Journal of Advances in Biology & Biotechnology

Volume 27, Issue 6, Page 118-126, 2024; Article no.JABB.116136
ISSN: 2394-1081

Soil Arthropods: An Unsung Heroes of Soil Fertility

Kishore SM [a++*], Priyadharshini TB [b++] and K. Sowmya [c++]

[a] Department of Agricultural Entomology, Keladi Shivappa Nayaka University Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India.
[b] Department of Soil Science, Keladi Shivappa Nayaka University Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India.
[c] Department of Agricultural Entomology, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad, Telangana, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2024/v27i6872

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/116136

Review Article

Received: 22/02/2024
Accepted: 26/04/2024
Published: 08/05/2024

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

[++] *PhD Scholar;*
**Corresponding author: E-mail: kp464751@gmail.com;*

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 [1]. 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 [2]. 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 [3,27-35]. Soil Arthropods include a wide variety of guilds: Specialised and Polyphagous Predators, Parasites, Phytophages, Fungivores, Microbivores, Saprophages, Detritivores, and Omnivores [4]. 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 [5,6,23-26].

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 [51-56]. 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 [42,43]. 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 [36-41].

2. ARTHROPODS IN SOIL

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 [7,8]. The general classification of phylum Arthropoda is given below (Fig.1). They can be found in all types of habitats, including land, water, and soil.

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 [44-50]. 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 [57-61]. 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 [9,62-69].

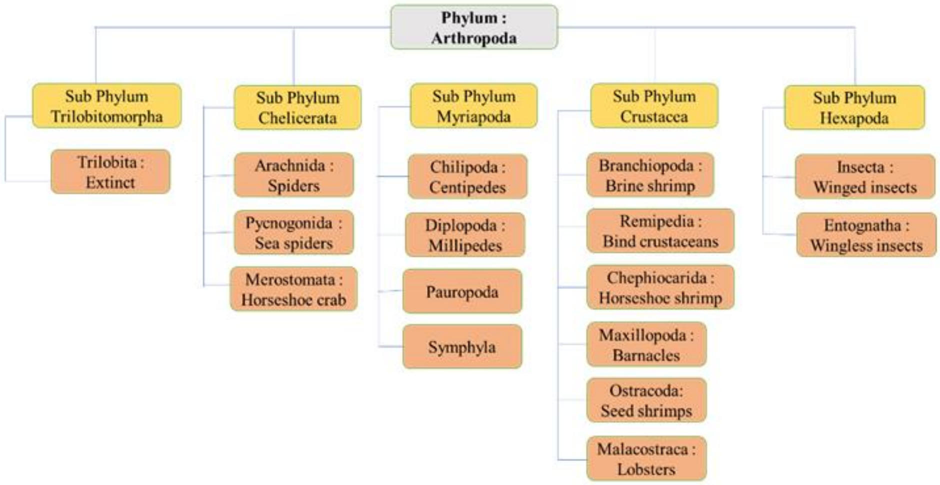

Fig. 1. Classification of phylum *Arthropoda*

3. ROLE OF ARTHROPODS IN SOIL FERTILITY

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. Some of the common Arthropods prevalently found in Indian soils are given below (Fig. 2).

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 [10]. 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 [11,12,13] 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 [70]. Leaf cutter ants (Hymenoptera), Ambrosia beetles (Coleoptera), and Springtails (Collembola) assimilate the woody materials that are predigested by extraintestinal microorganisms [14]. Dung beetles facilitate dung decomposition and help in transferring nutrients from the dung to the soil [15].

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 [16].

Fig. 2. Different arthropods in soil

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 [22]. 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 [17]. When Collembolan feed on fungi, it can lead to the release of more nitrogen (N) and calcium (Ca) into the environment [11]. 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 [18]. Arthropods that graze on the microflora have a regulatory effect on the rate of decomposition [19]. 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 [20]. 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 [17].

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 [16].

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 is an increase in water storage and the retention of top soil. It has been reported that termites can work the soil to depths of 50 meters or even more [21].

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 [18].

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.

