International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(4): 1687-1692

Received: 16-05-2019
Accepted: 18-06-2019

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Soil arthropods as a nutrient enhancer

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Abstract

Arthropods represents 85% of the soil fauna in terms of species richness and they comprises the meso- and macro-fauna of the soil mainly. In the soil eco-system, Isopoda, Myriapoda, Insecta, Acari, and Collembola are chiefly dominating. Two main function carried out by arthropods in soil system one is litter transformers and another is ecosystem engineers. Litter transformers decompose plant debris, enhancing soil nutrient quality through mineralization and helps in faster growth and dispersal of microorganism. Up to 60% of annual litters processed by termites. In other hand Ecosystem engineers modify the soil aggregates, increase void space, alter soil structure, mineral and organic matter composition. The burrowing arthropods, particularly the termites, ants make subterranean network of tunnels and galleries that improve aeration through increase in soil porosity and also increase water holding capacity (WHC), increase root penetration of plants, facilitate nutrient supplement to plant and prevent surface crusting and erosion of topsoil. They facilitate mixing of top soil mineral to lower horizon. Humus content of soil surface increases which intern support growth and development of plant. The organically bound form of minerals are available to plant through mineralization process.

Keywords: Decomposition, ecosystem engineers, humus, litter transformers

Introduction

From the beginning of agriculture in natural ecosystem due to active anthropogenic factor the soil environment subjected to many changes. The soil flora and fauna population modified by human activities for agricultural purposes. The community and density of soil micro-fauna determined by comparing the intensity of the present population with the original ecosystem after the perturbation. The ability of the various organisms to adapt to these changes will determine the ultimate community present in soil ecosystem. Furthermore, this community can be changed because of agricultural practices which will suit human needs and changing agricultural paradigms. Agronomy practices *viz.*, crop rotation, crop diversification, organic matter application on top soil and minimum tillage, less soil disturbances play an important role (Hendrix *et al.*, 1990). On other hand soil corrective and amendments practices may have both positive and negative effect on soil biota such as indiscriminating use of pesticide, fertilization and liming material. Use of pesticides, particularly insecticides, nematicides, herbicides are important inputs which determine soil fauna and are generally considered to have negative effects on most organisms. These antropogenic factor ultimate leads to compaction of soil, destroy soil physical property, facilitate erosion, contamination with xenobiotics and finally leads to pollution of soil ecosystem (Hendrix *et al.*, 1990). In order to achieve better soil heath trough soil fauna combination of the various practices adopted by a farmer at a particular site are important.

Table 1: Summary of the effect (positive or negative) of common agricultural practices on the soil biota (compiled from various sources).

Positive	Negative
☐ Organic matter (Mulch, manure, etc.)	☐ Pesticides
☐ Less physical disturbance (tillage)	☐ Frequent and deep tillage
☐ Green manures	☐ Burning
☐ Soil covers	☐ No surface protection/Erosion
☐ Crop rotations	☐ Monoculture
☐ Organic agriculture	☐ Fumigation/solarization

Soil Fauna

Soil ecosystem thought to harbour an outsized part of the world's biodiversity in trems of soil biotic community taken as consideration. It governs most important process where continues interaction between biotic and abiotic components that ultimate leads to flow of energy and recycling of material. They are the vital part of soil food web and key players in several supporting and regulating ecosystem services (Jeffery *et al.*, 2010). Soil ecosystems generally contain a large variety of animals, such as nematodes, microarthropods such as mites and Collembola, Symphyla, Chilopoda, Pauropoda, enchytraeids and earthworms. In addition, a large number of meso and macrofauna species (mainly arthropods such as beetles, spiders, diplopods, chilopods and pseudoscorpion, as well as snails) live in the uppermost soil layers, the soil surface and the litter layer.

In general, soil invertebrates are classified according to their size in microfauna, mesofauna, macrofauna and megafauna (Wallwork, 1970).

- Microfauna: organisms whose body size is between 20 µm and 200 µm. Example:,protozoa, is found wholly within this category; among the others, small mites, nematodes, rotifers, tardigrades and copepod crustaceans all fall within the upper limit.
- Mesofauna: organisms whose body size is between 200 µm and 2 mm. Microarthropods such as mites and springtails, are the main representatives of this group, which also includes nematodes, rotifers, tardigrades, small araneidae, pseudoscorpions, opiliones, enchytraeids, insect larvae, small isopods and myriapods.
- Macrofauna: organisms whose size is between 2 mm and 20 mm. This category includes certain earthworms, gastropods, isopods, myriapods, some araneidae and the majority of insects.
- Megafauna: organisms whose size exceeds 20 mm. The members of this category include large size invertebrates (earthworms, snails, myriapods) and vertebrates (insectivores, small rodents, reptiles and amphibians).

