ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 3.4
IJAR 2015; 1(3): 15-20
www.allresearchjournal.com
Received: 18-01-2015
Accepted: 08-02-2015

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The importance of soil food web for healthy environment and sustainable development

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Abstract
Soil food web is a natural network of consumer resource interactions among different functional groups of soil organisms which are occur in the soil ecosystem. Soil is a complex, unconsolidated mixture of inorganic, organic, and living material that is found on the immediate surface of the earth that supports many important functions for plants, animals, and humans. The soil food web is very dynamic, complex and interchanging depending on its ecosystem. Nutrients in soil in their most basic form come from fully decomposed organic matter which we call compost. Decomposition of organic matter is largely a biological process that occurs naturally. The organisms found in the soil food web carry out a large amount of microbial processes such as decomposition, mineralization, immobilization, respiration, and fixation along with many others. Without soil food web, plants would not obtain the nutrients which are necessary for growth. Nutrient exchanges between organic matter, water and soil are essential to soil fertility and need to be maintained for sustainable production. A diverse and complete soil food web where soils are well structured and fertile through an increasing organic matter percentage is the goal of modern day regenerative agriculture, organic gardening and permaculture design system. Healthy soil is the foundation of the food and food web system.

Keywords: Organic matter, Soil organisms, Nutrient cycle, Soil food web and Sustainable development.

1. Introduction
The soil food web is very dynamic, complex and interchanging depending on its ecosystem. The interactions found in the food web are soil organisms living all or part of their lives in the soil while producing energy and working together with plants to survive. The organisms found in the soil food web carry out a large amount of microbial processes such as decomposition, mineralization, immobilization, respiration, and fixation along with many others. These processes help to support above and below-ground plant growth and their processes make nourishment for plants. The soil food web consists of bacteria, fungi, including protozoa, nematodes, micro arthropods and a range of above ground predators, from earthworms to spiders, mice, birds (Ingham and Colema, 1986) etc. These food web varies with soil types (mineral composition, depth of horizons, structure, texture, etc) organic food resources present, prevailing temperatures, climate, etc. Food webs are used to know different energy interactions in a given ecosystem.

2. The Soil Food Web
The soil ecosystem can be defined as an interdependent life-support system composed of air, water, minerals, organic matter, and macro and microorganisms, all of which function together and interact closely (Alexandra Bot, 2005). The soil food web is the community of organisms living all or part of their lives in the soil. All food webs are driven by the primary producers such as the plants, lichens, moss, photosynthetic bacteria, and algae that use the sun's energy to fix carbon dioxide from the atmosphere. A food web diagram shows a series of conversions (represented by arrows) of energy and nutrients as one organism eats another. The living portion represents about 5 percent of the total soil organic matter. Micro-organisms, earthworms and insects help break down crop residues and manures by ingesting them and mixing them with the minerals in the soil.

The energy needed for all food webs is generated by primary producers: the plants, lichens, moss, photosynthetic bacteria and algae that use sunlight to transform CO2 from the atmosphere into carbohydrates. Most of the soil organisms get energy and carbon by consuming the organic compounds found in plants, other organisms, and waste by-products. A few bacteria, called chemoautotrophs, get energy from nitrogen, sulphur, or iron compounds rather than carbon compounds or the sun. As organisms decompose complex materials or consume other organisms, nutrients are converted from one form to another form and are made available to plants and to other soil organisms (Ingham and Horton, 1987).

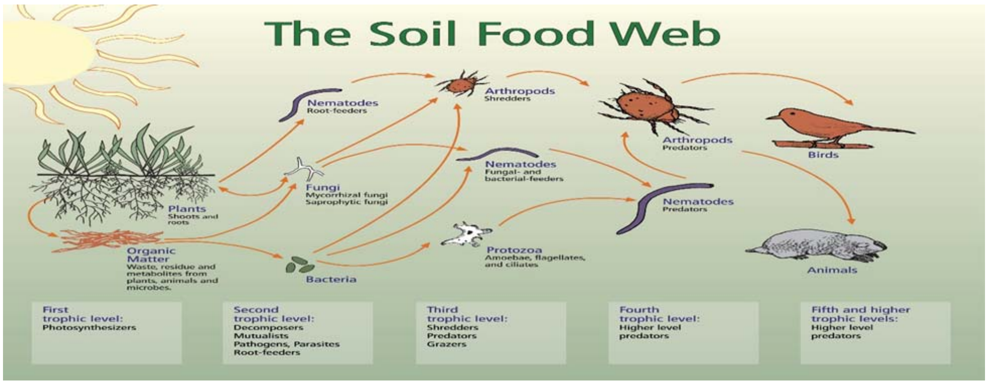

Fig 1: The Soil Food Web

The living part of soil organic matter includes a wide variety of micro-organisms such as bacteria, viruses, fungi, protozoa and algae. It also includes plant roots, insects, earthworms, and larger animals such as moles, mice and rabbits that spend part of their life in the soil.

