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The hidden workforce beneath our feet: Soil microarthropods and their role in sustainable agriculture

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Abstract

Soil microarthropods are important but often overlooked components of agricultural ecosystems. They primarily comprise Collembola (springtails) and Acari (mites), together with smaller populations of Protura, Diplura and other soil-dwelling arthropods. These organisms play significant roles in soil biological processes through their interactions with microorganisms, organic matter and other soil fauna. Their activities contribute to organic matter fragmentation, microbial regulation, nutrient mineralization, soil aggregation and plant growth. Certain predatory groups also participate in the regulation of soil-dwelling pests and plant pathogens. Furthermore, their sensitivity to soil disturbance, moisture, temperature and agricultural inputs makes them useful indicators of biological soil quality. Agricultural practices such as reduced tillage, crop rotation, cover cropping and organic matter incorporation can create favourable conditions for their survival and diversity. This article highlights the ecological functions of soil microarthropods, their contribution to soil health and crop productivity and their potential role in sustainable and regenerative agricultural systems.

Keywords: Soil micro arthropods; soil biodiversity; soil health; sustainable agriculture; nutrient cycling

Introduction

Soil is a dynamic living ecosystem that supports plant growth through complex interactions among physical, chemical and biological components. Besides microorganisms and larger soil fauna, soil mesofauna play an important role in maintaining soil fertility and ecosystem functioning. Among these organisms, soil microarthropods, particularly Collembola (springtails) and Acari (mites), are important contributors to decomposition, nutrient cycling and soil biological activity. Other groups, including Protura, Diplura and Pauropoda, also contribute to soil ecological processes (Neher and Barbercheck, 2019).

Soil mesofauna are generally classified according to body size, with a commonly used range of approximately 0.1–2 mm. Their abundance varies considerably with soil type, vegetation, climate, organic matter content and land-management practices. They inhabit soil pores, decomposing plant residues and the litter layer, where they interact closely with bacteria, fungi and other soil organisms.

Although these organisms are rarely visible during routine agricultural operations, their activities influence several processes associated with soil health and crop production. Recent research has also highlighted their potential to influence plant nutrition, crop development and plant–pathogen interactions (Jernigan *et al*., 2023). Therefore, understanding their ecological functions is important for developing sustainable agricultural management strategies.

Major Groups of Soil Microarthropods

The soil microarthropod community is dominated by two major groups:

Collembola (Springtails): These small, wingless arthropods are commonly found in moist soil, leaf litter and decomposing organic matter. Many species feed on fungi, bacteria, algae and decaying plant materials. Their feeding activities regulate microbial populations and contribute to organic matter transformation.

Acari (Mites): Soil mites represent a highly diverse group with different feeding habits.

Oribatid mites are predominantly associated with decomposing organic matter and fungi, whereas many mesostigmatid mites are predators of nematodes, insect eggs and other small soil organisms. Some prostigmatid mites are also important predators or microbial feeders.

Other groups: Protura, Diplura and Pauropoda occur in smaller numbers in many agricultural soils. They contribute to soil food-web interactions through microbial feeding, organic matter transformation and predation. The relative abundance of these groups varies with environmental conditions and agricultural disturbance.

Ecological Functions of Soil Microarthropods

Organic Matter Decomposition and Nutrient Cycling

One of the major ecological functions of soil microarthropods is their contribution to organic matter decomposition. Detritivorous springtails and mites fragment plant residues into smaller particles, increasing the surface area available for microbial colonization. This process facilitates the activities of decomposer microorganisms and supports the transformation of organic materials into simpler compounds.

Microarthropods also consume bacteria and fungi, regulating microbial populations and influencing nutrient turnover. During digestion and excretion, they produce faecal pellets containing partially processed organic matter and nutrients. These pellets can serve as localized microbial activity hotspots, promoting further decomposition and nutrient mineralization.

Kampichler and Bruckner (2009), through a meta-analysis of 101 litterbag experiments reported in 30 studies, demonstrated a moderate but statistically significant contribution of microarthropods to litter mass loss. However, their findings also highlighted that this contribution varies with experimental conditions, organic matter characteristics and land-use systems.

Stimulation of Microbial Activity

Soil microorganisms are responsible for many important biochemical processes, including decomposition, mineralization and nutrient transformation. Microarthropods influence these processes through selective grazing on bacterial and fungal communities. Their feeding activities can stimulate microbial turnover and redistribute microbial propagules within soil.

The relationship between microarthropods and microorganisms is particularly important in the rhizosphere, where root exudates provide energy resources for microbial communities. Microarthropod grazing can modify microbial activity and influence the availability of nutrients to plants. Thus, these organisms contribute indirectly to maintaining soil biological activity and nutrient availability (Neher and Barbercheck, 2019).

Soil Aggregation and Structural Stability

Soil structure is essential for root development, aeration, water infiltration and nutrient movement. Microarthropods contribute indirectly to soil aggregation by fragmenting organic residues, stimulating microbial growth and influencing fungal activity. Fungal hyphae and microbial extracellular substances act as binding agents that help stabilize soil particles into aggregates.