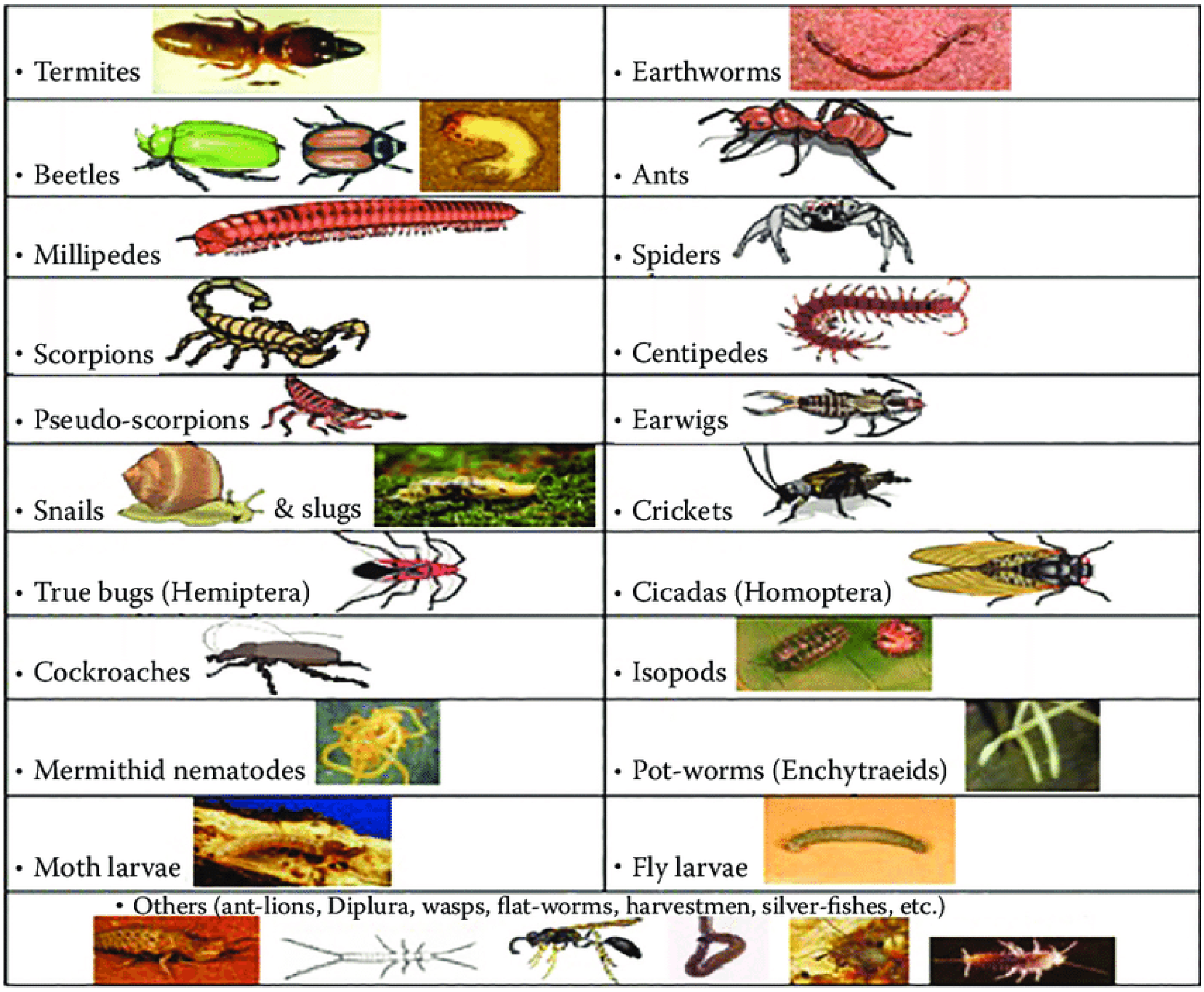

Fig 1: Representatives of the soil+surface litter macrofauna

Physical role of soil macrofauna

Five main physical effects of soil macrofauna can be highlighted:

- Macromixing
- Micromixing,
- Gallery Construction
- Fragmentation
- Aggregate Formation

