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Function of Microorganisms on Soil Health Maintenance: A Review Article

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Abstract

Soil is a key life support function and has multiple purposes in our life. It supports numerous terrestrial life forms through its critical purpose and upholds ecosystem on earth leads to offer support to human beings. This points us in keeping its healthiness in maintainable form for our sustainable existence. There are different indicators for soil healthiness (microbial population, diversity, nematodes and arthropods, ants and termites). However, this soil health is affected by different factors which are manmade and under natural environment. Application of high levels of nitrogen fertilizers cause soil acidity and this soil acidity decrease soil pH and affect rhizospheric microbes and plant growth.Large amounts of organic matter in the soil also have an adverse effects on soil health by increasing partial pressure of carbon dioxide and temperature, and forming organic acids during decomposition which leads to the net immobilization of plant nutrients. Additionally, soil fumigants and different pesticides could disturb soil health being as toxic to beneficial rhizospheric microbes. Microbes have great role in mitigating such problem through different mechanisms by decomposition process, changing soil physicochemical properties and act as biocontrol. Bacteria and fungi maintain soil health through breakdown of pesticides, plastic materials and pollutants in the soil known as biodegradation through the production of certain enzymes. Some microbes make the substrate more complex by addition of their secondary metabolites like amino acid, organic acids and methyle crown leads to the inactivation of pesticides. Among microbes *Pseudomonas* genera and *Bacillus* are the principal strain in maintaining soil health and novel microbes in most of mechanisms in solving soil health problems.

Keywords: biocontrol, microorganisms, pesticides, rhizosphere, soil health

1. Introduction

Soil is a nonrenewable resource, formed by chemical and biological weathering of underlying rocks. It used as mechanical support for plant, storage of water and organic matter and as whole support numerous terrestrial life forms through its critical function and maintain ecosystem on earth leads to provide support to human beings when it is only healthy soil. Soil Health refers to the ecological equilibrium and the functionality of a soil and its capacity to maintain a well-balanced ecosystem with high biodiversity above and below surface, and productivity (Cardoso et al., 2013). It is also the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health (Doran and Safley, 1997).

There are different factors which affect soil health and quality. The existences of the decrement of soil health lead the unbalance of ecosystem and indirectly affect the plant, animal and human health. Hence, considering a(biotic) which disturb the soil health is important in maintaining the natural ecosystem. Health soil is characterized by the presence of beneficial microorganism (bacteria, fungi, actinomycetes, nematodes, earth worms etc), rich in crop diversity and have abundance of different tree species (Zhou, L., & Ding, M. (2007). Microorganisms are the principal agents in maintaining soil health through various ways such as decomposition and recycling of nutrients, suppressing pathogenic microbes, root exudation to enhance hormone growth for plant and changing physicochemical properties of soil (Jacoby, R., et al., 2017)

Therefore, soil microorganism relationships created by intimate interactions with plants and animals strongly imply that they are important contributors to soil health. However, our understanding of the importance of microorganism in maintaining soil quality and health, in relation to plant and animal health is limited. Hence, the aim of this paper review is focused on general function of microbes in maintaining soil health and microorganisms as active indicator of soil health and the impact of soil microbes on soil health as well. Additionally, it also highlights key future research areas for scientists and policymakers, and increase overall understanding of role of soil microorganisms on maintaining soil health.

2. Indicators of soil health

1.1. Microorganisms as indicators of soil health

Biological indicators may reflect the overall number, type, and activity of microorganisms and the diversity of the living organisms in soil, particularly the microbial population (Ann C. et al., 2006). Soil microbes are of critical importance for maintaining long-term fertility of soils and are considered sensitive indicators for the impact of management practices on soil health (Cardoso, E., et al., 2013). A healthy soil harbours an abundant, active, diverse microbial community which is a key to many soil functions that impact soil productivity, including nutrient cycling and decomposition of organic matter (Kabuyah, R. 2012), erosion control and water regulationby the formation of water stable aggregates and soil structure (Forster, S. M. 1990), and pest and disease regulation through predation, antagonisms, and competition with harmful organisms.