Thus, the living part of the soil is responsible for keeping air and water available, providing plant nutrients, breaking down pollutants and maintaining the soil structure.

3. Composition of Soil

Soil is a complex body composed of five major components (Ratan kumar saha, 2009) such as -

a. Mineral matter obtained by the disintegration and decomposition of rocks
b. Organic matter, obtained by the decay of plant residues, animal remains and microbial tissues
c. water, obtained from the atmosphere and the reactions in soil (chemical, physical and microbial)
d. Air or gases, from atmosphere, reactions of roots, microbes and chemicals in the soil
e. Organisms, both big (worms, insects) and small (microbes).

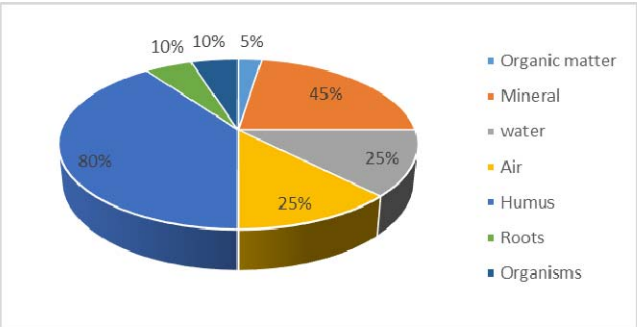

Fig 2: Composition of soil. (Source: Alexandra Bot, 2005)

4. Size of Soil Particles

Sediment/soil particles are usually sized on the basis of their diameter, and can be classified as a specific sedimentology. The distribution of particle size determines the texture of soil/sediment - whether it is predominantly sandy, loamy or clayey. Sand particles are generally irregular or round in shape, not sticky and hence are not plastic. Clay particles are very small, sticky, and plastic in nature and size varies from round to plate like structure. Silt particles are intermediate size between sand and clay having irregular and diverse in shape with some plasticity, stickiness and adsorptive capacity. Silt may cause soil to be compact unless it is mixed with organic matter. (Ratan kumar saha, 2009).

Table 1: Soil size

Soil separates	Diameter(mm)
Very coarse sand	2.00-1.00
Coarse sand	1.00-0.50
Medium sand	0.50-0.25
Fine sand	0.25-0.10
Very fine sand	0.10-0.05
Silt	0.05-0.002
Clay	< 0.002

(**Source:** Alexandra Bot, 2005)

5. Function of Soil

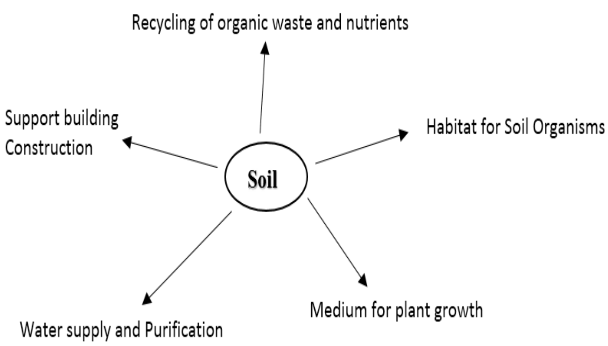

Fig 3. Function of soil

6. Organic Matter Act As An Engine For Soil Food Web

Soil organic matter is the storehouse for the energy and nutrients used by plants and other organisms. Bacteria, fungi, and other soil dwellers transform and release nutrients from organic matter. Organic matter is many different kinds of compounds - some more useful to organisms than others. Soil organic matter is made of coarsely equal parts to humus and active organic matter. Active organic matter is the portion available to soil organisms. Bacteria tend to use simpler organic compounds such as root exudates or fresh plant residue. Fungi tend to use more complex compounds such as fibrous plant residues, wood and soil humus. Intensive tillage triggers sprays of activity among bacteria and other organisms that consume organic matter (convert it to CO_2) and exhausting the active element first. When level of soil organic matter increases then the soil organisms perform a role in its conversion to humus to maintain a stable form of carbon sequestered in soils for longer duration.

