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Unraveling the Symphony of Soil Fauna and Quality Parameters for Soil Sustainability: A Thematic Review

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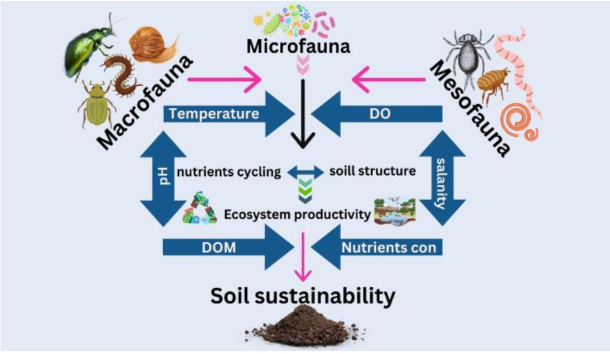
ABSTRACT

Soil fauna, ranging from micro to macrofauna, are vital for nutrient cycling, soil structure, and ecosystem productivity. The relationship between soil quality parameters and soil fauna is a complex one, with each influencing the other's abundance, diversity, and ecological functions. This review brings together current studies on how soil quality parameters interact with soil fauna, with a strong emphasis on the implications for ecosystem processes and sustainable soil nutrient management. We specifically highlight the impact of pH, salinity (Electrical conductivity), dissolved oxygen (DO), Dissolved organic matter (DOM), and nutrient concentration (soil organic carbon, nitrogen, phosphorus) on soil fauna. The integration of soil fauna considerations into soil health assessments is not just beneficial, but a critical step towards improving ecosystem resilience and informing conservation strategies. This comprehensive approach enhances our understanding of soil organism interactions and promotes sustainable soil management practices.



Keywords: Soil fauna, Soil quality parameters, sustainable soil management, ecosystem resilience

INTRODUCTION

Soil ecosystems are complex and dynamic systems that support various species known as soil fauna. Soil fauna comprise 23% of known animal species (Kudureti et al., 2023). These species include microfauna (protozoa, rotifers, tardigrades, and nematodes having body sizes of 1-2 µm for microflagellates), mesofauna (Collembola, dipluran, symphylan, enchytraeid range in size >40microns), and macrofauna (Isopoda, Mollusca, oligochaete and vertebrates: most visible soil faunas) (Decaëns, 2010; Swift et al., 1979). The diverse body sizes of soil fauna significantly impact multiple spatial scales. Lavelle et al. (1995) and Wardle, 2002 offer three levels of participation. Ecosystem engineers: Earthworms, termites, and ants alter soil structure, affecting nutrients and energy flow (Samson et al., 1996). Microarthropods: fragment decomposing litter and improve its availability to microbes. Micro-food webs include microbial groups and their direct predators (nematodes and protozoans) (Lavelle et al., 1995; Wardle & Van der Putten, 2002).

The soil's ability to sustain the productivity, diversity, and environmental services of terrestrial ecosystems" is known as soil health (Nations, 2020). Its irreplaceable significance is highlighted by supporting vital nutrients like nitrogen, phosphate, and potassium (Shrivastav et al., 2020) and controlling moisture levels critical for plant hydration (Bassiouni et al., 2023). Soil resilience and agricultural system sustainability are guaranteed by its ability to store carbon dioxide, nourish plant roots, and reduce erosion (Freschet & Roumet, 2017; Chadwick et al., 1994). Soil is an agricultural foundation supporting a diverse microbial community to improve fertility, crop growth, and ecological stability with shelter, water, and nutrients (Parikh & James, 2012). For Soil fauna, the physical makeup of soil offers cover and safety, enabling them to burrow, nest, and flourish inside its layers (Coleman et al., 2024). In addition, the organic materials in soil promote the growth, reproduction, and population dynamics of fauna species by acting as their primary food supply. Soil quality, moisture content, pH levels, and nutrient availability direct their abundance, diversity, and activity. This emphasizes the vital importance of healthy soil in maintaining soil fauna groups and their ecological roles.

Soil quality metrics include a wide range of physical and chemical characteristics of the condition and health of the soil. These physical and chemical factors include temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), nitrogen (N) concentration, and dissolved organic matter (DOM) concentration, among others (Maurya et al., 2020). These factors can significantly impact soil biological communities (soil fauna), affecting their abundance, diversity, activity, and geographic distribution across soil profiles. According to studies, soil temperature significantly impacts the dynamics of soil fauna groups (Kudureti et al., 2023). Temperature affects soil organisms' metabolic rates and reproductive activities (Snyder & Callaham, 2019). Warmer temperatures, for example, can accelerate decomposition rates while stressing some soil fauna species, influencing population dynamics and community structure. Soil pH, another essential parameter, impacts soil fauna diversity and function (Han et al., 2021). Acidic, alkaline soils can change the availability of nutrients and the solubility of hazardous chemicals, affecting soil organisms differently depending on their tolerance range (Duddigan et al., 2021). Soil pH gradient within ecosystems can create microhabitat that benefits some soil fauna species while taxing others, impacting biodiversity patterns (Zhao et al., 2018). Electrical conductivity (EC) reflects the soil's salinity, which can indirectly impact its fauna groups (Educators, 2014; Haj-Amor et al., 2022). Salinity gradients in soil profiles can induce niche differentiation among soil fauna species, resulting in spatial changes in community composition and diversity (H. Chen et al., 2022). Dissolved oxygen (DO) is essential for the soil fauna's respiration and activity. Oxygen availability in soil pores determines the distribution and behavior of aerobic and anaerobic soil organisms (Sharma & Kumar, 2023). Changes in soil moisture and aeration conditions can vary DO concentrations, influencing soil fauna populations and their involvement in nutrient cycling and organic matter decomposition (Neira et al., 2015). Dissolved organic matter (DOM) quality, as determined by chemical composition and microbial digestion, influences soil fauna diversity and trophic dynamics (Bolan et al., 2011). Changes in

DOM inputs, such as plant litter or organic supplements, might affect soil fauna activity and community structure (Heděnec et al., 2022). Soil organic carbon (SOC) is an energy source for microbes and soil microbial biomass. SMB is correlated with SOC (Bai & Cotrufo, 2022). Nitrogen (N) content in soil influences fauna communities through its effect on plant productivity, litter quality, and nutrient availability (Barrios, 2007). Soil fauna, particularly detritivores and decomposers, play a critical role in nitrogen transformation and recycling in the ecosystem (Betancur-Corredor et al., 2023). Phosphorus availability indirectly impacts soil fauna communities by changing plant-soil interaction and nutrient dynamics (Hou et al., 2018). Phosphorus-rich soils may support unique fauna assemblages than phosphorus-deficient soils, highlighting the role of nutrient stoichiometry in structuring soil ecosystems (X. Chen et al., 2022).

The relationships between soil quality measures and soil fauna are intricate and varied, frequently exhibiting nonlinear responses and feedback processes. Understanding this interaction is critical for developing effective sustainable soil management practices and conservation measures. Incorporating soil fauna concerns into soil quality assessments can help us better monitor ecosystem health and resilience. Furthermore, integrating knowledge from many ecological contexts, such as agricultural systems, natural ecosystems, and urban habitats, might provide valuable insights into soil faunas' ability to adapt to environmental changes. This review advances our understanding of soil ecosystem dynamics by examining the intricate interplay between soil characteristics and soil fauna groups.

Temperature

Global climate patterns influence soil invertebrates' diversity, with warmer, wetter climates having higher diversity but exceptions for hibernating species (Falvo et al., 2019; Kudureti et al., 2023; Snyder & Callaham, 2019). Although soil fauna evolved to a wide range of temperature fluctuations, long-term soil warming may impact their behavior, abundance, and ecosystem processes (Snyder & Callaham, 2019). Larger invertebrates such as earthworms, ants, and termites significantly impact the ecosystem by burrowing and creating nests. Increasing warmth minimizes the activity of insects, earthworms, and microarthropods by reducing their contribution to litter breakdown (Mukherjee, 2022). The reduction happens through two mechanisms: warmer temperature increases litter C/N ratio and fauna density, presumably due to smaller organisms. Increased microorganism activity utilizes all oxygen (O2) and produces carbon dioxide (CO2), thus limiting the activity of other fauna (Mukherjee, 2022). These conditions diminish soil fauna's contribution to decomposition. In contrast, increased wetness increases the diversity of soil fauna, which has a more significant impact on decomposition (Tan et al., 2021). Microbial activities increase with temperature (increased soil respiration), but the inverse effect on moisture level is due to the filling of pores by water. Drought affects soil porosity and water-holding capacity, decreasing fauna populations and altering community compositions. Climate and atmospheric CO2 changes can affect litter quality, prompting soil animals to adjust their diets and possibly restrict reproduction for survival. Habitat loss owing to deteriorating soil physical-chemical characteristics is a significant issue influencing soil fauna, with rising salt being especially harmful in acid environments (**Fig.1**) (Kudureti et al., 2023).