ACKNOWLEDGEMENT

The authors express their sincere gratitude towards their parents for providing them with constant support and encouragement.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Vargas Rojas R, Taboada M, Saynes Santillán V, Cardoso Lisboa C, and Olivera C. Soils for nutrition: state of the art; 2022.
2. Bhattacharyya R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, and Franzluebbers AJ. Soil degradation in India: Challenges and potential solutions. Sustainability. 2015;*7*(4):3528-3570.
3. Stork NE. How many species of insects and other terrestrial arthropods are there on Earth? Annual review of entomology. 2018;63:31-45.
4. Kumar U, and Singh R. Soil fauna: A retrospection with reference to Indian soil. International Journal of Research Studies in Zoology. 2016;2(3):1-22.
5. Begum F, Bajracharya RM, Sharma S, and Sitaula BK. Assessment of soil quality using microarthropod communities under different land system: A case study in the mid-hills of central Nepal. Journal of Life Sciences. 2011;5:66-73.
6. Xin XL, Yang WL, Zhu QG, Zhang XF, Zhu AN, and Zhang JB. Abundance and depth stratification of soil arthropods as influenced by tillage regimes in a sandy loam soil. Soil use and management, 2018;34(2):286-296.
7. Mans DR. Exploring the global animal biodiversity in the search for new drugs–spiders, scorpions, horseshoe crabs, sea spiders, centipedes, and millipedes. Journal of Translational Science. 2017;3 (5):1-18.
8. Chlup P. Protection of invertebrates in legal regulation of european union; 2022.
9. Andrés P, Mateos E, and Ascaso C. Soil arthropods. In ecology of mediterranean evergreen oak forests. Springer Berlin Heidelberg. 1999;341-354.
10. Wurst S, Sonnemann I, Zaller JG. Soil macro-invertebrates: Their impact on plants and associated aboveground communities in temperate regions. Aboveground–Belowground community ecology. 2018;175-200.
11. Ayayee P, Rosa C, Ferry JG, Felton G, Saunders M, Hoover K. Gut microbes contribute to nitrogen provisioning in a wood-feeding cerambycid. Environmental Entomology. 2004;43(4): 903-912.
12. Ni J, Tokuda G. Lignocellulose-degrading enzymes from termites and their symbiotic microbiota. Biotechnology Advances. 2013;31(6):838-850.
13. Brune A. Symbiotic digestion of lignocellulose in termite guts. Nature Reviews Microbiology. 2014;12(3):168-180.
14. Galante E, Marcos-Garcia MA. Decomposer insects. Encyclopedia of entomology. 2008;1158-1169.
15. Yamada D, Imura O, Shi K, Shibuya T. Effect of tunneler dung beetles on cattle dung decomposition, soil nutrients and herbage growth. Grassland Science. 2007;53(2):121-129.

