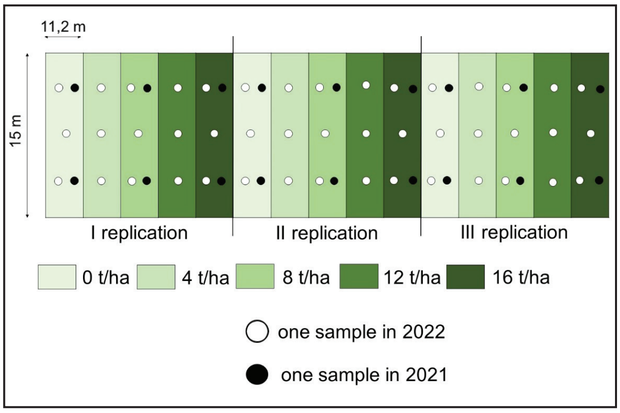

Figure 1. Sampling scheme. ● – samples taken in 2021, ○ – in 2022.

2.3 Taxonomic analysis.

Springtails were extracted from the samples according to the standard method using Tullgren funnels until completely dry (Phillipson 1971). All material was placed in permanent slides with Faure's liquid and identified down to the species level using taxonomic keys (Fjellberg 1998, 2007, Schneider & D'Haese 2013, Potapov 2001). Life forms of springtails were identified according to the classification of Stebaeva (1970). A total of 2150 specimens of 23 springtail species were analyzed.

2.4 Statistical methods

Statistical processing of the samples was carried out for the entire data set (2021–2022). Generalized random-effects log-linked linear models (GLMM) were applied to estimate the effect of mulch amount and composition (independent variables) on abundance, species richness and life forms (dependent variables). To assess the effect of mulch quantity and composition on species diversity (dependent variable), we used linear mixed-effects models. Species diversity was calculated using the Shannon-Weaver index ($H = -\Sigma pi *log2\ pi$, where pi is the share of each species in the community). The random factor was the repetition of sampling sites. To assess the significance of the effect of different amounts of mulch, we used diagnostic plots of Pearson's residuals. The package 'lme 4' (Bates 2010) in R software version 4.2.2 (R Core Team 2022) was used for data analysis.

The effect of the amount of mulch on the species structure of the springtail community over the 2-year study was assessed using permutational nonparametric multivariate analysis of variance (PERMANOVA) based on the Jaccard similarity index (), where a is the number of species in one sample, b is the number of species in another sample, c is the number of common species in two samples. PERMANOVA makes a calculation using the distance matrix, so the original data was reformatted into a distance matrix. The Jaccard similarity coefficient (from 0 to 1) was taken as the distance. Species complexes were analyzed using Principal Coordinate Analysis (PCoA). The 'vegdist' function in the 'vegan' package was used (Oksanen et al. 2013).

Redundancy analysis (RDA) was applied to assess the correlation between high-abundance springtail species and the independent variables (mulch amount and its composition). High-abundance species were set as having relative abundance exceeding 10 % of the total abundance at least in one of the experimental variants. The analysis was performed using the 'vegan' package (Oksanen et al. 2013) and 'packfor' (Dray et al. 2007).

3. Results

3.1 Effect of the mulch amount and composition on the abundance, species richness, and species diversity of the springtail community

The springtail community responded significantly to the introduction of various amounts of plant residues into the soil (Tab. 1). The total abundance of springtails increased when the plant residues were introduced. If the pea mulch was added, springtail abundance increased by about 2.5 times, with wheat mulch, by about fivefold (Fig. 2A). The abundance of springtails significantly increased if the mulch biomass was 8 and 16 t/ha (Fig. S1).

The effects of the amount and composition of mulch on the springtail species richness were variable. Insignificant opposite trends were observed when comparing the effect(s) of wheat and pea mulch at different amounts. The absolute number of species tended to increase slightly at the pea

Table 1. Estimation of parameters and their standard errors (SE) from GLMM and LM models containing parameters describing a Collembola community with different amounts and compositions of mulch.

Parameter	**Estimate ± SE**	***z*-value**	***p***
Abundance			
Intercept	1.07 ± 0.42	2.53	< 0.05
Amount of mulch	0.07 ± 0.02	4.41	< 0.001
Mulch composition	0.90 ± 0.23	3.97	< 0.001
Species richness			
Intercept	1.87 ± 0.22	8.40	< 0.001
Amount of mulch	-0.001 ± 0.01	-0.16	0.87
Mulch composition	-0.20 ± 0.12	-0.61	0.11
Parameter	**Estimate ± SE**	**t-value**	***p***
Species diversity			
Intercept	2.87 ± 0.30	9.44	< 0.001
Amount of mulch	-0.04 ± 0.01	-3.41	0.99
Mulch composition	-0.59 ± 0.17	-3.59	< 0.001

mulch presence, while the presence of the wheat mulch resulted in a reduction of the number of species (Fig. 2B). However, species diversity, estimated by the Shannon-Weaver index, significantly differed when plant residues of different composition were introduced (Fig. 2C). No effect on the species diversity of the springtail community was found when introducing varying amounts of mulch.

