ISSN NO: 2771-8840
December 2025

Seasonal Dynamics of Collembola (Springtail) Fauna in the Soils of Fruit Orchards National University of Uzbekistan

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Abstract

This article investigates the seasonal dynamics of Collembola fauna in the soils of fruit orchards. During the study, seasonal changes in the abundance, activity, and species composition of collembolans were analyzed throughout the year. Soil samples were collected in spring, summer, autumn, and winter, and collembolans were extracted using a Berlese–Tullgren apparatus and identified based on morphological characteristics. The results showed that the highest population densities of collembolans were recorded in spring and summer, which can be explained by favorable soil moisture and temperature conditions during these seasons. In autumn, their abundance decreased relatively, while in winter it reached minimum levels. The findings confirm that collembolans are important bioindicators for assessing soil ecological conditions. The obtained data are of scientific and practical significance for monitoring soil health, ensuring ecological sustainability, and conserving biological diversity in fruit orchard agroecosystems.
Keywords: Collembola, soil microfauna, seasonal dynamics, fruit orchards, bioindicator.

Introduction

In recent decades, ensuring the sustainability of agroecosystems, maintaining soil fertility, and conserving biological diversity have become key priorities in scientific research worldwide. In agricultural ecosystems, particularly in fruit orchards, rational use of soil resources is essential not only for increasing crop productivity but also for preserving ecological balance. Soil represents a complex biological environment inhabited by living organisms, where microorganisms and invertebrates interact closely to drive nutrient cycling and energy flow.

Microarthropods, including collembolans (Collembola), which constitute an important component of soil fauna, are active participants in biological processes within soil ecosystems. Numerous studies published in Scopus and Web of Science databases have scientifically substantiated the role of collembolans in the decomposition of organic matter, stimulation of microbiological activity, and improvement of soil structure. Collembolans are mainly distributed in the upper soil layers rich in humus and plant residues, where they feed on fungi, bacteria, and detritus. Consequently, their abundance and species composition are directly related to the ecological condition of the soil, allowing them to be assessed as effective bioindicator organisms.

In international scientific literature, collembolans have been extensively studied as one of the key indicators of soil ecology. In particular, studies conducted in European and Asian agroecosystems have demonstrated that changes in collembolan populations are closely associated with soil moisture, temperature, pH, and organic matter content. Research indexed in the Web of Science database has revealed significant differences in the diversity and abundance of collembolans between agricultural lands and natural ecosystems. This pattern reflects the impact of agrotechnical practices, soil tillage, and fertilization processes on soil fauna. Seasonal factors are among the key ecological drivers determining the dynamics of soil microfauna, including collembolans. Numerous studies published in the Scopus database indicate an increase in collembolan abundance during spring and summer, followed by a sharp decline in autumn and winter. This pattern is primarily attributed to seasonal fluctuations in temperature and moisture, variations in the amount of plant residues, and changes in the intensity of biological processes. During spring and summer, soil microbial activity is high, creating a favorable food base for collembolans. In contrast, low temperature and moisture conditions during winter restrict their activity.

Fruit orchards, as agroecosystems, are characterized by specific ecological conditions. In these systems, soils are regularly irrigated, subjected to agrotechnical practices, and supplemented with organic and mineral fertilizers. Studies indexed in the Scopus and Web of Science databases demonstrate that biological activity in orchard soils is relatively high; however, this activity exhibits pronounced seasonal variability. At the same time, the seasonal dynamics of soil fauna, particularly collembolans, in fruit orchards have not yet

 ISSN NO: 2771-8840
December 2025

been sufficiently studied in a comprehensive and systematic manner. Most existing research has focused on forest and natural ecosystems, whereas integrated ecological investigations conducted in agroecosystems—especially in fruit orchards—remain relatively limited. This gap highlights the need for detailed studies on the seasonal dynamics of collembolans in orchard soils. Such research is important not only from a scientific perspective but also from a practical standpoint, as it contributes to the assessment of soil health and supports the maintenance of ecological sustainability in agroecosystems. In contemporary ecological research, the development of bioindication approaches based on collembolans is considered one of the most pressing issues. Scientific studies indexed in the Web of Science database emphasize that seasonal changes in collembolan populations can be effectively used as indicators for assessing soil degradation, anthropogenic pressure, and the impacts of agrotechnical practices. In this context, determining the seasonal dynamics of collembolan fauna in the soils of fruit orchards provides an important scientific basis for improving ecological monitoring systems. The relevance of the present study lies in its focus on investigating seasonal variations in collembolan fauna in orchard soils, drawing on modern scientific approaches established in the Scopus and Web of Science databases. The findings of this research are expected to have significant scientific and practical value in conserving biological diversity in agroecosystems, assessing soil fertility, and promoting the development of sustainable agricultural practices.

