Influence of Soil Invertebrates on Soil Decomposition

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Abstract
Soil decomposition, a crucial component of nutrient cycling in terrestrial ecosystems, is a complex process orchestrated by a myriad of biotic and abiotic factors. Among the various contributors to this intricate web, soil invertebrates play a pivotal role in shaping decomposition dynamics. This review aims to synthesize current knowledge on the influence of soil invertebrates on soil decomposition processes, highlighting their diverse roles and interactions within the soil ecosystem. The review begins by examining the functional diversity of soil invertebrates involved in decomposition, ranging from macroscopic organisms such as earthworms and arthropods to microscopic decomposers like nematodes and mites. Emphasis is placed on their feeding habits, behavior, and ecological niches, providing a comprehensive overview of how different taxa contribute to the breakdown of organic matter. Furthermore, the review delves into the mechanisms through which soil invertebrates influence decomposition rates. This includes their physical activities, such as burrowing and fragmentation, which alter the physical structure of organic matter and affect microbial communities. Additionally, the role of invertebrates in nutrient cycling and microbial dynamics is explored, shedding light on the intricate feedback loops that govern decomposition processes. The interactive relationships between soil invertebrates and microorganisms are a focal point of discussion, encompassing mutualistic, commensal, and antagonistic interactions. Special attention is given to the emerging field of microbial symbionts associated with soil invertebrates and their potential impact on decomposition efficiency.

Keywords: Microflora, Microfauna, Megafauna, Mesofauna, Macrofauna, Soil, Invertebrates, Nutrient Cycling

Introduction

Soil represents one of the important reservoirs of biodiversity. It provides many ecosystem services defined as the goods and ecosystem functions that provide benefit to human populations. Ecosystem services are the conditions and processes by which natural ecosystems and their species sustain and fulfill human life (Daily 1997). The soil support a wide range of living components in the form of plants and animals on the earth. Soils accelerates production services through soil formation, nutrient cycling and also aids in primary production. Soil has the ability to sustain the environmental quality and promote plant, animal and human health(Blaire *et al.*, 1996).These are carried out by the organisms which falls in the micro to mega size through their interactions with environmental gradients. Being home for an extra ordinary range of soil biota, soils are great frontiers for biodiversity research. The soil characteristics that affect soil quality are influenced by living components of soil like microbes, plant roots, and soil invertebrates (Blaire, 1996). Soils are diversified by faunal communities by the combination of environmental gradients and interactions with the other biota. Soil invertebrates follows general community composition influenced by temperature and moisture content on large geographical scale.

Invertebrates plays significant roles in fulfilling the ecosystem services provided by soils said Lavelle *et al*., (2006). Soil invertebrates are enormously diverse. Of the total living organism's diversity, 23% (~ 36,000) is contributed by soil animals. Among these, arachnid represent 12%, then other arthropod 5%, followed by micro-invertebrates 2% and anneida1% and some vertebrates less than 1%. The remaining are insects, contributing 80% (Decaens *et al.*, 2006). Even though invertebrates are abundant in the soil, these are poorly explored. The number of actual species of soil invertebrates is often unknown and many species are yet to be described, and the organisms described are poorly known (Blair *et al*., 1996). The most diversified phylum of living organisms is arthropoda with 20 different lineages. Micro-arthropods have great ecological importance, in the role of litter breakdown and decomposition, cycling of nutrients, secondary production and energy flow. Soil arthropods act as "driving variables" that indirectly affecting pathways of energy transfer in soil. Soil arthropods includes a variety of guilds, having specialised and polyphagous predators, phytophages, parasites, microbivores, fungivores, saprophages, omnivores and detritivores.

Soil organisms and their interactions with abiotic factors are providing a variety of soil processes. Their movements and activities influence the soil ecosystem and enhance the different soil processes. The most important soil process they take part is decomposition of litter. They are the active trophic members of the detritivorous food chain.

Table: 1. Influences of soil biota on soil processes on ecosystems (Hendrix et al., 1990)

Soil organisms	Nutrient cycling	Soil structures
Microflora	Catabolize organic matter Mineralize and immobilize nutrients	Produce organic compounds that bind aggregates Hyphae entangle particles onto aggregates
Microfauna	Regulate bacterial and fungal populations Alter nutrient turnover	May affect aggregate structures through interactions with microflora
Mesofauna	Regulate bacterial and fungal populations Alter nutrient turnover Fragment plant residues	Produce faecal pellets Create biopores Promote humification
Macrofauna	Fragment plant residues Stimulate microbial activity	Mix organic and mineral partcles Redistribute organc matter and microorganisms Create biopores Promote humification Produce faecal pellets

Functional grouping of soil invertebrates

Due to the difficulty in identifying all the soil invertebrates, they are often grouped together to form various taxa or functional groups. One of the most appealing is grouping according to their body width. This is accepted because the responses and interactions with soil environment differs according to size of the organisms. According to the body width, soil invertebrates classified into microflora and microfauna (<100 μm), mesofauna (2mm), and macro and mega fauna (20mm).

Soil microfauna includes protozoa, rotifers and nematodes. They are living in the thin films of water found around the soil aggregates and inside the soil pores filled with water, thus called as microscopic aquatic organisms. Soil characteristics like texture of soil, availability of pore spaces, and water content influence the distribution of soil micro-fauna. In most soils, nematodes are the most abundant among the invertebrates. Nematodes have a wider range of feeding strategies such as plant root feeders, free living nematodes that feed on soil bacteria and fungi or feed on small invertebrates including other nematodes. The microbial feeding nematodes and their interactions often affect the nutrient cycling and decomposition (Anderson *et al*., 1981). According to Blair *et al.* (1996), in addition to earthworms, nematodes have more potential responses to soil disturbances, thus they are often selected with earthworms as potential indicators and nematodes are at a microsite level (soil pores, soil water, microbial populations). Earthworms also show changes in these factors but also other factors such as soil disturbances and organic matter levels.

