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A Short Review of the Diversity, Ecological importance and Factors affecting the Mesofauna Community dynamics in Soil Ecosystem

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Abstract

Soil is one of the most important natural resources, covering a large portion of the Earth's crust. Soil mesofauna are intermediate-sized organisms, typically ranging from 0.1 mm to 2 mm, that inhabit soil and leaf litter and are visible to the naked eye. These include mites, springtails (Collembola), nematodes, and small arthropods, all of which play a vital role in terrestrial ecosystem functioning. Soil mesofauna contribute significantly to the decomposition of organic matter, nutrient cycling, and soil structure formation. By feeding on microorganisms, organic materials, and other soil fauna, they influence microbial activity and promote the breakdown of plant residues, thereby enhancing soil fertility. Moreover, their burrowing activity improves soil aeration and water infiltration. Understanding the biodiversity, community structure, and functional roles of soil mesofauna is essential for assessing soil health and sustainability in both agricultural and natural ecosystems. Soil contaminants such as pesticides can profoundly affect soil mesofauna, leading to cascading impacts on essential ecosystem services such as soil fertility and plant growth. Numerous studies have shown that pesticide-treated soils experience significant declines in mesofauna populations, accompanied by disruptions in species composition and community structure. Pesticide exposure alters soil physicochemical properties and leaves toxic residues that impair the survival and activity of these vital organisms, potentially leading to long-term soil degradation and reduced ecosystem resilience. The present review emphasizes the implementation of eco-friendly pest management strategies, monitoring soil biodiversity, and prioritizing soil health as crucial steps toward maintaining the productivity and sustainability of soil and agroecosystems.

Keywords: Diversity; Ecological importance; Mesofauna; Soil Ecosystem; Pesticides

1. Introduction

Soil is one of the most complex ecosystems in the world, hosting a diverse array of organisms that interact with each other and with various abiotic factors. These interactions play key roles in biogeochemical cycling, maintenance of soil quality and organic matter decomposition, significantly contributing to soil ecosystem dynamics and supporting life on earth. Soil dwelling animals have been classified into three categories – microfauna, mesofauna and macrofauna, depending on their size [1]. Soil mesofauna, also called meiofauna, are intermediate-sized invertebrates that inhabit the soil ecosystem, typically ranging in size from 0.1 mm to 2 mm. These organisms include groups such as Collembola (springtails), Acari (mites), Enchytraeids, Psocoptera, Thysanoptera or Thrips, and small insect larvae, among which, mites and springtails often dominate [1-2]. These minute animals are distributed in various terrestrial habitats from forests to agricultural fields [3]. Soil mesofauna have limited burrowing ability and generally live within the soil pores. They may feed upon microflora (algae, bacteria, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes), decaying plant material and other soil invertebrates [4]. Belonging to diverse taxa, soil mesofauna are critical components of the soil food web and play an indispensable role in terrestrial ecosystem functioning by contributing to

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nutrient cycling, soil structure formation, and organic matter decomposition, and therefore they are considered as "Ecosystem Webmasters" [5]. The key function of soil mesofauna in organic matter decomposition provides the essential nutrients for plant growth [6]. Soil organic matter typically serves as the primary energy source for the food webs operating within the soil ecosystem, wherein mesofauna play a crucial role in its liberation, mineralization, and subsequent utilization [7].

According to Coleman *et al.* [8], soil mesofauna interact with microorganisms and other organisms to regulate ecosystem processes, and serve as a connecting link between microfauna and macrofauna, which together form an essential part of soil decomposer community. They perform and regulate a major proportion of the organic matter transformations and nutrient fluxes in soil, recycling of nutrients and, also help in mineralization of nitrogen and phosphorus [9]. These organisms are particularly sensitive to environmental disturbances, including chemical applications such as pesticides, which can significantly alter their diversity abundance and subsequently their ecological functions. The sensitivity of edaphic mesofaunal groups to various contaminants make them an important bioindicator of soil quality. The ecological role of soil microbiome, such as bacteria and microfungi, and macrofauna, such as earthworms, in soil functions is better understood [10-11]. However, the ecological role of soil mesofauna communities, such as Collembolla and Acari, among others, in soil ecosystem processes are less studied [12].