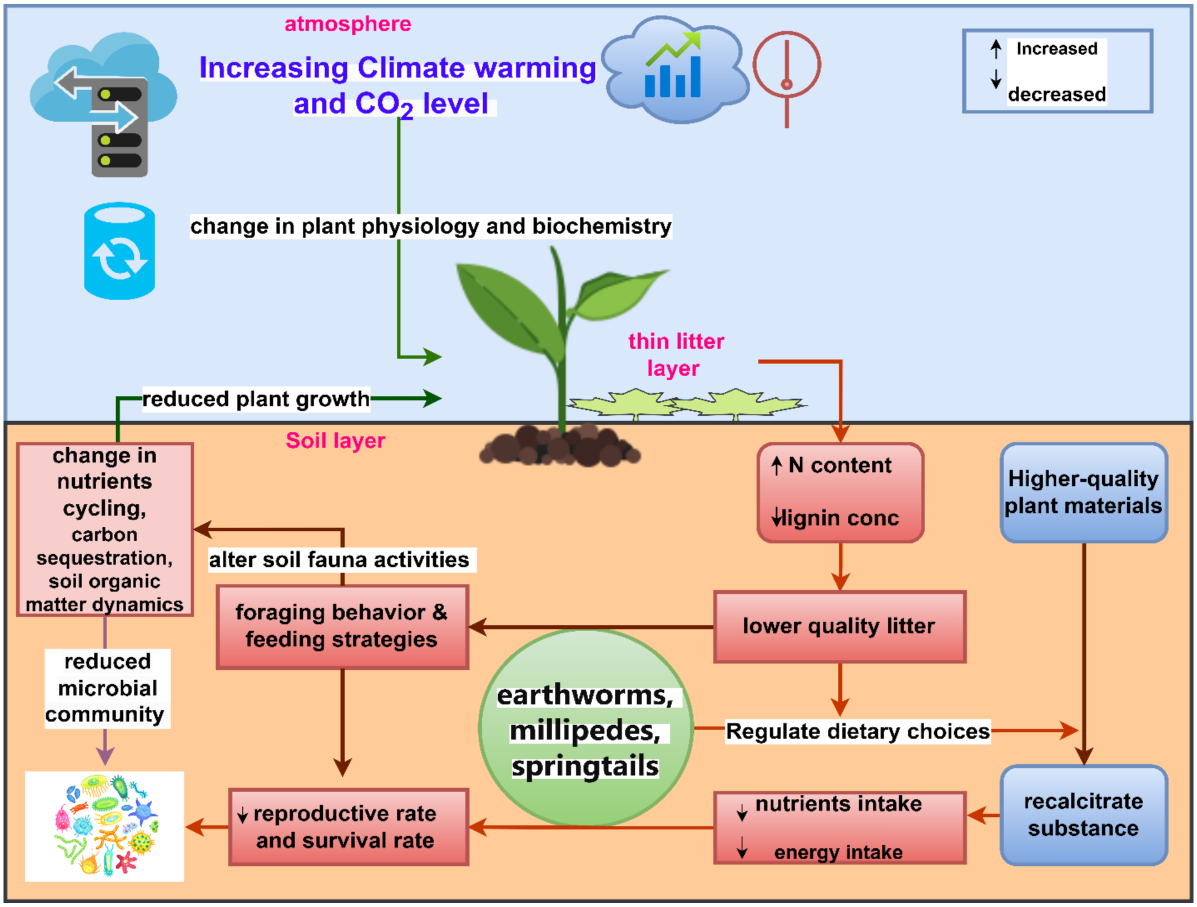


Figure 1. Impact of Temperature on soil fauna,

Soil respiration is the process by which microorganisms break down organic materials in the soil, releasing CO2 as a by-product. The temperature coefficient (Q_{10}) is commonly used to characterize the temperature soil respiration relationship (Hamdi et al., 2013). This coefficient denotes the factor by which the rate of a biological process (such as respiration) changes with each 10-degree rise in temperature. Recent studies have shown that the temperature response of soil microbial respiration is more complex than a simple Q10 connection. Therefore, researchers adopt the macromolecular rate theory instead (Alster et al., 2022). (Fig. 2) revealed that microbial mechanisms driving the temperature sensitivity of soil respiration vary by season. High-yield microorganism efficiently breaks down organic matter in soil carbon cycling, releasing CO2 throughout the decomposition process. R-strategies microbe breaks down organic materials and emits CO2 as they metabolize substrates. K-strategies microbe in soil serves an essential function in stabilizing organic materials and promoting humus development. Their activities prioritize long-term carbon storage and stability, leading to delayed release of CO2 (Malik et al., 2020). Temperature-induced reactions by soil fauna can have an impact on the nutrient cycle, carbon sequestration, and overall ecosystem health (Wang et al., 2021).

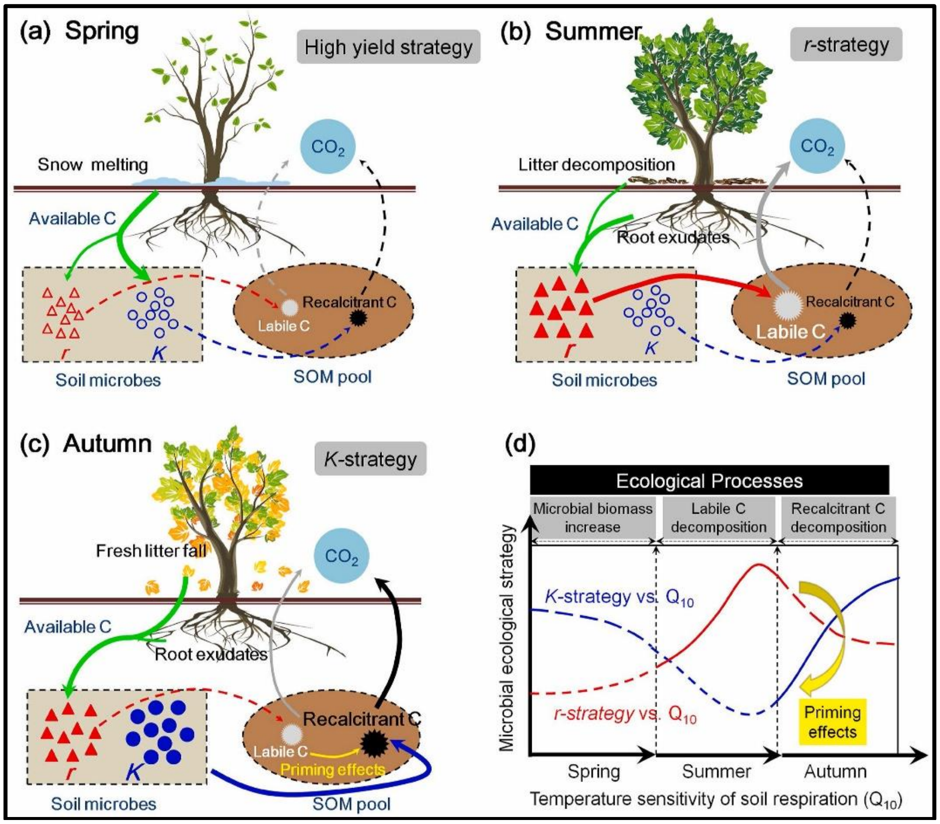


Figure 2. Microbial mechanisms driving the temperature sensitivity of soil respiration (source: (Yang et al., 2022))

pH:

Soil pH accounts for the acidity and alkalinity of the soil (Queensland, 2024). Soil abiotic factors, particularly pH, have been shown to influence soil biodiversity and organism distribution, mainly bacteria and fungi(Heděnec et al., 2022). Liming soil pH in both arable and grassland systems has increased the population of bacteria, nematodes, and earthworms while decreasing fungal abundance (Holland et al., 2018). Soil acidification influences the mobility of elements like Ca, Al, Mn, and P, influencing plant tissue chemistry and biomass ratios and affecting the richness and variety of soil fauna (Duddigan et al., 2021). Soil fauna interacts with soil pH through various physiological, ecological, and behavioral mechanisms influencing their abundance, diversity, activity, and geographic distribution within soil ecosystems. Physiological tolerance is essential, with different soil fauna species adapting differently to acidic and alkaline pH situations (Alexander, 1980; Duddigan et al., 2021). This adaptability is regulated by the soil's solubility of essential minerals and nutrients, directly impacting soil fauna’s nutrient acquisition and metabolic process. Furthermore, soil pH significantly affects the decomposition rates and chemical composition of organic matter, influencing the availability and quality of food resources for soil fauna (Barrow & Hartemink, 2023). Microbial interaction influences these dynamics, as soil pH affects the makeup and activity of soil microbial communities, which are essential components of soil food webs (Aciego et al., 2009; Han et al., 2021). Soil pH changes habitat appropriateness, with some soil fauna species preferring specific pH ranges for nesting, burrowing, and feeding Fig. 3. However, excessive pH values can be poisonous or stressful to soil fauna, forcing adaptive responses to counteract the negative consequences (Alexander, 1980; Wyman & Hawksley-Lescault, 1987). Soil pH regulates nutrient cycling, such as nutrient availability, mineralization, and immobilization rates, influencing nutrient dynamics and resource availability for soil fauna (Cheng et al., 2013). Understanding these complex relationships is critical for anticipating and regulating soil fauna's response to pH fluctuations caused by natural processes or human activities such as climate change and land management techniques. Different organisms adapted to different ranges of pH (e.g., earthworms(5.0-9.0) (S et al., 2016), nematodes(3.0-10.0) (Khathwayo et al., 2021), rotifers (6.0-8.0) (Yin & Niu, 2008), tardigrade (7.5+) (Sanchez-Martinez et al., 2023), springtails(5.0-7.5) (Wikipedia, 2024) etc.