Although the rate of crop residue decomposition and nutrient cycling is influenced by the composition of microbial community (Beare*et al.,* 1993), fungi and bacteria are group of microorganisms which have the capacity to decompose crop residue, organic matter and mineralizing (solubilizing) nutrients in huge amount. This process is accomplish in only where the soil is health and free from any toxic substances (Henriksen and Breland, 1999).

1.2. Soil microbial diversity as indicators of soil health

Microbial diversity and functional diversity may contribute greatly understanding of soil quality and the development of sustainable ecosystems (Hawksworth, 1991). Microbial diversity can directly influence plant productivity and diversity by influencing plant growth and development, plant competition and nutrient and water uptake through diversity richness and evenness (Price, 1988). Different microbial diversity has protecting the soil from wind and water erosion through their secondary extracellular metabolites. Changes in microbial diversity are considered to be the most important indicators for soil health and quality.Nutrient management significantly affects **soil microbial** abundance, **diversity** and activity.Soil microbial diversity plays an important role in evaluating ecosystems and maintaining ecological .equilibrum

1.3. Nematodes and earthworms as indicators of soil health

The high concentration of microorganisms in the rhizosphere leads to larger numbers of nematodes and protozoa that feed on bacteria and fungi, and in turn, high populations of microartbropods that prey on nematodes and protozoa.

Earthworms, which are not often diverse are the only biota that have been considered usable as biological indicators where its' cast is digested material that is excreted back into the soil. Cast is enriched with nutrients (N, P, K, and Ca) and microorganisms during its passage through the worm's digestive system (Snyder B. et al., 2008). Fresh cast is a site of intense microbial activity and nutrient cycling. Earthworms contribute nutrients to the soil and improve porosity, tilt, and root development. They also contribute to the building of soil structure and aggregate stabilization. (Frund H.C., 2011). Earthworms could help in maintaining soil temperature and aeration (Dick., 1983).

Rhizospheric bacteria such as *Azospirillum, Rhizobia, Pseudomonas, Bacillus, Azotobacter* are ingested by earthworms and increase their population. Therefore, those microbes are used as solubilizing un-available nutrient into available, produce extra-enzyme used for plant growth promoting hormones and keep the soil fertility and health (Sinha et al. 2010). Earthworms increased the number of microorganisms in soi1 (Edwards and Lofty 1977). Accordingly, the multiplication of soil microbes leads the improvement of rate of decomposition of organic matter followed by improvement of soil health followed by high nutrient uptake by plant and boost crop production. Earthworms promote the growth of 'beneficial decomposer bacteria' in wastewater and acts as aerators, grinders, crushers, chemical degraders, and biological stimulators (Dash 1978; Sinha et al. 2002).

1.4. Ants and termites as indicators of soil health

Ants and termites increase nutrients especially nitrogen, phosphorus and potassium, as well as calcium and magnesium exchange due to transport and decomposition of fresh material by their enzymatic system (De Bruyn L, Conacher, A 1990; De Bruyn L., 1999).

Termites play a major role in nitrogen fixation, acetogenesis, methanogenesis, soil transportation and nutrient movement. They change physicochemical properties of soil; such as texture, soil pH, moisture, nitrogen, calcium and phosphorous as well. According to the findings of Nithyatharani, R., &Kavitha, U. S. (2018), pot culture technique showed that the plant grown in termite soil shows more growth compared with chemically fertilized soil and this shows the soil healthiness. Termites also act as an important decomposer of tough tree fibers and breakdown into small unit and decay, recycling into soil particles. They also create a tunnel and aerate the soil and keep the soil health (Collins, N. M. (1981)).