Among the diverse members of soil mesofauna communities, sprigtails and oribatid mites represents the most abundant and diverse arthropod group, playing key role in soil organic matter transformations and dispersal of microbes, among other ecological functions; and are reported to exhibit sensitivity towards agricultural practices through reduction in their diversity, abundance and structural parameters [13]. The soil mesofauna communities exhibit marked sensitivity towards anthropogenic as well as natural upsets of the environment, which subsequently lead to loss of their diversity, species richness, abundance and stability, ultimately affecting the ecological functions within the soil [14]. With the significant ecological roles, and comparatively less studied component of the soil ecosystem; the soil mesofauna, their ecological functions, and factors affecting their diversity needs more attention and further studies. The present review encompasses these aspects about the ecology of soil mesofauna in brief.

1.1. Overview of Soil Mesofauna Diversity and Distribution:

Soil mesofauna, typically ranging in size from 0.1 mm to 2 mm, include diverse invertebrate groups such as Collembola (springtails), Acari (mites), Enchytraeidae (potworms), nematodes, and other microarthropods. These organisms are ubiquitous in terrestrial ecosystems and play vital ecological roles [15]. Their diversity and abundance are influenced by climatic, edaphic (soil-related), and anthropogenic factors. In tropical regions like India, studies have reported a rich assemblage of mesofauna, with Collembola and mites dominating most agroecosystems and forest soils [16-17]. Spatial and temporal variations in mesofaunal communities are often linked to seasonal changes in moisture and organic matter availability [18]. Some of the major soil mesofauna groups include the animals, such as:

- **Collembola:** These are among the most abundant and diverse mesofauna, with over 9,000 species described worldwide. They are sensitive to soil pollutants, making them excellent bioindicators **[19]**. Common genera include Folsomia, Isotoma, and Entomobrya.
- **Acari**: They are primarily oribatid mites, consist of more than 50,000 described species, many of which play roles in decomposing organic matter and regulating microbial populations **[20]**. Genera such as Oppia, Scheloribates, and Galumna are frequently found in forest and agricultural soils.
- **Enchytraeidae (potworms)**: These are actually belonged to a family of small annelids, thrive in moist, organic-rich soils, and are important in nutrient mineralization processes. Species like *Enchytraeus albidus* and *Fridericia galba* are common in temperate soils **[21]**.
- **Diplura and Protura:** These are less studied but contribute to soil fragmentation and organic matter processing. Genera such as Campodea (Diplura) and Acerentomon (Protura) have been recorded in Indian soils **[22]**.
- **Symphyla:** They are small, centipede-like arthropods that inhabit leaf litter and the upper soil layers. Though low in abundance, they are known for their role in organic matter decomposition **[23]**.

