# Effects of Straw Incorporation on Meso- and Micro-fauna Communities in Cultivated Mollisols (Postprint)

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## Abstract

To investigate the effects of straw return on soil fauna community structure in cultivated black soil, a fixed-point experiment was conducted in Hailun City, Heilongjiang Province from 2009 to 2011, examining the meso- and micro-fauna community structure in Plot A (17 kg straw returned with high-concentration decomposer), Plot B (8.5 kg straw returned with low-concentration decomposer), Plot C (control plot), Plot D (8.5 kg straw returned), and Plot E (17 kg straw returned).

A total of 21,779 meso- and micro-fauna individuals were collected, belonging to 58 taxa. Among them, Oribatida, Hypogastruridae, Onychiuridae, and Entomobryidae were the four most environmentally adaptable soil fauna groups in this region.

Analysis of soil fauna community structure indicated that the control plot C exhibited the highest soil fauna density (46,591.67 individuals/$m^2$), the greatest number of taxa (17.17), and the highest dominance index (0.37); plot D displayed the highest richness index (2.63); plot A showed the highest diversity index (1.72); and plot B demonstrated the highest evenness (0.64).

Meanwhile, soil fauna in all plots generally exhibited surface aggregation, with fauna in plot A tending to inhabit the upper soil layers more prominently.

Comprehensive comparative analysis demonstrated that the straw return method in plot A was relatively most conducive to soil fauna survival.

Principal component analysis revealed that different straw return methods significantly influenced soil fauna density, Oribatida, Isotomidae, and Prostigmata, which represent sensitive soil fauna indicators in cultivated black soil and may

serve as evaluation indices for assessing the fertility effects of straw return in cultivated black soil in future studies.

Furthermore, CAA analysis indicated that soil fauna taxa significantly influenced by soil environmental factors were predominantly dominant and common taxa in the study area, and soil fauna density was most closely correlated with soil organic matter, organic carbon, C/N ratio, and total phosphorus content.

## Full Text

## Preamble

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**Title:** Effects of Straw-Returning Management on Meso-Micro Soil Fauna in a Cultivated Black Soil Area

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## Abstract

Crop straw is an important material basis for nutrient cycling in agro-ecosystems. Straw returning is a method in which straw is applied to the soil to improve soil properties and is used for accelerating immature soil development in cultivated land and improving soil fertility. Soil fauna is an important component of the ecosystem and is involved in the straw decomposition process, improving the decomposition of organic matter and promoting nutrient absorption by plants. Therefore, research on the ecology of soil fauna and sustainable utilization of cultivated soil, including black soil, has been widely conducted. Understanding the correlation between soil fauna and straw returning will provide a scientific basis for the protection of the soil fauna community and sustainable utilization management of tillage ecosystems in black soil areas.

To investigate the effect of straw returning on meso-micro soil fauna communities in cultivated black soil, field experiments were carried out in Hailun, Heilongjiang Province from 2009 to 2011. The experiments were conducted in five selected plots: Plot A: 17 kg corn straw returning with high concentrations of microbial inoculants; Plot B: 8.5 kg corn straw returning with low concentrations of microbial inoculants; Plot C: control; Plot D: 8.5 kg corn straw returning; and Plot E: 17 kg corn straw returning. A total of 21,779 individuals, belonging to 58 groups, were extracted and identified in the plots. Among them, Oribatida, Hypogastruridae, Onychiuridae, and Cyphoderidae were most suitable to understand environmental changes in the study area.

Analysis of the soil fauna community structure showed that the density, group number, and Simpson Dominance Index of soil fauna were highest in the control Plot C (46,591.67 ind/$m^2$, 17.17, 0.37, respectively). The soil fauna richness index was highest in Plot D (2.63); the diversity index was highest in Plot A (1.72); and the evenness index was highest in Plot B (0.64). Meanwhile, the soil fauna was characterized by surface accumulation in the experimental plots. The group numbers of dominant soil fauna in Plot A in all soil layers were lower than those in other plots, and soil fauna was more dominant in the upper layer of the soil. Together, the method of straw returning in Plot A was the most productive for soil fauna.

