Review Article

Soil Arthropods: An Unsung Heroes of Soil Fertility

ABSTRACT

Soils are crucial elements of ecosystems, and their fertility is maintained mainly by the actions of their living organisms. The fertility of soil depends on its ability to provide plants with vital nutrients needed for their growth and reproduction. Additionally, soil acts as a physical medium that facilitates root growth and respiration while also maintaining its structural integrity against erosive forces. Arthropods play a significant role in enhancing the decomposition of plant litter in two ways. Firstly, they directly turn it into their tissues. Secondly, they indirectly alter it physically and chemically, turning it into substrates that can further be decomposed. Termites have higher assimilation efficiencies compared to other soil arthropods, which means they can convert a greater proportion of ingested litter into biomass directly. On the other hand, collembola, oribatid, myriapods, and Isopoda contribute to nutrient cycling indirectly as secondary decomposers. They condition litter for further breakdown by the microflora through comminution and passage through the gut. Arthropods, such as insects, can create tunnels and burrows in soil, which help to allow air and water to penetrate deeper into the soil. These tunnels also help to mix organic materials into the upper layers of soil. In addition, arthropod faeces serve as the starting point for the creation of soil aggregates that are necessary for maintaining the soil structure and integrity. Soil arthropods play a crucial role in the formation of humus, which helps to retain water and nutrients in the soil. In addition, they provide important ecosystem services, including provisional, supporting, and regulating services. Unfortunately, these tiny creatures' contributions to the environment are often undervalued and neglected.

Keywords: *Collembola, Decomposition, Humus,Microflora, Organic matter, Soil structure.*

1. INTRODUCTION

Soil is the essential foundation of life on our planet. Soil fertility refers to the soil's capacity to sustain plant growth and produce consistent crop yields. It also pertains to the soil's ability to provide plants with appropriate quantities and quality of water and nutrients over time. Fertile soil denotes soil with favourable chemical, physical, and biological properties that support plant growth (Vargas Rojas *et al.*, 2022). The excessive use of pesticides and agricultural chemicals in cropping fields, together with agricultural mechanisation, lead to a significant decline in soil quality. The acceleration of soil degradation brought on by unsuitable cultural practices (Bhattacharyya *et al.*, 2015). Soil fertility is maintained by several soil factors. These factors include soil organic carbon, cultural practices, climate, soil flora and fauna and so on. Soil fauna plays an important role in soil fertility as it interacts with the soil and keeps the soil’s physical, chemical and biological properties at optimal levels for plant growth.

Among the fauna, there may be representatives of around 20 different families of Arthropods, the most abundant phylum of organisms. They are found in a wide variety of soil environments in various ecosystems (Stork, 2018).Soil Arthropods include a wide variety of guilds: Specialised and Polyphagous Predators, Parasites, Phytophages, Fungivores, Microbivores, Saprophages, Detritivores, and Omnivores (Kumar and Singh, 2016). Arthropods commonly inhabit the soil and the layer of organic matter beneath it. Common types of arthropods found in soil and litter include mites, collembolans, pseudo scorpion, centipede, millipede, isopods, proturan, dipluran, symphylan, hymenopteran, coleopteran, and larvae forms of numerous other orders. Acarina and collembola are the most abundant and diverse Arthropoda in soil (Begum *et al*., 2011; Xin *et al*., 2018).

Soil arthropods are a vital component of soil-based communities and are crucial in preserving soil quality, health, and ecosystem services. They play a vital role in the soil ecosystem by breaking down organic matter, increasing soil aeration, and improving nutrient availability. Some arthropods feed on plant material and help to recycle nutrients back into the soil, while others are predators that feed on pests, helping to control their populations. Additionally, arthropods can contribute to soil structure by burrowing and creating channels that improve water infiltration and retention. Overall, arthropods are a crucial component of healthy soil and understanding their role in the ecosystem is essential for maintaining soil fertility. In this article, we'll dive deep into the fascinating topic of how arthropods contribute to soil fertility.

2. ARTHROPODS IN SOIL

Comment [H1]: Please refer Fig 1 in text!

Arthropoda is the scientific name for the phylum of invertebrates that includes insects and spiders. Arthropods are the largest animal phylum, with an estimated 1,170,000 to 5-10 million species (Mans, 2017; Chlup, 2022). They can be found in all types of habitats, including land, water, and soil.