Macromixing

Ants, termites, earthworms and ground beetles can move an important quantity of soil, bringing back to the surface mineral matters from deeper horizons and burying the organic matter from the surface horizons, from litter and from excrements. For example, a large nest of *Atta* ants comprises several million individuals. It forms a cavity in soil with numerous chambers. The excavated earth is deposited on the soil surface surrounding the nest. The removal of fine material in depth sometimes creates porous zones under the nest where water can be accumulated temporarily. The macromixing activity of earthworms is of major importance to soils. It can be measured by the quantity of casts found on the soil surface. Earthworms can produce 40–250 tonnes of casts per hectare per year. Some can produce up to 2 500 tonnes of casts per hectare per year. Some beetles (especially those of the subfamily Scarabeidae) are coprophagous – they are very efficient at incorporating and removing excrements that are on the soil surface. For example, just a couple of *Heliocopris dilloni*, a large African species, can bury a piece of dung in one night (Waterhouse, 1974).

Micromixing

Other groups of soil macrofauna influence soil structure in a less spectacular way, but the micromixing that they realize is as important as macromixing. These organisms, mainly represented by Diptera larvae, have a more limited capacity to dig the soil. They stay on the soil surface where they realize a fundamental task for the incorporation of organic matter to soil. However, they can be carried into soil by leaching to a depth of up to 60 cm.

Gallery construction

Gallery (burrow) formation is very important for soil aeration and water flux. For example, earthworms and termites develop networks of galleries that improve large spaces in the soil macro-porosity by 20–100 percent (Edwards and Bohlen, 1996). Earthworms can burrow an estimated 400–500 m of galleries per square metre in grasslands. These galleries are denser in the top 40 cm and can represent up to 3 percent of the total soil volume. In these conditions, the waterholding capacity of soil can increase by 80 percent and water flux can be from four to ten times faster. Earthworm activity is very important in agricultural soils with a high degree of compaction and a ploughing pan that prevents water flux. This situation decreases water infiltration and increases surface runoff and erosion. Earthworms pierce the ploughing pan, so improving water infiltration and offering new paths for root penetration. Termite excavation activity has a similar effect on soils (Gullan and Cranston, 1994), and in some cases can reduce the compaction of surface layers. Where organic matter is present in the soil, the bioturbating and decomposing activities of termites can reduce soil compaction, increase its porosity and improve its water infiltration and retention capabilities. Such conditions encourage root penetration, vegetative diversity and the restoration of primary productivity (Mando, 1997) [33, 34]. Thus, galleries make up a draining system that collects rainwater and facilitates its flow. Water drags small material into these tunnels, which become the preferential paths for soil penetration for roots and leached clays. Galleries are also the soil penetration paths for other surface invertebrates with more limited burrowing capacities, e.g. very small earthworms, slugs, insect larvae, and mesofauna.

Litter fragmentation

The fragmentation of dead wood (lignin material), carcass and litter is one of the most important activities of soil fauna. It has a major effect on organic matter evolution in soil, conditioning the activity of bacteria, fungi and microfauna populations. Fragmentation is performed by phytosaprophagous animals (i.e. animals feeding on decayed plant material and dead animals).

Aggregate formation

After litter has been fragmented, it is easier for organic matter to be broken down into the stable form known as “humus”, and then to form soil aggregates – the clumping together of soil particles forming a crumbly healthy structure. Earthworms, termites, millipedes, centipedes and woodlice ingest soil particles with their food and contribute to aggregate formation by mixing organic and mineral matter in their gut.

Functional roles of arthropods in maintaining soil fertility

The term “soil fertility” denotes the degree to which a soil is able to satisfy plant demands for nutrients (including water) and a physical matrix adequate for proper root development, which is significantly influenced by biological processes. Arthropods function on two of the three broad levels of organization of the soil food web (Lavelle *et al.*, 1995) [26]: they are “litter transformers” or “ecosystem engineers.” Litter transformers, of which the microarthropods comprise a large part, fragment, or comminute, and humidify ingested plant debris, improving its quality as a substrate for microbial decomposition and fostering the growth and dispersal of microbial populations. Ecosystem engineers are those organisms that physically modify the habitat, directly or indirectly regulating the availability of resources to other species (Jones *et al.*, 1994) [21]. In the soil, this entails altering soil structure, mineral and organic matter composition, and hydrology. Ants and termites are the most important arthropod representatives of this guild, the latter group having received the greater share of research attention (Lobry de Bruyn and Conacher, 1990) [29].