Soil mesofauna constituted of Enchytraeidae and several microarthropods. A group of small segmented organisms similar to earthworms are fall in the Enchytraeidae family. Mesofauna is characterised by a diverse assemblage micro arthropods, which form the lion share of the oraganisms. Microarthropods include small sized arthropods, the mites (Acari), Symphala, Collembola, Protura, Pauropoda, Diplura, small millipedes and centipedes and small insects. Among these Collembola and Mites constitutes about 90 to 95 %(Blaire et al. 1994). As the feeding habits of microarthropods spread to almost all trophic levels in the underground food web, they play a crucial role in decomposition and nutrient cycling and energy flow. This is carried out by their interactions with other invertebrates and microbes (Moore *et al*., 1988). Soil arthropod population abundance in soil relies on the number of factors such as competition and predation, presence or absence of organic matter, physio-chemical features of the soil such as temperature, moisture, compaction and pH which change from layer to layer in soil, these factors lead in vertical stratifications and changes the vertical distribution of soil fauna (Bardgett, 2005). The soil micro-arthropods exercise a decisive role in the perpetuation of the productivity of soils, through their activities in the breakdown and decomposition of litter and organic matter. The most numerically abundant of the soil mesofauna are Acari and Collembola, which together constitute 72 to 97 percentage of the total arthropod fauna of Indian soils (Wall work, 1976).

Soil macrofauna contains larger insects, other arthropods, annelida, mollusca and earthworms. They are free to move beneath the soil without any restriction. They are animals able to burrow through the soil thus create soil pores facilitating proper aeration and water infiltration. Through their movements in the soil, earthworms and other arthropods mix the soil with organic matter and their excreta and result in different stable soil aggregates (Tomlin *et al*., 1995). Blair *et al*. (1996), told that responses to soil disturbances by nematodes and earthworms will influence the soil processes significantly, and they can be serve as the useful indicator species. This is applicable during the assessment of effects of various land management practices or anthropogenic activities which in turn affect the quality of soil. The change in land use pattern, application of chemicals (Edward & Bohlen, 1992), practices like tillage (Lee, 1985), ploughing, presence of organic matters (Hendrix *et al*., 1992) etc can be related to earthworm population. Usually as the organic matter input increases, population density of earthworms also increase and reduce with respect to the increases in soil disturbances. So, Lavelle *et al*. (1987) noted the possibilities of manipulation of earthworm population and their activities as a measure for maintaining the soil quality of agroecosystems.

Ecological grouping of soil organism based on their feeding habits is given by Birch and Clark (1953). It include decomposers (bacteria, fungi, animals), bacterial feeders, fungal feeders, micro-predators and macro-predators. The plant litter feeders includes the Oligocheates, myriapods, crustacean, ants and termites, and various other arthropods. Collembola is one of the important fungal feeders. Bacterial feeders are protozoa, myxobacteria and nematodes.

While the micro-predators prayed up on bacterial feeders and algal feeders. They are rotifers, hymenomycets, phycomycetes, ciliata etc. the major macro-predators are mites and insects. Soil fauna is having tremendous species diversity, which in turn attributed to the different sorts of spaces and pores in the soil, to the heterogeneity of the solid constituents and to the diurnal and seasonal changes in temperature and moisture in the soil (Birch and Clark, 1953). Soil invertebrates are interacted with microbes in indirect and direct forms. Macroinvertebrates such as millipeds and isopods reduce fungal biomass through grazing and alter fungal community composition in direct form also they indirectly impact the soil microbes by altering the composition and distribution of microbial resources (Bray *et al*., 2019).