Electrical conductivity (EC):

The amount of saline water in the soil influences its electrical conductivity (EC) (Friedman, 2005). It indirectly has a wide range of complex effects on soil fauna, influencing their abundance, diversity, behavior, and ecological role within soil ecosystems. Elevated EC levels, commonly linked with increasing soil salinity, cause osmotic stress in organisms (Armstead et al., 2016), impacting physiological processes and reproductive success (Educators, 2014; Haj-Amor et al., 2022). Soil fauna reaction to EC gradient includes selected habitat preferences, with certain species tolerating saline environments and others sensitive to increased conductivity levels (H. Chen et al., 2022). This differential habitat selection contributes to changes in soil fauna community structure and diversity since salinity-tolerant species may predominate in salty soils, affecting trophic dynamics (Zhang et al., 2019; Kefford, 1998; Reid et al., 2021).

Salinity sensitivity varies among soil microorganisms. Prokaryotic α-diversity indices are significantly reduced as salt increases. Ascomycota was 1.3 times more common for fungi in saline habitat environments than Basidomycota (21% fewer) (H. Chen et al., 2022). Actinomycetes and fungi are less affected than bacteria, except halophilic bacteria, which flourish in salty environments (Dakota, 2024). With a significant drop in biodiversity under saline circumstances, these dominating microbial groups with high niche preferences will play a more critical role in regulating nutrients and energy transport and constraining soil organic carbon (SOC) dynamics (H. Chen et al., 2022). Elevated EC can inhibit microbial functions, including respiration and nitrification (Lai et al., 2012). Changes in EC upset the delicate balance between microbial diversity and biomass (Reid et al., 2021). It affects how organisms move and absorb critical nutrients. Earthworms, nematodes, and microarthropods are all essential components of nutrient cycling in soil. They degrade organic materials, releasing nutrients that are needed for plant absorption. High EC levels have the potential to influence soil fauna activity. For example, earthworms may avoid saline spots, which impacts nutrient distribution (Owojori & Reinecke, 2014). Changes in nutrient cycling of soil fauna by high EC affect plant health and growth, resulting in overall ecosystem function.

Dissolved oxygen (DO)

Dissolved oxygen (DO) in soil are tiny bubbles of gaseous oxygen (O2) mixed in water within the soil (Mukherjee, 2022). These dissolved oxygen molecules are available for respiration by organisms living in the soil, an essential activity for practically all life. The principal source of DO is the atmosphere and aquatic plants. Plant roots absorb oxygen through soil macropores and dissolved oxygen in soil moisture. The transport of O2 in soil porosity is critical as larger pores provide faster gas transport than smaller ones with less efficient aeration (Mukherjee, 2022). The gas diffusion coefficient (D_P) depends on soil texture, structure, pore size distribution, and tortuosity(Neira et al., 2015). Organic matter influences soil characteristics and structure as well as oxygen delivery. Adequate DO level is required for microbes, invertebrates, and other aquatic vertebrates (Kulkarni, 2016) because they promote their growth and survival (Sharma & Kumar, 2023). For example, earthworms obtain oxygen through cutaneous respiration (by skin). The skin of earthworms is moist and thin, which easily allows oxygen to pass from the soil into the body. DO significantly impacts the breakdown rates of various plant litters (*Phragmites et al., lutarioriparia, and Cares spp*). Adequate oxygen levels support these activities, which include organic matter decomposition and nutrient cycling (Sharma & Kumar, 2023). Litter decomposition releases carbon, nitrogen, and phosphorus into the water. It increases the release of C and N, but not specifically P. High DO encourages specific bacteria in litter breakdown, promoting nutrient cycling and lake eutrophication (Liu et al., 2022). Restricted O2 supply causes anaerobic conditions in the soil, damaging plant growth and yield. Many critical metabolic activities are hampered under such a setting. Poor oxygen availability reduces microbial activity, affecting processes such as nitrification and sulfur oxidation except for anaerobic adapted organisms, leading to methane CH4 production and global warming (Sharma & Kumar, 2023). DO level is affected by temperature, salinity, biological activity, and water turbulency. The maximal growth rate of nitrification processes appears to be regulated by dissolved oxygen concentrations ranging from 0.3 mg/l to 4.0 mg/l. According to studies, a dissolved oxygen content of more than 4.0 mg/l is required for maximum nitrification rates, but others found that 0.5 to 1.0 mg/l is sufficient (Stenstrom & Poduska, 1980).

Dissolved organic matter (DOM)

Dissolved organic matter (DOM) is an essential source for soil fauna, regulating their eating habits, growth rates, and community interaction. Dissolved organic matter (DOM) substantially impacts soil dynamics, influencing nutrients and pollutants' interaction with microbial function (Bolan et al., 2011). It is a sensitive indicator of ecological process changes, such as bacterial proliferation in the water distribution system. Additionally, it provides a carbon source for anaerobic soil organisms, contributing to the reduction and emission of greenhouse gases. Organic pesticides applied to soil and aquifers are partitioned preferentially into DOM, impacting pesticide migration into groundwater (Bolan et al., 2011). Soil DOM composition is strongly linked to plant types along the elevation gradient. Deterministic processes dominate the microbial community assembly at high elevations. Bacterial populations accelerate the breakdown of labile DOM molecules at low elevations. Fungal community diversity and composition are critical indicators of soil nutrient cycling (Wang et al., 2023). For example, microsymbionts, arbuscular mycorrhizal fungus (AMF), and earthworms play essential roles in soil structure change and nutrient cycling (Barrios, 2007).

Nutrient’s concentration

(a)Soil Organic carbon (SOC)

Soil organic carbon (SOC) is a measure of carbon present in Soil (about 58%) (Trivedi et al., 2018). Grassland stores roughly one-third of the total carbon stock (Bai & Cotrufo, 2022). Soil organic carbon (SOC) is a crucial energy source for bacteria, fungi, and invertebrates (Trivedi et al., 2018). It is derived from rotting plant and animal materials. SOC concentration encourages microbial proliferation and diversity (Bai & Cotrufo, 2022; Han et al., 2021). Soil microbial biomass (SBM) is essential in SOC turnover, mediating carbon and nutrient transformation. The size of the SBM pool is often positively correlated with organic matter input and SOC content, indicating a balance between SOM mineralization and stability. Changes in the SMB-C to SOC ratio can reflect shifts in ecosystem carbon balance, making it an essential indicator for tracking SOC changes (Wiesmeier et al., 2019).

Soil fauna and their interactions with the biotic and abiotic elements have a role in a variety of processes that promote carbon stabilization or mineralization (Fig. 3). Bioturbation incorporates SOM into the soil profile, making it available to the soil microbial community or protecting it from mineralization, by mixing with soil particles as a particulate organic matter POM or mineral associated organic matter (MAOM). Soil fauna manage microbial populations by inhibiting or stimulating microbial activity and altering the microbial community composition by selective grazing or inoculum dispersal (e.g., passive transfers of microorganisms).