3.1 The influence of the mulch amount on the abundance of life forms of springtails

The composition and amount of mulch significantly affected the abundance of all groups of life forms of springtails in different ways (Tab. 2). The abundance of all groups increased with the introduction of pea mulch. Epigeic springtails were the dominant group at the plots with no plant residues. The abundance of epigeic springtails increased insignificantly when the maximum amount of plant residues was introduced, but that of the hemidaphic Collembola increased fourfold, and an eightfold increase for the euedaphic springtails (Fig. 3A).

The different groups of springtail life forms responded inconsistently to the application of different amounts of wheat mulch (Fig. 3). Although epigeic springtails were present on the plots with no plant particles, their abundance barely changed as the amount of mulch varied. The response of the hemiedaphic group was the most pronounced. These species increased in abundance

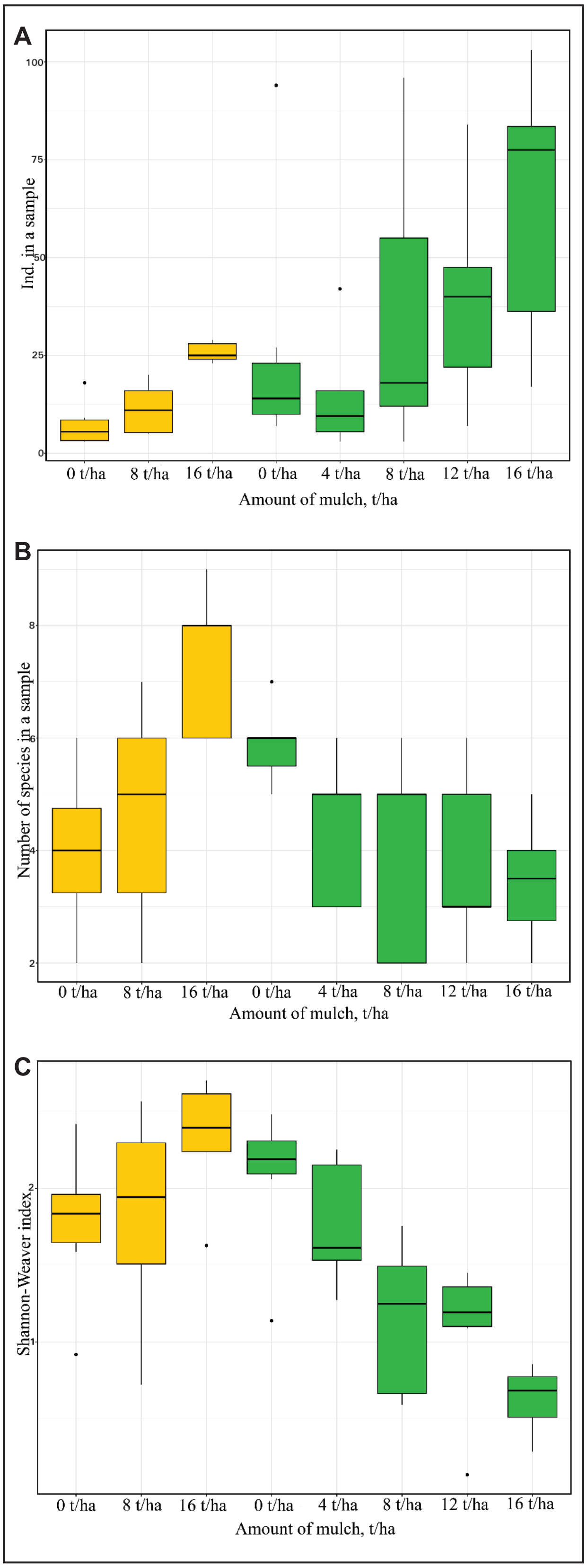

Figure 2. Influence of the amount of mulch on the total abundance (**A**), species richness (**B**), and species diversity (**C**) of a springtail community. 🟨 boxplot – plant residues of peas, 🟩 boxplot – plant residues of wheat.

Table 2. Estimation of parameters and their standard errors (SE) of the influence of the amount and composition of mulch on springtail life form groups using the GLMM model.

Parameter	Estimate ± SE	*z*-value	*p*
Plant residues of peas			
Intercept	1.02 ± 0.26	3.99	<0.001
Amount of mulch	0.09 ± 0.02	4.20	<0.001
Life forms	0.45 ± 0.18	-2.48	<0.05
Plant residues of wheat			
Intercept	2.01 ± 0.29	7.04	<0.001
Amount of mulch	0.15 ± 0.03	6.39	<0.001
Life forms	-1.27 ± 0.22	-5.77	<0.001

nearly immediately after a large amount of mulch (4 t/ha) was introduced to the plot. However, when the maximum amount of plant residues (16 t/ha) was added, their abundance increased by 60 times. The euedaphic group also responded positively to the introduction of plant residues, however, only when a maximum amount was added (Fig. 3B).

3.2 Influence of the mulch amount on the species structure of the springtail community

Over two years of research, 23 springtail species from 11 families were identified (Tab. S2). The most numerous species when pea mulch was added were *Desoria tigrina* Tullberg, *Parisotoma notabilis* Schäffer, *Sphaeridia pumilis* Krausbauer and *Pseudosinella alba* Packard, as well as species of the genus *Mesaphorura* Börner. *Sminthurinus elegans* Fitch, *Sminthurinus niger* Lubbock, *Ceratophysella succinea* Gisin, and species of the genus *Entomobrya* Rondani joined the list when wheat mulch was used, but in this case *P. alba*, *S. pumilis*, and *D. tigrina* reduced their numbers.