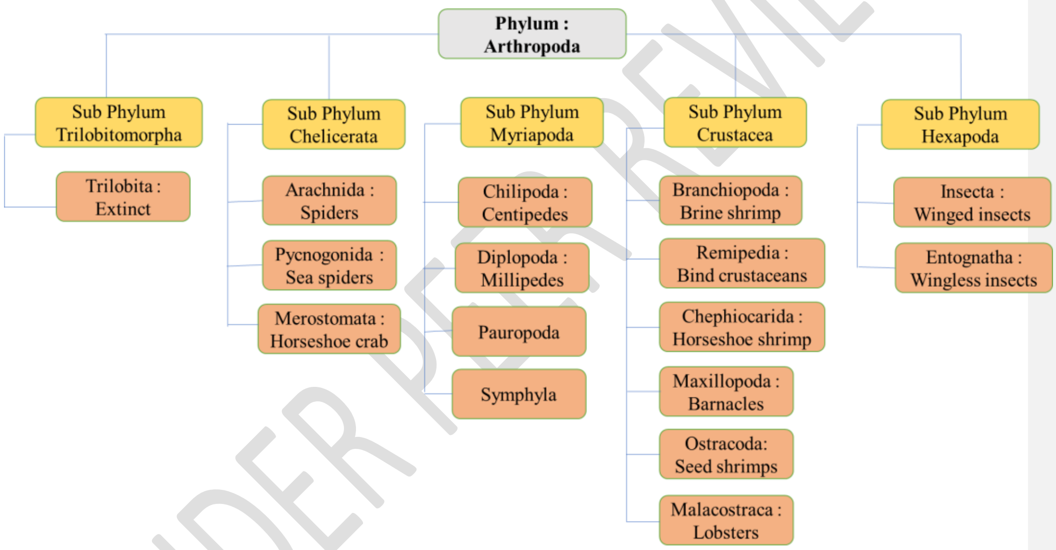

Fig. 1: Classification of Phylum Arthropoda

The litter marks the boundary between the above-ground and below-ground subsystems, and here the fauna is constantly changing with the seasons. When moisture levels are high, the litter is home to arthropods that live in the deeper layers of the soil. In contrast, arthropods living in the upper layers of the soil, such as on the top of plants or in temporary habitats like dung or fallen stumps, are mostly active from July to September. The activity pattern of organisms living above the soil surface is determined by their reproductive cycles and search for food. Most arthropods belowground are mycophages and detritivores. Colonization extends from the humus layers. The seasonal pattern in this case is closely linked to the rhythm of organic matter decomposition and the development of fungal colonies. The majority of mesofauna tend to seek shelter in the upper mineral soil only during periods of summer drought (Andrés *et al*., 1999).

3. ROLE OF ARTHROPODS IN SOIL FERTILITY

Comment [H2]: Please refer Fig. 2 in text!

As arthropods feed and burrow, they provide many benefits to soil health. Moving through the soil, they aerate and gently churn it, improving porosity, water infiltration rates, and bulk density. As they feed, they shred organic matter, speeding decomposition. And when they excrete waste products, they release mineralized plant nutrients and enhance soil aggregation because their waste is coated with mucus. Their feeding also curbs the populations of other soil organisms and opens the way for a wider variety of other, smaller decomposers.

Fig. 2 Different Arthropods in soil

3.1 Decomposition

Decomposition is the breakdown of a dead organism or it remains into its individual elements. Biotic and abiotic agents interact in this process, ultimately leading to the liberation of energy and mineralization of chemical nutrients. The arthropods involved in the process of decomposition of animal and plant remains belong to such taxa as Diplopoda, Isopoda, Collembola, Larval Diptera, Coleoptera, Acari. Arthropods are common decomposers in almost all land habitats,especially in temperate regions, playing a crucial role in waste degradation (Wurst *et al*., 2018). However, arthropods lack the ability to decompose the primary plant components cellulose and lignin directly. They form mutualistic bond with microorganisms present in their intestinal tract for the enzyme to degrade the cellulose and lignin (Ayayee *et al*., 2004; Ni and Tokuda, 2014; Brune, 2014)Termites (Isoptera) and Cockroach (Blattodea) are the well-known decomposers. Termite possess symbiotic bacteria and protozoans to assimilate wood. Millipedes (Diplopoda) specifically known to degrade the leaf litter. Another important cellulose decomposer is the woodlice (Isopoda) which contains microorganisms in their intestine that allows them to degrade cellulose. Leaf cutter ants (Hymenoptera), Ambrosia beetles (Coleoptera), and Springtails (Collembola) assimilate the woody materials that are predigested by extraintestinal microorganisms (Galante & Marcos-Garcia, 2008).Dung beetles facilitate dung decomposition and help in transferring nutrients from the dung to the soil (Yamada *et al*., 2007).

