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Review Article

Functional Significance of Plant-Associated Microbes in Soil Fertility Management

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ABSTRACT

Association between plants and soil microbes are very complex and are subject of an increasing number of studies. Soil microbes include viruses, bacteria, actinomycetes, fungi and nematodes. They participate in organic matter decay, nutrient release to crops, nitrification, nitrogen fixation and production of antibiotics. Microbes are found on or within every higher organism, including plants. They play critical roles in agricultural soils; some can cause plant diseases while others prevent diseases or enhance plant growth. Although it is well documented that plants create specific niches for their associated microbes by providing them nutrient in the rhizosphere, the phyllosphere as well as inside the plant; the roles and importance of the microbes in these plant-microbes partnership still are sometimes underestimated. At first, how do plant-associated microbes enhance plant growth and development in a direct or an indirect way? Secondly, how do soil structure, atmosphere and water affect the activities of microbes in soils? Thirdly, what is the functional significance of plant-associated soil microbes? Answers to these questions including various ways of promoting beneficial and preventing harmful soil microbes are contained in the paper.

Key Words: Plant-Associated Microbes and Soil Fertility Management

INTRODUCTION

Most of the microbes in terrestrial ecosystems are found in the soil. Soil organisms participate in the genesis of the habitat wherein they live. They, together with the total biota and especially the higher vegetation, constitute one of five interactive factors in soil information. The other four are climate, topography, parent materials and time. The physical and chemical breakdown of rocks to fine particles with large surface areas and the accompanying release of plant nutrients initiate the soil forming process. Two major nutrients that are deficient in the early stages of the process are carbon and nitrogen; therefore, the initial colonizers of soil parent material are usually organisms capable both of photosynthesis and nitrogen fixation. These are predominately the cyanobacteria, also known as the blue- green algae. After higher vegetation has become established a continuum of soil processes produces the dynamic mixtures of living and dead cells, soil organic matter (SOM) and mineral particles in sufficiently small sizes to permit the initial colloidal interactions characteristic of soil (Akinrinde and Adeoye, 1995; Wild, 1996 and Ibrahim, 2014). Soil organisms show their greatest diversity of species and usually their largest populations in agricultural soils. The size of the microbial biomass usually shows direct correlation with the amount of plant growth (the primary productivity) and with soil organic matter levels.

Soil Structure

Soil aggregation is one of the most important factors controlling microbial activity and SOM turnover. Aggregate formation is initiated when microflora and roots produce filaments and polysaccharides that combine with days to form organic matter –mineral complexes. Soil structure is created when physical force (drying, shrink – swell, free – thaw, root growth, animal movement and compaction) mold the soil into aggregates (Ibrahim, 2014). Most organisms exist on the outside of aggregates and in the small pore spaces between them; relatively few reside within the aggregate. Microorganisms occupy less than 1% of the total available pore space (Plaster, 1992).

Soil Atmosphere

The major gases in the soil atmosphere are those found in the atmosphere namely, N_2, O_2, and CO_2. Gases arising from biological activity, such as nitrogen oxides (NO), may at times be present, but because of their high reactivity transitory. In well- aerated soil, the O_2 content seldom falls below 18 to 20% and CO_2 seldom arise above 1 to 2 %. However, given a clay texture and high moisture content coupled with high microbial activity, CO_2 content of the soil atmosphere may reach as high as 10%. The solubility of gases in water depends on the types of gas, temperature, salt concentration and the partial pressure of the gases in the atmosphere (Singer and Munns, 1999; Agbede, 2009).

Some plants, such as rice and certain bog plants possess special channels that provide paths for the diffusion of air into the sub merged layers of the soil. Rice plants, for example, provide four times as great a diffusion of air into lower horizons than does barley. It thus produces aerobic micro sites around its roots in an otherwise anaerobic zone when grown under flooded conditions. Excess water in soil restricts micro organisms and their activities by preventing O_2 movement into and through the soil in sufficient quantity to meet the O_2 demand of organisms. With soil water contents such as those commonly found in cultivated field soils, O_2 moves into the soil largely by diffusion from the atmosphere. The gas pressure difference needed to move O_2 into the soils is only of the order of 1 to 3%. Thus O_2 content of agricultural soils rarely falls below the level of 18 to 20 % (Agbede, 2009). Similarly, once the level of respiratory CO_2 accumulation in the soil reaches 1 to 3%, a sufficiently large diffusivity gradient is established to move soil CO_2 into the atmosphere (0.035% CO_2) (Ibrahim, 2014).