Two different springtail groupings formed clearly (Fig. 4A, B) according to the results of nonparametric analysis (PERMANOVA). The first grouping was formed on the control plots and when the minimum amount of mulch was applied, the other one, at the plots, where a larger amount of mulch was introduced (8–16 t/ha). Both developed models showed a significant difference between these groupings. Although the species composition of the springtail community varied depending on the mulch composition (Tab. S2), the species structure remained similar in both cases. In both cases, the control plots (0 t/ha) were very similar in the structure of springtail local groupings. On the contrary, all plots with the introduction of mulch were characterized by a significant variability of groupings in individual samples, calculated using the Jaccard index.

3.3 Effect of mulch amount and composition on highly abundant springtail species

According to RDA (Fig. 5), the first canonical axis explained ~64 % of the variance ($F = 16.03, p > 0.001$). The highest correlation was established with the absence of plant residues (Tab. S4); among all the springtail species tested, *P. notabilis* exhibited the highest correlation (Tab. S4). The second axis of the RDA accounted for ~25 % of the variance ($F = 6.38$, $p > 0.001$). The highest correlation was found with mulch composition (Tab. S3), where *S. pumilis* was the most affected (Tab. S4).

A group of epigean springtail species such as *S. elegans, Entomobrya* sp. juv., *S. niger, C. succinea* were most abundant on the plots with little or no mulch. With the introduction of a large mulch amount (12 and 16 tons/ha), the abundance of hemiedaphic species *P. notabilis*

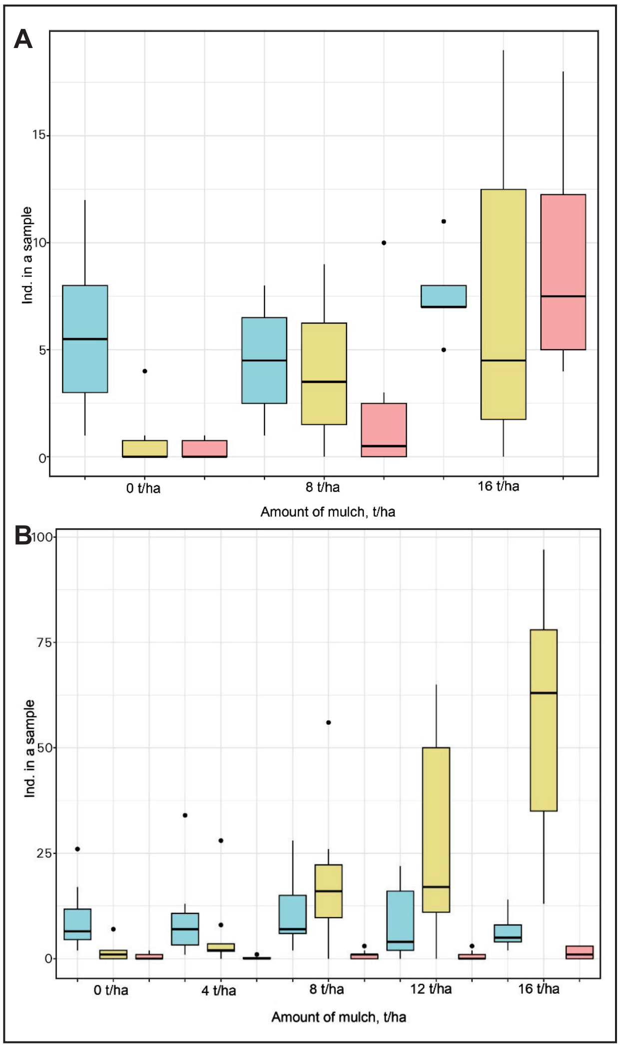

Figure 3. Effect of the mulch amount and composition on groups of life forms. 🟦 – epigeic, 🟨 – hemiedaphic, 🟥 — euedaphic. (**A**) plant residues of peas, (**B**) plant residues of wheat.