In addition, the results of a Principal Component Analysis (PCA) indicated that different methods of straw returning had a considerable effect on soil fauna density. Oribatida, Isotomidae, and Prostigmata were sensitive soil fauna that responded to different methods of straw returning, and could therefore be considered as an evaluating index to investigate the fertility effect of straw returning in cultivated black soil in the future. The results of the Canonical Correspondence Analysis (CCA) indicated that the dominant and common groups of soil fauna were considerably influenced by the soil environment, and the density of soil fauna was closely associated with organic matter, organic carbon, the carbon to nitrogen ratio, and total phosphorus in the soil.

**Keywords:** straw returning; cultivated black soil; meso-micro soil fauna; community structure; soil environment

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## 1. Study Area Overview

The study site was selected in the cultivated black soil area of Hailun City, Heilongjiang Province, which is located at 46°58 –47°52 N, 126°14 –127°45 E. The region has a mid-temperate continental climate with an elevation of 239 m, an average annual temperature of 1.2°C, and annual precipitation of 500–600 mm. The area is an important commodity grain base, with corn as the main crop and a growing season of approximately 120 days. The study plots were located in western Hailun, with each plot measuring 10 m × 4 m and spaced 0.5 m apart.

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## 2. Experimental Design

Five experimental plots with the same area of local cultivated black soil were established and treated with different methods of straw application and microbial inoculants:

- **Plot A:** 17 kg corn straw with high-concentration microbial inoculant solution
- **Plot B:** 8.5 kg corn straw with low-concentration microbial inoculant solution

- **Plot C:** Control (no treatment, maintaining original conditions)
- **Plot D:** 8.5 kg corn straw returning only
- **Plot E:** 17 kg corn straw returning only

The microbial inoculant used was Ruilaiwei microbial decomposition accelerator. For the high-concentration solution, 0.5 kg of inoculant was dissolved in 10 kg water and stirred for 24 hours. This solution was then diluted by half to create the low-concentration solution. For all treated plots, straw was first crushed before being sprayed with water or microbial inoculant solution. All plots except the control received conventional tillage management.

Straw decomposition rates were monitored annually. The net decomposition rates for plots A, B, C, D, and E were 52.21%, 48.90%, 39.19%, 44.42%, and 48.20% in 2009; 30.88%, 29.34%, 20.60%, 22.64%, and 24.70% in 2010; and 8.97%, 8.46%, 7.68%, 7.83%, and 8.34% in 2011, respectively. The cumulative decomposition rates were 90.52%, 88.24%, 67.47%, 74.88%, and 81.24%, showing a 逐年 decreasing trend in decomposition rate.

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## 3. Sample Collection and Animal Identification

Sampling was conducted in October 2009, 2010, and 2011. Each plot had 5 replicate sampling points. Soil samples were collected using a soil auger with a sampling area of 10 cm × 10 cm. Soil was collected from four layers: 0–5, 5–10, 10–15, and 15–20 cm. At each sampling point, 1 kg of soil from the 0–20 cm layer was collected for physicochemical analysis.

Soil fauna were extracted using a Tullgren funnel. Soil fauna identification primarily followed Yin Wenying et al.' s "Soil Animal Identification Atlas." Soil pH was measured using a pH meter (PB-10). Soil organic matter was determined by the potassium dichromate volumetric method. Total nitrogen was measured using a Kjeldahl nitrogen analyzer (K9840). Total organic carbon was measured with a Vario-EL elemental analyzer (Elementar, Germany). The C/N ratio was calculated accordingly. Total phosphorus was determined by sulfuric acid-perchloric acid digestion method. Total potassium was measured by flame photometry. Soil physicochemical properties varied among different straw returning treatments .

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## 4. Data Processing

Soil fauna dominance was classified as: dominant groups (>10% of total individuals), common groups (1-10%), and rare groups (<1%). Community characteristics were analyzed using the Simpson dominance index, Shannon-Wiener diversity index, Pielou evenness index, and Margalef richness index. One-way ANOVA was used for variance analysis and mean comparison of soil fauna indices among plots. Principal Component Analysis (PCA) was used to analyze the response relationship between main community indices and straw returning. Canonical Correspondence Analysis (CCA) was used to analyze relationships between soil fauna density and environmental factors. All data analysis and mapping were performed using Excel 2003, SPSS 17.0, and CANOCO 4.5.