Soil water

Soil water affects not only the moisture available to organisms but also the soil aeration status, the nature and amount of soluble materials, the osmotic pressure and the pH of the soil solution. The shape of water molecule, with an HOH angle of 105^0, results in its polarity. This explains many of waters proprieties relative to physical and chemical reactions. It explains why water is attracted to charged ions. Cations such as Na^+, Ca^{2+} and K^+ become hydrated because of their attraction to the negatively charged oxygen end of the water molecule. The polar nature of water also explains hydrogen bond formation by water. The bonding of each water molecule to other water molecules and to other biological components explains the solution properties, viscosity and high specific heat of soil water (Agbede, 2009 and 2013).

Functional Significance of Plant-Associated Soil Microbes

a) Decomposition of Organic Matter

The most important biological processes taking place in soils are the decomposition of organic matter or humification, nitrogen transformation and the translocation of materials from one place to another. These processes are mediated by various microorganisms found in the soil. In most natural ecosystems a large part of the sun's energy fixed each year by photosynthesis is released as shed plant tissues to the soil, where decomposition processes release organically bound nutrients for reuse by green plants (Ibrahim, 2014).

The soil is deficient in photosynthetic organisms and so does not have the capacity to capture significant quantities of solar energy itself. Instead it depends on the energy contained in plant and animal residues. The decomposition of these residues, or litter, is brought about by a sequence of biological processes involving both microbes and the soil fauna (fungi, bacteria, actinomycetes, worm and termites).

Two major groups of microbes are involved in organic matter decomposition, the fungi and the bacteria. Both use the same basic mechanism to decompose insoluble substance, namely the hydrolysis of complex compounds by exoenzymes. However, the physical organization of fungi gives them an advantage over bacteria in the breakdown of cellulosic plant remains. Bacteria have no intrinsic mechanism for penetrating plant tissues, and their progress as celluloses decomposers is limited to surface erosion. Because the rate at which they breakdown their substrate is proportional to the rate at which exoenzymes are produced and diffuse out from the bacterial colonies (Steve, 2008).

Fungi, on the other hand, supplement the action of exoenzymes with mechanical pressure from their elongating hyphae and furthermore, their filamentous habit permits them to ramify throughout dead plant tissue with relative ease. Only in anaerobic habitats, such as waterlogged peats and in the rumen of cattle, do cellulolytic bacteria predominate over fungi. There are some fungi, the so - called mycorrhizal fungi, which are generally incapable of decomposing organic matter, yet which greatly influence the process of nutrients cycling in many ecosystems. These fungi satisfy their energy requirements by entering into a close anatomical and physiological association with the roots of many plants, so that a small fraction of the photosynthate produced by the plants is passed directly to the fungi and the fungi in turn provide them with mineral nutrients. The end result is that the soil system receives an increased input of energy (Bonkowski, 2004).

b) Nutrient Cycles

The exchanges of chemical elements between the living and non - living parts of the ecosystem constitute the nutrient or mineral cycles. Bacteria and fungi not only make a major contribution to nutrient cycling (and energy flow), but also have great significance for the geochemical cycles of elements in the biosphere. There are several reasons, apart from their metabolic diversity, why bacteria and are such potent agents of geochemical change. Because of their small size, they have a large surface to volume ratio that permits rapid interchange of materials between their cells and the environment. Equally important is their extremely rapid rate of reproduction. In addition, they are ubiquitous in distribution (Baron and Zambryski, 1995).