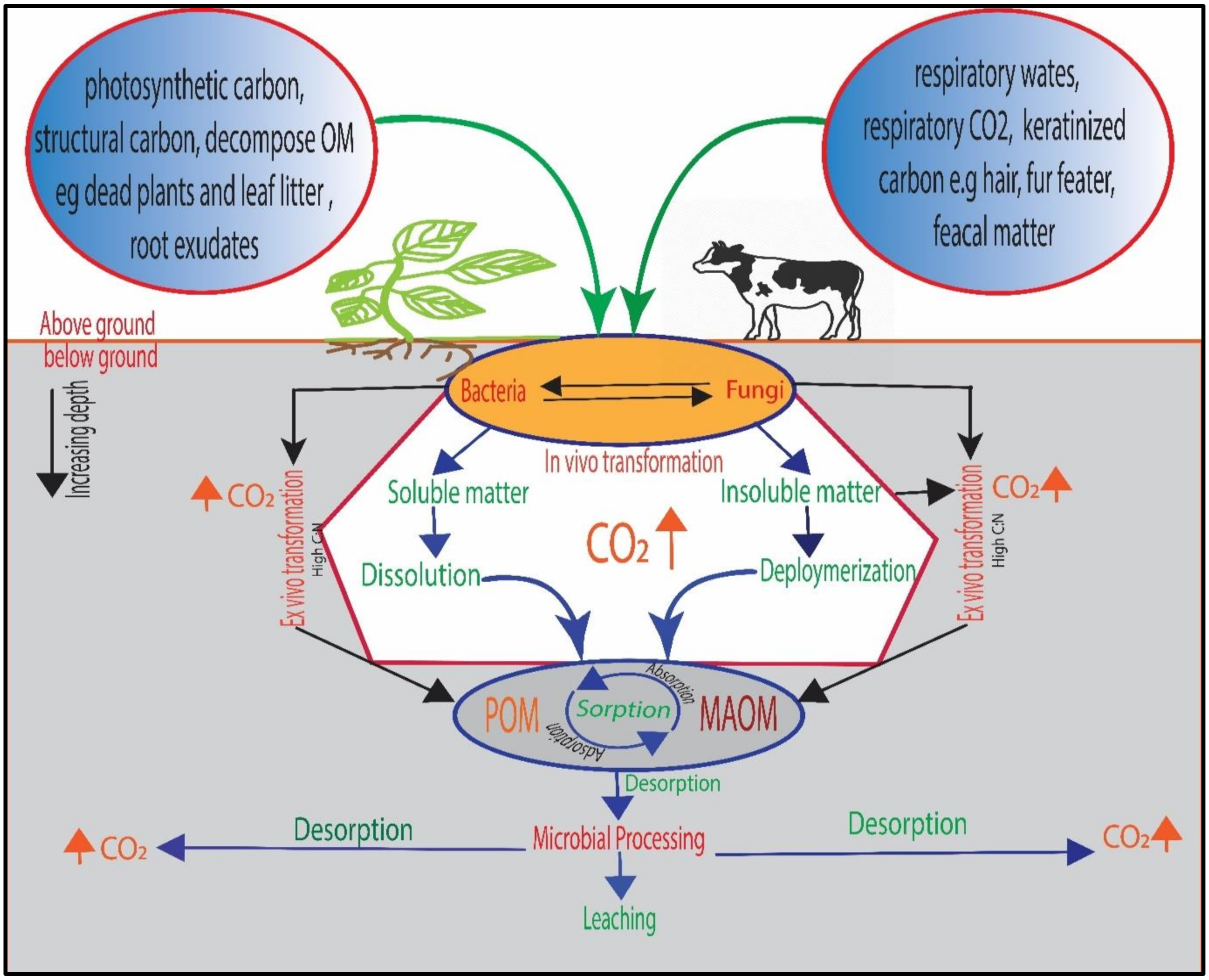


Figure 3. Mechanism of carbon sequestration (source: (Bai & Cotrufo, 2022))

Carbon sequestration involves absorbing, securing, and storing CO2 from the atmosphere. The goal is to keep carbon in solid and dissolved forms, preventing it from contributing to global warming. This is done by bio-sequestration (Carbon (CO2) is captured by the process of photosynthesis and stored in the biomass of plants and organisms or soil) or geologic carbon sequestration (injecting CO2 into geological formations like deep underground reservoirs or saline aquifers). This process relies heavily on soil fauna, such as earthworms, insects, and bacteria. Soil fauna reduces organic substances (fallen leaves and plant detritus) to small particles. This degradation releases carbon molecules into the soil (Heděnec et al., 2022). Earthworms and other burrowing organisms produce channels in the soil, improving aeration and mixing. This accelerates the breakdown of organic material and encourages carbon storage. Soil animals contribute to nutrient cycling by digesting organic matter and excreting nutrient-rich excrement. This has a direct impact on the carbon cycle. Soil fauna interacts with soil microbes, which affects microbial activity and decomposition rates (Heděnec et al., 2022; Trivedi et al., 2018). Microbes further convert organic matter into stable forms. Soil fauna aids in soil aggregation by producing aggregates that preserve organic carbon from fast degradation (Wiesmeier et al., 2019). (**Table. 1**) represents the role of s in the Carbon cycle.

Table 1. Role of organisms in the carbon cycle

Organisms	Role in carbon cycle	Impact	Reference
Plants	Intake of carbon (photosynthesis) Outlet carbon (respiration)	Higher trophic level carbon transformation	(da Fonseca-Pereira et al., 2020)
Microalgae, e.g., *Rhodophyta, Chlorophyta, Heterokontophyte, diatoms*	Convert CO2 from the atmosphere into biomass through photosynthesis	Enhance C availability in aquatic ecosystems	(Dolganyuk et al., 2020)
Terrestrial green plants	C transfers to herbivores and omnivores	Links food chain (herbivores intake carbon by plant consumption)	(Coq et al., 2022) (da Fonseca-Pereira et al., 2020)
Detritivores, e.g., millipedes, earthworms, woodlice, snails)	Release C from organic matter (CO2)	Decomposition C connection	(Hobbie & Villéger, 2015)
Decomposer bacteria, e.g., cyanobacteria	return C to the environment by dead plants and animals' consumption	Soil C enrichment	(Gougoulias et al., 2014; Raza et al., 2023)
Carbon-fixing bacteria, e.g., *Synechococcus, Prochlorococcus)*	Fix CO2 by photosynthesis	Establish symbiotic relationships (plants-microorganism symbiotic relationship)	(Gougoulias et al., 2014; Raza et al., 2023)
Fossil fuel burning, e.g., Human activity)	Increment of CO2 in air	Change in natural climate balance (anthropogenic climate change)	(Raza et al., 2023)
Phytoplankton (Aquatic), e.g., diatoms, *Prochlorococcus*	Support marine carbon cycle by C-fixing	Support diverse marine ecosystem	(Hobbie & Villéger, 2015)
Fungi e.g., *Trichoderma, Phanerochaete chyrysosporium, Stropharia rugosoannulata*	Return C to environments during decomposition.	Enhance C cycle in soil	(Raza et al., 2023)
Oceanic Zooplankton, e.g., *diatoms, Krill, Salps, Chaetognaths*	Marine food web C transfer	Marine C transport	(Hobbie & Villéger, 2015)
Forests and soil	C- sink	Regulate atmospheric CO2 level	(Fung et al., 2005)

(b) Nitrogen (N)

Nitrogen is essential to amino acids, proteins, and nucleic acids. Microbes play an important part in nitrogen cycling, converting it into various forms (such as ammonium, nitrate, and organic nitrogen) (**Fig. 4**) (**Table. 2**) (Barrios, 2007; Han et al., 2021). However, investigations have shown inconsistencies due to variances in soil faunal taxonomy, N deposition rate, and ecosystem types. According to the study of (Cole et al., 2008), (N) addition increases the abundance of mesostigmatan (mites) and Collembola (springtails) but no change for Oribatid mites' abundance. Nematode's abundance decreases with N addition rates ranging from <50 kg/ha/year to >150 kg/ha/year. Inorganic nitrogen (e.g., NH4NO3, NaNO3) has a deleterious impact on nematodes, but organic fertilization has no appreciable effect. Adding nitrogen to grasslands and crop ecosystems reduces nematode abundance but does not impact the forest ecosystem (Hu et al., 2022). Under warm and all-year humid climate conditions, the proportion of potentially mineralizable nitrogen in the soil's total nitrogen is much lower than in dry or temperate situations (Nendel et al., 2019). Application of organic fertilizers indicates a positive impact on springtails, mites, and earthworms' abundance compared to inorganic fertilizer application, which has a detrimental impact on earthworms' density (Betancur-Corredor et al., 2023). Soil fauna (meso and macrofauna) can impact nitrogen dynamics in mineral soil by influencing surface chemical composition. Fauna influences the mineralization through litter quality indicators (e.g., C/N, %N, %P). The effect of fauna on litter composition is time-dependent, with a more significant effect during the early and intermediate stages of decomposition (Carrillo et al., 2011).