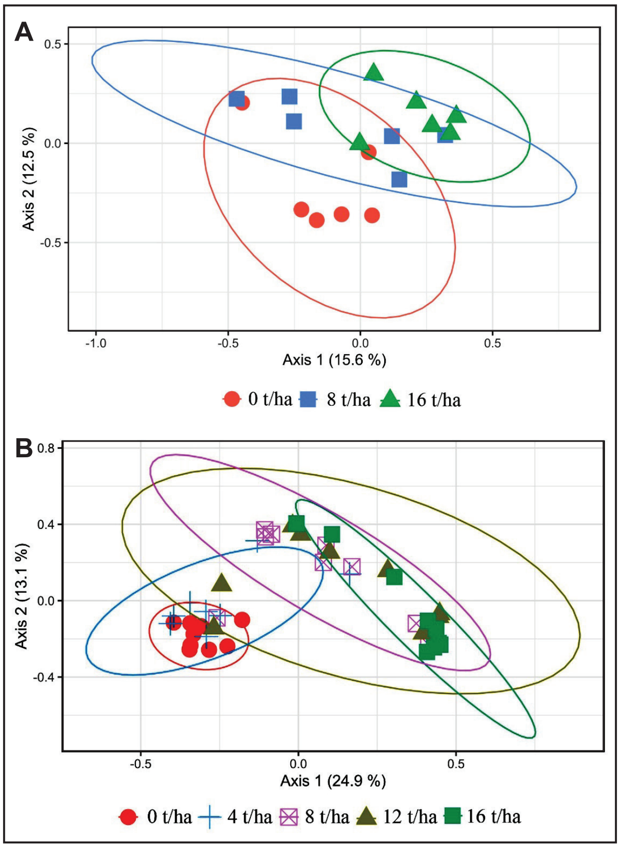

Figure 4. Non-metric PCoA plots of the Collembola community The Jaccard similarity coefficient was taken as the distance between dots. (**A**) plant residues of peas, (**B**) plant residues of wheat.

increased. Abundance of *D. tigrina, S. pumilis, P. alba,* and of the species of the genus *Mesaphorura* correlated with mulch composition significantly (Fig. 5, Tab. S2).

4. Discussion

Effect of the mulch amount and composition on the abundance, species richness and species diversity of the springtail community. The increase in the abundance of springtails with the preservation of plant residues on the soil surface is associated with the maintenance of favorable and more stable conditions of humidity and temperature, as well as with an increase in food resources (Culik et al. 2002, Nakamoto & Tsukamoto 2006, Wang et al. 2011). The addition of mulch contributes to the improvement of the capacity of the springtail environment, which is associated with both the addition of food resources and the expansion of habitable space ('living litter' concept, Fujii et al. 2020). The addition of mulch stimulates fungal decomposition (Nakamoto & Tsukamoto 2006), and micromycetes are springtails' main food resource (Berg & Bengtsson 2007). Even though the stimulating effect of adding crop residues has been repeatedly shown, information on the effect of different amounts and composition of mulch within the same experiment is practically absent. In our experiment, the abundance of springtails began to increase significantly in steppe chernozem soils with the introduction of 8.0 tons/ha. Almost the same results were obtained in a study on dark meadow soils (Jiang et al. 2021). An increase in the abundance of springtails with the addition of plant residues in our experiment may indicate the effectiveness of this method in conditions of insufficient moisture, since springtails are known as a generally moisture-loving group (Hopkin 1997). Data on the effect of mulch on springtail species richness and diversity are mixed. In some cases, this indicator increases in subtropical and tropical agroecosystems (Culik et al. 2002, Nakamoto & Tsukamoto 2006). In the others, the diversity of soil animals (including springtails) drops; this is explained by an increase in the abundance of predatory arthropods and/or with the overdominance of certain species, for which optimal conditions and resource base are formed (Kromp 1989, Brennan et al. 2006, Buchholz et al. 2017). In our study, with the introduction of different amounts of plant residues, no significant change in the diversity of springtails (according to the Shannon-Weaver index) was found, but it was found that the composition of the mulch affects this indicator (Fig. 2C, Tab. 1).

The influence of the mulch amount on the abundance of life forms of springtails. Springtails of different life forms have different migratory activities. The most mobile epigean forms, living on the soil surface, can colonize open areas by migrating from nearby areas (Ojala & Huhta 2001, Ponge et al. 2006, Ponge & Salmon 2013). Perhaps this is why, in our experiment, springtail

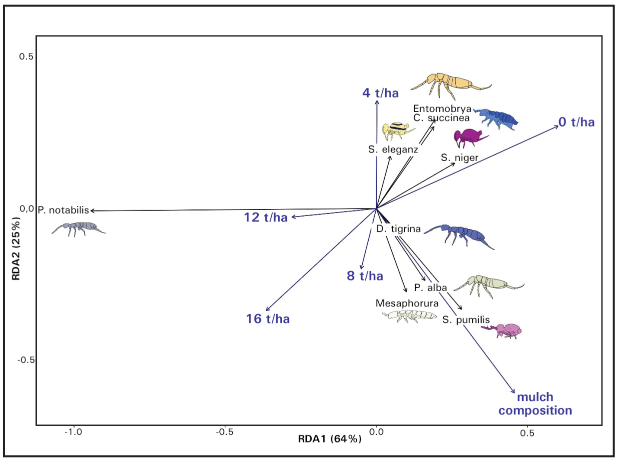

Figure 5. Species-treatment plot resulting from redundancy analyses (RDA) of Collembola community composition.

communities in the control and in areas with a minimum amount of plant residues were represented by epigean species. The dispersal possibilities of hemiedaphic forms living in the upper soil layer were limited. When more mulch was added, their numbers increased. This happened not due to migration, but due to the creation of optimal microenvironmental conditions and an increase in food resources. This resulted in stimulation of the reproduction of hemiedaphic species living in mulch areas (Moos et al. 2020, Santorufo et al. 2021). In our samples, euedaphic springtails were low in abundance. On the one hand, this may be explained by the relatively shallow sampling depth of 15 cm. It is known that on chernozem soils, species of this group may also penetrate into deeper layers, half a meter or even more (Shveenkova 2022). On the other hand, according to this author, in the steppe zone, euedaphic springtails are sparse and usually do not reach a high abundance. Therefore, the study of deeper soil layers would significantly increase the sampling effort but would add little information to achieve the study goal. A significant response of euedaphic springtails to the mulch introduction was noted only for its maximum amount in plots with the introduction of wheat plant residues.