Being an important portion of soil fauna, soil arthropods such as ants are involved in many soil processes such as organic matter decomposition and translocation, nutrient cycling, microflora activity regulation and bioturbation. One of their most important roles is to physically break up organic matter within the soil and make it accessible to the microbial component. Therefore, these soil invertebrates are a good bioindicators of soil quality and health (Menta, C., &Remelli, S. (2020). They are sensitive to soil quality change due to their survival is based on feeding and reproducing in the soil (Parisi, V., 2005). The number of ant species in dry soils is small, while species richness is affected by pronounced variation in humidity, and is smaller during the dry season (Bestelmeyer, B.T.; Wiens, J.A., 1996). Ants are widely regarded as 'ecosystem engineers' because their nest construction and contributions to nutrient cycling change the biological, chemical, and physical properties of the soil around their nests (Sankovitz, M. A., et al., 2019).

2. Factors affecting soil health

The random use and misuse of agricultural chemicals contribution to environmental problems and soil health as well. This factors neglect the power of soil function. According to different findings, *factors affecting soil health* are natural and man-induced, including agricultural practices in general (Bai, Z.,et al.,2018). Soil acidity, soil alkality, different pesticides and herbicides, soil fumigants, some chemicals, high levels of nitrogenous fertilizer and ammonium concentration, heavy metals and mono-cropping practices are the key problem causing on soil health. The presence of high concentrations of ammonium inhibits nitrogen fixation and stimulates nitrification (Reinprecht, Y., et al., 2020).

Application of high levels of nitrogen fertilizers can lead to acidification in some soils and consequent effects on the soil microbial diversity. According to the report of (Edwards., 1993), there are the wide range of impacts of a pesticides on specific groups of soil organisms, soil food webs and, to a more limited extent, biological processes in soil. Similarly, pesticides have disruptive effects on the biological regulatory capacity of the soil community with damaging consequences for all soil functions (Edwards and Bohlen., 1995; Edwards., 2002).

The soil pH can also influence plant growth by its effect on activity of beneficial microorganisms; bacteria that decompose soil organic matter are hindered in strong acid soils. This prevents organic matter from breaking down, resulting in an accumulation of organic matter and the tie up of nutrients, particularly nitrogen, that are held in the organic matter (Haslam., and Tibbett, M. (2009). Soils polluted with heavy metals have loss its healthiness and become common across the globe due to increase in geologic and anthropogenic activities. Plants growing on these soils show a reduction in growth, performance, and yield. Heavy metals affect the number, diversity, and activities of soil microorganisms. (Chibuike and Obiora., 2014). Additionally, heavy metals exhibit toxic effects towards soil biota by affecting key microbial processes and decrease the number and activity of soil microorganisms (Singh et al., 2011).

Moreover, application of large amounts of organic matter, i.e. the material with high BOD (Biochemical Oxygen Demand) and COD (chemical oxygen demand), have an adverse effects on soil health by increasing partial pressure of carbon dioxide (pCO2) and temperature, and forming organic acids during decomposition which leads to the net immobilization of plant nutrients (Chhonkar, et al., 2000).

Monocropping practices depletes the soil of nutrients (making the soil less productive over time), reduces organic matter in soil and can affect soil health through significant erosion (Magdoff, F., & Van Es, H. (2000). Some studies show that glyphosate (also known as RoundUp) decreases microbial biodiversity in soil; other studies show this chemical's adverse effects on earthworms (Benslama, O., &Boulahrouf, A. (2013). Other types of pesticides may have similar effects on soil microbiology, impacting nitrogen-fixing microbes important to soil health and fertility (Hussain, et al., 2009).

Soil fumigants are toxic to human health and can escape into the environment after application. In some cases, as in the production of grapes, fumigants accumulate in soils, often at levels beyond legal limits, also affecting soil microbial health and earthworms, both of which are vitally important to soil health and fertility (Ibekwe, A. M et al., 2001). Micro plastics and macro plastic materialscan also interact with soil fauna, affecting their health and soil functions. “Earthworms, for example, make their burrows differently when micro-plastics are present in the soil, affecting the earthworms’ fitness, the soil condition and soil health as well (Wang et al., 2019).