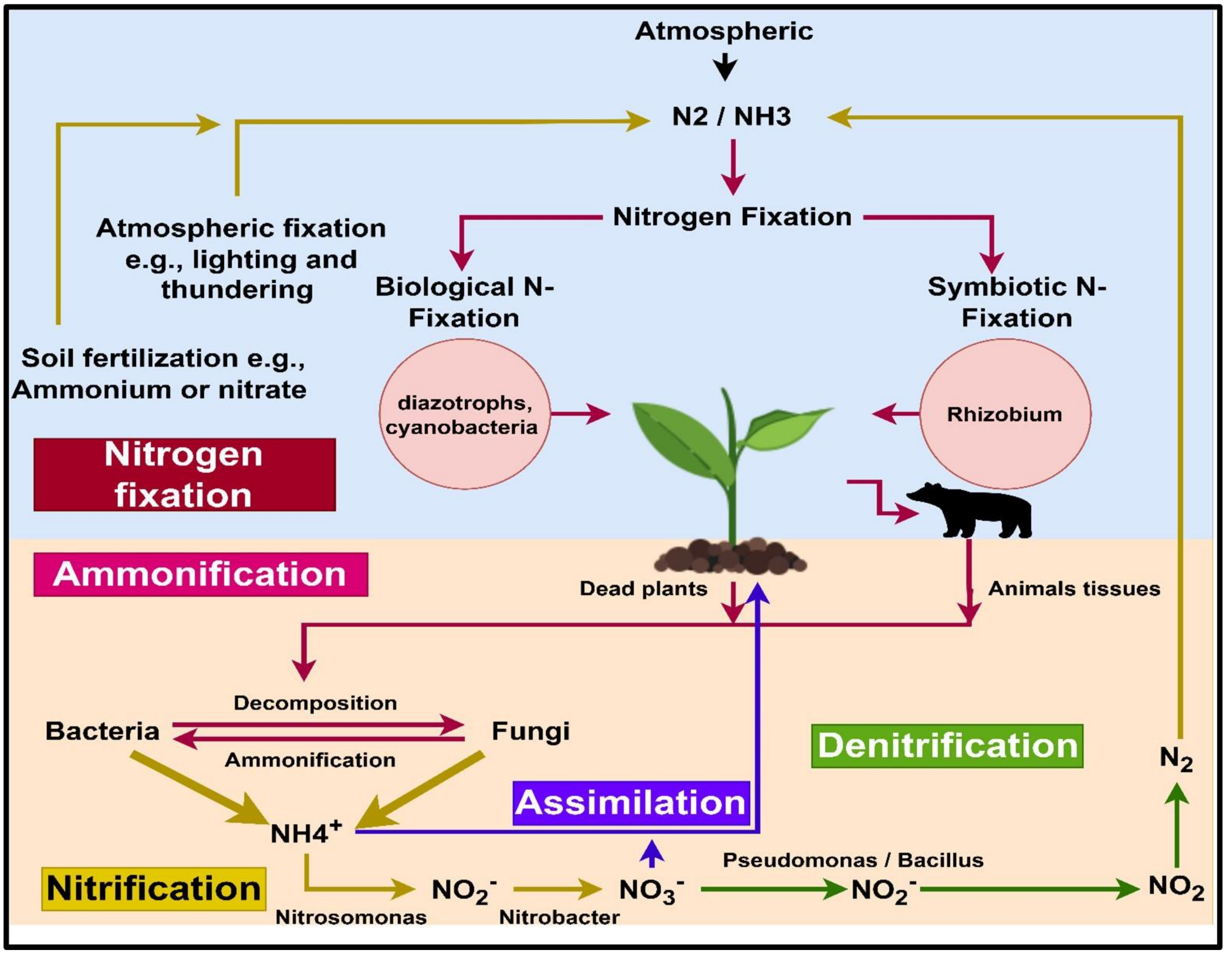


Figure 4. Nitrogen cycle.

Table. 2 Role of the organisms in the nitrogen (N) cycle

Organisms	Role in the N cycle	Impact	References
N- Fixing bacteria Free-living e.g., *Azotobacter, Beijerinckia, Clostridium, Cyanobacteria (Ababaena, Nostoc)* Symbiotic, e.g., *Rhizobium, Frankia, Azospirillium*	Convert atmospheric N_2 into NH_3 or (NO^{3-})	Make nitrogen available to plants	(Bernhard, 2010; Singh, 2021)
Nitrifying bacteria, e.g., *Nitrosomonas, Nitrosococcus, Nitrospira, Nitrospinota, etc.*	Convert ammonia NH_3 to NO^{2-} and NO^{3-}	Plants N uptake facilitation.	(Bernhard, 2010; Singh, 2021)
Denitrifying bacteria, e.g., *Thiobacillus denitrificans, Micrococcus denitrificans, Seratia species, Achromobacter, Psedomonas*	Convert NO^{3-} back into atmospheric N_2	Regulate N_2 level	(Bernhard, 2010; Singh, 2021)
Ammonifying bacteria, e.g., *Clostridium, Streptomyces, Proteus, Bacillus*	Decompose organic nitrogen into $NH^{4+.}$	N cycling by NH3 decomposition	(Bernhard, 2010; Singh, 2021)
Plants	Nitrogen uptake NO^{3-} or NH^{4+} form	Food web and plant growth	(Hobbie & Villéger, 2015; Koller-France E, (2021))
Decomposers (Fungi) Mycorrhizal Fungi, e.g., *Trichoderma, Mucor, Aspergillus* saprophytic e.g., *AMF, ECM* Litter-decomposing, e.g., *Phanerochaete chrysosporium, Pleurotus ostreatus* Endyphytic e.g., *Claviceps purpurea, Epichloe sp*	Release nitrogen by OM decomposition	Soil nitrogen enrichment	(Singh, 2021; Ye et al., 2024)
Animals, e.g., herbivores, carnivores, scavengers, etc.	Nitrogen consumption by animals and plants intake	Nitrogen transfer in the food chain, nutrient cycling	(Koller-France E, (2021))
Human activities	Waste management, industrial usage, fertilizers	Ecosystem N2 level change	(Bernhard, 2010; Koller-France E, (2021))

Ammonia= NH_3, nitrate= NO^{3-}, Nitrite= NO^{2-}, ammonium= NH^{4+}, OM= organic matter, *Arbuscular Mycorrhizal Fungi= AMF, Ectomycorrhizal Fungi= ECM*

(c)Phosphorus (P)

Phosphorus (P) concentration alters soil by affecting plant growth, microbial activity, and nutrient cycling pathways (Hou et al., 2018) (**Table 3**). Soil fauna considerably impacts P release during litter decomposition (Mackenzie et al., 2002). The rate of P release mediated by animals is more sensitive to plant species (quality of the original litter). The rate of P emission by animals is regulated by local scale environmental conditions (e.g., temperature) (Zhang et al., 2022). Soil fauna effects are most noticeable in the dry valley, followed by ecotone and montane forests. The effect of soil fauna varied between decomposition periods; winter in the dry valley boosts P release mediated by soil fauna. The type of ecosystem is critical in determining how soil fauna affects P release (Peng et al., 2015). The initial litter quality influences the rate of P release (Pei et al., 2019). Temperature is a significant modulator of the P release rate mediated by fauna (Peng et al., 2019). According to (X. Chen et al., 2022), phosphate activity and accessible P levels are 6.8%, 8.5%, and 4.6% higher in species combinations than monocultures. Promoting plant diversity may boost soil phosphatase activity and P availability, supporting terrestrial ecosystem production in the present and future. (Fig. 5) represents the comprehensive overview of the phosphorus cycle.

Table 3. Organisms' role in the phosphorus cycle

Organisms	**Role in P cycle**	**Impact**	**Reference**
Plants and algae, e.g., diatoms, green algae, cyanobacteria, euglenoids	Assimilation and transformation of P	Ecosystem productivity and nutrient cycling	(Cembella et al., 1984)
Microorganisms, e.g., actinomycetes, Pseudomonas, Bacillus, Aspergillus Penicillium	P solubilization	Nutrient uptake assistant and recycling	(Hobbie & Villéger, 2015)
Decomposer Bacteria e.g., *Trichoderma harzianum*	P release from dead organism	Soil P enrichment	(DyhrMaN et al., 2007)
Aquatic organism e.g., C*yanobacteria, rotifers*	Pickup P containing compound from water	Change water quality and eutrophication	(Istvánovics, 2008)
Mycorrhizal fungi e.g., *Arbuscular Mycorrhizal (AM), Trichodema harzianum*	Enhance phosphorus uptake by symbiotic association	Enhance plant growth and nutrient acquisition	(Hobbie & Villéger, 2015)
Terrestrial animals (e.g., earthworms, millipedes)	Mineralization and immobilization process	P availability regulation in soil	(Le Bayon & Milleret, 2009)
Freshwater zooplankton, e.g., daphnia, copepods	Algae grazing, P cycling in aquatic ecosystem	Affects nutrient dynamics in lakes and ponds	(Istvánovics, 2008)
Marine phytoplankton, e.g., cyanobacterium, i.e., *diazotrophic cyanobacteria, Prochlorococcus, Synechococcus*	Marine food web support by fixing P from seawater	Ocean productivity	(DyhrMaN et al., 2007; Istvánovics, 2008)