The influence of mulch amount and composition on species composition and community structure. The increased heterogeneity of springtail communities is one of the most noticeable effects of mulching. In our experiment, the formation of two contrasting communities of springtails, differing in species structure, occurs due to changes in microenvironmental conditions and resource base. These changes are provided by the addition of mulch in the amount of 8 t/ha or more, which is consistent with our results above. When mulch of different composition is added, the species structure of springtails does not change. In our study, the distribution of highly abundant springtail species into two groups, confined to plots with minimal mulch and those with maximum mulch, corresponds to the distribution of life form groups. The first grouping includes the epigeic species *S. elegans*, *Entomobrya* sp. juv., *S. niger* and the hemiedaphic *C. succinea* are associated with agroecosystems or are eurytopic. This group is fast-dispersal and easily occupies open habitats (Ponge et al. 2006). The second group is represented by a single hemiedaphic dominant species *P. notabilis*, which is a eurytopic colonizing species. This species is a parthenogenetic, so rapid reproduction allows it to colonize new territories and use all available resources (Coulibaly et al. 2017, Potapov 2001). In our study, the abundance of this species increased by two orders of magnitude. In addition, other studies have shown that the abundance of this species is positively correlated with the abundance of *Fusarium* species, which is a soil pathogen on wheat and other plants (Chernov et al. 2020). The likely reason for this association is the feeding of *P. notabilis Fusarium* spp. Thus, the addition of mulch stimulates an increase in the abundance of *P. notabilis*, a species capable of controlling cereal diseases caused by pathogenic *Fusarium* species.

5. Conclusions

The application of mulch in agroecosystems contributes to the increase in the number of microarthropods, such as springtails, which play a significant role in the decomposition of plant residues, returning nutrients to the field soil. At the same time, species diversity depends on the composition of mulch, and total springtail abundance on mulch quantity. The optimal amount of mulch in agroecosystems on chernozem soils with unstable moisture was ≥ 8 t/ha in our study. When such an amount of mulch is applied, the springtail community increases not only its total abundance, but also changes its species structure. The most sensitive springtails to the increase in the amount of mulch were hemiedaphic life forms. The results of our study may provide guidance to agricultural management practitioners to increase biodiversity and improve the functioning of sustainable soil ecosystems in the future.

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7. References

Badejo, M. A., G. Tian, L. & Brussaard (1995): Effect of various mulches on soil microarthropods under a maize crop. – Biology and Fertility of Soils **20**: 294–298.

Baker, C. J., & K. E. Saxton, (2007): The 'what'and 'why'of no-tillage farming. – In: Baker, C. J., & K. E. Saxton (eds): No-tillage seeding in conservation agriculture. – CAB International, London: 1–3.

Barrios, E. (2007): Soil biota, ecosystem services and land productivity. – Ecological economics **64**(2): 269–285.

Basche, A. D., T. C. Kaspar, S. V. Archontoulis, D. B. Jaynes,

T. J. Sauer, T. B. Parkin & F. E. Miguez (2016): Soil water improvements with the long-term use of a winter rye cover crop. – Agricultural Water Management **172**: 40–50.

Bates, D. M. (2010): lme4: Mixed-effects modeling with R. – Springer: 131pp.

Bender, S. F., C. Wagg & M. G. van der Heijden (2016): An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. – Trends in ecology & evolution **31**(6): 440–452.

Berg, M. P. & J. Bengtsson (2007): Temporal and spatial variability in soil food web structure. – Oikos **116**(11): 1789–1804.

Brennan, A., T. Fortune & T. Bolger (2006): Collembola abundances and assemblage structures in conventionally tilled and conservation tillage arable systems. – Pedobiologia **50**(2): 135–145.

Buchholz, J., P. Querner, D. Paredes, T. Bauer, P. Strauss, M. Guernion, J. Scimia, D. Cluzeau, F. Burel, S. Kratschmer & et al. (2017): Soil biota in vineyards are more influenced by plants and soil quality than by tillage intensity or the surrounding landscape. – Scientific Reports **7**(1): 17445.

Chahartaghi, M., R. Langel, S. Scheu & L. Ruess (2005): Feeding guilds in Collembola based on nitrogen stable isotope ratios. – Soil Biology and Biochemistry **37**(9): 1718–1725.

Chernov, T. I., N. A. Kuznetsova, I. P. Taranets, A. K., Tkhakakhova, M. I. Kartashov & A. A. Goncharov (2020): Springtails Parisotoma notabiilis (Collembola: isotomidae) indicate favourable conditions for Fusarium species in arable soil: an experimental study in a winter wheat field. – In: Conceptual and applied aspects of scientific research and education in the field of invertebrate zoology: collection of articles V International conference. – Tomsk: Tomsk State University Press: 55–58.

Cluzeau, D., M, Guernion , R. Chaussod, F. Martin-Laurent, C. Villenave, J. Cortet, N. Ruiz-Camacho, C. Pernin, T. Mateill, L. Philippot & et al. (2012): Integration of biodiversity in soil quality monitoring: Baselines for microbial and soil fauna parameters for different land-use types. – European Journal of Soil Biology **49**: 63–72.