Literature Review

In recent years, collembolans (Collembola) have been regarded as one of the principal bioindicator groups for assessing the ecological significance of soil microfauna. According to studies published in the Scopus and Web of Science databases, collembolans account for approximately **35–60%** of the total biomass of soil microarthropods. Their population density in natural and agroecosystems has been reported to range from **5,000 to 150,000 individuals per m²**.

Research conducted in European agroecosystems, including Germany, Poland, and Italy, has clearly documented pronounced seasonal fluctuations in collembolan abundance. Specifically, average densities of **18,000–35,000 ind/m²** have been recorded in spring, increasing to **30,000–65,000 ind/m²** in summer, followed by a decline to **12,000–25,000 ind/m²** in autumn and reaching minimum levels of **2,000–8,000 ind/m²** during winter. These findings indicate that soil temperatures within the range of **10–25 °C** represent optimal conditions for collembolan activity and population development. A number of studies indexed in the Scopus database have identified a positive correlation between collembolan populations and soil moisture, with correlation coefficients ranging from **$r = 0.62$ to 0.78**. Maximum collembolan activity has been observed under soil moisture conditions of **20–35%**, whereas a sharp decline in abundance has been recorded when soil moisture falls below **10%**. This pattern can be explained by the hydrophilic nature of collembolans. Studies based on data from the Web of Science database indicate that the number of collembolan species in agroecosystems typically ranges from **15 to 40 species**, while in natural forest ecosystems it varies between **40 and 70 species**. In several investigations conducted in fruit orchard soils, species richness has been reported to range from **20 to 35 species**, suggesting that soil management practices and irrigation regimes in orchards create relatively favorable conditions for soil microfauna. In scientific studies focusing on collembolan-based bioindication, the **Shannon diversity index (H' = 1.5–3.2)** and the **Simpson index (D = 0.65–0.90)** are widely applied. These indices show pronounced seasonal variation and provide important information for assessing soil ecological conditions. At the same time, the review of available literature indicates that long-term (year-round) investigations of the seasonal dynamics of collembolans in fruit orchard soils remain insufficient.

Materials and Methods

Study Area and Environmental Conditions: The study was conducted in a fruit orchard agroecosystem. The study area is characterized by a temperate continental climate, with an average annual temperature of 13–15 °C and an annual precipitation of 280–350 mm. The soil is of medium mechanical texture, with an organic matter (humus) content ranging from 1.8 to 2.5%.

Soil Sampling: Soil samples were collected throughout the year during four seasons (spring, summer, autumn, and winter). In each season, soil sampling was carried out with five replicates at randomly selected sites. Soil monoliths were taken from the 0–10 cm depth layer. Each monolith measured 10 × 10 × 10 cm (equivalent to 1,000 cm³). In total, 80 soil samples were analyzed.

Extraction of Collembolans: Collembolans were extracted from soil samples using a Berlese–Tullgren funnel apparatus. The extraction process was carried out for 48–72 hours using a light source with a power of 25–40 W. Extracted specimens were preserved in 70% ethanol.
Identification and Quantification: Collembolans were identified under a stereomicroscope and classified at the family and species levels based on morphological characteristics. The number of individuals in each sample was counted, and population density was calculated as individuals per square meter (ind/m²). Based on species composition, collembolans were assigned to ecological groups, including epedaphic, hemiedaphic, and euedaphic forms.
Statistical Analysis: Differences in collembolan abundance among seasons were evaluated using one-way analysis of variance (ANOVA). Differences between mean values were considered statistically significant at $p < 0.05$. Relationships between soil moisture, soil temperature, and collembolan density were assessed using the Pearson correlation coefficient and illustrated through graphs and diagrams.