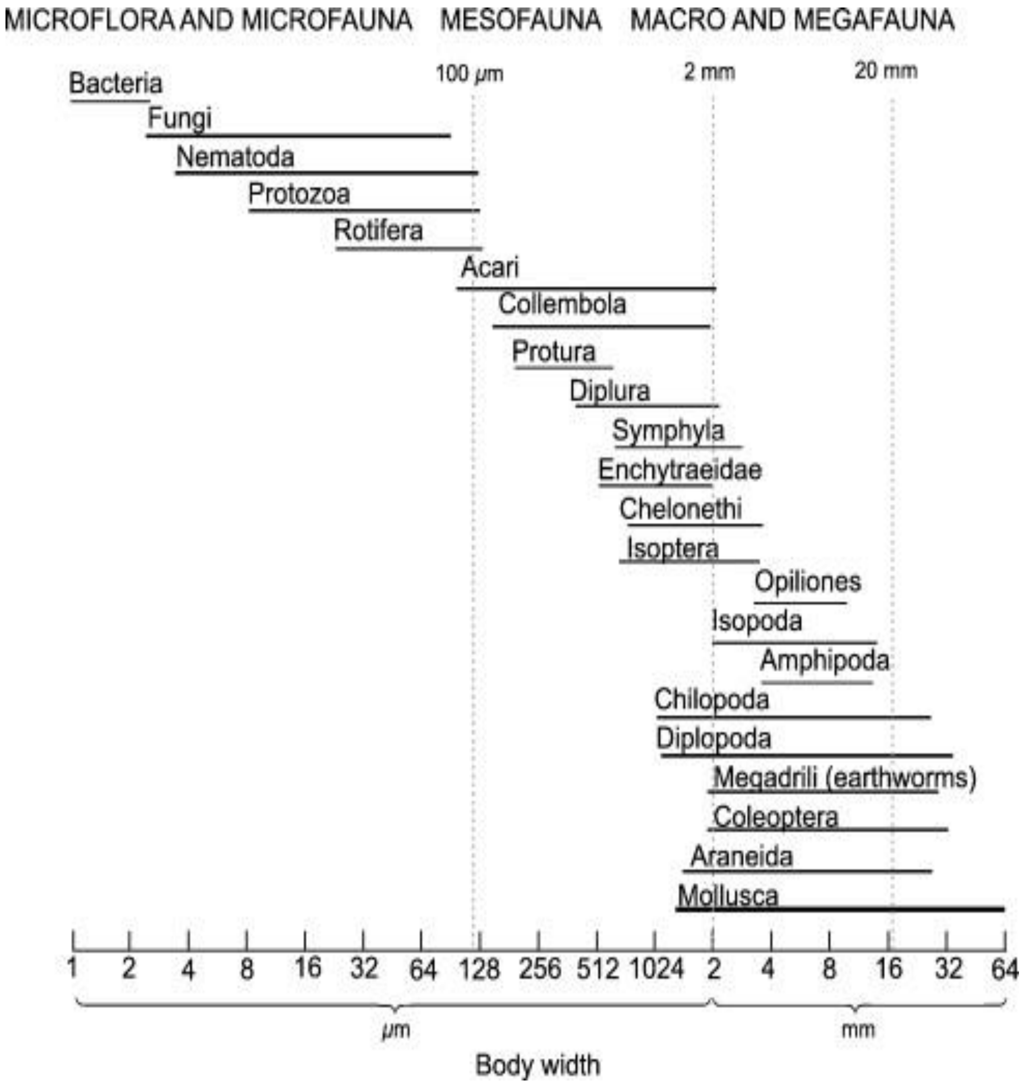


Figure: 1. Size-based classification of soil invertebrates (Swift *et al*., 1979)

Discrete scales in soil function

Soil function is envisaged as a hierarchy of gearing effects that link small scale, fast developing processes to progressively larger scales and slower processes (Lavelle *et al*., 2006). According to him there are five discrete scales of soil function; among these invertebrates are the major actors at the three of them. They are microbial biofilms, micro-food webs, functional domains of ecosystem engineers, mosaics of functional domains at plot scale, and landscape/ watershed level.

At each scales interactions among the organisms of one group or several groups develop within the boundaries of such structures as bio films, micro aggregates or the functional domains of invertebrate ecosystem engineers (Lavelle *et al*., 2006).

Microbial biofilms are the smallest habitat including mineral and organic particle assemblages (aggregates, ~ 20μm). Microbial mediated chemical processes which are altering nutrient cycling and fertility are operated in these microbial biofilms. At sometimes, microorganisms may leave their usual micro habitat (microspores filled with water) and enter into the outside environment. It determines the accessibility of resources, exposure to predators and inclusion in micro-food. In that cases they have different strategies for the rapid renewal of their population to withstand the constant pressures caused by predation and fluctuations in environment. Even though, they will avoid predation as much as possible by living with in the microspores itself creating localized micro- food webs (Postma and Van Veen, 1990).

Functional domains of soils formed by the ecosystem engineers along with abiotic factors. These will design the soil architecture through the accumulation aggregates and soil pores. These are extend horizontally from decimeters to 20-30m and from a few centimeters up to a few meters in depth, which will be depends on the organism (Jimenez and Rossi, 2001). Different functional domains are distributed with discrete or nested pattern and together form a mosaic of patches. That means these patches of functional domains will cause contrasting effects in the soils. This level is known as the mosaics of functional domains at plot scale (Lavelle et al., 2006).

The last level, landscape/watershed level, includes different ecosystems in a mosaic with clearly defined patterns. When we consider the ecosystem service; soil formation at regional level, it integrates different processes over all the scales and takes long period of times and is significantly influenced by the climatic conditions and parent material (Lavelle *et al*., 2006).

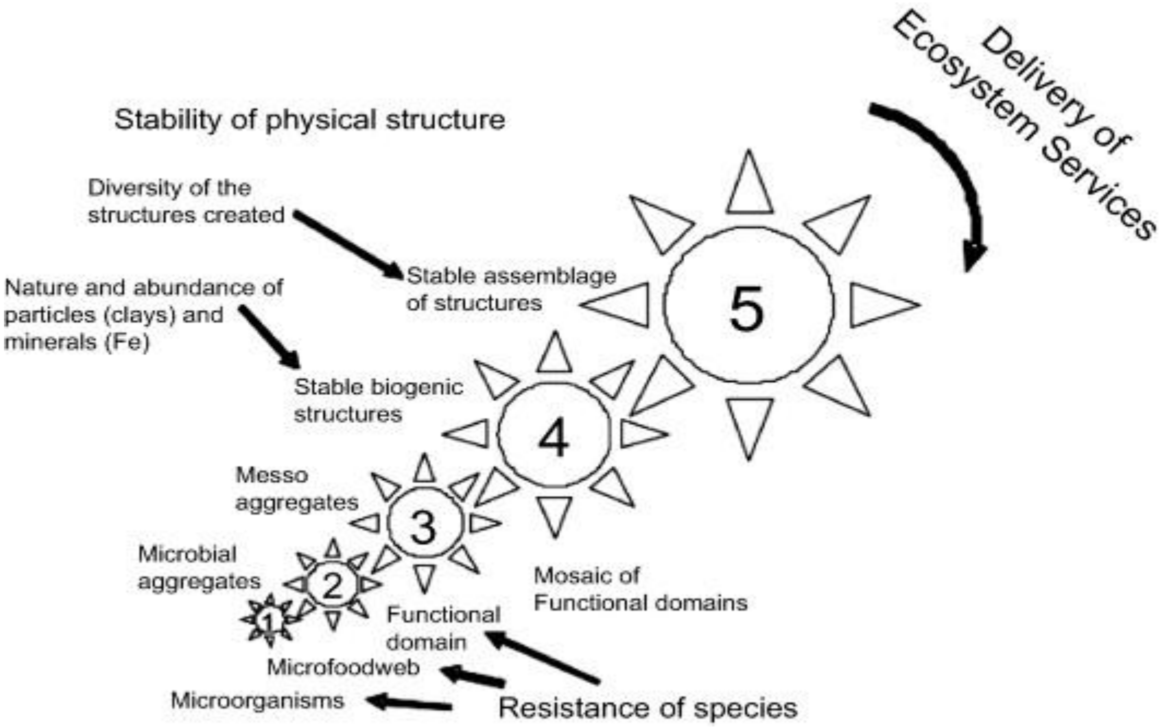


Figure: 2. Self-organizing systems in soils at different scales from microbial biofilms to the landscape

