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SOIL BIODIVERSITY AND ECOSYSTEM SERVICES

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"We are ever ready to talk about and fight about land, without the slightest inkling about or concern for the land that we are so willing to fight for. Land comprised of four basic elements, its water, its rocks, its soil and its biodiversity"

Ranil Senanayake

ABSTRACT

Soil is a complex ecosystem inhabited by a highly diverse biotic community that uses soil either as a permanent or temporary habitat. Organisms that live in soil range in size from minute microorganisms to more conspicuous mesofana and macrofauna. This wide range of soil biota performs many critical ecosystem services such as soil formation, organic matter decomposition, carbon sequestration, nitrogen fixation, facilitation of nutrient uptake by plants, suppression or induction of plant diseases, provision of food and bioremediation of degraded and contaminated soils. Soil organisms also influence water infiltration and runoff and moisture retention as they affect the soil structure and composition. These services are critical to the efficient functioning of natural or agro ecosystems. However, modern agricultural practices that focus heavily on establishing large scale monocultures with excessive chemical and mechanical inputs have resulted in the progressive degradation of both above and below ground biological diversity, and thereby loss of ecosystem services rendered by them. The current agricultural practices not only result in a monoculture production, but as pointed out by Vandana Shiva '*a monoculture of mind*', they only seek to make money with little or no concern for the land, water and air that bare fundamental requirements of life. The consequence of this mindset would be to create a mass of consumers with no other goal but to consume more and more, which will disrupt the fragile life support systems that sustain the earth. Therefore, there is a pressing need to develop a strategic approach to use the components of soil biodiversity to increase the agricultural production in a manner that does not lead to their long-term decline. However, current knowledge in this area is fragmented and remains largely in the research domain with limited practical application by farmers. Therefore, challenge before us is to identify and address the knowledge gaps in the current level of understanding on soil biodiversity that prevents us from attaining this long term goal.

Soil Biodiversity

Soil biodiversity is the variety of life present in the soil. This includes a complex assemblage of species including microorganisms, plant roots, invertebrates and vertebrates. The invertebrates and microorganisms make up bulk of the biomass in soil communities. The primary role of the soil biota is maintenance of fertile soil, by replenishing its mineral and organic contents that are constantly consumed by plants and making them available for the above ground food chain. Therefore, soil dwelling species, even though invisible in most instances, play an important role in maintaining healthy ecosystems.

The soil microorganisms comprise of Bacteria, Archaea, Actinomycetes, Cyanobacteria and Fungi. Soil bacteria can be broadly categorized into free living and symbiotic species. The symbiotic species are associated with nitrogen fixation while the free living species plays many roles in the soil (Reid & Wong, 2005). These include decomposition and mineralisation of organic compounds, synthesis of organic compounds, immobilisation of nutrients and serve as a food resource for grazing microfauna. Some bacteria can act as pathogens of plants or soil animals or helpers in mycorrhizal associations. Archaea, albeit much less numerous compared to bacteria, plays an important role in methanogenesis and ammonia oxidation (Nicol *et al.* 2003). Actinomycetes are predominantly decomposers and are responsible for giving soil its characteristic earthy smell. Actinomycetes are also a major source of antibiotics. Cyanobacteria are a special group of bacteria that can photosynthesize, and in many cases fix nitrogen.

Similar to bacteria, fungi also comprise of symbiotic or free living species. The symbiotic fungi form relationships with trees and shrubs where the fungus derives food from the plant and in return helps the plant to absorb essential nutrients from the soil. The free living fungi play a very important role as decomposers of organic matter and contributes to nutrient cycling. Some fungi act as pathogens or parasites that are important in maintaining the population equilibrium of soil dwelling species (Jenkins, 2005). The mushrooms, fruiting bodies of the fungi, with a high protein and lipid content acts as an important source of nutrients for terrestrial animals including man.

The soil fauna include a wide range of organisms such as protozoa, rotifers, nematodes, earthworms, molluscs, arthropods, amphibians, reptiles, birds and mammals. Soil fauna can be classified based on their body size (Wallwork, 1970). Body size of soil fauna ranges from less than 200 μm in diameter to several centimeters in length and can be divided into microfauna, mesofauna and macrofauna. Soil animals with a body diameter between 20 to 200 μm are referred to as microfauna that includes rotifers and protozoans. Mesofauna range from 200 μm to 2 mm and in length and include mites, collembolans, enchytraeids and nematodes. All soil fauna larger than 2 mm are in length referred to as Macrofauna and include spiders, pseudoscorpions, millipedes, earthworms, insects, insect larvae, molluscs and soil-dwelling vertebrates.