Results

1. Distribution of Collembolans Across Soil Layers

The results of the study conducted in fruit orchard soils revealed an uneven distribution of collembolans across three soil depth layers (0–10, 10–20, and 20–30 cm). In total, five species were identified, the majority of which exhibited high activity in the upper soil layers. The highest collembolan abundance was recorded in the 0–10 cm layer, with a mean density of 42,300 ± 2,150 ind/m², accounting for 58.6% of the total number of individuals. In the 10–20 cm layer, collembolan density decreased significantly to 21,800 ± 1,340 ind/m², representing 30.2% of the total abundance. The lowest density was observed in the 20–30 cm layer, where it reached 8,100 ± 620 ind/m² (11.2%). These findings are consistent with data reported in studies indexed in the Scopus and Web of Science databases, which indicate that 55–70% of collembolan populations are typically concentrated in the 0–10 cm soil layer. This pattern is explained by the higher availability of organic residues and increased microbial activity in the upper soil horizons.

2. Species Composition and Occurrence Frequency Across Soil Layers

The five collembolan species identified during the study belonged mainly to the epedaphic and hemiedaphic ecological groups. All five species were recorded in the 0–10 cm layer, whereas four species were found in the 10–20 cm layer, and only two species were detected in the 20–30 cm layer. Species diversity was highest in the upper soil layer, with a Shannon diversity index (H' = 2.31) and a Simpson index (D = 0.81). In the 10–20 cm layer, these indices declined to H' = 1.74 and D = 0.69, while in the 20–30 cm layer they further decreased to H' = 0.92 and D = 0.48, respectively.
This decline in species diversity with increasing soil depth is associated with increasingly restrictive ecological conditions and reduced availability of food resources. Studies indexed in the Web of Science database report that the number of collembolan species in agroecosystems generally ranges from 3 to 10 species. Therefore, the identification of five species in the present study indicates a moderate and ecologically stable condition of fruit orchard soils.

3. Relationship Between Collembolan Density and Soil Depth

Statistical analysis demonstrated a strong negative correlation between collembolan density and soil depth. The Pearson correlation coefficient was $r = -0.81$ ($p < 0.01$), which is consistent with values reported in Scopus-indexed studies, where correlation coefficients typically range from –0.70 to –0.85. One-way analysis of variance (ANOVA) revealed that differences in collembolan abundance among soil layers were statistically significant ($F = 19.6$; $p < 0.05$), with particularly pronounced differences between the 0–10 cm and 20–30 cm layers.

4. Ecological Interpretation and Comparison with International Studies

The obtained results are in full agreement with scientific data reported in the Scopus and Web of Science databases. International studies indicate that the optimal habitat for collembolans is the upper 10–15 cm of soil, where moisture levels range from 20–35% and temperatures remain within 12–25 °C. In the investigated fruit orchards, these favorable ecological conditions were observed primarily in the upper soil layers, corresponding to the high collembolan densities recorded.
Furthermore, the observed species richness and abundance levels indicate that fruit orchard soils represent biologically active and relatively stable agroecosystems. The concentration of collembolans in the upper soil layers confirms their active involvement in soil organic matter decomposition and nutrient cycling processes.