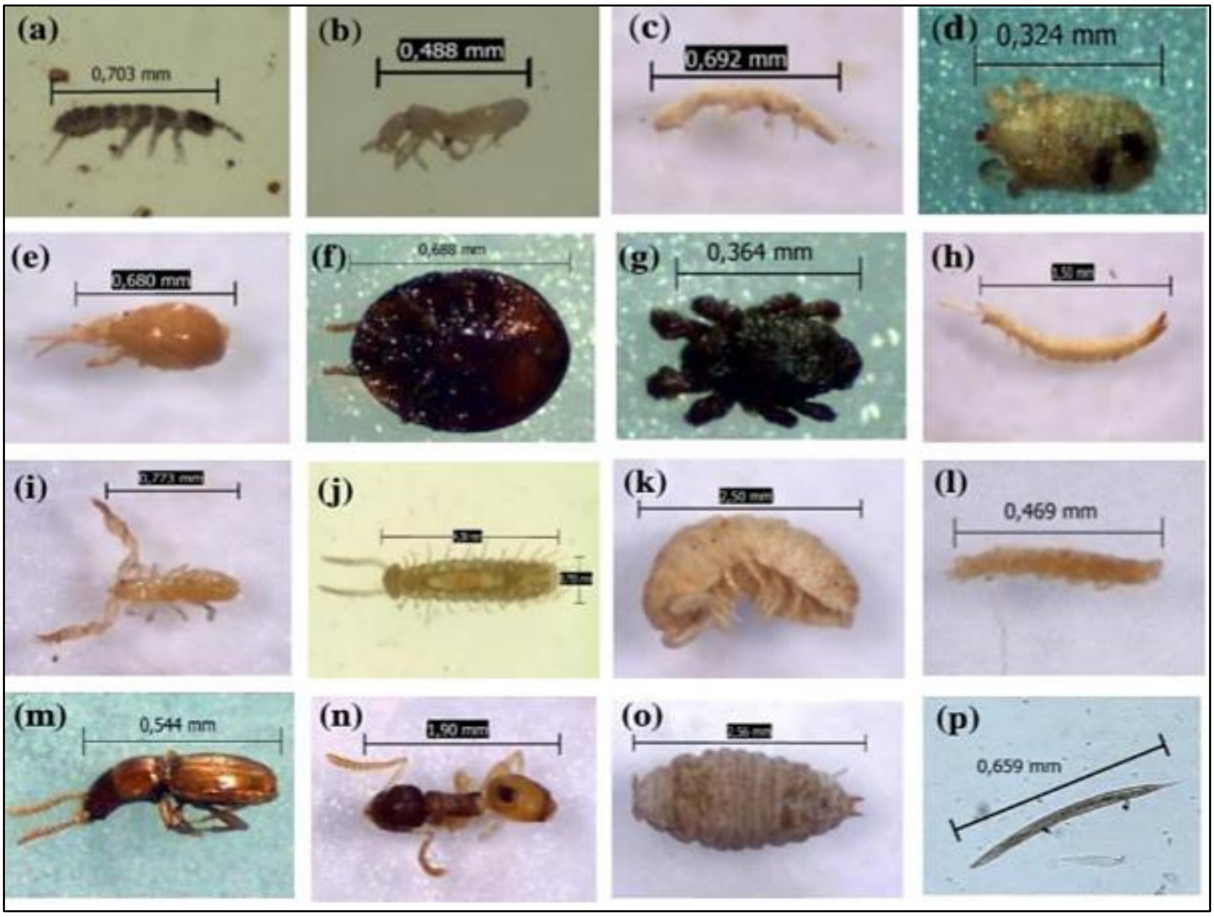

Figure 1 Soil mesofauna groups: (a) order Collembola suborder Entomobryomorpha; (b) order Collembola suborder Symphypleona; (c) order Collembola suborder Poduromorpha; (d) order Acarina suborder Oribatida; (e) order Acarina suborder Mesostigmata; (f) order Acarina suborder Prostigmata; (g) order Acarina suborder Astigmata, (h) order Diplura; (i) order Pseudoscorpiones; (j) order Symphyla; (k) order Diplopod; (1) order Pauropod; (m) order Coleoptera, (n) order Hymenoptera; (o) Unidentified; and (p) order Nematodes. [24]

2. Ecological Role of Soil Mesofauna

Soil mesofauna are a key component of the soil food web, interacting with microorganisms and other organisms to regulate ecosystem processes [25]. They play a crucial role in regulating nutrient cycling, decomposition, and soil structure, making them essential for plant growth and development [26]. They execute significant functions in soil formation and structure maintenance through their burrowing activities, which aerate the soil and improve its porosity [27]. Soil mesofauna contribute to biodiversity and ecosystem services by providing habitat and food for other organisms, and by influencing ecosystem processes such as decomposition and nutrient cycling [25]. The major ecological functions of soil mesofauna includes:

2.1. Decomposition and Nutrient Cycling:

Soil mesofauna, such as springtails and mites, contribute to decomposition and nutrient cycling by breaking down organic matter and releasing nutrients back into the soil, stimulating the microbial activity. Their grazing on fungi and bacteria enhances microbial turnover, which accelerates nutrient mineralization and availability [28-29]. Studies by Beare *et al*. [30] have shown that Collembola and mites significantly increase nitrogen availability in soil systems through their feeding and excretion activities.

2.2. Soil Structure and Aggregation:

Through their movement and feeding, mesofauna influence soil porosity, aeration, and aggregate formation. Earthworms and enchytraeids create biopores, while arthropods contribute to microaggregate stability [2]. Soil mesofauna help reduce soil compaction and improve water holding capacity through their burrowing activities, which can reduce soil erosion and increase water availability [31]. The mucus and faeces of these organisms act as binding agents, enhancing soil structure and water-holding capacity [32].

2.3. Plant Growth and Health:

Mesofauna impact plant productivity both directly and indirectly. By enhancing nutrient cycling, they promote root development and plant vigour [33]. Soil mesofauna help regulate soil pH and nutrient availability through their activities, which can influence nutrient uptake by plants [26]. Some mesofauna also suppress soil-borne pathogens by promoting beneficial microbial communities, thus improving overall soil health [7]. Setälä *et al.*, [34] showed mesofauna play a functional role in regulating microbial biomass, thus affecting plant growth indirectly through nutrient availability.

