Role of Microorganisms in Soil Fertility

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Introduction

- A renowned microbiologist, Jacob Lipman, once remarked, “a soil devoid of microorganisms is a dead soil”.
- Fertile soils contain a wide variety of microbes which include different species of bacteria, fungi, protozoa, algae, and viruses.
- Mostly, they are found in the rhizosphere (the region of soil closely surrounding the plant-roots) where they decompose organic matter (plant and animal debris, human waste and dead microbes) into humus.
- Humus is composed of well decomposed organic matter.
- Organic matter is composed of molecules of celluloses, hemicelluloses, sugars, lignins, waxes, nucleic acids, proteins, and amino acids.
- These molecules, in turn, are made up of various types of elements.
- Essential elements required by most plant species.

- Regardless of the molecular source of these elements (organic matter or inorganic fertilizers), they must be broken down into simpler ionic forms before they can be absorbed by the plant roots or shoots.
- The conversion of complex molecular compounds into ionic forms is carried out by microorganisms either directly or indirectly.
- The process is called “**mineralization**”.
- Mineralization can be visualized as preparation of plant food by microorganisms.
- Various elements go through cooking cycles called nitrogen cycle, carbon cycle, sulfur cycle, and phosphorus cycle.

Nitrogen Cycle

- Primary source of nitrogen for plants is atmospheric nitrogen gas (N_2).
- Four steps are involved in the N_2 cycle.
- a. Nitrogen Fixation: Three types of bacteria fix N_2 in plant.
  - 1) Cyanobacteria fix N_2 (photo-synthesizing) in tropical trees.
  - 2) Actinomycetes (Filamentous bacteria) fix N_2 in most trees or shrubs.
  - 3) Rhizobium species fix N_2 in legumes: The host plant provides the bacteria ATP energy from metabolism of carbohydrates, and bacteria, in turn, provide ammonium by fixing it in the nodules. The bacterial enzyme used in nitrogen fixation is called nitrogenase.
- b. Ammonification: When plants and animals die and produce organic matter, which contains nitrogen in proteins and amino acids, it is decomposed by microorganisms. In this process ammonium is released through a process called "deamination".
- c. Nitrification: Ammonium obtained from above two processes is converted to nitrates (NO_3) by the help of microorganisms. First step is oxidation of ammonium into inorganic nitrite (NO_2) by Nitrosomonas bacterial species. Second step is to convert nitrite into nitrate (NO_3) with the help of Nitrobacter bacterial species. Nitrates are taken up by the plants as food.
- d. Denitrification: Denitrification is an anaerobic process carried out by a certain bacterial species by which nitrates are reduced back to atmospheric nitrogen (N_2). This process completes the nitrogen cycle.

Phosphorus Cycle

- Phosphorus is second to Nitrogen in importance as food for plants.
- It is found in both organic and inorganic forms in the soil.
- Bacterial species of genus *Pseudomonas*, *Bacillus*, and *Mycobacterium* solubilize bound phosphorus and make it available to the plants.
- Microorganisms solubilize phosphorus by producing organic acids.
- Acids convert phosphorus salts of calcium, iron, aluminum, and magnesium into dibasic and monobasic phosphates which are taken up by the plants.
- Microorganisms release bound organic and inorganic phosphorus through four processes.
  - a. Alteration of solubility of inorganic compounds of phosphorus
  - b. Mineralization of organic compounds with the release of inorganic phosphorus
  - c. Immobilization of inorganic phosphorus into the plant cell
  - d. Bringing about oxidation and reduction of inorganic phosphorus compounds.

…Phosphorus Cycle

- Mineralization and immobilization are particularly important in the phosphorus cycle in nature.
- Both are medicated by microorganisms.
- **a. Mineralization:** Different microorganisms release elemental phosphorus from different phosphorus containing compounds present in the organic matter.
- The enzymes they produce to release phosphorus are collectively called phosphatases.
- Both bacterial and fungal species produce these enzymes. Bacterial species belonging to genera *Streptomyces*, *Pseudomonas*, and *Bacillus* are of particular importance.
- Fungal species of *Aspergillus*, *Penicillium*, and *Rhizopus* can also release phosphorus.
- **Immobilization:** Microorganisms decompose organic matter and produce available forms of phosphorus.
- First of all microorganisms build their own population by immobilizing phosphorus in their own cells.
- During this period they create phosphorus deficiency in the soil which can be fulfilled by phosphorus fertilizers.
- It is therefore desirable to add only those bacterial species that release elemental phosphorus from the organic matter.
- **c. Solubilization:** In addition to organic source of phosphorus, inorganic compounds (calcium, phosphate) are abundant in the soil.

Potassium Utilization

- Potassium occurs in ionic (K^+) form in the soil and is taken up as such by the plants.
- No special bacterial decomposition is required.
- However, organic and inorganic acids produced by microorganisms help to solubilize potassium locked into rocks.
- Potassium is required for sugar translocation and starch formation in the plants.
- It helps root growth and is also toxic to fungal diseases.
- It increases quality and size of fruits, grains, nuts, and vegetables (tuberous vegetables such as potato).