16. Sagi N, Hawlena D. Arthropods as the engine of nutrient cycling in arid ecosystems. Insects. 2021;12(8):726.
17. Sagi N, Grünzweig JM, and Hawlena D. Burrowing detritivores regulate nutrient cycling in a desert ecosystem. Proceedings of the Royal Society B. 2019;286(1914):20191647.
18. Culliney TW. Role of arthropods in maintaining soil fertility. Agriculture. 2013; 3(4):629-659.
19. David JF. The role of litter-feeding macro arthropods in decomposition processes: A reappraisal of common views. Soil Biology and Biochemistry. 2014;76:109-118.
20. Crowther T. Effects of grazing soil fauna on the functioning and community composition of saprotrophic basidiomycete fungi (Doctoral dissertation, Cardiff University); 2012.
21. Holt JA, Lepage M. Termites and soil properties. Termites: Evolution, sociality, symbioses, ecology. 2000;389-407.
22. Akhila A, Entoori K. Role of earthworms in soil fertility and its impact on agriculture: A review, International Journal of Fauna Biological Studies. 2020;9(3):55-63.
23. Apori SO, Murongo MF, Hanyabui E, Muli GK, and Wamuyu B. Role of military termites (*Pseudocanthotermes militaris*) in improving soil productivity in tropical agroecosystems; 2020.
24. Austin AT, Vivanco L. Plant litter decomposition in a semi-arid ecosystem controlled by photodegradation. Nature. 2006;442(7102):555-558.
25. Bagyaraj DJ, Nethravathi CJ, and Nitin KS. Soil biodiversity and arthropods: Role in soil fertility. Economic and ecological significance of arthropods in diversified ecosystems: Sustaining regulatory mechanisms. 2016;17-51.
26. Balasubramanian A, Sivakumar B, Hari Prasath CN, Swathiga G, Vasanth V, Thirumoorthy P, Nilav Ranjan Bora, and Manoj Prabhakar SJ. Influence of soil invertebrates on soil decomposition. Journal of Survey in Fisheries Sciences 2023;10(3):618-629.
27. Bazelet CS, Samways MJ. Identifying grasshopper bioindicators for habitat quality assessment of ecological networks. Ecological Indicators. 2011;11(5):1259-1269.
28. Brennan A, Fortune T, and Bolger T. Collembola abundances and assemblage structures in conventionally tilled and conservation tillage arable systems. Pedobiologia. 2006;50(2):135-145.
29. Byrd JH, Tomberlin JK. Forensic entomology: The utility of arthropods in legal investigations. CRC Press; 2019.
30. Chisanga K, Mbega ER, Ndakidemi PA. Prospects of using termite mound soil organic amendment for enhancing soil nutrition in Southern Africa. Plants. 2020;9(5):649.
31. Coleman DC, Geisen S, and Wall DH. Soil fauna: Occurrence, biodiversity, and roles in ecosystem function. In Soil microbiology, ecology and biochemistry. Elsevier. 2024;131-159.
32. Cortet J, Ronce D, Poinsot-Balaguer N, Beaufreton C, Chabert A, Viaux P, and de Fonseca JPC. Impacts of different agricultural practices on the biodiversity of microarthropod communities in arable crop systems. European Journal of Soil Biology. 2002;38(3-4):239-244.
33. Coulibaly SF, Coudrain V, Hedde M, Brunet N, Mary B, Recous S, and Chauvat M. Effect of different crop management practices on soil Collembola assemblages: A 4-year follow-up. Applied Soil Ecology. 2017;119:354-366.
34. Crespo-Pérez V, Kazakou E, Roubik DW, and Cárdenas RE The importance of insects on land and in water: A tropical view. Current Opinion in Insect Science. 2020;40:31-38.
35. David JF. The role of litter-feeding macroarthropods in decomposition processes: A reappraisal of common views. Soil Biology and Biochemistry. 2014;76:109-118.
36. Dulaurent AM, Houben D, Honvault N, Faucon MP, and Chauvat M. Beneficial effects of conservation agriculture on earthworm and Collembola communities in Northern France. Plant and Soil. 2023;1-11.
37. Fartmann T, Krämer B, Stelzner F, and Poniatowski D. Orthoptera as ecological indicators for succession in steppe grassland. Ecological Indicators. 2012; 20: 337-344.
38. Gonçalves F, Nunes C, Carlos C, López Á, Oliveira I, Crespí A, and Torres L. Do soil management practices affect the activity density, diversity, and stability of soil arthropods in vineyards? Agriculture, ecosystems & environment. 2020;294: 106863.