3.2 Nutrient cycling and mineralization

Nutrient cycling is important for soil because it ensures the supply of nutrients that plants need to grow. Nutrient cycling involves the exchange of nutrients between different components of a cell, community, or ecosystem. The destiny of the litter eliminated by arthropods is highly diverse. A considerable amount of the eliminated litter is transferred without being consumed, for later use. The fragmented litter offers more surface area for microbial colonization and results in a faster decomposition rate compared to intact litter. Arthropods that ingest litter either use it for secondary production or excrete it as faecal matter. Some of the nutrients they use are released back into the environment as CO_2, ammonia, uric acid, guanine, or phosphate, which speeds up the cycling of plant nutrients. The undigested litter is released back into the environment as fragmented and partly decomposed faecal pellets. Faeces decompose faster than unprocessed plant litter (Sagi and Hawlena, 2021).

Burrowing detritivores transfer nutrients from the surface to belowground through fragmented plant litter, faeces, and excretions. Animal burrows enhance soil conditions by improving water infiltration, soil aeration, and thermal buffering, creating a favourable microclimate for microbes and mesofauna, which promote the mineralization of nutrients via the intertwined effects of climatic and nutrient facilitation. The concentrations of ammonium, nitrate, and phosphate increased by 1.5, 2, and 1.3 times, respectively, in the vicinity of the vertical burrow of desert isopods as compared to 20 cm distant from the burrow (Sagi *et al*., 2019). When Collembolan feed on fungi, it can lead to the release of more nitrogen (N) and calcium(Ca) into the environment (Ayayee *et al*., 2004). This can have important implications for nutrient availability, especially in environments like acidic forest soils, where large nutrient reserves are usually trapped in stored organic matter (Culliney, 2013). Arthropods that graze on the microflora have a regulatory effect on the rate of decomposition (David, 2014). This helps to prevent sudden microbial blooms, which in turn helps to mineralize nutrients and release them from detritus. The result is that the nutrients become more readily available for plant uptake in a controlled and continuous manner, while their loss from the system is minimized.

Soil arthropods such as Collembola, Oribatids, Isopoda, and Diplopoda can store significant amounts of K^+, PO_4^{3-}, N, Na^+, and Ca^{2+} within their biomass (Crowther, 2012). This makes them an important source of nutrients that can temporarily immobilize these ions, preventing them from leaching out of the soil. When the arthropods die, the nutrients they have stored in their tissues are released into the soil. The nests of termites create perfect conditions for various microbial species that are crucial for breaking down litter and releasing nutrients. The annual deposit of gallery cartons by subterranean termites in a North American desert ecosystem is at least 2.6 tonnes per hectare, resulting in a nitrogen input of 380 grams per hectare (Sagi *et al.,* 2019).

Ant nests have a tendency to accumulate large amounts of organic matter from plant and animal sources in their refuse dumps. This material, combined with metabolic wastes and secretions from the ants themselves, gets decomposed and mineralized by the microflora. As a result, the nutrients get accumulated and concentrated locally, making the ant nests rich in nutrients compared to the surrounding soil. Following the death of a colony, the nutrient-rich soil in the nests of certain ant species can attract different plant species, which can accelerate the process of ecological succession. This shift in vegetation can cause a change from pasture to woodland. These ants help break down plant materials, aiding in the decomposition process and promoting nutrient cycling.

Climate and nutrient facilitation promote the activity of microorganisms and mesofauna, leading to faster mineralization of litter-derived nutrients such faecal pellets and litter residues within burrows.The transport of nutrients by arthropods between different patches within and between ecosystems, and the fixation of nitrogen by arthropod gut symbionts, may help explain the spatiotemporal spread of nutrients (Sagi and Hawlena, 2021).