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## 5. Soil Fauna Community Composition Characteristics

A total of 21,779 meso-micro soil fauna individuals were collected across the three sampling years, belonging to 58 groups. The dominant groups were Oribatida, Prostigmata, and Isotomidae, accounting for 74.43% of total individuals. Common groups included Mesostigmata, Hypogastruridae, Onychiuridae, and Cyphoderidae, accounting for 22.94%. The remaining groups were rare, comprising 2.63%.

Soil fauna composition varied among treatment plots . Plot C (control) had the highest number of individuals (20,475.00 ind/m$^2$), while Plot D had the highest number of groups (17.17). Oribatida was the dominant group in all plots, while Hypogastruridae and Onychiuridae were common groups across all treatments, indicating these taxa are most adaptable to environmental changes in this region. Mesostigmata and Isotomidae were either dominant or common in all plots, suggesting they are widely adapted taxa in this area.

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## 6. Horizontal Spatial Distribution of Soil Fauna Community Indices

Soil fauna density in straw-treated plots was significantly lower than in the control plot ($P < 0.05$). Plot A showed the highest diversity index (1.72), significantly higher than the control. Plot B had the highest evenness index (0.64), also significantly higher than the control. Plot D exhibited the highest richness index (2.63), while Plot C had the highest dominance index (0.37). These results indicate that straw returning treatments significantly affected soil fauna communities, creating substantial differences from the control plot. Different straw returning methods had varying effects on different soil fauna characteristic indices.

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## 7. Vertical Distribution of Soil Fauna Community Indices

Different straw returning methods altered the vertical distribution patterns of soil fauna individuals and groups compared to the control. For individual numbers, straw-treated plots showed significantly fewer individuals than the control in the 0–5 cm layer ($P < 0.05$). In the 5–10 cm layer, Plots B, D, and E had significantly fewer individuals than the control. In the 10–15 cm layer, Plots A, D, and E showed significantly fewer individuals. In the 15–20 cm layer, straw-treated plots had significantly fewer individuals than the control.

For group numbers, the 0–5 cm layer in straw-treated plots had significantly fewer groups than the control ($P < 0.05$), while other layers showed no significant differences. All plots exhibited surface aggregation (epigeic distribution), with significantly more individuals and groups in the 0–10 cm layer than in the 10–20 cm layer ($P < 0.05$). This epigeic characteristic was more pronounced in straw-treated plots [Figure 1: see original paper].

The distribution of dominant groups across soil layers also differed among treatments . Oribatida was present in all layers across all plots, confirming it as a widely adapted dominant group. Isotomidae and Mesostigmata were dominant in almost all layers, while Prostigmata appeared dominant in most layers of straw-treated plots, suggesting adaptation to straw decomposition environments.

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## 8. Effects of Straw Returning on Main Soil Fauna Community Indices

PCA was conducted on seven soil fauna characteristic indices: individual number, density, diversity index, evenness index, richness index, dominance index, and the individual numbers of dominant groups (Oribatida, Prostigmata, Isotomidae) and common groups (Mesostigmata, Staphylinidae). The first two principal components explained 99.99% of the variance .

The comprehensive scores, calculated by weighting each principal component by its eigenvalue proportion, showed that the top five most sensitive indicators were: soil fauna density, individual number, Oribatida group, Isotomidae group, and Prostigmata group . These indicators can serve as sensitive metrics for evaluating the fertility effects of straw returning in cultivated black soil.

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## 9. Relationships Between Soil Fauna Density and Environmental Factors

Soil habitat conditions determine the taxa and density of soil fauna. CCA analysis revealed that Prostigmata and Curculionidae densities were significantly positively correlated with soil organic matter and organic carbon content. Mesostigmata, Prostigmata, and Aphididae densities were significantly positively correlated with soil C/N ratio, while Geophilomorpha density was significantly negatively correlated. Mesostigmata, Prostigmata, and Staphylinidae larvae densities were significantly positively correlated with total phosphorus, whereas Geophilomorpha density was significantly negatively correlated with total potassium [Figure 2: see original paper].