Conti, F. D. (2015): Conservation agriculture and soil fauna: only benefits or also potential threats? A review. – ECronicon Agriculture **2**: 473–482.

Coulibaly, S. F., V. Coudrain, M. Hedde, N. Brunet, B. Mary, S. Recous & M. Chauvat (2017): Effect of different crop management practices on soil Collembola assemblages: A 4-year follow-up. – Applied Soil Ecology **119**: 354–366.

Culik, M. P., J. L. de Souza & J. A. Ventura (2002): Biodiversity of Collembola in tropical agricultural environments of Espırito Santo, Brazil. – Applied Soil Ecology **21**(1): 49–58.

Dabney, S. M., J. A. Delgado & D. W. Reeves (2001): Using winter cover crops to improve soil and water quality. – Communications in Soil Science and Plant Analysis **32**(7-8): 1221–1250.

Dray, S., P. Legendre & G. Blanchet (2007): Packfor: forward selection with permutation. – R package version 0.0-7.

Fjellberg, A. (1998): The Collembola of Fennoscandia and Denmark. Part I: Poduromorpha. – Brill, Leiden: 186pp.

Fjellberg, A. (2007): The Collembola of Fennoscandia and Denmark, Part II: Entomobryomorpha and Symphypleona. – Brill, Leiden: 265pp.

Frey, S. D., E. T. Elliott & K. Paustian (1999): Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. – Soil Biology and Biochemistry **31**(4): 573–585.

Fujii, S., M. P. Berg & J. H. Cornelissen (2020): Living litter: dynamic trait spectra predict fauna composition. – Trends in Ecology & Evolution **35**(10): 886–896.

Gagnarli, E., G. Valboa, N. Vignozzi, D. Goggioli, S. Guidi, F. Tarchi, L. Corino & S. Simoni (2021): Effects of Land-Use Change on Soil Functionality and Biodiversity: Toward Sustainable Planning of New Vineyards. – Land **10** (4): 358.

Gardi, C. & V. Parisi (2002): Use of microarthropods as biological indicators of soil quality: The BSQ sinthetic indicator. – In: 7. International Meeting on: Soils with Mediterranean Type of Climate. – Valenzano, Italy: 297–304.

Groen, A. H., & S. W. Woods (2008): Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. – International Journal of Wildland Fire **17**(5): 559–571.

Hågvar, S. & K. Klanderud (2009): Effect of simulated environmental change on alpine soil arthropods. – Global Change Biology **15**(12): 2972–2980.

Hobbs, P. R. (2007): Conservation agriculture: what is it and why is it important for future sustainable food production? – The Journal of Agricultural Science **145**(2): 127.

Hopkin, S. P. (1997): Biology of the springtails: (Insecta: Collembola). – OUP Oxford: 334pp.

Jiang, Y., H. Xie & Z. Chen (2021): Relationship between the amounts of surface corn stover mulch and soil mesofauna assemblage varies with the season in cultivated areas of northeastern China. – Soil and Tillage Research **213**: 105091.

Kassam, A., T. Friedrich & R. Derpsch (2019): Global spread of conservation agriculture. – International Journal of Environmental Studies **76**(1): 29–51.

Knapp, S. & M. G. van der Heijden (2018): A global meta-analysis of yield stability in organic and conservation agriculture. – Nature communications **9**(1): 3632.

Kromp, B. (1989): Carabid beetle communities (Carabidae, Coleoptera) in biologically and conventionally farmed agroecosystems. – Agriculture, ecosystems & environment **27**(1-4): 241–251.

Kulintsev, V. V., E. I. Godunova & L. I. Zhelnakova (2013): System of New Generation Agriculture of the Stavropol territory. – Stavropol. Agrus of Stavropol, State Agrarian University: 520pp. (In Russ.).

Lal, R. (2015): Restoring soil quality to mitigate soil degradation. – Sustainability **7**(5): 5875–5895.

Moos, J. H., S. Schrader & H. M. Paulsen (2020): Minor changes in collembolan communities under different organic crop rotations and tillage regimes. – Journal of Sustainable and Organic Agriculture **70**: 113–128.

Mordhorst, A., S. Peth & R. Horn (2014): Influence of mechanical loading on static and dynamic CO2 efflux on differently textured and managed Luvisols. – Geoderma 219: 1–13.

Nakamoto, T. & M. Tsukamoto (2006): Abundance and activity of soil organisms in fields of maize grown with a white clover living mulch. – Agriculture, ecosystems & environment **115**(1-4): 34–42.

Ojala, R. & V. Huhta (2001): Dispersal of microarthropods in forest soil. – Pedobiologia **45**(5): 443–450.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'hara, G. V. Simpson, P. Solymos, M. H. H. Stevens & H. Wagner (2013): Package 'vegan'. – Community ecology package, version **2**(9): 1–295.

Phillipson, J. (1971): Methods of study in quantitative soil ecology: population, production and energy flow. – Oxford, Paris.