7. Organic Decomposition

Decomposition is a biological process that includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma, 1998). Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and micro- and macro-organisms between the soil, plants and the atmosphere (Figure 4). Successive decomposition of dead material and modified organic matter results in the formation of a more complex organic matter called humus (Juma, 1998). This process is called humification. Humus affects soil properties.

8. Humus

Humus is the remaining part of organic matter that has been used and transformed by many different soil organisms. It is a relatively stable component formed by humic substances, including humic acids, fulvic acids, hymatomelanic acids and humins (Tan, 1994). One of the most striking characteristics of humic substances is their ability to interact with metal ions, oxides, hydroxides, mineral and organic compounds, including toxic pollutants, to form water soluble and water-insoluble complexes.

8.1 Type Of Humic Substances

A. Fulvic acids-

The fraction of humus that is soluble in water under all pH conditions. Their colour is commonly light yellow to yellow-brown.

B. Humic acids

The fraction of humus that is soluble in water, except for conditions more acid than pH 2. Common colours are dark brown to black.

C. Humin

The fraction of humus that is not soluble in water at any pH and that cannot be extracted with a strong base, such as sodium hydroxide (NaOH). Commonly black in colour.

9. Food Source For Organisms

Growing and reproducing are the primary activities of all living organisms. "Soil organic matter" includes all the organic substances in or on the soil. Soil organisms support plant health as they decompose organic matter, nutrients cycle, enhance soil structure, and control the populations of soil organisms including crop pests.

Some common terms used to describe different types of organic matter (Ingham *et al.,* 1986a).

- **Recalcitrant organic matter:** Organic matter such as humus or lignin-containing material that few soil organisms can decompose.
- **Living organisms:** Bacteria, fungi, nematodes, protozoa, earthworms, arthropods, and living roots.
- **Dead plant material; organic material; detritus; surface residue:** All these terms refer to plant, animal, or other organic substances that have recently been added to the soil and have only begun to show signs of decay. Detritivores are organisms that feed on such material.
- **Labile organic matter:** Organic matter that is easily decomposed.
- **Particulate organic matter (POM) or Light fraction (LF) organic matter:** POM and LF have precise size and weight definitions. They are thought to represent the active fraction of organic matter which is more difficult to define. Because POM or LF is larger and lighter than other types of soil organic matter, they can be separated from soil by size (using a sieve) or by weight (using a centrifuge).
- **Lignin:** A hard-to-degrade compound that is part of the fibers of older plants. Fungi can use the carbon ring structures in lignin as food.
- **Active fraction organic matter:** Organic compounds that can be used as food by microorganisms. The active fraction changes more quickly than total organic matter in response to management changes.
- **Humus:** Humus is important in binding tiny soil aggregates, and improves water and nutrient holding capacity. Humus is not readily decomposed because it is either physically protected inside of aggregates or chemically too complex to be used by most organisms.
- **Root exudates:** Soluble sugars, amino acids and other compounds secreted by roots.

These soil organisms, including micro-organisms, use soil organic matter as food. As they break down the organic matter, any excess nutrients (N, P and S) are released into the soil in forms that plants can use. This release process is called mineralization. The waste products produced by micro-organisms are also soil organic matter.

9.1 Classification of Soil Organisms

The activity of soil organisms follows seasonal as well as daily patterns. Not all organisms are active at the same time.

Table 2: Classification of Soil Organisms

Micro-organisms	**Microflora**	**< 5µm**	**Bacteria and fungi**
	Microfauna	**< 100 µm**	**Protozoa and Nematodes**
Macro-organisms	Meso-organism	100 µm - 2mm	Springtails and mites
	Macro-organisms	2-20mm	Earthworms, millipedes, woodlice and Snail and slugs
Plants	Algae	10 µm	
	Roots	> 10 µm	

Note: clay particles are smaller than 2 µm.
(Source: Alexandra Bot, 2005)

10. Significance of Soil Food Web

Soil decomposers (bacteria, fungi and possibly certain arthropods) are responsible for nutrient retention in soil. If nutrients are not retained within an ecosystem; future productivity of the ecosystem will be reduced as well as cause problems for systems into which those nutrients move, especially aquatic portions of the landscape (Hendrix *et al*., 1986). As ecosystems become more productive, the total amount of nutrients retained within the system increases. Predator populations and the rates at which they perform mineralization processes are important to ecosystem stability. The activity of predator-prey interactions (which determines the rate at which mineralization occurs) controlled by higher level predators such as millipedes, centipedes, beetles, spiders, and small mammals. As succession occurs, nutrients are increasingly immobilized which are less available for plants and animals, such as phytates, lignins, tannins, humid and fulvic acids (Coleman *et al*., 1992).