Protozoa are represented in the soil by rhizopods, ciliates and flagellates. These organisms are grazers that feed on bacteria. Some ingest organic litter and fungi and even may be able to digest cellulose. Protozoa are decomposers and their actions may contribute significantly to turnover available nutrients and enhancement of biochemical activity in soils (Stout and Heal, 1967).

Nematodes are perhaps the single most abundant group of animals that occur in the soil. The feeding habits of soil nematodes vary considerably (Yeates, *et al.*, 1993). Some inhabit decaying organic matter and ingest liquified components of decomposing animals and plants. Others feed on algae, bacteria, fungi, plant roots or animals, while still others parasitize plants, beetles, worms and slugs. The feeding activity of nematodes generally does not contribute significantly to the decomposition of organic material or to the formation of soil humus, but they do provide an important food source for other members of the soil community (Wallwork, 1970).

Enchytraeids are white or transparent minute earthworms that are important members of the mesofauna in many soil ecosystems (Hansson 1990). They are detritivores and microbial feeders and form an important component of the decomposition system in soils.

Earthworms comprise the largest faunal biomass in the soil. Earthworms are important for speeding up decomposition of organic matter and improving the structure of mineral soil. This action converts the bound nitrogen in organic complexes to ammonia, nitrites and nitrates that are more readily available to vegetation. Earthworms also influence soil drainage, fertility and stability (Wallwork, 1970) and promote the redistribution of organic debris.

Molluscs are represented in soil communities by slugs and snails. Land snails exhibit several types of feeding habits including herbivory, fungivory, predation and detritus feeding. This group probably influences soil most by feeding on surface vegetation, then moving into soil subsurface layers, thus incorporating organic material into the mineral structure of the soils.

Arthropods frequently dominate all other groups of the soil meso and macrofauna, both in numbers of individuals and species. Soil arthropods can be divided into crustaceans (wood lice), arachnids (scorpions, pseudoscorpions, spiders and mites), myriapods (millipedes and centipedes) and insects. Wood lice are the most commonly occurring form of crustaceans in soils. They are omnivores that feed on dead plant material, faeces and invertebrate carrion, and thereby play an important role in the decomposition of organic material. Arachnids are predatory arthropods and frequently inhabit vegetation on the soil surface and loose leaf litter. The arachnids are important predators of insect populations and like all animals contribute organic matter to the soil when they die. Millipedes and centipedes are common in many soils. Millipedes generally feed on plant detritus (Wallwork, 1982) and assist in the decomposition of organic matter, while centipedes are primarily predators. Numerous orders of insects are represented in soil fauna. Many insect species simply use the soil for the egg or pupal stages of their life cycle. The most abundant insect groups with respect to soil ecology are the termites and ants (Wallwork, 1982). Members of both groups construct extensive galleries in the soil, and many species transport large amounts of organic material from the surface to underground chambers; termites are particularly important in this respect. These activities can contribute significantly to nutrient cycling (Moldenke *et al.*, 2000). Other species of insects may use the soil during part of their life cycles, such as those whose larval stages inhabit the soil.

One of the key soil processes in which arthropods participate is nutrient cycling. The most abundant soil arthropods are fungivores, such as mites and collembolaans. They indirectly affect nutrient cycling by grazing on the fungal biomass. In doing so, nutrients are released from the microbial biomass and made available for plants. Grazing can also reduce the rate of decomposition of orgamic matter by keeping microbial biomass levels low. This may be important in conserving nutrients. The types of fungal and bacterial species inhabiting the soil can also be affected by the feeding of arthropods. The production of faecal matter due to grazing is also an important component of nutrient cycling. Converting litter into faecal matter changes their chemistry and shape, which changes their availability for microbial decomposition. The movement of soil fauna leads to the transport of organic matter and microbes through the soil. This may prove to be one of the most critical roles of soil arthropods (Moldenke *et al.*, 2000). On a large scale, some of the macro arthropods can move between soil horizons, (e.g. between the rhizosphere, and coarse woody debris). On the other hand smaller arthropods move between pores and aggregates that will result in the redistribution of organic matter to and from the rhizosphere. The effect of this movement on nutrient cycling may be especially important for otherwise immobile nutrients, such as phosphorus.