2.4. Ecosystem Resilience and Stability:

Soil mesofauna contribute to ecosystem resilience by maintaining functional redundancy and buffering the system against environmental disturbances. Their diversity ensures sustained ecosystem services, even under stress conditions like drought or pollution [35]. The complex interactions between mesofauna and soil biota play a key role in ecological stability and recovery processes.

3. Factors affecting Soil Mesofauna and soil ecosystem dynamics:

3.1. Climate and seasonal Change:

Climate change affects mesofauna through altered temperature, precipitation patterns, and soil moisture regimes. These changes influence mesofauna survival, reproduction, and community structure [36]. According to some studies, warming can lead to a shift in species composition, favouring drought-tolerant taxa. Lang *et al.* [37] reported that the climate change, particularly increased dryness and temperature can adversely impact the soil food webs including mites and collembola, which may lead to disturbances at the higher trophic levels. Kardol *et al.* [38] demonstrated that in subtropical climate, the precipitation and temperature can alter the soil moisture content, which subsequently impact the soil mesofauna communities, mainly collembola and acari to a greater extent, in comparison to the warming or increased CO_2 content. Studies have also reported the reduction in collembola species richness and alterations in community structure in response to climate warming and seasonal drought, indicating the role of precipitation in these seasonal or climate changes [39-40]. In case of Acari, Markkula *et al.* [41] reported a significant reduction in the numbers of Gamasida and Oribatida mites in response to warming treatments in subarctic ecosystem. Alatalo *et al.* [42] performed a long-term experiment in Tundra ecosystem and reported that the warming adversely affects the juveniles of Oribatida, but no significant impact on the adults was observed. Thakur *et al.* [4] reported that the climate warming can produce adverse alterations in the soil biomass distribution of the microarthropod groups including mites and collembola.

The occupancy of different mesofauna groups in different depths of the soil along with their diverse feeding habits makes them affected by the climate or environmental changes in a diversified manner. The surface-dwelling species are more vulnerable to the climate changes in comparison to the euedaphic species, which are deep-dwelling and possess low metabolic activities [43]. Hemiedaphic species are mostly litter-dwelling and possess the intermediate characters between deep-dwelling euedaphic species and surface-dwelling epigeic species [18].

3.2. Land Use and Agriculture Practices:

Land conversion from forest to agriculture or urban landscapes significantly reduces mesofaunal diversity and abundance due to habitat loss and disturbance [44]. Practices like tillage, pesticide application, and monoculture cropping disrupt soil habitats, often leading to simplified and less functional communities [45]. Agricultural practices can reduce species richness and abundance of soil fauna through soil habitat disrupting phenomena such as field traffic and tillage [46]. Sahdra *et al.* [47] reported the variations in the composition of mesofauna communities in different habitat types, such as forested blocks and low woody-vegetation drainage bank sites. Furthermore, the cultivation practices and land processing can lead to adverse alterations in soil pH, soil temperature and air temperature, which can affect the diversity and even existence of soil mesofauna [43]. Yin *et al.* [48] reported that the land use practices and climate change can adversely impact the collembola life forms. The cultivation practices through agrochemical and mechanized methods can lead to transformation of natural ecosystems into more specialized agroecosystems with limited opportunities for the growth, survival and distribution of soil organisms including mesofauna communities, along with undesirable changes in the physical structure of the soil [2]. Socarrás and Izquierdo [49] reported that the agriculture practices can adversely impact the diversity of edaphic mesofauna. Several studies indicate that agricultural practices and land reforms should be integrated into sustainable land management strategies to preserve soil biodiversity and conserve soil ecosystem dynamics.

3.3. Pollution and Contaminants:

Heavy metals, pesticides, and industrial pollutants negatively affect mesofauna populations by causing mortality, reducing reproduction, and impairing physiological functions [50]. Chronic exposure to pollutants alters community composition and reduces ecosystem services such as decomposition and nutrient cycling. Zheng *et al*. [51] reported that the oil exploitation in wetlands have an adverse impact on the diversity of soil mesofauna. The soil mesofauna could be adversely affected by soil contaminants or pollutants like microplastics, heavy metals, pesticides, among others, which may subsequently lead to reduction in their diversity, abundance, alterations in gut microbiome, and ultimately their ecological functioning, leading to impairment in soil quality and fertility [52]. According to Beaumelle *et al.* [53] species richness of soil mesofauna was significantly reduced in fumigants pesticide-affected areas. Most of the soil contaminants can kill soil microbes and microfungi, reducing the food resources available for mesofauna. These soil contaminants can produce changes in the physicochemical properties of the soil, such as organic matter content and water retention capacity, subsequently leading to adverse alterations in the distribution and abundance of soil mesofauna [54]. The ecological functioning or the activities of soil mesofauna can get slower due to the presence of soil contaminants, which subsequently lead to slower decomposition process, adversely affecting the nutrient cycling [55].