Engineers of the self organized soils

Soil invertebrates are the key mediators of the soil functions that happening at different ecosystems. Ecosystem engineers of any kind have the potential to enhance the ecosystem function in the soil. Soil engineers are any organisms which can modify the environment or habitat of other organisms. Through their engineering, they make transformations in the resources of other organisms at physical, chemical and biological levels. Comparing to their biomass, the magnitude of their services and effects are incredibly vast. They participate in the regualton of ecosystem processes and the delivery of ecosystem services at the usually large scale at which they are perceived, from parcels allocated to one type of land use to landscapes or watersheds. Among the number of organisms in the soil, earthworms, ants and termites are the most which cause the bioturbation of the soil. Their activities modulates soil resources availability and also makes modifications in the microbial and soil invertebrate communities. We can define ecosystem engineering in the soil as Physical engineering, Chemical engineering and Biological engineering (Lavelle *et al*., 2006).

Physical engineering

The ability of the organisms to alter the environments of other organism through their mechanical activities is physical engineering. At different scales of soil functions, physical engineering is happening. At the Scale 1, micro engineering is carried out by the stimulation of soil microaggregation by microbial biofilms and microtubules formation by fungal hyphae. Through the food webs, they circulate minerals and nutrients in the soil and the biogenic structures formed by them modify the soil through chemical and biological processes. At scale 3, these engineers along with abiotic factors will determine the soil architecture by the accumulation of aggregates and pores of different size. Experiments shown that soil which had been dispersed as units <2mm can be enriched in large aggregates by endogenic earthworms. That much influence being provided by the soil invertebrates on the ecosystems. Sudden changes in the ecosystems like deforestation will change the diversity pattern of soil invertebrates which in turn make changes in the production of biogenic structures (pores, voids, fabrics and aggregates of different sizes) and results differences in the hydraulic properties of the soil of a large area. Similarly they can induce changes at the land scape level also. In sloping regions, presence of earthworms will increase the soil creep through the continuous erosion of surface casts (Lavelle *et al.*, 2006). Isopods regulate the soil erosion and chemical soil processes like soil desalinization at the scale of watersheds in the Southern Negav Desert Highlands, Israel (Jones *et al*., 2006).

Chemical engineering

Some organisms will produce chemical substances with hormone-like or other physiological effects. In the temperate forest litters, invertebrates release organic acids in the faecal pellets which trigger mineral weathering. The casts of anecic earthworms (those that ingest a mixture of soil and surface litter and inhabit galleries) are macro-aggregates of 2.5–10 mm in diameter and form 'macro aggregate closed systems' in which intense microbial activity favors a rapid flocculation of soluble organic compounds that have no effect on mineral weathering (Lavelle *et al*., 2006).While soil arthropods will produce faecal pellets of small size and unstable. They have very low microbial activity and prone to intense leaching. Macro invertebrates impact soil microbes directly and indirectly by altering the composition and distribution of microbial resources. They can also alter the litter chemistry through litter ingestion and gut passage, changing resource availability and quality for microbes. Production of root exudates, earthworm and termite saliva, intestinal and cutaneous mucus of earthworms etc. expected to be influence the soil chemistry (Lavelle *et al*., 2006).

Biological engineering

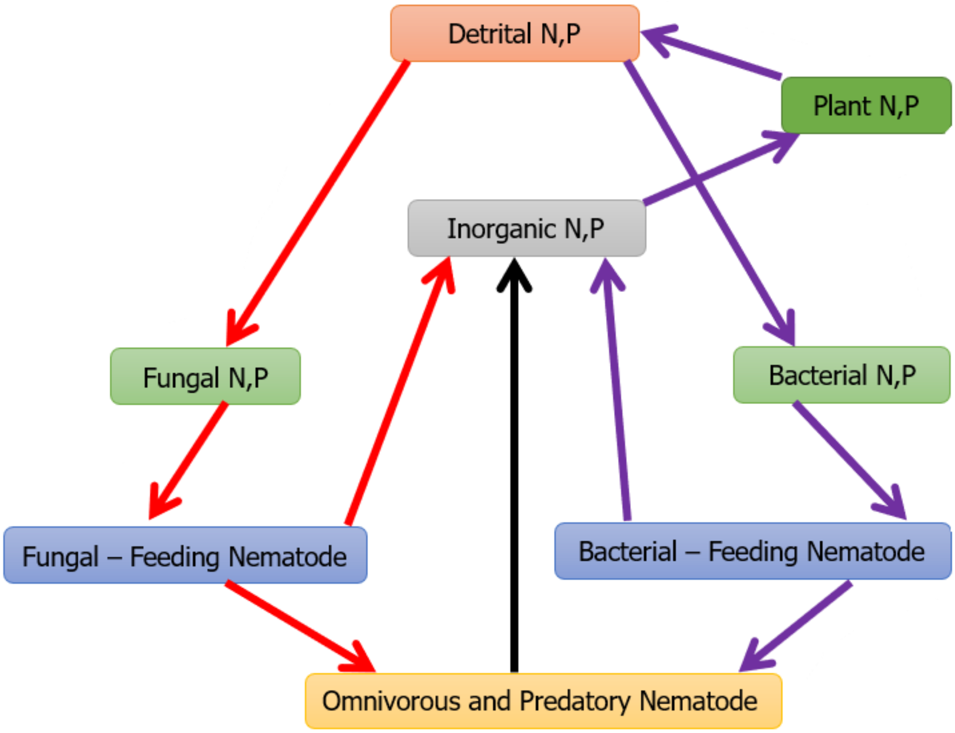
Due to the activities of invertebrates there will be changes in the communities of soil. Interactions of below ground communities with plants and other above-ground communities often result in significant modifications to successional dynamics. This may sometimes be a consequence of a general effect of invertebrates on nutrient cycling: Bernier and Ponge, (1994) thus described how the intense activity of earthworms in the senescent and early phases of natural succession in alpine spruce forests boosts the growth of tree seedlings and prevents the forest from being replaced by Myrtilus shrub communities. From their study, De Deyn *et al*., (2003) show that soil fauna strongly affects the composition of natural vegetation and suggest that this knowledge might improve the restoration and conservation of plant species diversity. They observed that Soil fauna from a series of secondary grassland succession stages selectively suppress early successional dominant plant species, thereby enhancing the relative abundance of subordinate species and also that of species from later succession stages. The study shows how the parasitic nematodes may accelerate plant successions from weak plant populations to healthier plants. Natural soil fauna communities were applied to the experimental grassland communities which consist of combinations of plant species from production (early succession), restoration (mid succession) and conservation grasslands (target of secondary grassland succession). All plant communities were established in sterilized soil and were inoculated with soil fauna from one of the three successional stages. This made it possible to determine the role of the soil fauna from a range of secondary succession grasslands on the outcome of interactions between the plant species from their own and from the other two successional stages. Results show that the soil fauna communities from early succession, mid-succession and target stages of secondary grassland profoundly enhance vegetation succession and the homogeneity of the plant community by reducing the biomass of the dominant plant species (De Deyn *et al*., 2003). Willems and Hujisman, (1994) provide experimental evidence for vertical seed movements in the soil and changes occurring in the soil seed banks due to the presence and activities of earthworms. Also we can consider the worm casts as an important regeneration niche.