Influence of arthropods on nutrient cycling

Upwards of 90% of net terrestrial primary production ultimately may enter detritus food webs (Polis and Strong, 1996) [39] where it is decomposed and recycled. Much of it originates in leaves and woody materials falling to the soil surface. However, the below-ground contribution to detrital mass has been estimated at 1.75 times that of all above-ground litter inputs, and roots may provide 2.3 times more nitrogen to the soil pool than all other inputs (Witkamp and Ausmus, 1976) [1]. Plant litter is a mixture of labile substrates (e.g., sugars, starch) easily digested by soil biota, and other components (cellulose, lignins, tannins) more resistant to breakdown (Coleman *et al.*,1980). Decomposition of this material results from an interaction between physical and biological processes (Crossley, 1977) [9]. Litter first must be physically weathered before it becomes suitable for further degradation by the soil microflora and fauna. Fungi are the important initial colonizers of plant litter (Harley, 1971) [16]. With increasing disintegration and solubilization of the substrate, bacteria increase in importance. After this initial microbiological phase, the breakdown process slows, and might come to a halt altogether were it not followed by animal activity (Burges, 1965) [4]. Saprophagous arthropods affect decomposition directly through feeding on litter and adhering microflora, thus converting the energy contained therein into production of biomass and respiration, and indirectly, through conversion of litter into feces and the reworking (re-ingestion) of fecal material, comminution of litter, mixing of litter with soil, and regulation of the microflora through feeding and the dissemination of microbial inoculum (Lavelle,1997 and Swift *et al.*, 1979) [25, 46]. With the exception of some termite groups (Wood, 1976) [53], only a small proportion of net primary production is assimilated by soil arthropods (e.g., <10% in oribatids, 4%–20% in millipedes and isopods (Berthet, 1967 and Van der Drift, 1965) [3, 45] Thus, the indirect influences of these consumers on decomposition and soil fertility are considered, in general, to be of greater importance (Chew, 1971 and Witkamp, 1974).

Mineralization of nutrient elements

For nutrients to be available for uptake by plant roots, they must be present in the soil in inorganic form. Mineralization is the catabolic conversion of elements, primarily by decomposer organisms, from organic (*i.e.*, bound in organic molecules) to inorganic form, such as the generation of CO2 in the respiration of carbohydrates and breakdown of amino acids into ammonium (NH4+) and ultimately nitrate (NO3−). The direct or indirect actions of arthropods in processing plant litter, which may be nutritionally poor or resistant to decomposition, increase available nutrient concentrations in the soil. Micro-organisms efficiently convert the low-quality, recalcitrant resources of plant litter, such as the structural polymers comprising cell walls, into living tissue with much narrower carbon: nutrient ratios and of higher food value for animals, providing a rich source of nutrients at low metabolic cost to the consumer (Swift *et al.,* 1979) [46]. A major proportion of the nutrients in the litter/soil system is concentrated and temporarily stored, or immobilized, in microbial biomass, and subsequently in consumers, particularly the microarthropods, ultimately to be liberated in feces and upon death (Ausmus *et al.,* 1976 and McBrayer *et al.,* 1974) [2, 37] The microbial mineralization of nutrients may be stimulated by arthropod grazing. Several studies (Filser, 2002) have demonstrated that grazing by Collembola has a strong stimulatory effect on fungal growth and respiration. Hanlon & Anderson (Hanlon and Anderson, 1979 and Hanlon and Anderson, 1980) [14, 15] showed that carbon mineralization by fungi and bacteria in comminuted litter was enhanced by an optimal level of grazing by micro- and macroarthropods; increased grazing pressure above the optimum inhibited microbial respiration. Collembolan grazing on fungi can result in increased mobilization of available N and Ca, with implications for nutrient availability in particular environments, such as acidic forest soils, in which large nutrient pools tend to be immobilized in stores of accumulated organic matter (Ineson *et al.,* 1982) [19]. Isopod (*P. scaber*) feeding on oak and alder litter colonized by the microflora increased microbial respiration 10- and 20-fold, respectively, over that in plots, in which isopods were absent, and resulted in increased availability of the macronutrients, C, N, P2O5-P, K+, Mg2+, and Ca2+, in the topsoil, attributable to the increased availability of feces as substrates for further decomposition (Kautz, and Topp, 2000) [22]. Arthropod grazing on the microflora also acts to regulate the rate of decomposition, preventing sudden microbial blooms (Ausmus *et al.,* 1974) [1], with the result that nutrients are mineralized and released from detritus, and made available for plant uptake, in a controlled and continuous fashion and their loss from the system minimized (Reichle, 1977) [40].