3.4. Impact of pesticides on soil mesofauna:

The irrational use of pesticides in agricultural fields by the local farmers, lacking scientific knowledge for proper dosage, is one of the major contributors towards soil contamination or pollution, which subsequently leads to adverse alterations in soil fauna communities and soil ecosystem dynamics. Beaumelle *et al*. [53] conducted a meta-analysis of 54 studies and found a consistent decline in both abundance and diversity of soil mesofauna due to pesticide application. The study identified that broad-spectrum substances and combinations of multiple pesticides had the most detrimental impact, reducing the diversity of key functional groups like detritivores and microarthropods. Römbke *et al*. [50] further highlighted the value of field studies using enchytraeids and mites in environmental risk assessment. Their results confirmed that pesticide exposure in field conditions causes a measurable decline in mesofauna populations. In a study focusing on cyclohexane-based pesticides. Silva *et al.* [56] demonstrated how volatile organic pesticide formulations lead to sub-lethal effects such as reduced reproduction and moulting inhibition in springtails (Collembola). Their findings also suggested a reduction in soil respiration and microbial biomass in treated plots, pointing toward a broader ecosystem-level impact. Jat *et al*. [57] reviewed the impact of pesticides on soil ecosystem functioning and reported that the exposure of herbicides and insecticides in soil can lead to reduction in soil fauna communities and produce adverse impact on their growth, survival and trophic dynamics by disrupting the food webs within the soil ecosystem. It has also been evident that different groups of pesticides affect different mesofauna communities differently. Konestabo *et al*, [58] reported that Imidacloprid exposure resulted into a significant reduction in the abundance of springtails in a dose-dependent manner, whereas no impact was observed on mites, indicating less sensitivity of mites towards neonicotinoids. Another study by Cortet *et al*. [59] revealed that the insecticides Fipronil and Carbofuran, and the herbicides Atrazine and Alachlore have shown adverse impact on soil microarthropod populations and decomposition process in the soil. However, despite of available knowledge, more work in this area is needed for comprehensive understanding of the use of pesticides and their possible impacts on the soil fauna community dynamics and soil ecosystem processes.

Sharma and Parwez [60], in a study from an Indian agroforestry habitat, also documented that chemical exposure led to notable reductions in mesofauna density. Notably, the plots treated with cyclohexane pesticide showed a marked decline in mesofauna abundance, indicating a toxic or repellent effect of the pesticide. Ghosal and Hati [61] reported similar declines in soil arthropod populations following pesticide exposure. The reduced abundance in treated plots suggests a disruption in the soil food web, potentially affecting organic matter decomposition and nutrient turnover. In addition to the direct impact on population size, Sharma and Parwez [60] reported that the pesticide-treated plots also showed lower species diversity, especially among more sensitive taxa such as Symphyla and Diplura. This decline in biodiversity poses a long-term risk to soil ecosystem functioning, as mesofauna contribute significantly to soil structure, aeration, and nutrient recycling, which could affect long-term soil fertility and crop productivity. Some recovery was observed in aged pesticide plots, suggesting resilience, but not restoration to pre-application conditions.

4. Impact of pesticides on diversity and abundance of soil mesofauna:

A few studies have reported the impact of soil contaminants such as pesticides on soil mesofauna diversity and abundance.

4.1. Decline in Total Abundance

A few studies have reported a significant decline in the overall population of soil mesofauna in pesticide-treated soil compared to control or normal soil. Konestabo *et al*. **[58]** have reported that the treatment of soil with pesticide (for ex. Chloropyrifos) resulted into a 47% decrease in Collembola population. Other groups such as diplura, symphyla, and enchytraeids showed a notable reduction or were completely absent in heavily treated areas.

4.2. Loss of Species Diversity

According to Beaumelle *et al*. **[53]** species richness was significantly reduced in fumigants pesticide-affected areas. Control plots exhibited a more complex and diverse mesofauna community, including rare taxa. In contrast, fumigants treated plots showed species homogenization, with only a few pesticide-tolerant species persisting, and absence of key decomposers such as enchytraeids, crucial for nutrient cycling.