Most vertebrates spend only part of the time in the soil as they usually feed on the surface. Therefore, their importance in the food web of soil ecosystems is often overlooked or deemed minimal and they are seldom considered as soil fauna. However, some vertebrates have a significant impact on soil ecosystems. Most soil vertebrates (*e.g.* rats, bandicoots) mix soils due to their burrowing actions while others may dig and scratch through the upper soil layers in search of food (*e.g.* Jungle fowl, mongoose) or to lay eggs (*e.g.* lizards, turtles). The burrowing vertebrates include burrowing snakes, limbless amphibians frogs that bury themselves in soil during dry periods rats, mice, bandicoots, porcupines and pangolins. Excavation of underground passageways and chambers affects the soil climate and alters soil horizons. Further, burrowing mammals raise soil from lower profiles to the surface where they are broken down, incorporated with organic matter or carried off by water and wind. Mixing deep and surface materials also may have significant effects on the texture and composition of soils at various levels. Also, burrowing animals usually improve soil structure by loosening soil particles and in turn influence the ability of soils to absorb water.

Soil dwelling mammals also redistribute materials. For instance rats, mice and bandicoots store plant materials, including seeds, in subsurface chambers. A great variety of rodents, birds, bats and other vertebrates make their dens and nests in openings between rocks. Mice and bats use crevices in the faces of high cliffs. Raptors build nests on ledges. In doing so, these animals introduce organic matter, some of which undoubtedly promotes weathering of bedrock and its conversion to new soil that supports vegetation. Bat and bird excreta are natural organic fertilizers, and large concentrations of these animals may have a significant influence on the chemical nature of soil. The cattle and buffaloes loosen the sandy soils by overgrazing that accelerates both wind and water erosion. The dens or chambers created by mammals and reptiles often become mini ecosystems. When unoccupied by their creators, these underground chambers are frequently used by non-burrowing animals, such as beetles and frogs. The build up of organic debris in the dens promotes growth of fungi, which, in turn, is eaten by insects and mites that become food for vertebrates.

Ecosystem Services

Ecosystem services can be defined as the benefits provided by ecosystems to humans (MEA 2003). Ecosystem services can be broadly divided into four categories, namely, provisioning services, cultural services, supporting services and regulating services. Biodiversity both directly and indirectly mediates many of these ecosystem services. Some ecosystem services confer direct benefits while others provide indirect benefits to man.

Soil biodiversity primarily provides supporting services such as soil formation, and nutrient cycling. This in turn will influence provisioning services such as production of food, timber, fuel and fibre, as soil fertility is a strong determinant of plant species diversity and primary production. Soil biodiversity also provides direct provisioning services such as food and medicine. Further, soil biodiversity provides a number of regulating services such as reduction of green house gas emissions, bioremediation and maintenance of the water quality and quantity. Since soil biota influences the soil structure, water storage capacity and available nutrients in the soil, they directly impact the vegetation communities that are capable of growing in a given location and indirectly impact the diversity of wildlife that can be supported in an area. A summary of the ecosystem services provided by soil biodiversity is given in table 1. The value of the ecosystem services provided globally by soil biota is estimated to be more than 1500 billion US dollars (Table 2).

Table 1. A summary of ecosystem services provided by soil biodiversity

Ecosystem Service	Ecosystem process	Organisms
Provisioning Services		
Wild food	Decomposition,	Earthworms[1], Fungi[2], soil dwelling vertebrates etc.,
Antibiotics (bacterial secondary metabolites)	Decomposition of soil organic matter	Actinomycetes[3]
Use in mining industry		Microorganisms[4]
Supporting Services		
Soil structure and composition	Soil and sediment alteration and redistribute of organic matter both laterally and vertically	Ants, termites, earthworms and burrowing vertebrates such as rats, frogs, snakes *etc.*,
Recycling of nutrients	Decomposition	Bacteria and fungi
Increasing soil N	Biological Nitrogen fixation	Bacteria & Cyanobacteria
Biocontrollers	Predation	Insects, nematodes, bacteria, viruses and fungi
Regulating Services		
Reduction of greenhouse gasses	Primary production	Plant roots, algae, diatoms
	Consumption of trace gases	Microorganisms[5]
Carbon sequestration	Bioassimilation of carbon	Soil biota[6]
Bioremediation of soils	Decomposition of organic matter	Soil microorgnisms[7]
Regulation of soil hydrological processes	Facilitate water filtration and purification	Decomposers, plant roots and burrowing organisms