Pittelkow, C. M., X. Liang, B. A. Linquist, K. J. van Groenigen, J. Lee, M. E. Lundy, N. van Gestel, J. Six, R. T. Venterea & C. van Kessel (2015): Productivity limits and potentials of the principles of conservation agriculture. – Nature **517**(7534): 365–368.

Plaas, E., F. Meyer-Wolfarth, M. Banse, J. Bengtsson, H. Bergmann, J. Faber, M. Potthoff, T. Runge, S. Schrader & A. Taylor (2019): Towards valuation of biodiversity in agricultural soils: A case for earthworms. – Ecological economics **159**: 291–300.

Ponge, J. F., F. Dubs, S. Gillet, J. P. Sousa & P. Lavelle (2006): Decreased biodiversity in soil springtail communities: the importance of dispersal and landuse history in heterogeneous landscapes. – Soil Biology and Biochemistry **38**(5): 1158–1161.

Ponge, J. F. & S. Salmon (2013): Spatial and taxonomic correlates of species and species trait assemblages in soil invertebrate communities. – Pedobiologia **56**(3): 129–136.

Potapov, M. (2001): Synopses on Palaearctic Collembola: Isotomidae. – Abhandlungen und Berichte des Naturkundemuseums Görlitz **73**: 1–603.

Santorufo, L., S. Joimel, A. Auclerc, J. Deremiens, G. Grisard, M. Hedde, J. Nahmani, C. Pernin & J. Cortet (2021): Early colonization of constructed technosol by microarthropods. – Ecological Engineering **162**: 106174.

Schneider, T. K. M. Keiblinger, E. Schmid, K. Sterflinger-Gleixner, G. Ellersdorfer, B. Roschitzki, A. Richter, L. Eberl, S. Zechmeister-Boltenstern & K. Riedel (2012): Who is who in litter decomposition? Metaproteomics reveals major microbial players and their biogeochemical functions. – The ISME journal **6**(9): 1749–1762.

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.

Shveenkova, Yu. B. (2022): The collembolan fauna (Hexapoda: Collembola) of the «Privolzhskayalesostep» reserve and adjacent territories in the Penza region. – Russian Journal of Ecosystem Ecology **7**(4): (In Russ.).

Siczek, A. & J. Lipiec (2011): Soybean nodulation and nitrogen fixation in response to soil compaction and surface straw mulching. – Soil and Tillage Research **114**(1): 50–56.

Singh, B. & Z. Rengel (2007): The Role of Crop Residues in Improving Soil Fertility. – In: Marschner, P. & Z. Rengel (eds): Nutrient Cycling in Terrestrial Ecosystems. – Soil Biology, vol 10. – Springer, Berlin, Heidelberg: 183–214.

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.

Stebaeva, S. K. (1970): Life forms of springtails (Collembola). – Zoologicheskii zhurnal **49**(10): 1437–1455 (in Russian).

Thakur, M. P. & S. Geisen (2019): Trophic regulations of the soil microbiome. – Trends in microbiology **27**(9): 771–780.

Thomson, L. J. & A. A. Hoffmann (2007): Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macro invertebrates in vineyards. – Agricultural and Forest Entomology **9**(3): 173–179.

Turnbull, M. S. & Z. Lindo (2015): Combined effects of abiotic factors on Collembola communities reveal precipitation may act as a disturbance. – Soil Biology and Biochemistry **82**: 36–43.

Vandermeer, J., M. van Noordwijk, J. Anderson, C. Ong & I. Perfecto (1998): Global change and multi-species agroecosystems: concepts and issues. – Agriculture, Ecosystems & Environment **67**(1): 1–22.

Wall, D. H. & U. N. Nielsen (2012): Biodiversity and ecosystem services: is it the same below ground. – Nature Education Knowledge **3**(12): 8.

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

Yin, R., L. Gruss, N. Eisenhauer, P. Kardol, M. P. Thakur, A. Schmidt, Z. Xu, J. Siebert, C. Zhang, G.-L. Wu & M. Schädler (2019): Land use modulates the effects of climate change on density but not community composition of Collembola. – Soil Biology and Biochemistry **138**: 107598.

8. Appendix

Table S1. Technology of cultivation of the studied crops (peas, winter wheat) in the experiment.

No-till technology (NT)
Peas
1. Spraying plots with a continuous herbicide from the group of glyphosates Rap-600 with a drug consumption rate of 1.8 l/ha using a trailed sprayer OP-2000 (5-7 days before sowing).
2. Sowing with fertilizers at a dose of $N_{10}P_{40}$ (82 kg / ha of ammophos) with a seeder Gimetal (March-April).
3. Single spraying of crops during the growing season with Agritox herbicide at a rate of 0.7 l/ha. Single treatment in the flowering phase of plants with a mixture of insecticides Fastak with a consumption rate of 0.15 l/ha and BI-58 with a consumption rate of 1.0 l/ha.
4. Harvesting was carried out by the Niva combine (July).
Winter wheat
1. Spraying plots with a continuous herbicide from the group of glyphosates Rap-600 with a drug consumption rate of 1.8 l/ha using a trailed sprayer OP-2000 (through 2-3 weeks after pea harvesting).
2. Spraying plots with a continuous herbicide from the group of glyphosates Rap-600 with a drug consumption rate of 1.8 l/ha using a trailed sprayer OP-2000 (5-7 days before sowing).
3. Sowing with fertilizers at a dose of $N_{20}P_{20}K_{20}$ (125 kg/ha nitroammophoska) with a seeder Gimetal (October).
4. Top dressing mineral fertilizer (88 kg/ha ammonium nitrate - N_{30}) spreader RMG-4 (March).
5. Spraying with herbicide Lancelot at a dose of 30 g/ha (April).
6. Treatment of crops with Akanto Plus fungicide at a dose of 0.5 l/ha (May)
7. Harvesting was carried out by the Niva combine (July).