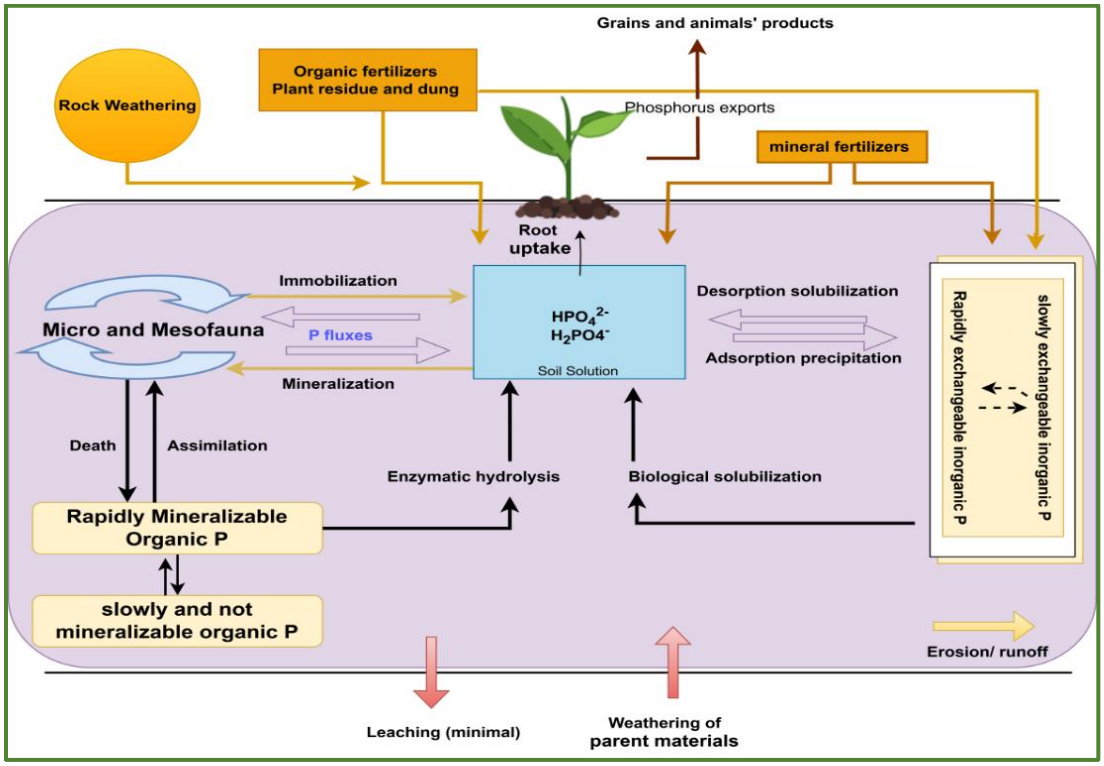


Figure 5. Phosphorus cycle

Assessment and implications

The faunal community in soil has a strong relationship with soil quality. Using the soil faunal community as an indicator of soil quality is not cost-effective due to the complicated taxonomic distinctions and identification. Also, the assessment's potency is limited to soil function. The FAI (Abundance-based fauna index) method assesses soil quality by considering soil fauna diversity and functional traits. However, this method requires detailed taxonomic knowledge and can be labor-intensive due to complex identification processes (Yan et al., 2012). Bioassay can directly evaluate the impacts of soil pollutants on live organisms, providing evidence of soil toxicity or health (Shi et al., 2017). However, they may not reflect long-term or subtle effects on soil fauna and can be influenced by external influences. Biodiversity surveys provide a snapshot of soil fauna, which can be used to assess soil health and ecosystem function. They may miss seasonal or temporal fluctuations, which can be time-consuming. Molecular techniques (fluorescence In-Situ Hybridization (FISH), quantitative polymerase chain reaction (qPCR), real-time PCR (RT-PCR, next generation sequencing NGS)) can detect and quantify single organisms or groups, providing precise insights on soil biodiversity (Váradi et al., 2017). However, they needed specialized equipment and knowledge and may not provide information on the functional roles of organisms found. Modeling forecasts the influences of various management strategies on soil quantity and fauna without requiring substantial fieldwork. However, the limitation of the model is that it is only as good as the data and assumption upon which they are built and may fail to represent all of the intricacies of the soil ecosystem (Van Leeuwen et al., 2019). The optimal technique for assessing the impact of soil quality on soil fauna is determined by the targeted soil fauna accessible resources and the study's objectives. Each method has pros and cons; thus, combining methodologies will provide the most robust assessment of soil quality's impact on soil fauna. Measuring SMB is a low-cost and precise method for estimating microbial biomass pool size and evaluating SOC dynamics (Wiesmeier et al., 2019)

Temperature, precipitation, and fire regime changes influence soil fauna diversity and abundance. Overgrazing and land use conversion deplete soil carbon storage. Fauna-mediated variations in nitrogen availability can impact ecosystem production (Carrillo et al., 2011). Soil animal diversity is best described by various life history techniques and soil heterogeneity rather than severe competition (Cole et al., 2008). Understanding the soil DOM composition helps to predict climate change's impact on soil carbon sequestration and advise ecosystem management (Wang et al., 2023). Ensuring adequate soil aeration is critical for optimal plant growth and microorganism activity. Drainage, organic matter addition, and optimal tillage all contribute to maintaining the ideal O2 level in the soil (Sharma & Kumar, 2023). Plant and litter mix with higher species richness are expected to improve soil fauna diversity. Using less intensive farming practices, such as organic fertilization, in conjunction with site-specific N fertilization regimes, is an effective strategy for conserving and improving healthy soil fauna ecosystems (Betancur-Corredor et al., 2023). Increasing plant diversity can improve soil organic carbon (SOC) storage. Sustainable grazing strategies improve SOC sequestration. Planting leguminous crops in pastures aids in carbon capture (Bai & Cotrufo, 2022).

CONCLUSION

Soil fauna, spanning diverse taxa from microorganisms to larger invertebrates, significantly impact nutrient cycling, organic matter decomposition, and soil structure formation. Soil quality indicators, such as temperature, pH, Electrical conductivity, dissolved organic matter, and nutrient availability, directly and indirectly affect soil fauna communities. These parameters shape their abundance, diversity, and functional roles. Understanding these interactions is essential for sustainable soil ecosystem management.

Soil fauna's response to changing environmental conditions has cascading effects on ecosystem processes, highlighting the interconnectedness of biological and abiotic factors in soil ecosystems. For example, Changes in soil temperature can influence microbial activity, which in turn influences soil fauna’s nutrient availability and quality. These changes subsequently affect the functional roles of soi fauna in nutrient cycling and organic matter decomposition processes. Similarly, changes in soil pH can directly impact soil fauna physiology behavior, cascading through the ecosystem process.

Integrating Soil fauna consideration into soil health assessments is critical for holistic ecosystem management approaches. Evidence-based strategies informed by scientific knowledge of soil distribution organic matter, organic matter decomposition, and soil structure formation guide conservative efforts and enhance ecosystem services. Understanding these intricate interactions becomes essential for anticipating and managing ecological responses to climate change, particularly as global temperature rise and environmental pressure intensify.

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REFERENCES

1. Aciego Pietri, J.C., Brookes, P.C., 2009. Substrate inputs and pH control microbial biomass, activity, and community structure in arable soil. Soil Biology and Biochemistry 41, 1396-1405.
2. Alexander, M., 1980. Effects of Acidity on Microorganisms and Microbial Processes in Soil. In: T. C. Hutchinson & M. Havas eds. Effects of Acid Precipitation on Terrestrial Ecosystems. Springer US, 363-374.
3. Alster, C.J., Robinson, J.M., Arcus, V.L., Schipper, L.A., 2022. Assessing thermal acclimation of soil microbial respiration using macromolecular rate theory. Biogeochemistry 158, 131-141
4. Armstead, M.Y., Bitzer-Creathers, L., Wilson, M., 2016. The Effects of Elevated Specific Conductivity on the Chronic Toxicity of Mining Influenced Streams Using Ceriodaphnia dubia. PLoS One 11, e0165683
5. Bai, Y., Cotrufo, M.F., 2022. Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science 377, 603-608
6. Barrios, E., 2007. Soil biota, ecosystem services and land productivity. Ecological economics 64, 269-285
7. Barrow, N.J., Hartemink, A.E., 2023. The effects of pH on nutrient availability depend on both soils and plants. Plant and Soil 487, 21-37
8. Bassiouni, M., Manzoni, S., Vico, G., 2023. Optimal plant water use strategies explain soil moisture variability. Advances in Water Resources 173, 104405
9. Bernhard, A., 2010. The Nitrogen Cycle: Processes, Players, and Human Impact. Nature Education Knoldge.https://www.nature.com/scitable/knowledge/library/the-nitrogen-cycl processes-players-and-human-15644632/#. Accessed 04 April, 2024
10. Betancur-Corredor, B., Lang, B., Russell, D.J., 2023. Organic nitrogen fertilization benefits selected soil fauna in global agroecosystems. Biology and Fertility of Soils 59, 1-16