Without soil food web, plants would not obtain the nutrients which are necessary for growth (Nannipieri *et al*., 1990). Interactions of decomposers with their predator groups (protozoa, nematodes and micro arthropods) maintain normal nutrient cycling processes in all ecosystems (Coleman 1985, 1992). The numbers, biomass activity and community structure of the organisms which comprise the soil food web can be used as indicators of ecosystem health because these organisms perform critical processes and functions. Plant growth is dependent on microbial nutrient immobilization and soil food web interactions to mineralize nutrients (Nannipieri *et al*. 1990). Soil saprophytic bacteria, symbiotic bacteria, saprophytic fungi, mycorrhizal fungi, protozoa, and nematodes, with respect to their total biomass and activity, can be used to indicate effects of contaminants on soil health. Development of the relationship between soil food web structure and function and assessment of potential toxic impact could be extremely useful for assessing ecosystem health. Relationships between ecosystem productivity, soil organisms, soil food web structure plant community structure and dynamics can be extremely important determinants of ecosystem processes (Ingham and Thies, 1995).

11. Maintenance of Soil Food Web

Bacterial dominance is maintained by mixing plant material into the soil. Plant material needs to be mixed in enough to maintain bacterial dominance, but too much mixing results in soil degradation. But the bacteria and fungi eat this material at an incredibly rapid speed. Fungi can be maintained by letting litter accumulate on the soil's surface. Larger soil organisms like millipedes, centipedes, earthworms, and ants mix plant material into soil and open air channels, especially important in wet periods in heavy clay soils. It's important to remember that grassland, garden and forest soils represent a gradient from bacterial to fungal dominance. Gardens require equal amounts of bacteria and fungi, while trees require fungi.

A healthy food web ensures that nutrient cycling speeds along giving the plants exactly what they need and through symbiosis the plant is providing the soil food web the food resources and overall niche for their proliferation. By breaking down carbon structures and rebuilding new ones or storing the carbon into their own biomass, soil biota plays the most important role in nutrient cycling processes.

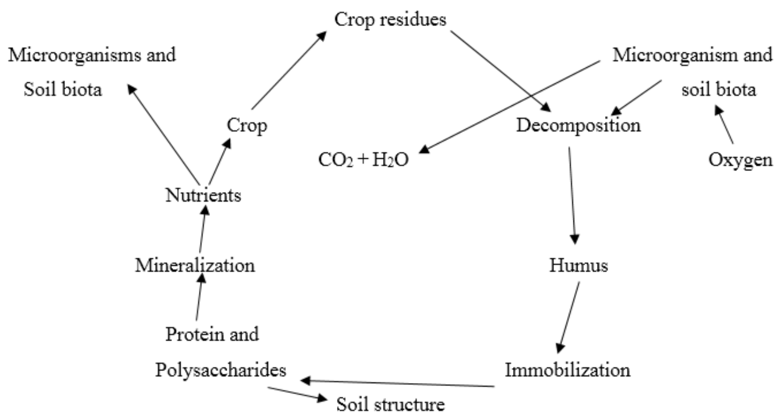

Fig 4. Carbon cycle

12. Nitrogen Cycle In Soil

The process of nitrogen fixation, the conversion of N2 to ammonia or organic nitrogen is carried out by a limited number of bacterial species. A few microorganisms are able to use atmospheric nitrogen directly and other microorganisms, plants and animals depend on the availability of fixed forms of nitrogen for incorporation in to their cellular biomass. Ammonia is the first detectable product of nitrogen fixation.

Nitrogen cycle occurs through four process. Nitrogen fixation, ammonification, Nitrification, Denitrification.

a. Nitrogen Fixation

The fixation of atmospheric nitrogen depends on the nitrogenase enzyme system. Nitrogenase is very sensitive to oxygen and the process of nitrogen fixation requires high energy input.

b. Nitrogen Fixation In Soil

In soil, the process is carried out by free living bacteria (Azotobacter) and by bacteria living in symbiotic association with plants (Rhizobium).Symbiotic nitrogen fixation is important in agriculture, these bacteria live in association with leguminous crop plants and determines soil fertility.

c. Ammonification

Nitrogen in organic matter is found in the reduced amino acids. Many microorganisms are capable of converting organic amino nitrogen to ammonia. This process is known as ammonification. The microbial decomposition of urea results in the release of urea results in the release of ammonia, which may be released to the atmosphere or may occur in neutral aqueous environments as ammonium ions which can be taken up by several organisms.