3. Function of microorganism in the soil health

3.1. Decomposition and Nutrient cycling

The soil develops by degeneration of rocks as well as minerals, through biotic actions of microbes sustained by them (Bahadur et al. 2017). Soil organic matter is the rich components of macro-elements and micro-elements such as sulfur, nitrogen and phosphorous. These elements are transformed by extra-enzymatic process produced from soil microbes. Soil enzymes are involved in the biochemical processes during organic matter decomposition (Blankinship, J. C.,2014). Decomposition is the progressive breakdown of organic materials, ultimately into inorganic constituents, and is mediated mainly by soil microorganisms, which derive energy and nutrients from the diverse range of molecules in SOM. The important soil enzymes are amylase, arylsulfatase, cellulase, chitinase, dehydrogenase, phosphatase, and urease which are released from plants, animals, organic compounds, and microorganisms and soils (Gupta et al. 1993; Ganeshamurthy et al. 1995).

Hence, microorganisms play a crucial role in the cycling of nutrients such as nitrogen, sulphur, and phosphorus, and the decomposition of organic residues, considering their limited amount in the soil. They impact the cycling of nutrients and carbon on a global scale (Pankhurst *et al*., 1997). That is to say, from the microbial decomposition of dead plant and animal organic matter, the energy input into the soil ecosystems is extracted. In this way, organic residues are converted to biomass or mineralized into CO_2, H_2O, phosphorus, mineral nitrogen, and other nutrients (Bloem et al.. 1997). When microbes are grazed by microbivores such as protozoa and nematodes, mineral nutrients that are immobilized in microbial biomass are subsequently released (Bloem*et al*., 1997. The transformation and degradation of waste materials and synthetic organic compounds are further related to microorganisms (Torstensson*et al.,* 1998).

The breakdown of organic matter carried out in four stages. Firstly, breakdown of compounds that are easy to decompose – like sugars, starches, and proteins, secondly, breakdown of compounds that take several years to decompose like cellulose which are an insoluble carbohydrate found in plants and lignins, thirdly, breakdown of compounds that can take up to ten years to decompose like some waxes and the phenols; and finally, breakdown of compounds that take thousands of years to decompose which include humus-like substances which are the result of integration of compounds from breakdown products of plants and those generated by microorganisms (Chakroborty and Sen 1967)

3.2. Change physical properties of soil

A

n excellent indicator of soil health is microbial diversity and changes in the microbial population or activities precede changes that can be observed as early signs of soil degradation or improvement in some instances (Nielsen, 2002). Plant growth in both natural and agro-ecosystems is determined by water and nutrient supply from the soil, especially N and P. The vegetation above ground is the ultimate source of C for the microbes in the rhizosphere that support the macro-fauna in turn (Bhatia, 2008). Thus, the above ground vegetation affects the structure and soil properties of the below ground microbial community (Orwin, 2005)

Bacteria are important in producing polysaccharides that cement sand, silt and clay particles together to form micro aggregates and improve soil structure (Hoorman, 2011). A coating of polysaccharides or glycol proteins that coats the surface of soil particles is formed by many bacteria. These substances play an important role in cementing particles of sand, silt and clay soil into stable micro aggregates that reinforce the structure of the soil.

Fungi and actinomycetes produce hyphal threads that bind soil particles together as well as produce extracellular polysaccharides. These binding together increase soil aggregation and water infiltration towards soil.

3.3. Biocontrol

Biological control is the control of disease by the application of biological agents to a host plant that prevents the development of disease by a pathogen. The micro flora present in the soil (especially in the rhizosphere) has demonstrated its potential to control soil-borne diseases through the bio control process, and the microbes used in this technique are referred to as bio-agents or bio-control agents. The bio-control agents are usually bacterial or fungal strains isolated from the endosphere or rhizosphere (O'Brien. 2017).