11. Bolan, N.S., Adriano, D.C., Kunhikrishnan, A., James, T., McDowell, R., Senesi, N., 2011. Chapter One - Dissolved Organic Matter: Biogeochemistry, Dynamics, and Environmental Significance in Soils. In D. L. Sparks Eds. Advances in Agronomy 110, 1-75
12. Carrillo, Y., Ball, B.A., Bradford, M.A., Jordan, C.F., Molina, M., 2011. Soil fauna alter the effects of litter composition on nitrogen cycling in a mineral soil. Soil Biology and Biochemistry, 43, 1440-1449
13. Cembella, A.D., Antia, N.J., Harrison, P.J., Rhee, G.Y.,1984. The utilization of inorganic and organic phosphorous compounds as nutrients by eukaryotic microalgae: a multidisciplinary perspective: part 2. CRC Critical Reviews in Microbiology 11, 13-81
14. Chadwick, O.A., Kelly, E.F., Merritts, D.M., Amundson, R.G., 1994. Carbon dioxide consumption during soil development. BIOGEOCHEMISTRY 24, 115-127
15. Chen, H., Ma, K., Huang, Y., Fu, Q., Qiu, Y., Yao, Z., 2022. Significant response of microbial community to increased salinity across wetland ecosystems. Geoderma 415, 115778.
16. Chen, X., Chen, H.Y.H., Chang, S.X., 2022. Meta-analysis shows that plant mixtures increase soil phosphorus availability and plant productivity in diverse ecosystems. Nature Ecology & Evolution 6, 1112-1121.
17. Cheng, Y., Wang, J., Mary, B., Zhang, J.b., Cai, Z.C., Chang, S.X., 2013. Soil pH has contrasting effects on gross and net nitrogen mineralizations in adjacent forest and grassland soils in central Alberta, Canada. Soil Biology and Biochemistry 57, 848-857
18. Cole, L., Buckland, S.M., Bardgett, R.D., 2008. Influence of disturbance and nitrogen addition on plant and soil animal diversity in grassland. Soil Biology and Biochemistry 40, 505-514
19. Coleman, D.C., Geisen, S., Wall, D., 2024. Soil fauna: Occurrence, biodiversity, and roles in ecosystem function. In Soil microbiology, ecology and biochemistry, 131-159
20. Coq, S., Ganault, P., Le Mer, G., Nahmani, J., Capowiez, Y., Dignac, M.F., Rumpel, C., Joly, F.X., 2022. Faeces traits as unifying predictors of detritivore effects on organic matter turnover. Geoderma 422, 115940.
21. da Fonseca-Pereira, P., Batista-Silva, W., Nunes-Nesi, A., Zsögön, A., Araújo, W.L. 2020. The Multifaceted Connections Between Photosynthesis and Respiratory Metabolism. In: A. Kumar, Y.Y. Yau, S. Ogita, R. Scheibe, Eds. Climate Change, Photosynthesis and Advanced Biofuels: The Role of Biotechnology in the Production of Value-added Plant Bio-products. Springer Singapore, 55-107
22. dakota, S., 2024. Soil Electrical Conductivity. Soil health coalition https://www.sdsoilhealthcoalition.org/technical-resources/chemical properties/soilelectrical-conductivity/.Accessed 30 March 2024
23. Decaëns, T., 2010. Macroecological patterns in soil communities. Global Ecology and Biogeography 19, 287-302
24. Dolganyuk, V., Belova, D., Babich, O., Prosekov, A., Ivanova, S., Katserov, D., Patyukov, N., Sukhikh, S., 2020. Microalgae: A Promising Source of Valuable Bioproducts. Biomolecules 10
25. Duddigan, S., Fraser, T., Green, I., Diaz, A., Sizmur, T., Tibbett, M., 2021. Plant, soil and faunal responses to a contrived pH gradient. Plant and Soil 462, 505-524
26. DyhrMaN, S.T., Ammerman, J.W., Van Mooy, B. A., 2007. Microbes and the marine phosphorus cycle. Oceanography 20, 110-116
27. Educators, G.f., 2014. Soil electrical conductivity USD& NRCS United state department of Agriculture Retrieved April 1, from https://www.nrcs.usda.gov/sites/default/files/2022-10/Soil%20Electrical%20Conductivity%20Educators.pdf
28. Falvo, C. A., Koons, D. N., Aubry, L.M., 2019. Seasonal climate effects on the survival of a hibernating mammal. Ecol Evol 9,3756-3769
29. Freschet, G. T., Roumet, C., 2017. Sampling roots to capture plant and soil functions. Functional Ecology 31, 1506-1518.
30. Friedman, S.P., 2005. Soil properties influencing apparent electrical conductivity: a review. Computers and Electronics in Agriculture, 46, 45-70
31. Fung, I. Y., Doney, S.C., Lindsay, K., John, J., 2005. Evolution of carbon sinks in a changing

climate. Proceedings of the National Academy of Sciences 102, 11201-11206

32. Gougoulias, C., Clark, J.M., Shaw, L.J., 2014. The role of soil microbes in the global carbon cycle: tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. J Sci Food Agric, 94, 2362-2371
33. Haj-Amor, Z., Araya, T., Kim, D.G., Bouri, S., Lee, J., Ghiloufi, W., Yang, Y., Kang, H., Jhariya, M. K., Banerjee, A., Lal, R., 2022. Soil salinity and its associated effects on soil microorganisms, greenhouse gas emissions, crop yield, biodiversity and desertification: A review. Science of The Total Environment 843, 156946
34. Hamdi, S., Moyano, F., Sall, S., Bernoux, M., Chevallier, T., 2013. Synthesis analysis of the temperature sensitivity of soil respiration from laboratory studies in relation to incubation methods and soil conditions. Soil Biology and Biochemistry 58, 115-126
35. Han, W., Wang, G., Liu, J., Ni, J., 2021. Effects of vegetation type, season, and soil properties on soil microbial community in subtropical forests. Applied soil ecology 158, 103813
36. Heděnec, P., Jiménez, J.J., Moradi, J., Domene, X., Hackenberger, D., Barot, S., Frossard, A., Oktaba, L., Filser, J., Kindlmann, P., Frouz, J., 2022. Global distribution of soil fauna functional groups and their estimated litter consumption across biomes. Scientific Reports 12, 17362
37. Hobbie, S.E., Villéger, S., 2015. Interactive effects of plants, decomposers, herbivores, and predators on nutrient cycling. Trophic Ecology: Bottom-Up and Top-Down Interactions across Aquatic and Terrestrial System, 233-259.
38. Holland, J.E., Bennett, A.E., Newton, A.C., White, P.J., McKenzie, B. M., George, T.S., Pakeman, R. J., Bailey, J. S., Fornara, D. A., Hayes, R.C., 2018. Liming impacts on soils, crops and biodiversity in the UK: A review. Science of The Total Environment, 610-611 316-332
39. Hou, E., Chen, C., Luo, Y., Zhou, G., Kuang, Y., Zhang, Y., Heenan, M., Lu, X., Wen, D., 2018. Effects of climate on soil phosphorus cycle and availability in natural terrestrial ecosystems. Global change biology 24, 3344-3356
40. Hu, J., Zhou, S., Tie, L., Liu, X., Liu, X., Zhao, A., Lai, J., Xiao, L., You, C., Huang, C., 2022. Effects of nitrogen addition on soil faunal abundance: A global meta-analysis. Global Ecology and Biogeography 31, 1655-1666.
41. Istvánovics, V., 008. The role of biota in shaping the phosphorus cycle in lakes. Freshwater reviews 1, 143-174.
42. Kefford, B.J., 1998. The relationship between electrical conductivity and selected macroinvertebrate communities in four river systems of south-west Victoria, Australia. International Journal of Salt Lake Research 7, 153-170.
43. Khathwayo, Z., Ramakuwela, T., Hatting, J., Shapiro-Ilan, D.I., Cochrane, N., 2021. Quantification of pH tolerance levels among entomopathogenic nematodes. J Nematol 53.
44. Koller-France E., Wilcke W., Oelmann Y., 2021. Does Plant Biodiversity Influence Nutrient Cycles? Front Young Minds 9, 557532
45. Kudureti, A., Zhao, S., Zhakyp, D., Tian, C., 2023. Responses of soil fauna community under changing environmental conditions. Journal of Arid Land 15, 620-636.
46. Kulkarni, S.J., 2016). A review on research and studies on dissolved oxygen and its affecting parameters. International Journal of Research and Review 3, 18-22.
47. Lai, L., Zhao, X., Jiang, L., Wang, Y., Luo, L., Zheng, Y., Chen, X., & Rimmington, G. M., 2012. Soil respiration in different agricultural and natural ecosystems in an arid region.
48. Lavelle, P., Lattaud, C., Trigo, D., Barois, I., 1995. Mutualism and biodiversity in soils. The Significance and Regulation of Soil Biodiversity. In: Proceedings of the International Symposium on Soil Biodiversity, Michigan State University, East Lansing, May 3–6, 1993
49. Le Bayon, R.C., Milleret, R., 2009. Effects of earthworms on phosphorus dynamics–a review. Dyn. Soil Dyn. Plant 3, 21-27
50. Liu, S., He, G., Fang, H., Xu, S., Bai, S., 2022. Effects of dissolved oxygen on the decomposers and decomposition of plant litter in lake ecosystem. Journal of Cleaner Production 372, 133837