Microfauna soil decomposition

The most abundant groups of soil microfauna (<100 μm body width) are animal like protists, nematodes, and rotifers. Animal like protists (commonly known as protozoa) were traditionally classified based on body structures and movement, into flagellates, cilates, naked amebae, and testate ameba (those with an outer protective shell). However, phylogenic classification based on genetics, ultrastructure, and biochemistry has resulted in reorganization of their taxonomy. Animallike protists are generally heterotrophic, unicellular organisms that live in soil water films and mostly feed on bacteria (often by phagocytosis) but a few are fungivores, predators or detrivores. They are abundant in the litter layer and in the surface soil and populations often reach 10^4–10^7 individuals g^{-1} (Foissner, 1997; Whalen and Sampedro, 2010).
Nematodes (roundworms) are multicellular eukaryotes belonging to the phylum *Nematoda* and they are very numerous in soils (e.g., 10^6–10^8 individuals m^{-2} in temperate soils comprising 50–200 species) (Bernard, 1992; Yeates and Bongers, 1999; Yeates, 2007; Whalen and Sampedro, 2010). Free-living nematodes inhabit soil water films while plant parasitic nematodes live in plant roots. Common soil nematodes belong to the orders *Rhabditida*, *Tylenchida*, *Aphelenchida*, and *Dorylaimida* but often nematodes are grouped according to feeding habits. Indeed, they differ widely in their feeding strategy and are present at all levels of the food web (Neher, 2010). Based mainly on the shape of their mouthparts they can be divided into bacterial feeders, fungal feeders, predators, saprophytes, and plant parasites (Yeates, 1998). Another group of microfauna are the Rotifers, which are multicelled microscopic animals that live in water films. They typically feed on bacteria, fungi, green algae, organic material, and plant cells (Whalen and Sampedro, 2010).

Nematode influence on decomposition

- Fungi, Bacterial and Root Feeders
- Interaction with other soil invertebrates
- Nutrient cycling
- Beneficial in the decomposition of organic material
- Recycling of nutrients in soil
- Nematode influences on bacteria and fungi to decompose SOM



Mesofauna soil decomposition

Mesofauna are 0.1 to 2mm in size. They include arthropods, such as mites, collembola and enchytraeids. In some soils these are very abundant. For example, over 200,000 arthropods have been recorded in just a square metre of old grassland soils. Some mesofauna feed on bacteria, fungi and algae, others scavenge on degraded organic matter. They all contribute to the breakdown of organic matter, stimulation of microorganisms and deposition of faeces which increase soil fertility.

- Soil Mesofauna accelerated litter decay of perennial dominant species in grassland
- The contribution of soil mesofauna was larger in high-quality than low-quality litter
- The contribution of soil mesofauna to decay was larger in fine root than leaf litter
- Litter quality interacted with organ and decay time to affect mesofaunal contribution
- Soil fauna, litter quality and organ are important factors for biogeochemical process

Mites influence on decomposition

- Residue decomposition
- Breaking down larger particles into smaller size
- Enhance Litter Decomposition and Mineralization Process
- Regulation of Microbial Populations
- Root Feeder – Rhizosphere Region
- Nutrient Recycling

Macrofauna soil decomposition

Soil macrofauna have both direct and indirect effects on litter decomposition and nutrient cycling, but their net effects are best considered within the context of the entire soil fauna community. As a class, detritivores are characterized by relatively low assimilation efficiencies; estimates vary but range from 10 to 30%. (Some termite species are a notable exception and have assimilation efficiencies that exceed 50%). This requires a high consumption rate, and the soil fauna in total processes 20–40% of the annual litter input.

The process of litter decomposition is greatly facilitated by the physical comminution and redistribution of plant residues by soil macrofauna. These 'macroshredders' break down leaf and woody residues into smaller particles and, along with other soil animals, transport them from the surface deeper within the litter layer and soil mineral horizons. This physical fragmentation and transport of residues renders them more accessible as substrates for smaller fauna and soil microorganisms. Soluble nutrients are more readily leached into the soil from these small particles and enhance both microbial activity and plant growth. Decomposition rates are greatly reduced in the absence of soil fauna, especially in forests, where the volume of litter input is large and tends to be of relatively low quality, and in arid environments where climate limits microbial activity.

Soil macroinvertebrates also stimulate microbial activity through the production of large numbers of fecal pellets that are deposited throughout the soil profile and which serve as resource-rich microsites for microbial activity. Fecal pellets are generally associated with higher concentrations of soluble C, mineral forms of N and P, and available forms of mineral nutrients such as Ca, Mg, and K. The fecal pellets produced by earthworms and other soil-dwelling macroinvertebrates consist of a mixture of mineral soil particles and organic material, and contribute to the formation of stable soil aggregates. They are often characterized by numerous, small voids that provide habitable pore space for microorganisms.