Well-structured soil provides favourable conditions for root penetration, water retention and gaseous exchange. Although microarthropods are not the principal soil engineers responsible for aggregate formation, their interactions with microorganisms and organic matter contribute to the biological processes involved in soil structural development (Maaß *et al*., 2015).

Plant Growth and Nutrient Acquisition

The influence of soil microarthropods on plant growth is mainly indirect and occurs through interactions with microorganisms, nutrient cycling and soil physical conditions. Their grazing activities can influence nutrient mineralization, microbial community composition and the availability of nutrients in the rhizosphere.

Jernigan *et al*. (2023) reviewed the interactions between soil microarthropods, microorganisms and plants and concluded that their effects on plant growth are primarily mediated through microbial processes, organic matter decomposition, nutrient cycling and plant–pathogen interactions. More recent experimental work by Jernigan *et al*. (2024) also investigated the interactions between microarthropods and organic fertilizers in relation to oat nutritional quality and soil biological activity.

Biological Control and Plant Health

Certain predatory soil mites and other predatory microarthropods contribute to the natural regulation of soil-dwelling pests. They feed on small arthropods, nematodes and insect eggs, thereby influencing the population dynamics of other soil organisms. Some soil

microarthropods may also indirectly influence plant resistance and tolerance to pests and pathogens by modifying microbial communities and plant nutritional status.

Neher and Barbercheck (2019) emphasized that microarthropods contribute to pest suppression through both direct feeding and indirect interactions involving plant defence and soil food webs. However, their biological control potential is species-specific and should be evaluated under particular crop and soil conditions.

Soil Microarthropods as Bioindicators of Soil Health

Soil microarthropods are sensitive to changes in soil moisture, temperature, organic matter, pesticide application and cultivation practices. Consequently, their abundance, diversity and community composition can provide useful information about the biological condition of agricultural soils.

A diverse microarthropod community generally indicates the availability of suitable habitats and food resources, although high abundance alone does not necessarily demonstrate good soil health. Biological assessment should therefore consider taxonomic composition, functional groups and soil properties together.

In India, research on tropical home gardens has also demonstrated the usefulness of soil microarthropod communities for evaluating biological soil quality (Lakshmi *et al*., 2017). The QBS-ar (Soil Biological Quality based on Arthropods) approach is another useful method for assessing soil biological quality through the presence of soil arthropods.

Agricultural Management Practices for Conserving Soil Microarthropods

Agricultural practices strongly influence the abundance and diversity of soil microarthropods. Intensive tillage, excessive pesticide application, removal of crop residues and prolonged soil exposure can disturb their habitats and reduce food availability.

The following practices can help conserve their populations:

- **Reduced tillage:** Minimizing mechanical disturbance helps preserve soil pore networks, organic residues and favourable microhabitats.
- **Organic matter incorporation:** Compost, farmyard manure and crop residues provide food resources and improve soil habitat conditions.
- **Cover cropping and mulching:** Maintaining soil cover helps regulate temperature, conserve moisture and provide organic substrates.
- **Crop rotation and diversification:** Different crops support diverse root systems, microbial communities and organic matter inputs.
- **Judicious pesticide use:** Selective application and integrated pest management can reduce unnecessary exposure of beneficial soil organisms to pesticides.
- **Balanced irrigation:** Maintaining adequate soil moisture supports the survival and activity of moisture-sensitive microarthropods while avoiding waterlogging.

A global meta-analysis by Betancur-Corredor *et al*. (2022), based on 133 studies from 33 countries, reported that reduced tillage or no-tillage increased springtail density by approximately 35% and mite density by 23%, compared with more intensive tillage. These findings provide quantitative evidence for the importance of conservation-oriented soil management.

Implications for Sustainable Agriculture and Future Prospects

Soil microarthropods have considerable potential to support sustainable agricultural production through their contributions to decomposition, microbial regulation, nutrient cycling and biological pest suppression. Their conservation may strengthen soil biological functioning and improve the ecological resilience of cropping systems.

Future research should focus on understanding the interactions among microarthropods, soil microorganisms, crop roots and plant pathogens under different cropping systems. Advanced molecular identification, DNA metabarcoding, soil biodiversity monitoring and long-term field experiments could improve our understanding of their functional diversity.

In Indian agricultural conditions, particularly in intensively cultivated regions, further studies are required to evaluate the effects of tillage, crop diversification, organic amendments and pesticide regimes on soil microarthropod communities. Integrating biological indicators into routine soil health assessment may provide additional information for developing sustainable soil-management practices.

Conclusion

Soil microarthropods are essential biological components of agricultural ecosystems, despite their small size and limited visibility. Collembola, Acari and other soil-dwelling groups contribute to organic matter transformation, microbial regulation, nutrient cycling and soil biological functioning. Their interactions with microorganisms and plant roots can influence crop nutrition and plant health, while predatory groups contribute to natural pest regulation. Their sensitivity to agricultural disturbances also makes them valuable indicators of soil biological quality. Conservation practices such as reduced tillage, crop rotation, organic matter incorporation, cover cropping and judicious pesticide use can help maintain favourable conditions for these organisms. Therefore, conserving soil microarthropod diversity should be considered an important component of sustainable, regenerative and ecologically balanced agricultural production.

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