d. Nitrification

Only a few organisms are capable of nitrification. Nitrification is the process in which ammonium ions are initially oxidized to nitrite ions and subsequently to nitrate ions. The two steps of nitrification are carried out by different microbial population. Nitrosomonas is the important group involved in the conversion of ammonia to nitrite. Nitrobacter in the conversion of nitrite to nitrate.

e. Denitrification

It is the process of conversion of fixed forms of nitrogen to molecular nitrogen that is mediated by microorganisms. Several bacteria can involve in the process. Some bacteria like E.coli are able to reduce nitrate to nitrite. Many other bacteria (Pseudomonas, Moraxella, Thiobacillus, and Bacillus) reduce Nitrite ion to nitrous oxide gas and then to molecular nitrogen.

13. Enhancement Of Soil Food Web

- Vermicompost (worm farming)
- Using of Organic matter
- Plant ferments such as comfrey tea or nettle tea
- Mycorhyzal inoculants (fungi)
- Chop and drop of tree and biomass plants
- Application of biofertilizer and minimum/no use of chemical fertilizer
- Rotational grazing and animal integration
- Growth of plant in multi-layered
- Biodiverse plantings and Azolla planting
- Hot compost
- Teas and extracts derived from compost sources
- Rhizobium Innculants (nitrogen fixing bacteria)
- Infiltration earthworm, which stabilize soil system
- Humanure

14. Function Of Soil Food Web

- Nutrients are cycled into the right forms at the right rates for the plant. The correct ratio of fungi to bacteria is needed for this to happen, as well as a balanced level of natural predator activity.
- Building the soil structure, so that the oxygen, water and other nutrients can easily absorb into the soil thus permitting plants to develop a deep, well-structured root system. When the biology is functioning properly, water use is reduced, the need for fertilizers is reduced, and plant growth is increased.
- Retention of nutrients so they do not leach or pass off as vapour from the soil.
- Suppression of disease-causing organisms via competition with beneficial, by setting up the soil and foliar conditions so as to assist the beneficially as opposed to diseases.
- Protection of plant surfaces, above or below ground, This is achieved by making certain the foods created by the plant surfaces release into the soil and are used by beneficial, not disease organisms, thereby ensuring that infection sites on plant surfaces are occupied by beneficial, and not disease-causing organisms.
- Retaining the natural nutrients means a decrease in the need for fertilizer usage.
- Production of plant-growth-promoting hormones and chemicals that assist in plants developing larger stronger root systems.
- Control of toxic compounds through the breakdown or decay of these organic materials.

15. Compost Tea

Compost tea is a brewed liquid produced by leaching soluble nutrients and extracting bacteria, fungi, protozoa and nematodes from compost. A large diversity of food resources is extracted from compost. The species diversity of organisms in actively aerated compost tea is much higher than those hundred or so species of bacteria that grow on the food resources added by people. Diversity of organisms in compost will clearly be enhanced by increasing the diversity of the food resources from which the pile is made, by maintaining aerobic conditions and improving nutrient cycling in the pile (Ingham, 2005).

16. uses of compost tea

The use of compost tea is suggested that any time the organisms in the soil or on the plants are not at optimum levels.

Compost tea is used for two purpose such as

- To inoculate microbial life into the soil or onto the foliage of plants, and
- To add soluble nutrients to the foliage or to the soil to feed the organisms and the plants present.

Chemical-based pesticides, fumigants, herbicides and some synthetic fertilizers kill a range of the beneficial microorganisms that encourage plant growth, while compost teas improve the life in the soil and on plant surfaces.

17. Conclusion

Soil food web is a natural network of consumer resource interactions among different functional groups of soil organisms which are occur in the soil ecosystem. There are diverse group of organisms contribute in this food web. Compost contains mostly beneficial organisms, since any pathogenic organisms will be out-competed, suppressed and inhibited by the enormous diversity of organisms growing in compost. Nematodes, which have a great number and live freely in the soil food web in decomposing soil organic matter and mineralizing nutrients. Bacterial- feeding nematodes and fungal nematodes have more important role of decomposing and mineralizing than other types of nematodes, and plant-feeding nematodes give negative effect on plant growth (Irda safni, 2002). Liquid composts will also give great benefits, as long as the organisms are present and functioning in the liquid compost, or aerated compost tea.

Therefore, the beneficial predator prey interaction produce plant available nutrients which create conditions for optimal photosynthesis to occur. When the food web is strong, the plant are strong, which help with pest and disease resistance and provide food for diverse group heterotrophs or non-photosynthetic organisms by means of photosynthesis process.

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