The net influence of soil macrofauna on nutrient cycles at the ecosystem level is complex and remains poorly understood. Soil animal activity is generally associated with higher rates of C, N, and P mineralization. Termite mounds in arid regions of Australia, for instance, may account for up to 20% of the ecosystem flux of CO_2; in more mesic ecosystems, soil macrofauna contribute proportionally much less to CO_2 flux, within the range of 2–10%. Experiments comparing N mineralization in soils with and without fauna (e.g., millipedes, earthworms) have shown that mineralization is enhanced by 10–30% in the presence of fauna. Through litter fragmentation and the production of fecal pellets, the fauna increase microbial production and activity, but through microbivory also regulate the degree to which nutrients are immobilized within the microbial biomass. While the fragmentation of detrital material enhances mineralization, the concomitant process of burial within the soil ensures that a proportion of it that would otherwise decompose on the surface is physically protected within soil aggregates and eventually contributes to the formation of stable soil organic matter. Feedback from all these processes may serve to maintain net ecosystem productivity.

Termites influence on decomposition

- Redistribution of soil particles
- Faecal Matter ingestion
- Nutrient Cycling
- Litter Decomposition
- Nutrients and Minerals
- Carbon Building Material
- Enriches Microbial Action
- Modifies Soil Temperature

Crabs influence on decomposition

- Bioturbation - Reworking of soils and sediments
- Accelerates litter decomposition in mangrove floor
- Recycling of Nutrients and enhance the degree of aeration

The potential influence of fiddler crab burrow density on the processes controlling organic matter (OM) accumulation was examined in Virginia salt marshes. As burrows may affect important chemical and biological processes that influence belowground plant production and decomposition, experimental manipulations were designed to modify fiddler crab burrow density by either increasing them (artificially constructed holes) or decreasing them (exclosures) and comparing them to areas naturally with and without fiddler crab burrows. The only significant difference among treatments was associated with the presence of holes without regard for whether they were artificial or natural. Higher burrow density resulted in an increase in soil redox potential, which most likely caused higher decomposition, even though sulfate-reduction rates were not different among treatments. Belowground production decreased with increased burrow density resulting in less OM addition to the soil. Higher decomposition and lower belowground production resulted in a net loss of 3 g C m^{-2} yr^{-1} in marshes with higher burrow densities, while areas with few to no burrows accumulated up to 245 g C m^{-2} yr^{-1}, equaling a surface accretion rate of 4 mm yr^{-1}. Examination of 6 other salt marshes in the region revealed a negative correlation between fiddler crab density and soil OM content, lending strength to the argument that bioturbation is a potentially important explanatory factor of OM accumulation in salt marshes and may influence how sea level rise impacts coastal marshes.

Megafauna soil decomposition

Megafauna, in soil science, animals such as earthworms and small vertebrates (*e.g.*, moles, mice, hares, rabbits, gophers, snakes, and lizards). The food habits of soil megafauna vary; earthworms ingest both soil and organic matter, but most of the vertebrates feed on plant material, invertebrates, and other small vertebrate animals. Megafauna are the principal agents of soil turnover and distribution; this movement loosens soil structure, improves aeration and drainage, and distributes soil microorganisms.

Earthworms influence on decomposition

Earthworms play an important role in breaking down dead organic matter in a process known as decomposition. This is what the earthworms living in your compost bin are doing and earthworms living in soils also decompose organic matter. Decomposition releases nutrients locked up in dead plants and animals and makes them available for use by living plants. Earthworms do this by eating organic matter and breaking it down into smaller pieces allowing bacteria and fungi to feed on it and release the nutrients.

Earthworms are also responsible for mixing soil layers and incorporating organic matter into the soil. Charles Darwin referred to earthworms as 'nature's ploughs' because of this mixing of soil and organic matter. This mixing improves the fertility of the soil by allowing the organic matter to be dispersed through the soil and the nutrients held in it to become available to bacteria, fungi and plants.

Soil invertebrates influence on decomposition processes

Nutrient cycling

Soil invertebrates are active participants in nutrient cycling through the ecosystem process such as decomposition, humification, and regulation of nutrient losses. These processes are take place due to their communition of litter and the association with microorganisms for carrying out their metabolism. Since invertebrates have limited digestive abilities they will rely on the microorganisms to digest a wide range of substrates for them by predation, external rumen strategy and internal mutualism (Lavelle *et al*., 2005). Predation on microorganisms facilitates release of carbon and nitrogen into the soil. Soil invertebrates feed on the litter and covered it in their saliva and release it as faecal pellets into the soil. Later microorganisms will enhanced on these faecal pellets and starting to digest the substances; then it will re-ingested by the soil invertebrates and they will assimilate the end products of external digestion made on the faecal pellets. This is followed by fungus growing termites and leaf-cutting ants by forming fungus cultures. This is called as external rumen strategy.
Internal mutualism is present in the case of large invertebrates like earthworms and termites to regulate their efficiency of digestion on the ingested litter, soil and other substrates. It will regulate their interaction with the microorganisms and microflora that they have been ingested. The biogenic structures produced by the invertebrates will act as a microsite for processes like carbon and nutrient sequestration. Experiments show that invertebrates actively take part in the nutrient cycling of carbon, nitrogen, sulfur then phosphorus and as per the requirement, other mineral nutrient also. So invertebrates along with the association of microorganisms, create a significant role in the buffering systems that allow the efficient nutrient cycling and prevent leakage of nutrients and other substances (Lavelle, *et al*., 2005). The nitrogen is cycled mainly through the biological nitrogen fixation facilitated by the symbiotic, associative and freeliving microbes (Lavelle *et al.* , 2006). While the phosphorus is make available to the plants by arbuscular mycorrhizal fungi (Jakobson et al., 1992).
Some species of ants affect the nutrient concentration in soils around the nest discs which in turn affect the composition and biomass production of vegetation in the surrounding of the nest, shown by the studies in Chihuahuan desert (Whitford, 1996). What is more interesting is that these species accounts for less than one quarter of the total ant species in that desert. Soil nutrient enrichment effects are only shown by the ant species in which individual nests last for decades but these effects will also depends on the soil of the particular area too. The short-time period nests will alter the soil physical properties and influence the soil formation rather than changing chemistry of the soils. The species with short-lived colonies transport sub-surface soils to the surface and accumulate subsurface soils in their nest craters and these are more susceptible to redistribution by wind and water. In the grasslands of Chihuahuan desert, four species of short-lived colonies of ants transported 21- 86 kg/ha/yr of subsoil to the surface (Whitford, 1996).