Fungi have the capacity to act as an effective bio sorbent of toxic metals such as cadmium, copper, mercury, lead, and zinc though the accumulation of dead organic matter exist in the form of biomass, carbon di oxide and organic acids on their fruiting bodies (Baldrian, 2003).

As biological agents that influence soil health, their function is very important in plant defense against pathogenic microorganisms through decomposing organic matter and releasing essential nutrients for plants and plant uptake this nutrient become health plant. These mechanisms is important in keeping the plant against deleterious pathogen and also act as biological agents for maintaining soil health (Frac et al., 2015).

Microbial inoculation in the soil could suppress plant disease in more than diverse pathogen or single pathogen. Rhizospheric microbial communities also combat against soil born disease through producing extracellular enzymes. *Pseudomonads* known to produce the antibiotic 2, 4-diacetylphloroglucinol (DAPG) may also induce host defences (Iavicoli et al. 2003). Additionally, DAPG-producers can aggressively colonize roots, a trait that might further contribute to their ability to suppress pathogen activity in the rhizosphere of wheat through competition for organic nutrients (Raaijmakers and Weller 2001). Hence, this mechanism keeps the soil health through diminishing pathogenic and opportunistic disease causing microbes. Therefore, enhancing beneficial microbes in the soil is used to protect pathogenic microbes.

Stable and diverse populations of soil bacteria develop antibiotics that protect the soil and plants from organisms and plant pathogens causing disease. Diverse species of bacteria compete for the same soil nutrients and water and aim to serve as a system of control and balance by reducing the species of organisms that cause disease (Lowenfels& Lewis, 2006). Rhizosphere organisms can compete with pathogens for attachment to the plant root and essential nutrients for growth. Soil bacteria that produce siderophores can deprive pathogenic fungi of Fe because fungal siderophores have less affinity for Fe. Certain bacteria can detoxify pathogenic viruses, while others can trigger "induced systemic resistance" in plants. In general, healthy soil bacteria populations will produce antibiotics that hold the pathogenic types in the soil.

4. How bacteria and fungi maintain soil health?

Bacteria mostly feed on dead plant materials and organic wastes through composting process of degradable organic products and wastes into stable food for their purpose (Pathma, J., &Sakthivel, N. (2012). These help in the recycling of farm wastes and improve soil physicochemical properties and add essential nutrients to the soil (Kadir et al., 2016). This biodegradation and conversion of residual into compost activity is processed by the microbial community (Hafeez et al., 2018). In this decomposition process, bacteria and fungi have the highest population and responsibility over other microbes (Galitskaya et al., 2017). Among bacteria, *Bacillus subtilis* and *Pseudomonas fluorescens* are the principal crop residue decomposer especially in the early stages of decomposition when moisture levels are high and at final stage decomposition fungi tend to dominate (Jafari, T.H., and Duric, S.,2012). This all mechanisms actually increase soil fertility, microbial diversity and population and soil health as well.

According to the findings of different scholars, *Pseudomonas* can induce the plant systematic resistance which is used for the suppression of soil born pathogen (Haas, D. and Defago.,2005) and can also produce siderophores and antibiotics for the mitigation of pathogen purpose (Kumar, M., et al., 2016). Additionally, they modify plant phytohormone concentration and contribute a vital role in plant growth (Leveau, J.H.J and Lindow, S.E., 2005). Like *Pseudomonas*, *Bacillus* also used as biological control through different mechanisms (inducing the plant defence systems by production of plant growth hormones, the production of antifungal compounds and toxic substances as well (Srivastava, S., et al., 2016, Palma, L., et al., 2014, Choudhary, D.K.andJohri, B.N., 2009). They also transform complex nutrient compounds of soil essential macro-elements in to available form which easily available for plant to uptake (Alori, E.T. et al., 2017).