Sulfur Cycle

- Sulfur is the fourth major element required for healthy plant growth.
- It is an essential component of the amino acids (cysteine, methionine, and vitamin B complex) required for protein synthesis.
- Sulfur is also required for nodule formation in leguminous crops (alfalfa, beans, lupins, vetches, etc).
- Sulfur is primarily available to plants in the sulfate form (SO_4^{-2}).
- Sulfur is often present in the soil in suboptimal quantities, therefore, sulfur based fertilizers are needed.
- The main reserve of sulfur in the soil is the organic matter.
- Organic sulfur can only be released by microorganisms.
- Sulfur cycle in soil is analogous to nitrogen cycle and microbes are the sole agents to convert organic sulfur into available inorganic forms such as sulfates.
- Four processes of sulfur metabolism operate in the soil, i.e.
    - mineralization,
    - immobilization,
    - oxidation, and
    - reduction

…Sulfur Cycle

- In the soil, organic sulfur is bound as hydrogen sulfide (H_2S).
- Bacterial species of the genus *Thiobacillus* and *Beggiatoa* oxide H_2S to elemental sulfur (S).
- Elemental sulfur aggregates as crystals inside the phototropic species of bacterium *Chromatium*.
- Other bacterial species of *Chlorobium* and E*ctothiorhodospira* also oxidize hydrogen sulfide but release elemental sulfur into the soil.
- Elemental sulfur is oxidized first to sulfite (SO_3^-) followed by sulfuric (H_2SO_4) acid produced by *Thiobacillus thiooxidans*.
- These bacteria grow well under acidic soils (pH 2.0 – 3.5) and can be used to reduce alkalinity in the soil by applying sulfur.
- Sulfates are eventually reduced to sulfides (H2 S) by another bacterial species of genus *Desulfovibrio*.
- These bacteria work under anaerobic conditions.

Microbial Transformation of Micronutrients

- **Iron:** Iron is essential for chlorophyll formation in plants.
- It is often in abundance in western soils.
- Its deficiency occurs due to excessive zinc and manganese in the soil and causes chlorosis of young leaves.
- Iron occurs in pyrite form, a typical iron disulfide which is slowly oxidized to iron sulfate ($FeSO_4$) by bacterial species Thiobacillus thiooxidans.
- Organically iron forms complexes with sugars and simple organic acids in the soil.
- Organically bound iron is attacked by bacteria of genus *Pseudomonas*, *Bacillus*, *Klebsiella*, *Streptomycetes*, and some filamentous fungal species.
- **Manganese:** Manganese and iron are essential for chlorophyll formation.
- It is taken up by the plant in the ionic (Mn^{++}) form.
- In plants it exists in several oxidization states (divalent manganous ion, tetravalent manganous ion).
- Divalent form (Mn^{++}) is absorbed by plants but tetravalent (Mn^{+4}) need to be transformed by microflora.
- Bacterial genus *Bacillus*, *Arthrobacter*, *Pseudomonas*, and *Klebsiella* release ionic manganese from complex compounds ($MnCO_3$).
- Manganese oxidizers varies from soil to soil but they often account for 5-15 percent of total microflora in the soil.

Metabolism of other Micronutrients

- Metabolism of other micronutrients, copper (Cu^{++}), boron (H_3BO_3), zinc (Zn^{++}), molybdenum (MoO_4), and chlorine (Cl) is not known to involved microorganisms, as yet.
- However, they are very important for plant health.
- For example, plants require molybdenum to transform nitrate nitrogen into amino acids, and legumes cannot fix nitrogen molybdenum.
- Boron is taken up by plants as boric acid (H3BO3) and plays a definitive role in cell differentiation of actively dividing meristematic cells.
- Copper is a co-factor in several enzyme activity in plants.
- Similarly chlorine has been found to be important in carrying out the photosynthesis in plants.

Life without Microorganisms:

- Soil organic matter holds more than 95% of soil nitrogen, 5-60% of total phosphorus and about 30% of soil sulfur.
- Availability of these nutrients is conditional to the decomposition of organic matter by microorganisms.
- Lack of microorganisms may result in:
  - a. Accumulation of organic matter which can adversely affect the soil fertility by clogging the soil texture.
  - b. Accumulation of Humus can result in locking the carbon and other important component of plant skeletons (celluloses and hemicelluloses).
  - c. Extensive utilization of fertilizers which will cause water and soil pollution.

Microorganisms and fertilizers

- Microorganisms may not supply enough nutrients for plants.
- Therefore the use of chemical fertilizers is evident.
- It is important to use high grade chemical fertilizers having low salt index and high solubility otherwise they can harm the soil fertility by adding undesirable heavy metals and increasing salt index.
- High grade fertilizers are analogous to “fast food outlets”and also help build high microbial population in the soil.
- Efficiency of microbial activity is directly related to their number in the soil, therefore, it is a “microbial number game”.
- If the number in the soil is inadequate, microbes should be added along with the liquid fertilizers.
- Practice of adding microorganisms through fertilizers or otherwise is now recognized as a viable additional source of increasing soil fertility.
- Conclusion: Microorganisms (cooks) use raw organic matter from the soil and artificial fertilizers (groceries) to cook plant food in the rhizosphere (kitchen) using enzymes (recipes).