Primary production

Presence and activities of invertebrates will affect the primary production both in direct and indirect way. Invertebrates in the soil enhance the primary production by providing substances essential for plant metabolism and creating efficient environment and better soil qualities. There are five major explanation which facilitates this

- Nutrient release to the soil
- Stimulation of mutualistic micro-organisms, mycorrhizae and N-fixing micro-organisms.
- Enhance plant vigour and pest and disease control
- Enhance soil physical structures by improving the soil porosity, air circulation, water holding capacity etc.
- Production of plant- growth regulators by micro-organisms.

When there is an extensive competition occur between the plant parasites, systematic application of pesticides for the pest eradication will unknowingly decimate the natural enemies of parasites and the pests will started to appear again when the activity of applied pesticides had been ceased. As a result, the productivity of the land and yield will decrease significantly. So rather than the eradication of pests during such situations, must develop management practices for enhancing the population of natural enemies and competitors and thereby productivity will increase (Gromadzki, 2005).
Also the land condition and grazing will influence the soil invertebrate assemblages in the ecosystem, said Roth (2004). This is explained by the higher levels of earthworm activities and water infiltration in the areas which have been excluded from grazing. Likewise, with in the range from poor to fair land condition, significant changes in macro invertebrate assemblages and water-holding capacity were occurred. Being one of the hardy groups in the soil macro invertebrates, some termite species are able to survive in poor lands with crusted soils having high bulk density and this can be taken as

a method for the recovery of degraded soil. Several previous studies proved that the major groups of macro invertebrates known to respond individually to the changes in ecosystem and land use change (Lavelle,*et al*.1997). Thus the ratio of earthworms to termites has been taken as a sensitive indicator of the health the environment (Decaens, *et al*., 1994). Through the initiation of termite activities in the degraded lands by providing mulch will lead to the creation of soil pores and the subsequent restoration of the crusted soil (Mando & Miedema, 1997).

Climate regulation

Soil aggregation and humification are the mechanisms involved in the climate regulation. Soil invertebrates facilitate the Carbon sequestration in compact and stable aggregates and preventing their rapid release as green house gases. As the stability of the biogenic substances formed increases, the chance of further decomposition and the release of Carbon into the atmosphere will reduce. Without the soil fauna, whatever aggregates formed by trapping soil particles in the fungal hyphae or gluing with the bacterial mucilages, have weaker stability than the earthworm casts or termite fabrics. Activities and movements of soil invertebrates in the soil will form pores with different sizes, and produce biogenic substances which in turn increase the rate of infiltration and storage of water in these pores thereby regulate the surface runoff and erosion (Lavelle *et al*., 2006).

Soil formation and maintenance of soil quality

Soil invertebrates facilitates the pedogenesis process through improving the quality of soil being formed. Some invertebrates like earthworms, termites etc. feed on the soil and eliminate the faecal to the soil which increase the organic content and thereby the fertility of the soil. Occurrence of incidents which affect the invertebrate communities like rapid forest clearing or the sudden explosion of invasive species will change the soil profiles within a short period. In Amazonia, earthworm(*Pontoscolex corethrursus*) invasion in the pastures developed from forests, triggered the very fast change of oxisols towards gleysols with including anoxic horizon having showing colour shifts from red to grey through the oxidation of Fe(Lavelle, *et al*., 2006). Likewise, invasion of earthworm (*Dendrobaena octaedra*) in the soils of Northern American forest resulted shift in several parameters of soil function and humus profiles (Burtelow *et al.*, 1998).

Soil invertebrates in the arid ecosystem

The functional importance of soil organisms in the arid and semi-arid areas depends on the climate, which in turn influence the soil water potential and temperature over the time; thus the functionally active fraction of soil biota varies over time as a function of soil water content and temperature (Whittford, 1994). Santos and Whitford (1981) gave an explanation for the importance of individual species of soil organism by the comparison of decomposition rates occurred in the two litter samples where one is treated with fungicides and insecticides and latter remained as untreated. The mycelial density was less in treated litter than the control, but they were able to extract some fungi of the genera *Alternaria, Rhizopus,* and *Cunninghamella* from the treated litter. But fungi of these genera accounts for a very small fraction of the soil fungi in the untreated litter but they were able to decompose the litter at a higher rate than the expected rate according to their proportion of the species pool in the untreated litter(Santos and Whitford,1981). After the leaching of the fungicides from the treated litter, other fungi colonized the litter there is no surety that the recolonized fungi are the same functional groups as that of untreated litter. This shows that the complete assemblage of species are required for the decomposition process especially in the initial stages, but we cannot say that it is essential for the occurrence of the process (Whitford, 1996).