Interactions between plants microbes in soil, the final frontier of ecology, determine the availability of nutrients to plants and thereby primary production of terrestrial ecosystems. Nutrient cycling in soil is considered a battle between autotrophs and heterotrophs in which the latter usually outcompete the former, although recent studies have questioned the unconditional reign of microbes on nutrient cycle, plant the plants' dependence on microbes for breakdown of organic matter (Paungfoo-Lonhienne *et al.*, 2010).

c) Nitrogen Transformations

The main forms of nitrogen transformations are ammonification, nitrification and nitrogen fixation. Ammonification is the process whereby nitrogenous compounds in plant and animal tissues are decomposed to produce ammonia which is changed by nitrification into nitrite and then into nitrate, each stage being accomplished by specific microorganisms. The formation of ammonia is accomplished by heterotrophic bacteria but the other stages are brought about by autotrophic bacteria. Ammonia is oxidized by Nitrobacter, Nitrosomonas and nitrococcus and the nitrite is oxidized by nitrobacter. These processes require aerobic conditions, under anaerobic conditions the nitrate is reduced by denitrification to nitrogen and nitrous oxides which are lost to the atmosphere (Lugtenberg and Kamilova, 2009).

Nitrogen fixation is the process during which soil bacteria take up nitrogen from the soil atmosphere to form their body protein. The organisms include Azotobacter, clostriidium pasteurianium and Beijerincka which upon death enter the nitrogen cycle and are decomposed to form nitrate for plant uptake. There are also a number of bacteria which enter the roots of certain plants, particularly members of the Leguminoseae. There they multiply, form nodules and fix atmospheric nitrogen which passes into the conducting system of the plant as an essential element. Roots and nodules are formed by the bacterium Rhizobinum sp. beneath the epidermis of the roots of these legumes and as they fix atmospheric nitrogen, it passes into the plant as a nutrient (Steve, 2008). Microorganism will decompose most carbonaceous materials in soils including pollutants. This helps to reduce the build- up of pesticides and herbicides and organic industrial wastes. Initially pesticides may cause a reduction in the microbial population but gradually resistant strains develop.

d) Translocation

Another important role played by these organisms is translocation. This refers to those biological processes that bring about churning and translocation. The most dramatic manifestations of these processes are brought about by earthworms, enchytraeid worms and termites. This helps to improve plant roots penetration, soil aeration and water infiltration leading to free movement of air and water into the soil.

Direct and Indirect Role of Plant-Associated Microbe in Agricultural Soils

Direct plant growth promoting mechanisms may involve nitrogen fixation; the supply of unavailable nutrients such as phosphorus and other mineral nutrients, production of plant growth regulators such as auxins, cytokinins and gibberellins and suppression of ethylene synthesis by 1-aminocyclopropane-1-carboxylate (ACC) deaminase activity. Plant-associated bacteria can indirectly benefit the plant by preventing the growth or activity of plant pathogens through competition for space and nutrients, antibiosis, production of hydrolytic enzymes, inhibition of pathogen-produced enzymes or toxic and through induction of plant defense mechanisms (Steve, 2008).

Remediation of Contaminated Soils and (Ground) Water

Beside the application of plant growth promoting bacteria to increase biomass production in function of food, feed and raw materials for industrial processes, a very promising area for the exploitation of plant-microbes partnerships is the remediation of contaminated soils and (ground) water. In case of phytoremediation of metal contaminated soils and (ground) water, plant-associated bacteria possessing a metal-sequestration system can reduce metal phytotoxicity and enhance translocation to the upper ground plant parts. Besides, rhizosphere bacteria producing siderophores and/or organic acids can increase plant availability of metals (Baron and Zambryski, 1995).

During phytoremediation of some organic contaminants, plants rely on their associated microorganisms possessing the appropriate degradation pathway to obtain an efficient degradation of organic contaminants resulting in decreases of both phytotoxicity and evapotranspiration of volatile contaminants and/or degradation intermediates to the atmosphere (Wikipedia, 2008). Therefore, a systems biology approach to understand the synergistic interactions between plants and their beneficial microbes represents an important field of research, which is facilitated by the sequencing of the genomes of model plant species and their associated beneficial microbes (Nasholm *et al.*, 2009).

Nitrogen Fixing Root Nodules

A soil microbe that enters the root of plants-both aerobic and anaerobic, produces enzymes stimulates abnormal growth of the root cells; this form into nodules on the root metabolism of the microbe supplies nitrogen to the plant in a form the plant can then metabolize as a nutrient. This phenomenon is called "NITROGEN FIXING ROOT NODULES" (Wikipedia, 2008; Steve, 2008). Plants and microbes have evolved detrimental and beneficial relationships. Detrimental relationships involve pathogens including fungi, bacteria and viruses and the suppression and interference with plant immune responses (Bonkowski, 2004).