Soil mixing and the development of pores and voids

Biotic pedoturbation refers to the displacement or mixing of soil material through the actions of organisms (Wilkinson, 2004) In general, the mesofauna are not considered important in this process because they are too small to move most soil particles (although some Collembola and oribatid mites are said to make active "microtunnels" in the soil matrix (Rusek, 1985) [44]; these animals instead rely on existing cracks and crevices, and the channels and spaces created by the larger fauna to aid their mobility within the soil (Lepage, 1974) [28]. The subterranean network of tunnels and galleries that comprise termite and ant nests plays an important role in enhancing aeration and water infiltration through the soil profile, increasing water storage, and retention of top soil. Termites have been reported to work the soil to depths of 50 m or more (Martius, 1990) [36]. The heaps of accumulated old nest material of an *Anoplotermes* species in Amazon floodplain forest had infiltration rates more than 27 times higher than in surrounding, unmodified soil [207]. In experimental studies, Elkins *et al.* (1986) [10] and Whitford, (1991) [41] found plots, from which subterranean termites had been eliminated, to have significantly reduced water infiltration and storage, and increased runoff and sediment flow (bedload) compared to plots populated with termites. Mando *et al.* (1996, 1997, 1997) [35, 33, 34] showed that active encouragement of termite activity through the application of surface mulches significantly improved the hydraulic properties of degraded soils. Under such conditions, soil, in which termites (*Macrotermes subhyalinus (*Rambur) and *Odontotermes* sp.) were active, had infiltration rates ranging from 2 to 6 to above 9 cm3 s−1, 2–3 times those in soil without termites (Léonard and Rajot, 2001) [27]. Infiltration rates around the nests of four abundant species of ant averaged 120 mL min−1, more than 3 times as rapid as through the surrounding farmland soil (Majer,1987) [32]. The infiltration pathways and sinks provided by ant nests limited post-fire hill-slope erosion by reducing overland water flow rates following heavy rainfall events (Richards, 2009) [41, 50]. Experimental crop yield increased 36% and infiltration rates 3-fold in plots supporting ant and termite populations over those in plots, from which the insects had been excluded (Evans, 2011) [11]. The system of chambers and galleries comprising ant and termite nests, which increases the porosity of soil, improving aeration and water infiltration, together with the organic matter (from feces, salivary and other secretions, food remnants (Gillman *et al.,* 1972 and Rogers, 1972) [13, 43] accumulating therein, which enhances water-holding capacity, creates an environment favorable for the penetration of plant roots (Robinson, 1958 and Pętal, 1978) [42].

Formation of soil aggregates

Soil aggregates, or peds, the basic units of soil structure, are formed by natural processes, commonly involving the activity of organisms (Hole, 1981 and Lynch and Bragg, 1985) [18, 31]. Fecal pellets, combining fine mineral particles with undigested organic matter, are the major contribution of invertebrates to the formation of soil aggregates (Rusek, 1985 and Pawluk, 1985) [44]. Mucilaginous substances, byproducts of microbial decomposition, bind the feces with other soil components into stable microstructures (Harris, 1966 and Oades, 1993) [17]. These organomineral complexes are substrates, on which inorganic nutrients may become adsorbed and so available to plants (Kuhnelt, 1976) [24]. The resulting humus, an amorphous colloidal material comprising partially decomposed organic matter that makes up topsoil and increases the soil's capacity to store nutrients (e.g., cations) and prevent their rapid leaching, thus is largely derived from animal feces (Ciarkowska *et al.*, 2002, Loranger *et al.*, 2003, Pawluk, 1987, Kubiena, 1955, Jackson, 1966, Schaller, 1950 and Dunger, 1958) [7, 30, 38, 23, 20, 45]. The humus of well-developed soils represents a significant pool of macronutrients, such as N, P, K, Ca, and Mg, which may be stored in amounts exceeding 1 tonne ha−1 (Weetman, and Webber, 1972). It also is involved in chelation reactions, which aid in the micronutrient nutrition of plants, buffers the soil against rapid changes in pH, and supports an abundance and diversity of micro-organisms, promoting increased mineralization activity (Burns, 1986) [5].

Conclusion

Soils are integral parts of ecosystems, and are maintained in a fertile state largely through the actions of their constituent biota. Fertility is a function of a soil's capacity to provide plants not only with essential nutrients for growth and reproduction, but also with a physical matrix that facilitates root growth and respiration, and maintains its structural integrity against erosive forces.

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