Table S2. Species composition and total abundance (ind./m^2) of springtails with different amount and composition of mulch.

Family, species	**plant residues and amount of mulch**							
	peas			**wheat**				
	0t/ha	8t/ha	16t/ha	0t/ha	4t/ha	8t/ha	12t/ha	16t/ha
Hypogastruridae								
Ceratophysella succinea	133.3		400.0	1777,4	925.0	600.0	400.0	66.7
Onychiuridae								
Mesaphorura sp.	66.7	100.0	1300.0	22.2			133.3	222.2
Mesaphorura macrochaeta		300.0	433.3	88.9	25.0	177.7		
Mesaphorura krausbaueri		66.7	100.0					
Isotomidae								
Desoria tigrina	300.0		10400.0	44.4				311.1
Folsomides parvulus				222.2	50.0			
Parisotoma notabilis	33.3	233.3	1233.3	44.4	1075.0	5244.4	5000.0	11377.8
Proisotoma minima				44.4				
Hemisotoma thermophila		33.3						
Folsomia quadrioculata	33.3							
Entomobryidae								
Entomobrya sp.				466.7	400.0	155.6	66.7	88.9
Entomobrya marginata	33.3	66.7	166.7					
Entomobrya multifasciata			33.3	22.2	25.0	22.2		

Family, species	plant residues and amount of mulch							
	peas			wheat				
	0t/ha	8t/ha	16t/ha	0t/ha	4t/ha	8t/ha	12t/ha	16t/ha
Lepidocyrtus cyaneus		66.7	633.3			44.4	22.2	
Lepidocyrtus langinosus	133.3			88.9	25.0			22.2
Pseudosinella alba	100.0	533.3	233.3			88.9	22.2	
Arrhopalitidae								
Arrhopalites caecus						22.2		
Sminthuridae								
Sminthurus nigromaculata		33.3						
Sminthurus viridis				22.2				
Katiannidae								
Sminthurinus niger	66.7	200.0	33.3	555.6	150.0	66.7		
Sminthurinus elegans	333.3	166.7	300.0	777.8	375.0	1333.3	1000.0	788.6
Dicyrtomidae								
Dicyrtoma fusca			66.7					
Neelidae								
Megalothorax perspicillum					25.0		22.2	22.2
Sminthurididae								
Sphaeridia pumilis	133.3	300.0	400.0	0	25.0		88.9	66.7
Bourletiellidae								
Fasciosminthurus sp.	33.3	66.7	33.3					

Table S3. Centroids for factor constraints of the first two RDA axes. Highest absolute values in RDA 1 and RDA 2 are indicated in bold font.

Factors	RDA 1	RDA 2
0 t/ha	**0.78**	0.35
4 t/ha	0.01	0.46
8 t/ha	-0.07	-0.26
12 t/ha	-0.37	0.04
16 t/ha	-0.47	-0.44
Compositions mulch	0.59	**-0.79**

Table S4. Species scores of Collembolan massive species for the first two RDA axes. Highest absolute values in RDA 1 and RDA 2 are indicated in bold font.

Massive species	RDA 1	RDA 2
Mesaphorura	0.1	-0.27
S. elegans	0.05	0.17
P. notabilis	**-0.94**	0.01
D. tigrina	0.06	-0.06
S. niger	0.26	0.15
Entomobrya	0.19	0.29
C. succinea	0.19	0.27
P. alba	0.16	-0.24
S. pumilis	0.28	**-0.33**

Appendix continued.

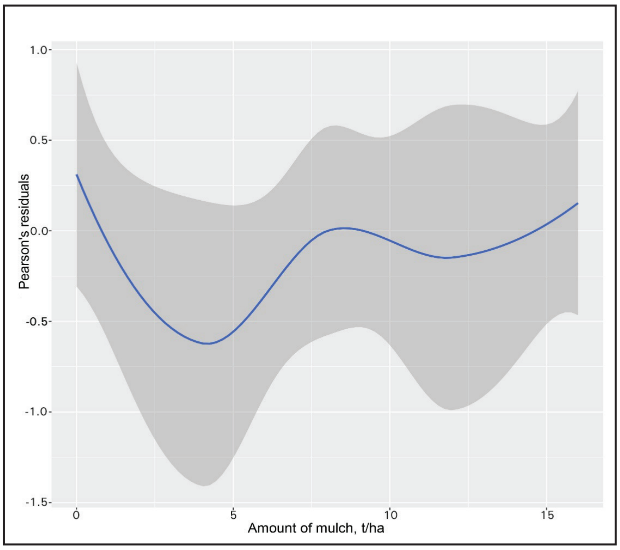

Figure S1. Residual plots for GLMM