Bacteria maintain soil health through breakdown of pesticides, plastic materials and pollutants in the soil known as biodegradation through the production of certain enzymes. *Bacillus amylolyticus* degrades plastic more in one month (30% weight loss/month) period compared to others bacterial species (Thakur, P. (2012). Bacteria degrade pesticides through mineralization and co-metabolisms through breakdown or transformation of complex substrate into simpler products. According to the finding of Doolotkeldieva, T.,et al., (2018), active bacterial strains from the *Pseudomonas fluorescens* and *Bacillus polymyxa* population were selected which demonstrated high rates of degradation activity on pesticide Aldrin. Some microbes make the substrate more complex by addition of their secondary metabolites like amino acid, organic acids and methyle crown leads to the inactivation of pesticides (Huang, Y.,2018)

Additionally, the expression of plasmid gene and chromosome gene in the bacteria could degrade the pesticides. Different groups of microbes which help in biodegadations are *Pseudomonas, Flavobacterium, Maycobacterium, nocardia*and *Bacillus* degradealdrin, chlorpyrifos, ddt, diazinon, endosulfan, endrin, hexachlorocycloxane, methyl parathion (Verma et al., 2014;Upadhyay, L. S., &Dutt, A. (2017), under oxic environment and desulfomonas species under anoxic environment (Kafilzadeh et al., 2015).

Bacteria maintain soil health through immobilizing and retaining nutrients in their cells. This leads to prevent the loss of nutrients from the rhizosphere and rhizoplane (Jacoby, R., 2017). Additionally, through nitrogen fixation bacteria have added atmospheric nitrogen to soil through biological nitrogen fixation and increase the soil nitrogen which is available for plant uptake. In this process, the soil bacterial decompose the plant leaf and total biomass and release organic carbon and other beneficial nutrients. These processes have a key role in maintaining soil health (Enrico, J. M., 2020).

Lithotrophic or chemoautotrophs bacteria obtain its energy from compounds of nitrogen, sulfur, iron or hydrogen instead of from carbon compounds. These species are important to nitrogen cycling and degradation of pollutants and maintain the sustainability of soil and its healthiness (Plante, A. F., et al,.2015)

Similar to bacteria, fungi act as decomposers; they degrade complex organic materials in the environment to simple organic compounds and inorganic molecules (Kabuyah, R. (2012). In this way C, N, P and other critical constituents of dead organisms are released and made available for living organisms. In the same manner, the mycorrhizal fungi colonize plant roots and exchange for carbon from the plant, mycorrhizal fungi benefit to make phosphorus soluble and transport soil nutrients (phosphorus, nitrogen, and micronutrients) to the plant (Shah, F., et al., 2016).

5. Conclusion /future prospects

Soil health is an ecological balance of soil in an ecosystem to sustain biological productivity and which could be affected by different factors are also possibility to tackle such challenges. The exploitation of chemical fertilizers and agricultural chemicals pollutes not only soil health, but also rivers, the sea, and other environments, and is directly related to environmental pollution on a global scale. Realized the harm of such chemicals through man experience, and warned of the long-term adverse effects on farming systems that used these chemicals. Therefore, it is important to keep the soil health for survival of all living things by using bacteria and fungi inoculants rather than using synthetic products for agricultural input is environmentally friend approach and have sustainable role for health crop production. Maintaining not to pollute the soil and to allow the power of soil to be fully expressed, in energizing soil for the purpose of suppressing diseases and insects is our message. Understanding the role of microorganisms in maintaining soil health is the only productive solution for us and better for creating paradise on earth by minimizing factors affecting soil health. This is achieved through teaching the community to keep the soil health. Moreover, identifying and giving further attention towards affected soil is the big home take message for all concerned bodies through research supported soil health identification and measurement techniques. Indicators of soil health provide early information about mineralization processes, nutrient availability and fertility, as well as effects resulting from factors affecting soil health as well. Finally, isolating and evaluating the microbes which have mechanical influence on soil health is the future research.

Acknowledgments

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