Santos et al. (1981) and Santos and Whitford (1996) given the evidence of the importance of individual organisms in decomposition; it said that the rate of mass loss during the initial stages of decomposition in desert soil, was regulated by the tydeid mites who were the predators of the bacteriophagous nematodes, but with the elimination of mites, number of nematodes increased and overgrazed the bacteria which in turn reduce the decomposition rates (Santos et al, 1981). Thus the tydeid mite was a keystone species. As the decomposition process proceeds, changes in trophic functional groups will occur like shift in bacteriophages nematodes and a tydeid mites to fungiphagous nematodes and fungi-feeding mites (Whitford, 1982). The decomposition food-web of mesic ecosystems and arid ecosystems are different in terms of active trophic levels because of the drastic differences in the abiotic factors. In mesic-ecosystems, the mineralization of immobilized nitrogen on fungal biomass carried out by protozoan and nematodes while in arid soil it is done by fungi-feeding mites because the nematodes and protozoans are encysted for a long time in the deserts due to harsh climate and low water content (Whitford, 1989). These active groups of mites include tydeid mites and other taxa of mites and are very important regulators of decomposition rates (Santos and Whitford, 1981). Santos et al., (1978) said that diversity and composition of microarthropods in desert ecosystem differs according to the presence, absence and depth of the litter layers surrounding vegetation and the chemical/ physical characteristics of the litter. Eventhough there is significant difference in the climate like varying rainfall at different areas, the microarthropod communities found under the same vegetation at different areas will be somewhat similar to each other. Unlike microarthropods, studies about protozoans and nematodes done by assuming them as trophic groups or guild categories. The documentation of these studies reporting that the desert soils have Cephalobid (bacteriophagous) nematodes in larger in the early stages of decomposition later replaced by the fungivorous and omnivore-predator trophic groups. Desert soils have ants and termites which helps the transport of sub-surface soils to the surface. Some species of termites produce fragile easily erodible galleries and some produce hard ground matters which are highly resistant to soil erosion, but over the time it will decay and aid in the soil formation. The importance of the termites as the decomposers of the dung, wood, leaf litter and grass along with their significance in the maintenance of soil macroporosity has led to the consideration of termites as a keystone species in desert ecosystems (Whitford, 1996).

Soil invertebrates: bioindicators of soil quality

Human activities, agriculture, transport and buildings will negatively affect the soil functionality, leading to alterations of several processes that could weaken the ecosystem (Santorufo *et al*., 2011). Urbanization will lead to pollution, conversion of indigenous habitats to various land use, habitat fragmentation and loss, and soil community changes (McIntyre, 2000). Since we have little knowledge about the impact of human activities on urban soils, we can consider soil invertebrates as the excellent candidates for studying the consequences of human activities happening in the environment (McIntyre, 2000). Their abundance and easiness to sample, along with the rapid responses against the soil disturbances make them suitable for assessing the soil quality. As invertebrates are sensitive to changes in soil conditions, they can be considered valuable indicators of soil disturbances (Nahmani and Lavelle, 2002).

Santorufo *et al.,* (2011) studied the abundance and density of invertebrate communities of urban soils with the aim to find out the relationship of soil fauna with respect to soil physical and chemical properties and to identify the tolerance of different taxa towards soil stressors. Soil quality is assessed by invertebrate community indices (Shannon, Simpson, Menhinick and Pielou indices), Acarina/ Collembola ratios and soil biological quality indices (QBS) were calculated. They collected ten samples of surface soils (0-10cm depth and 10cm diameter) from five urban areas and chemical and physical analyses, Arthropod and enchytraeid community analyses and biological indices were done. The collected soils highly differed in terms of physical and chemical properties. Abundance and diversity better than taxa richness, reflected the trend of soil physical and chemical characteristics (Santorufo et al., 2012). Both organism density and taxa richness were high in soils with high organic matter content and water content and low in soils with high metal concentrations, but no statistically significant correlations found. Presence of ants, termites, earthworms, millipeds, and other soil macrofauna create porosity in the soil and facilitate the water and gas transport. Individual abundance is more affected by soil characteristics than the taxa richness. The more resistant taxa to urbanization and ubiquitous in the investigated soils were Acarina, Enchytraeids, Collembola and Nematoda. The most sensitive to disturbances in the soil properties is collembolans. Formicidae was abundant in the soil with low metal contents and Isopoda were more tolerate to metal contamination. Soil metal pollution seemed to cause an increase in the invertebrate diversity and evenness. Shannon and Simpson indices should use to evaluate soil quality and community structure. While the Menhinick and Pielou evenness indices were higher for the soils with high metal content and low pH; A/C ratio is positively related to soil metal contamination. The QBS index is highest in the soil with the lowest metal content. From this study, it shown that highest density and taxa richness of the invertebrate community seems most appropriate for soil quality assessment (Santorufo, 2012).

Conclusion

Soil is the essential source of different ecosystem services. These different ecosystem services are provided by the interaction of abiotic and biotic factors in the soil ecosystem. Soil is the home for different kinds of living components including plant and animals. Microflora, microfauna, mesofauna, and macrofauna also plant roots are the living components in the soil. Soil invertebrates are participating in the production, regulation and the delivery of ecosystem services at different scales. They are water supply, nutrient cycling, soil formation, primary production, flood and erosion control and climate regulation. Movement and activities of soil invertebrates makes pores of different sizes in the soil and promote the transport of gases and water in the soil. It will increase the water infiltration and water holding capacity of the soil. The biogenic structures produced by the soil organisms will form soil aggregates and increase the organic matter content in the soil. Thus the productivity of the different land use systems can be examined by assessing the soil invertebrate diversity and abundance.

The significance of soil invertebrates in the current scenario is very important. Since the soil invertebrates are very sensitive to the disturbances in soil ecosystems, we can use them as biological indicators for assessing the pollution and the health of the different land use systems. Because the sudden changes in the soil characteristics due to different activities like land use change, pesticide application, pollution, flooding and soil erosion etc. would influence the diversity and the abundance of soil invertebrates of the area. There is still the need of further studies that address the functional role of soil invertebrates in soil function, the effects of land management and the consequences for landscape health.

There are studies showing the contributions of earthworms, termites and other invertebrates and their significant roles in sustaining the arid ecosystems and other land use systems. Also soil invertebrates play significant role in the monitoring of pollutant effects. Using the soil invertebrates we can test the toxicity in the soil ecosystems through standardised tests. It will lead to evaluation of environmental quality of different soils. Despite the large range of soil invertebrates, they are the poorly explored taxonomic groups.

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