Beneficial relationships include symbiosis diazotrophic endophytes that supply the plant with fixed nitrogen and other endophytic associations that promote plant growth by producing phytohormones, volatiles, defence compounds, and enzymes (Bonkowski, 2004; Nasholm *et al.*, 2009). A less-defined beneficial relationship involves the association of plant root with microbes in the rhizosphere. Roots attract soil microbes by exuding nutrient sources including carbohydrate, organic and amino acids and the density of microbes in the rhizosphere is much higher than in bulk soil.

According to the "soil microbial loop" concept, nutrients and carbon are cycled between soil and microbial pools, and inorganic and organic nutrients of low molecular mass become available through microbial turnover of soil organic matter and are subsequently 'scavenged' by the plant root (Chisholom *et al.*, 2006; Hematy *et al.*, 2009).

Fungi and Plants

How this helps the plant, fungus metabolism, provides the plant with phosphate that it cannot absorb from the soil fungus creates a web like formation called a HARTIGNET around and between roots leading to increased in absorbance, water/nutrients-more tolerant and competitive to environment which also lead to increased in resistance, less drought, less poor soil, less diseases, less stresses. HARTIGNET also gives structure/support to plant." Litter layers" are formed that encourage the production of enzymes which aid digestion of soil (Bonkowski, 2004; Weyens, *et al.*, 2010).

Fungi and plants form mutually-beneficial relationships called Mycorrhizal Associations. The fungi increase the absorption of water and nutrients by the plants, and benefit from the compounds produced by the plants during photosynthesis. The fungus also protects the roots from diseases. Some fungi form extensive networks beneath the ground, and have been known to transport nutrients between plants and trees in different locations (Lugtenberg and Kamilova, 2009).

Fungi and plant roots form two different kinds of associations. In type, the fungus grows outside the roots as a thickmat, or between certain cells in the root. The fungus, however, never enters any of the plant cells. With the other type of association, the fungus actually penetrates the cell walls of the roots. They break through the cell wall, but not the inner plasma membrane. In both types, the fungus extends its filaments outward to collect nutrients and water from the soil, which is in turn passed onto the plant (Baron and Zambryski, 1995; Paungfoo-Lonhienne *et al.*, 2010).

CONCLUSION

Soil micro flora consists mainly of bacteria, actinomycetes, fungi and algae while protozoa and nematode (eelworms) are the chief groups of micro fauna usually prevalent in soils. Their functions in soil are both beneficial and detrimental to crop plants. They participate in organic matter decay, nutrient release to crops, nitrification, nitrogen fixation and production of antibiotics (APS, 2000).

Way Forward

Healthy soil should be populated with healthy and beneficial micro organisms through Inoculation; that is, purposely infecting soil with useful organisms (Wild, 1996). Soils could be inoculated with non symbiotic nitrogen fixers, mycorrhizae and other friendly micro-organisms. Inoculants are usually applied to seeds, such as legume seeds, to ensure good nodule growth on the roots of host crop. Good soil conditions for the growth of microorganisms could be achieved in the following ways.

1. For successful microbial population, there must be a steady supply of fresh organic matter.
2. Good aeration will supply oxygen to the most important organisms in agricultural soils.
3. Adequate moisture is needed for active growth and multiplication.
4. Conducive soil temperature for most soil organisms is between 25 – 35 °C.
5. Most organisms grow maximally at neutral pH level.

Control of harmful organisms such as nematodes, parasitic fungi and bacteria is a way of making the soil healthy for crop growth. This is usually achieved by applying sterilant chemicals which could be in form of gases and solids injected in to the soil (Plaster, 1992; Singer and Munns, 1999). Other practicable methods are as follows.

1. Plant disease - free seeds.
2. Obey plant quarantines which are intended to prevent transportation of parasitic nematodes and other diseases into uninfected agricultural soils.
3. Control of soil pH to match the type of crops to be grown.
4. Crop rotation could kill some organisms that are host-specific.
5. Decay organisms can be promoted with the application of large quantities of organic matter, the decay organisms can “fight off” the harmful ones.
6. Soil sterilization is necessary in green house work to prevent soil - borne diseases.

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