51. Mackenzie, F.T., Ver, L.M., Lerman, A., 2002. Century-scale nitrogen and phosphorus controls of the carbon cycle. Chemical Geology 190, 13-32
52. Malik, A. A., Martiny, J.B., Brodie, E.L., Martiny, A.C., Treseder, K.K., Allison, S.D., 2020. Defining trait-based microbial strategies with consequences for soil carbon cycling under climate change. The ISME Journal,14, 1-9.
53. Maurya, S., Abraham, J. S., Somasundaram, S., Toteja, R., Gupta, R., & Makhija, S., 2020. Indicators for assessment of soil quality: a mini-review. Environmental Monitoring and Assessment 192, 604
54. Mukherjee, S., 2022. Soil Air and Temperature. In Current Topics in Soil Science: An Environmental Approach. Springer International Publishing, 105-115
55. Nations, F.a.A.O.o.t.U., 2020. FAO soil Portal, soil properties. https://www.fao.org/soils-portal/data-hub/soil-properties/en/. Accessed 20 March, 2024
56. Neira, J., Ortiz, M., Morales, L., Acevedo, E., 2015. Oxygen diffusion in soils: Understanding the factors and processes needed for modeling. Chilean journal of agricultural research 75, 35-44
57. Nendel, C., Melzer, D., Thorburn, P.J. 2019. The nitrogen nutrition potential of arable soils. Scientific Reports 9, 5851
58. Owojori, O. J., Reinecke, A.J., 2014. Differences in ionic properties of salts affect saline toxicity to the earthworm Eisenia fetida. Applied soil ecology 83, 247-252
59. Parikh, S. J., James, B., 2012. Soil: the foundation of agriculture. Nature Education Knowledge 3, 2
60. Pei, G., Liu, J., Peng, B., Gao, D., Wang, C., Dai, W., Jiang, P., Bai, E., 2019. Nitrogen, lignin, C/N as important regulators of gross nitrogen release and immobilization during litter decomposition in a temperate forest ecosystem. Forest Ecology and Management 440, 61-69
61. Peng, Y., Yang, W., Li, J., Wang, B., Zhang, C., Yue, K., Wu, F., 2015. Contribution of soil fauna to foliar litter-mass loss in winter in an ecotone between dry valley and montane forest in the upper reaches of the Minjiang River. PLoS One 10, e0124605.
62. Peng, Y., Yang, W., Yue, K., Tan, B., Wu, F., 2019. Impacts of soil fauna on nitrogen and phosphorus release during litter decomposition were differently controlled by plant species and ecosystem type. Journal of Forestry Research 30, 921-930
63. Queensland., 2024. Soil pH. Queensland Government.https://www.qld.gov.au/environment/land/ management/soil/soil-properties/ph-levels. Accessed 20 March, 2024
64. Raza, T., Qadir, M.F., Khan, K.S., Eash, N.S., Yousuf, M., Chatterjee, S., Manzoor, R., Rehman, S.U., Oetting, J.N., 2023. Unrevealing the potential of microbes in decomposition of organic matter and release of carbon in the ecosystem. Journal of Environmental Management 344, 118529
65. Reid, R.P., Oehlert, A.M., Suosaari, E.P., Demergasso, C., Chong, G., Escudero, L. V., Piggot, A. M., Lascu, I., Palma, A.T., 2021. Electrical conductivity as a driver of biological and geological spatial heterogeneity in the Puquios, Salar de Llamara, Atacama Desert, Chile. Scientific Reports 11, 12769
66. S, K. K., Ibrahim, M. H., Quaik, S., Ismail, S.A., 2016. Optimal Conditions and Environmental Factors Involved in Breeding Earthworms for Vermicomposting. In: Prospects of Organic Waste Management and the Significance of Earthworms. Springer International Publishing , 147-165
67. Samson, F.B., Knopf, F.L., Jones, C. G., Lawton, J. H., Shachak, M., 1996. Organisms as ecosystem engineers. Ecosystem management: selected readings, 130-147.
68. Sanchez-Martinez, S., Nguyen, K., Biswas, S., Nicholson, V., Romanyuk, A. V., Ramirez, J.F., KC, S., Akter, A., Childs, C., Usher, E.T., 2023. Labile assembly of a tardigrade protein induces biostasis. bioRxiv, 2023.2006. 2030.547219.
69. Sharma, P. K., Kumar, S., 2023. Soil Air and Plant Growth. In Soil Physical Environment and Plant Growth: Evaluation and Management. Springer International Publishing, 155-174
70. Shi, Z., Tang, Z., Wang, C., 2017. A brief review and evaluation of earthworm biomarkers in soil pollution assessment. Environmental Science and Pollution Research 24, 13284-13294

71. Shrivastav, P., Prasad, M., Singh, T. B., Yadav, A., Goyal, D., Ali, A., & Dantu, P. K. (2020). Role of Nutrients in Plant Growth and Development. In: M. Naeem, A.A. Ansari, S.S. Gill eds. Contaminants in Agriculture: Sources, Impacts and Management. Springer International Publishing, 43-59
72. Singh, M., 2021. Fungi and Nitrogen Cycle: Symbiotic Relationship, Mechanism and Significance. In: C. Cruz, K. Vishwakarma, D.K. Choudhary, A. Varma, eds. Soil Nitrogen Ecology, Springer International Publishing, 91-406
73. Snyder, B. A., Callaham, M. A., 2019. Chapter 11 - Soil fauna and their potential responses to warmer soils. In: J. E. Mohan, Eds. Ecosystem Consequences of Soil Warming. Academic Press 279-296
74. Stenstrom, M. K., Poduska, R.A., 1980. The effect of dissolved oxygen concentration on nitrification. Water Research 14, 643-649
75. Swift, M.J., Heal, O.W., Anderson, J.M., Anderson, J., 1979. Decomposition in terrestrial ecosystems (Vol. 5). Univ of California Press.
76. Tan, B., Yin, R., Zhang, J., Xu, Z., Liu, Y., He, S., Zhang, L., Li, H., Wang, L., Liu, S., You, C., Peng, C., 2021. Temperature and Moisture Modulate the Contribution of Soil Fauna to Litter Decomposition via Different Pathways. Ecosystems 24, 1142-1156
77. Trivedi, P., Singh, B.P., Singh, B.K., 2018. Chapter 1 - Soil Carbon: Introduction, Importance, Status, Threat, and Mitigation. In: B. K. Singh, eds. Soil Carbon Storage. Academic Press , 1-28
78. Van Leeuwen, J. P., Creamer, R. E., Cluzeau, D., Debeljak, M., Gatti, F., Henriksen, C. B., Kuzmanovski, V., Menta, C., Pérès, G., Picaud, C., 2019. Modeling of soil functions for assessing soil quality: Soil biodiversity and habitat provisioning. Frontiers in Environmental Science 7, 113.
79. Váradi, L., Luo, J.L., Hibbs, D. E., Perry, J.D., Anderson, R.J., Orenga, S., Groundwater, P.W., 2017. Methods for the detection and identification of pathogenic bacteria: past, present, and future. Chemical Society Reviews 46, 4818-4832
80. Wang, C., Morrissey, E.M., Mau, R. L., Hayer, M., Piñeiro, J., Mack, M.C., Marks, J. C., Bell, S. L., Miller, S.N., Schwartz, E., Dijkstra, P., Koch, B.J., Stone, B. W., Purcell, A.M., Blazewicz, S.J., Hofmockel, K. S., Pett-Ridge, J., Hungate, B.A., 2021. The temperature sensitivity of soil: microbial biodiversity, growth, and carbon mineralization. The ISME Journal, 15, 2738-2747
81. Wang, S., Heal, K.V., Zhang, Q., Yu, Y., Tigabu, M., Huang, S., Zhou, C. 2023. Soil microbial community, dissolved organic matter and nutrient cycling interactions change along an elevation gradient in subtropical China. Journal of Environmental Management 345, 118793
82. Wardle, D., Van der Putten, W., 2002. Biodiversity, ecosystem functioning and above-ground-below-ground. Biodiversity and ecosystem functioning: Synthesis and perspectives, 155.
83. Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Ließ, M., Garcia-Franco, N., Wollschläger, U., Vogel, H.J., & Kögel-Knabner, I., 2019 . Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales. Geoderma, 333, 149-162.
84. Wikipedia., 2024. Springtails. https://en.wikipedia.org/wiki/Springtail. Accessed 28 March, 2024
85. Wyman, R. L., Hawksley-Lescault, D.S., 1987. Soil acidity affects distribution, behavior, and physiology of the salamader Plethodon Cinereus. Ecology 68, 1819-1827
86. Yan, S., Singh, A.N., Fu, S., Liao, C., Wang, S., Li, Y., Cui, Y., Hu, L., 2012. Asoil fauna index for assessing soil quality. Soil biology & biochemistry, 47, 158-165
87. Yang, S., Wu, H., Wang, Z., Semenov, M.V., Ye, J., Yin, L., Wang, X., Kravchenko, I., Semenov, V., Kuzyakov, Y., Jiang, Y., Li, H., 2022. Linkages between the temperature sensitivity of soil respiration and microbial life strategy are dependent on sampling season. Soil Biology and Biochemistry 172, 108758
88. Ye, R., Huo, W., Shao, Y., Wang, H., Lu, W., Zhang, H., 2024. Fungal community diversity and their contribution to nitrogen cycling in in-situ aerated landfills: Insights from field and laboratory studies. Waste Management 179, 1-11

89. Yin, X. W., Niu, C. J.. 2008. Effect of pH on survival, reproduction, egg viability and growth rate of five closely related rotifer species. Aquatic Ecology 42, 607-616
90. Zhang, J., Zhou, J., Lambers, H., Li, Y., Li, Y., Qin, G., Wang, M., Wang, J., Li, Z., & Wang, F., 2022. Nitrogen and phosphorus addition exerted different influences on litter and soil carbon release in a tropical forest. Science of The Total Environment 832, 155049
91. Zhang, W.W., Chong, W., Rui, X., Wang, L.j., 2019. Effects of salinity on the soil microbial community and soil fertility. Journal of Integrative Agriculture, 1360-1368
92. Zhao, S., Liu, J.J., Banerjee, S., Zhou, N., Zhao, Z.Y., Zhang, K., Tian, C.-Y., 2018. Soil pH is equally important as salinity in shaping bacterial communities in saline soils under halophytic vegetation. Scientific Reports 8, 4550

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