3.3 Soil structure building

Soil structure affects soil fertility because it affects how much nutrients are available to plant roots, as well as how well roots can develop laterally and along the profile. A well-structured soil provides enough water, nutrients and oxygen for plant growth, as well as plenty of space for roots to enter. A poorly-structured soil impedes root growth, water circulation and drainage. Arthropods affect the structural properties of soils in various ways. The underground system of passageways and chambers that make up termite and ant colonies have a crucial role in improving the soil's aeration and water infiltration. This results in an increase in water storage and the retention of topsoil. It has been reported that termites can work the soil to depths of 50 meters or even more (Holt and Lapage, 2000).

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Millipedes are able to tunnel through tightly packed soil particles and create burrows using the thrust generated by their numerous dual leg pairs. They also leverage the labrum, collum, or flat back (depending on the species) to achieve this. Additionally, by consuming decaying root systems, they indirectly aid in increasing water infiltration by opening up channels within the soil. Ants and termites that live underground can have a remarkable impact on the size distribution of soil particles. These insects tend to remove the smaller and finer soil particles from the lower layers of the soil, which creates a more distinct texture difference between the topsoil (A horizon) and subsoil (B horizon). This can affect various soil processes such as the development of suspended water tables or an increase in the redox potential within the soil. These changes in turn affect nutrient availability and the ability of soil to support vegetation (Culliney, 2013).

The faecal pellets of Collembola have the ability to easily agglomerate and form water-stable aggregates within the soil. The strong interparticle cohesive forces present within the faecal pellets contribute significantly to their persistence. The faeces of Collembola and other microarthropods make up a significant proportion of the humic material in developing sand dunes. It is believed that they contribute to dune consolidation and stabilization by binding sand grains into larger aggregates.

4. ARTHROPODS IN AGRICULTURE – CURRENT SCENARIO

Agricultural intensification has been found to have a negative impact on taxonomic richness and diversity across different groups of organisms, particularly soil biota. This is because agricultural management practices such as tillage, use of fertilizers and pesticides, and reduced crop diversity, harm the composition and abundance of living organisms when compared to the natural landscape. Pesticides are designed to harm specific organisms, but they can also affect other species that are connected to them, such as parasitoids. Although pesticides have species-specific reactions, they can still have an impact on the makeup of arthropod communities. Long-term and repeated use of glyphosate, which supposedly has no long-term effect on soil microbial biomass, enzyme activity, or respiration, has been found to reduce beneficial microflora. As a result, plants are more susceptible to soil-borne fungal pathogens.

According to most reports, herbicides tend to have an indirect impact on insect populations by altering their survival rates or egg production. This is often caused by changes in the population of host plants. Herbicides can also lead to a reduction in predatory arthropods and pollinators by removing their sources of food, shelter, and nesting sites like plant hosts, pollen, nectar, and overwintering sites. When insecticides are used on crops, they can harm both the target pests and other non-target insects. Although the pests may eventually die, it can take anywhere from a few minutes to a few days, depending on the amount of exposure to the insecticide. Meanwhile, natural predators that feed on the affected species may also be harmed by the insecticide and experience secondary poisoning, which can reduce their ability to hunt or even cause their death. Sublethal impacts of insecticides on detritivores arthropods can harm aquatic ecosystems by impairing trophic relationships and reducing decomposition and nutrient recycling. It is crucial to comprehend the indirect consequences of pesticides to successfully manage pests, weeds, and diseases. Unfortunately, chemicals often fail to produce the intended outcomes. Hence, it is essential to learn from past mistakes and integrate pest and weed management programs accordingly.

5. CONCLUSION

Soil is an essential component of ecosystems and is maintained in a fertile state mainly due to the actions of various organisms present in it. Arthropods aid in the degradation of plant litter by directly transforming plant litter into their tissues and indirectly by physically and chemically converting plant litter into substrates suitable for further degradation. Arthropods, create tunnels and burrows in the soil. These channels allow air and water to pass through, and also help mix organic matter into the upper layers of soil. The faeces of these arthropods act as nuclei for soil aggregates, which are important for maintaining the soil's structure and integrity. Additionally, their faeces contribute to the formation of humus, which helps the soil retain water and nutrients. Soil arthropod biodiversity serves as an indicator of soil quality. Although the biomass of fauna constitutes a small proportion of the total soil mass, especially in mineral soil, their activity plays a crucial role in moving material against gravity and fluid flow, altering soil fabric and micro-topography, changing the distribution patterns of soil materials and plant nutrients, as well as in relating processes and assemblages of materials. Thereby soil arthropods plays a major role in soil fertility.

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