39. Gongalsky KB. Soil macrofauna: Study problems and perspectives. Soil Biology and Biochemistry 2021;159:108281.
40. Guedes RNC, Rix RR, Cutler GC. Pesticide-induced hormesis in arthropods: Towards biological systems. Current Opinion in Toxicology. 2022;29:43-50.
41. Hansen AA, Chatterjee A, Gramig G, Prischmann-Voldseth DA. Weed and insect management alter soil arthropod densities, soil nutrient availability, plant productivity, and aphid densities in an annual legume cropping system. Applied soil Ecology. 2018;130:120-133.
42. Javed A, Ali E, Afzal KB, Osman A, and Riaz S. Soil fertility: Factors affecting soil fertility, and biodiversity responsible for soil fertility. International Journal of Plant, Animal and Environmental Sciences, 2022;12(1):21-33.
43. Judd TM, Landes JR, Ohara H, Riley AW. A geometric analysis of the regulation of inorganic nutrient intake by the subterranean termite Reticulitermes flavipes Kollar. Insects. 2017;8(3):97.
44. Kardol P, Reynolds WN, Norby RJ, Classen AT. Climate change effects on soil microarthropod abundance and community structure. Applied Soil Ecology. 2011;47 (1):37-44.
45. Kumar NG, Ammagarahalli B, and Gopalkrishna HR. Soil fauna and sustainable agriculture. Innovative pest management approaches for the 21st Century: Harnessing Automated Unmanned Technologies. 2020;211-226.
46. Lakshmi G, Okafor BN, and Visconti D. Soil microarthropods and nutrient cycling. Environment, climate, plant and vegetation growth. 2020;453-472.
47. Malematja E, Manyelo TG, Sebola NA, Kolobe SD, Mabelebele M. The accumulation of heavy metals in feeder insects and their impact on animal production. Science of the Total Environment. 2023;163716.
48. Menta C, Remelli S. Soil health and arthropods: From complex system to worthwhile investigation. Insects. 2020;11 (1):54.
49. Menta C, Conti FD, Pinto S. Microarthropods biodiversity in natural, seminatural and cultivated soils—QBS-ar approach. Applied Soil Ecology. 2018;123:740-743.
50. Menta C, Conti FD, Lozano Fondón C, Staffilani F, Remelli S. Soil arthropod responses in agroecosystem: Implications of different management and cropping systems. Agronomy. 2020;10(7):982.
51. Muhammad A, Auwal Y, Usman AH. Determination of heavy metals (Co, Cu, Cd, Fe, Pb, Zn) in some edible insects and fingerlings in Dutsin-Ma Town. Fudma Journal of Sciences. 2022;6(4): 6-11.
52. Mullins A, Chouvenc T, Su NY. Soil organic matter is essential for colony growth in subterranean termites. Scientific Reports. 2021;11(1):21252.
53. Munir I, Ghaffar A, Aslam A, Shahzad MK, Jafir M. Impact of weeds on diversity of soil arthropods in Bt cotton field in Faisalabad Pakistan; 2020.
54. Muon R, Ket P, Sebag D, Boukbida HA, Podwojewski P, Hervé V, Jouquet P. Termite constructions as patches of soil fertility in Cambodian paddy fields. Geoderma Régional. 2023; 33: e00640.
55. Neher DA, Barbercheck ME. Soil microarthropods and soil health: Intersection of decomposition and pest suppression in agroecosystems. Insects. 2019;10(12):414.
56. Nsengimana V. Use of soil and litter arthropods as biological indicators of soil quality in southern rwanda (Doctoral dissertation, Venuste NSENGIMANA); 2018.
57. Nuria R, Jérôme M, Léonide C, Christine R, Gérard H, Etienne I, Patrick L. IBQS: A synthetic index of soil quality based on soil macro-invertebrate communities. Soil Biology and Biochemistry. 2011;43(10): 2032-2045.
58. Peck SL, Mcquaid B, Campbell CL. Using ant species (Hymenoptera: Formicidae) as a biological indicator of agroecosystem condition. Environmental Entomology. 1998;27(5):1102-1110.
59. Potapov AM, Goncharov AA, Semenina EE, Korotkevich AY, Tsurikov SM, Rozanova OL, Tiunov AV. Arthropods in the subsoil: Abundance and vertical distribution as related to soil organic matter, microbial biomass and plant roots. European Journal of Soil Biology. 2017;82: 88-97.
60. Raza MB, Bhoi TK, Samal I. Soil arthropods as a nutrient enhancer. International Journal of Chemical Studies. 2019;7:1687-1692.
61. Santorufo L, Van Gestel CA, Rocco A, Maisto G. Soil invertebrates as

bioindicators of urban soil quality. Environmental pollution. 2012;161:57-63.
62. Sapountzis P, De Verges J, Rousk K, Cilliers M, Vorster BJ, Poulsen M. Potential for nitrogen fixation in the fungus-growing termite symbiosis. Frontiers in Microbiology. 2016;7:234760.
63. Singh B, Minick KJ, Strickland MS, Wickings KG, Crippen TL, Tarone AM, Pechal JL. Temporal and spatial impact of human cadaver decomposition on soil bacterial and arthropod community structure and function. Frontiers in Microbiology. 2018;8:308137.
64. Sofo A, Mininni AN, Ricciuti P. Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. Agronomy. 2020;10(4):456.
65. Tilahun A, Cornelis W, Sleutel S, Nigussie A, Dume B, and Van Ranst E. The potential of termite mound spreading for soil fertility management under low input subsistence agriculture. Agriculture. 2021;11(10):1002.
66. Ulyshen MD. Insect-mediated nitrogen dynamics in decomposing wood. Ecological Entomology. 2015;40:97-112.
67. Viana-Junior AB, Reis YT, Costa APM,Souza VB. Termite assemblages in dry tropical forests of Northeastern Brazil: Are termites bioindicators of environmental disturbances? Sociobiology. 2014;61(3): 324-331.
68. Wurst S, De Deyn GB, Orwin K. Soil biodiversity and functions. Soil ecology and ecosystem services. 2012;28-44.
69. Yadav SK, Kerketta S, Kumar D. Biodiversity of soil arthropods: Symbol of soil health. Research trends in life sciences. 2018;25-44.
70. Yang X, Li T. Effects of terrestrial isopods on soil nutrients during litter decomposition. Geoderma. 2020;376: 114546.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/116136