[1] It has been recorded that 32 Amazonian Indian tribes consume more than 100 species of soil invertebrates due to their high nutritional value. For instance Orinoco Llanos, an ethnic group in Colombia, consume swarming females of the ant species *Atta laevigata*, which carry a high content of sugar and lipids. The Ye'Kuana, an ethnic group in Venezuela, collect and consume two different edible earthworm species (Paoletti *et. al.*, 2000).

[2] Wild mushrooms serve as a food source for humans as well as other animals.

[3] Actinomycetes produce several antibiotics such as actinomycetin, micromonosporin, mycetin, actinomyces lysozyme, actinomycin, proactinomycin, streptothricin, and streptomycin (Waksman *et al.*, 2010).

[4] Many countries use microorganisms in the mining industry to recover metals from poor ores or mine tailings *e.g.* Australia and America produce copper and nickel, Canada produce uranium and Russia produces gold and manganese. (Mehtha an Panday, 2008)

[5] Soil microbial (Methanogenic and denitrifying bacteria) activity leads to the production and consumption of a variety of trace gases (carbon dioxide, nitrous oxide, methane, carbon monoxide and sulfur gases).

[6] World soils collectively comprise the third largest global Carbon pool (2000 Pg of organic C and 750 Pg of inorganic C to a depth of one metre). This total is 3.2 times the atmospheric pool (720 Pg) and 4.1 times the biotic pool (560 Pg) (Lal, 2004).

[7] Soil biota acts as a mass biological filter that detoxifies large number of pollutants/ poisons that man applies to the environment such as pesticides and industrial waste.

Table 2. Global economic benefits from ecosystem services provided by soil biodiversity (Source: Pimentel *et. al.*, 1997)

Ecosystem Service	Component of Soil Biodiversity Involved	Economic Benefits (in US$ 10^9/year)
Waste recycling	Fungi, bacteria, actinomycetes and saprophytic, litter feeding invertebrates (detritivores)	760
Pollination	Life cycle of many pollinators have a phase in soil	200
Wild food	Mushrooms, earthworms, small arthropods and arthropod larvae and soil dwelling vertebrates	180
Biological control of pests	Life cycles of many natural enemies of pests have a phase in soil. Further, soil biota such as mycorrhizae contributes to host plant resistance and plant pathogen control	160
Bioremediation of chemicals	Use of soil biota for bio-treatment to remove toxic compounds in soil	121
Nitrogen fixation	Biological nitrogen fixation by soil bacteria	90
Soil formation	Contribution of soil biota such as earthworms, fungi and termites for soil formation	25
Biotechnology	Soils provide nearly half of the current economic benefits of biotechnology related to agriculture, pharmaceuticals *etc.*,	6
	TOTAL	1542

Present Status

Soil biodiversity is important for mediating a number of ecological processes. However, the current land use practices as well as water and waste management approaches taken by man have many negative impacts on the physical and chemical properties of soil. This in turn will have an impact on the organisms that inhabit the soil leading to a reduction in soil biodiversity and thereby, loss of services rendered by them. Some of the human activities that affect the soil biodiversity include.

Intensification of landuse: Large scale farming practices have resulted in increased use of heavy machines for land preparation that leads to soil compaction. Compaction reduces the porosity of soil and thereby alters the moisture conditions of soils. Both, soil porosity and moisture are important requirements for soil biota and therefore, will result in reduction of habitat quality and loss of species diversity in soil.

Salinization of soil: The modern farming practices are coupled with intense irrigation systems that allow year round cultivation compared to rain-fed agriculture. Intense irrigation leads to salinization or increase in the salt content of the land that will negatively impact the soil biodiversity.

Influence of fertilisers and pH: Application of fertilisers and the changes in soil pH influence the structure of the soil biota. Low pH favours fungi over bacteria and a reduces the abundance of earthworms. On the other hand high nitrogen concentrations result in increased bacterial concentrations.