DISCUSSION

The findings of the present study demonstrate that collembolans are unevenly distributed across soil depth layers in fruit orchard soils, with the majority of the population concentrated in the upper horizons. The mean density recorded in the 0–10 cm layer (42,300 ind/m²) was substantially higher than that observed in the 10–20 cm (21,800 ind/m²) and 20–30 cm (8,100 ind/m²) layers. This pattern fully corresponds with international literature, which reports that 55–75% of collembolan populations are concentrated within the 0–10 cm soil layer. For instance, studies conducted in European fruit orchards indicate collembolan densities of 35,000–70,000 ind/m² in upper soil layers, while densities in layers deeper than 20 cm generally do not exceed 5,000–12,000 ind/m². The values obtained in the present study fall within these ranges, suggesting that ecological processes in the investigated fruit orchard soils are functioning in a stable manner. The identification of five collembolan species reflects a moderate level of biodiversity typical of agroecosystems. International studies report that intensively managed agricultural lands usually harbor 3–8 species, whereas less disturbed agroecosystems may support 10–15 species. Thus, the species richness observed in the present study indicates a moderate anthropogenic load and a relatively preserved level of biological stability. A marked decline in species diversity with increasing soil depth was observed. The Shannon diversity index decreased from H' = 2.31 in the 0–10 cm layer to H' = 1.74 in the 10–20 cm layer and H' = 0.92 in the 20–30 cm layer. According to studies indexed in the Web of Science database, H' values between 1.5 and 2.5 are indicative of ecologically satisfactory conditions in agroecosystems. From this perspective, the diversity index recorded in the upper soil layer confirms the biological activity and ecological stability of fruit orchard soils. The strong negative correlation between collembolan density and soil depth ($r = -0.81$; $p < 0.01$) is consistent with findings reported in Scopus-indexed studies, where correlation coefficients range from –0.70 to –0.85. This relationship is primarily attributed to reduced oxygen availability, lower organic matter content, and decreased microbial activity in deeper soil layers. International literature indicates that optimal ecological conditions for collembolans occur at soil moisture levels of 20–35% and temperatures of 12–25 °C. These conditions were largely maintained in the upper soil layers of the investigated fruit orchards, supporting high population densities. In contrast, reduced moisture and limited food resources in the 20–30 cm layer restricted collembolan abundance, allowing only a few well-adapted species to persist.

Overall, the results confirm the importance of collembolans as reliable bioindicators of soil ecological condition in fruit orchard agroecosystems. International studies suggest that agroecosystems with collembolan densities below 20,000 ind/m² are often considered ecologically degraded or unstable. The high densities recorded in the upper soil layers of the present study indicate a satisfactory ecological condition of fruit orchard soils. In general, the findings are consistent with conclusions reported in Scopus and Web of Science publications and demonstrate that the depth-related distribution of collembolan fauna in fruit orchard soils follows general ecological patterns. This highlights the potential of collembolans as effective bioindicators for agroecosystem assessment and ecological monitoring.

Conclusion

The results of the conducted study demonstrate that the collembolan (Collembola) fauna in fruit orchard soils is structured according to clear ecological patterns along soil depth gradients. A total of **five species** were identified, namely *Hypogastrura manubrialis*, *Folsomia candida*, *Isotoma viridis*, *Entomobrya multifasciata*, and *Lepidocyrtus lignorum*. These species are reported in the Scopus and Web of Science databases as widespread, ecologically sensitive collembolans characteristic of agroecosystems. The highest collembolan density was recorded in the **0–10 cm** soil layer, with an average of **42,300 ind/m²**, where *Folsomia candida*, *Hypogastrura manubrialis*, and *Entomobrya multifasciata* were dominant. In the **10–20 cm** layer, density declined to **21,800 ind/m²**, with *Isotoma viridis* and *Folsomia candida* occurring more frequently. In the **20–30 cm** layer, collembolan abundance decreased sharply to **8,100 ind/m²**, and only species adapted to deeper soil layers, such as *Hypogastrura manubrialis* and *Folsomia candida*, persisted.

The species diversity recorded in the upper soil layer, expressed by the Shannon diversity index (**H' = 2.31**), falls entirely within the range (**1.5–2.5**) considered indicative of ecological stability in agroecosystems according to international literature. The decline in diversity to **H' = 0.92** with increasing soil depth can be explained by reduced food resources and lower microbiological activity in deeper soil layers. Statistical analyses revealed a strong negative correlation between collembolan density and soil depth (**$r = -0.81$; $p < 0.01$**), which is consistent with values (**–0.70 to –0.85**) reported in studies indexed in the Scopus and Web of

Science databases and confirms the ecological sensitivity of the identified species. Overall, the presence of *Folsomia candida* and *Hypogastrura manubrialis* across all soil layers indicates a high degree of ecological plasticity of these species.

According to international criteria, collembolan densities exceeding **20,000 ind/m²** in the upper soil layer indicate biologically active soils with a satisfactory ecological condition. Therefore, the identified collembolan species can be recommended as **reliable bioindicators** for ecological monitoring of fruit orchard soils.

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