4.3. Alteration in Community Structure

According to Rombke *et al*. **[50]** the structure of the mesofaunal community changed significantly in response to Chlorpyrifos pesticide treatment. Predatory mites and sensitive taxa like nematodes and enchytraeids were the first to decline or vanish. Opportunistic and pesticide-resistant species dominated the treated plots and the ecological balance between detritivores and predators was disrupted.

4.4. Temporal Impact and Partial Recovery

According to Sharma and Parwez **[60]**, initial effects were most severe in the first 2–3 weeks after Carbofuran pesticide application. Some degree of biological recovery was observed in plots sampled 60–90 days post-application. Recolonization by Collembola and Acari was evident but at lower densities than baseline levels. Full species richness and functional recovery were not achieved, indicating long-term ecological disruption.

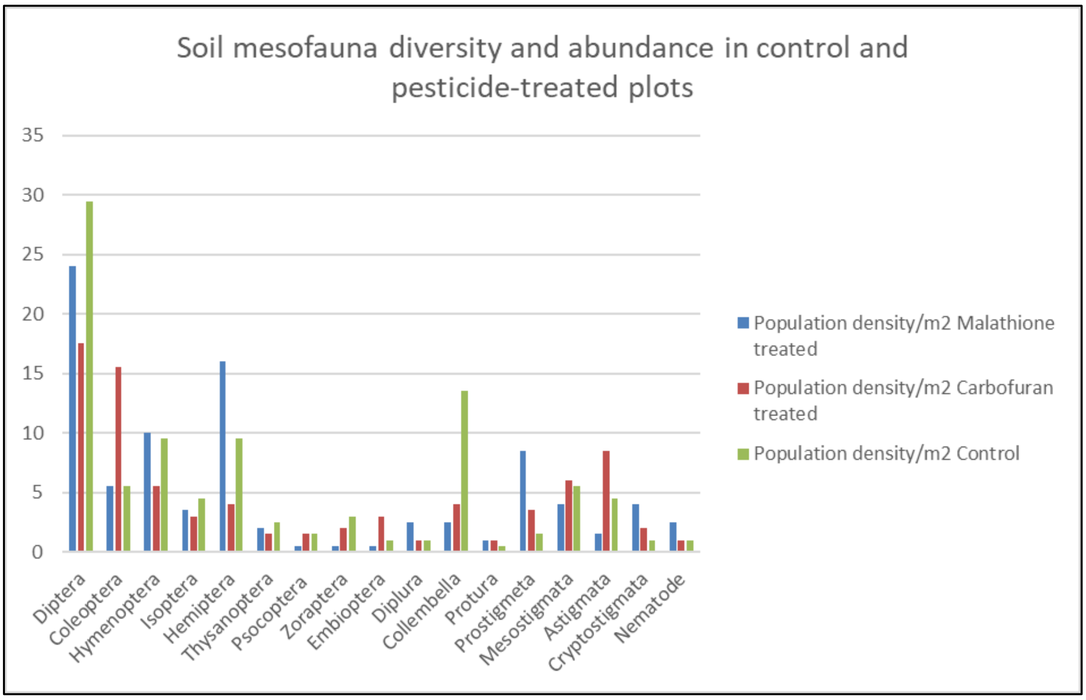

Figure 2 Graph showing comparative abundance of different soil mesofauna groups in control and pesticide-treated plots (Adapted from Sharma and Parwez), [60]

5. Conclusion and future prospective

Soil mesofauna, comprising vital organisms like Collembola, Acari, Diplura, and others, play a critical role in maintaining soil health, promoting nutrient cycling, enhancing soil structure, and supporting overall ecosystem resilience. The present findings emphasize their sensitivity to environmental changes and anthropogenic disturbances, especially pesticide application. Given their ecological importance, the future of soil mesofauna research should focus on long-term monitoring and developing sustainable agricultural practices that minimize chemical inputs. Advanced molecular tools and bioindicator-based assessment methods must be incorporated to better understand the subtle impacts of pollutants on mesofauna diversity. Furthermore, restoration ecology should include strategies to rehabilitate soil biota for degraded lands, ensuring biodiversity conservation and soil productivity.

As global concerns over soil degradation and climate change rise, soil mesofauna research offers promising pathways to ensure ecological balance, food security, and sustainable land use. Further studies in this context is needed for greater policy attention and interdisciplinary collaboration, which will be crucial in translating research findings into effective soil management and conservation strategies.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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