Influence of tillage and crop residues: Tillage results in loss of stratification of the soil microhabitat, which in turn results in a decreased abundance of species. Further, tillage improves aeration in the soil leading to rapid mineralisation of organic matter and substantial loss of nutrients. Crop residues also influence activity and diversity of soil microbial communities. Reduced tillage with surface placement of residues creates relatively stable environments, which results in more diverse decomposer communities and slower nutrient turnover. A no-till system favours fungi over bacteria, as decomposition of plant residues occurs on top of the soil.

Pesticides application: Pesticides have both targeted and non-targeted effects that may cause a shift in the composition of the soil biota. When organisms are suppressed others can proliferate in the vacant ecological niches. The effect of pesticides strongly depends on the physical and chemical properties of soil which affect their availability. Initially pesticides affect at the level of biochemical and cellular processes. Subsequently, the structure of the DNA in an organism may be affected leading to modification and eventual evolution of resistant or tolerant organisms.

Changes in farming practices: Replacement of agricultural practices such as crop rotation and mixed cropping that increase below ground C and N content, with large scale monocultures that relies on high chemical inputs have resulted in loss of soil biodiversity. Crop rotation or mixed cropping that includes legumes or fibrous rooted crops, enhances microbial populations.

Pollution: Pollutants in general influence the organisms living in the soil. Chronic exposure of organisms to sublethal doses of stress results in different effects. In soils contaminated with heavy metals the ratio of the resistant and sensitive bacteria increases. Metal-resistant bacteria are much less effective in the decomposition of a number of organic pollutants than the trace elements sensitive bacteria.

Soil erosion: Soil displacement exposes new and possibly poorer substrates from deeper in the soil profile which take some time to be colonized and become stable productive environments. In addition, soils that are greatly disrupted become biologically pioneering environments that may be susceptible to invasion by a variety of organisms that are alien to the intact ecosystem. Other organisms, such as disease causing organisms, may also use this opportunity to establish themselves. Losses of soil due to erosion and mass wasting, will also remove soil volume and reduce the biological legacy of the soil.

GAPS

In Sri Lanka, most of the studies on soil have focused on the physical or chemical nature of soil, while soil biodiversity has been largely ignored. As a consequence, most of the soil-inhabiting species remain undescribed. Likewise, the ecological roles and lifecycles of many soil-living species are poorly known. Further, the impact of different land use practices on soil biodiversity has not been explored and therefore, one can only postulate the types of changes that may have taken place in the soil biodiversity based on findings elsewhere in the world. Also, awareness on below ground biodiversity remains low compared to above ground biodiversity. Therefore, there is a pressing need in Sri Lanka to promote further research on soil biodiversity as well as to establish mechanisms to monitor changes in the soil biodiversity. Further; it is necessary to establish a well planned campaign to create awareness about the value of soil biodiversity and how it can be utilized in a sustainable manner.

CONCLUSIONS

In Sri Lanka, agricultural practices mostly focus on improving the physical and chemical neture of soil that has lead to "high input chemical agriculture". Studies done elsewhere in the world has clearly demonstrated that this type of synthetic fertilizer based agriculture is denuding the soil of its nutrients as well as changing its structure and composition, leading to loss of ecological processes in the soil. However, such high input chemical agriculture is still being promoted in Sri Lanka through pervasive incentives provided to farmers such as fertilizer subsidies, even though it has been demonstrated to be harmful to human health, local biodiversity, environmental functions, sustainability of production and local economies.

Sri Lanka has remained un-submerged by the ocean for over twenty million years which has lead to the development of a unique biodiversity as evidenced by large soil dwelling snakes, bipedal or limbless soil dwelling lizards and limbless amphibians. However, very little attention has been given to soil biodiversity which remains largely unexplored. History demonstrates that our soil capital was lost with the advent of large scale plantation agriculture during the colonial era. The current land use practices adopted in agriculture and forestry is likely to destroy the remaining bits of living soil with heavy reliance on use of artificial fertilizers and large scale monoculture plantations. Therefore, the challenge before us is to identify and address the knowledge gaps in the current level of understanding of our soil biodiversity as well as to revise the current land use and agriculture practices in a manner that will enable the use of our natural soil capital in a sustainable manner.

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