The first two CCA axes explained 60.9% and 42.0% of the variation in habitat and species relationships, respectively. Taxa most influenced by soil environmental factors were predominantly dominant and common groups in the study area. Soil fauna density was most closely related to organic matter, C/N ratio, and total phosphorus content. Oribatida, Hypogastruridae, and Onychiuridae were the most environmentally adaptable groups, while Mesostigmata, Prostigmata, and Isotomidae were widely adapted taxa.

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## 10. Discussion

### 10.1 Soil Fauna Community Structure After Straw Returning

Agricultural practices alter soil physicochemical properties to increase crop yield. Straw returning involves the transformation of complex organic compounds into simpler organics and inorganics through leaching, microbial decomposition, and soil fauna feeding. In this study, soil fauna density decreased in straw-treated plots compared to the control, primarily due to reduced Oribatida and Isotomidae populations. This may result from secondary metabolites produced during straw decomposition, which often have low microbial utilization rates and may be toxic to soil organisms, inhibiting reproduction of Oribatida and Isotomidae.

Although straw-treated plots had slightly fewer soil fauna groups than the control, most taxa survived, indicating general adaptability. The dominance index was highest in Plot C (control) due to high Oribatida numbers, while Plot A' s dominance index differed from the control, suggesting its environment was more suitable for Oribatida—possibly because high-concentration microbial inoculants accelerated straw decomposition and improved soil structure. However, secondary metabolites still suppressed Oribatida populations compared to the control.

Diversity and evenness indices were higher in straw-treated plots than the control, likely because straw improves soil moisture, reduces bulk density, increases aeration, and provides diverse habitats, promoting soil biological activity. Plot A, with high-concentration microbial inoculants combined with straw, showed the highest diversity index, highest straw decomposition rate, and improved soil humus content, creating favorable conditions for soil fauna.

### 10.2 Vertical Distribution Characteristics After Straw Returning

Soil fauna typically exhibit epigeic distribution, with individual and group numbers decreasing with soil depth. This study confirmed that straw-treated plots maintained epigeic characteristics, with more pronounced surface aggregation than the control. Although straw decomposition metabolites suppressed Oribatida growth to some extent, this taxon remained well-adapted to the regional environment, persisting across all layers.

Isotomidae and Mesostigmata were confirmed as common dominant groups, while Prostigmata appeared adapted to straw-treated environments. Different straw returning quantities and methods created varying habitats, affecting food availability and environmental modification intensity. Microbial inoculants accelerated straw decomposition, increasing soil humus and benefiting meso-micro soil fauna. Since straw resides primarily in upper soil layers, nutrient and food sources were concentrated there, further enhancing epigeic distribution. The combination of microbial inoculants and straw in Plot A created optimal conditions, with higher fauna numbers in upper layers, suggesting this method is most beneficial for meso-micro soil fauna.

### 10.3 Main Effects of Soil Environmental Factors

Straw returning improves soil structure, increases porosity, and promotes microbial activity and root development, thereby altering soil fauna habitats. Different straw returning methods created varying decomposition rates and soil interaction intensities, resulting in different physicochemical properties. Soil fauna, being active and responsive to environmental changes, can serve as early indicators of soil degradation or improvement.

Previous studies have shown that earthworm communities indicate soil type, organic matter content, pH, and moisture, while nematode abundance can predict long-term fertilization effects. This study' s PCA identified soil fauna density, individual number, Oribatida, Isotomidae, and Prostigmata as the most sensitive indicators to straw returning treatments. These five metrics can be quantified and used as evaluation indices for straw returning fertility effects in cultivated black soil.

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## 11. Conclusion

Different straw returning methods significantly affected soil fauna communities in cultivated black soil, though effects varied among characteristic indices. Straw-treated plots maintained epigeic distribution, with more pronounced surface aggregation than the control. The combination of corn straw with high-concentration microbial inoculants (Plot A) yielded relatively higher community indices compared to other treatments, with greater numbers of individuals and groups in upper soil layers, indicating better soil fertility.

Different straw returning methods significantly influenced soil fauna density, individual number, Oribatida, Isotomidae, and Prostigmata. These five indicators represent sensitive responses to straw returning in cultivated black soil and can serve as evaluation metrics for assessing the fertility effects of straw returning practices.

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*Note: Figure translations are in progress. See original paper for figures.*