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Microbial Inoculants for Improving Soil Health and Crop Productivity

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INTRODUCTION

Soil is a living biological ecosystem which plays an essential role in plant growth providing support, water, nutrients and habitat for various microorganisms. Bacteria, fungi, actinomycetes, algae and other microorganisms play significant roles in the process of nutrient cycles, decompositions of organic materials, soil formation, stimulation of plant growth and inhibition of pathogens. Nevertheless, intensive agricultural techniques, usage of high amounts of chemical fertilizers and pesticides, monocultures, soil erosion, reduction of organic materials and improper irrigation techniques may adversely affect soil biology. Consequently, deterioration of soil quality results in low nutrient-use efficiency, reduction of crop yield and sustainability of agriculture.

Rising demands on foodstuffs, fodder, fibre and horticulture products imply the need of sustainable practices which will ensure productivity and conservation of soil and environment resources. Microbial inoculants represent a promising biotechnology for improvement of soil fertility and crop performance. The inoculants include selected microorganisms which are used to inoculate seeds, soil, roots, compost, nursery media or planting materials.



Microbial inoculants can enhance the growth of plants by various means. Some microbes can fix nitrogen from the air, and some can solubilize or mobilize nutrients like phosphorous, potassium, zinc, and iron. A number of microorganisms associated with plants can generate plant hormones and metabolites that promote root growth. Beneficial microbes can also compete with pathogens, generate antimicrobial substances, trigger defense mechanisms in plants, and help plants withstand environmental stress. Thus, microbial inoculants have great potential for enhancing soil and crop health and minimizing over-reliance on agricultural chemicals.

2. Concept of Microbial Inoculants

Microbial inoculants are biological preparations of live or dormant beneficial microorganisms which are added to soil or seeds or roots or plants for agricultural benefits. They are also known as biofertilizers, microbial biostimulants or microbial biocontrol agents based on the predominant mode of action of the inoculant.

An inoculant can have only one type of microorganism or more than one kind of microorganisms. The efficacy of the inoculant is determined by the nature and vitality of the microbes, their survival after inoculation, their interactions with soil microbes and their colonization of rhizosphere or plant parts. The major types of microorganisms which act as agricultural inoculants include nitrogen-fixing bacteria, phosphate solubilizing microorganisms, potassium solubilizing microorganisms, zinc solubilizing bacteria, arbuscular mycorrhizal fungi, plant growth promoting rhizobacteria, beneficial fungi and microbial biocontrol agents.

3. Importance of Microorganisms in Soil Health

Microorganisms are vital in maintaining soil health since they control decomposition and nutrient cycling. Microorganisms decompose organic residues in the soil; thus, there is release and conversion of nutrients into usable forms by plants. The activities of microorganisms are associated with the formation of soil aggregates and stabilizing organic carbon.

Effective microorganisms can enhance the biological aspect of soil health through increased microbial biomass, increased enzymatic activity, and diversity in functions. There are microorganisms that form tight relationships with plant roots whereby the surface area of the roots is increased for improved water and nutrient uptake. Microorganisms also produce certain substances that limit harmful microorganisms and minimize soil-borne diseases.

4. Nitrifying Microbes

Nitrogen is a nutrient needed for crop growth in sufficient quantities. But nitrogen present in the atmosphere cannot be used directly by most crops. There are some microbes that have the capacity to convert atmospheric nitrogen to usable form by biological nitrogen fixation.

4.1 Rhizobium

Rhizobium along with other nitrogen-fixing bacteria nodulate the roots of leguminous crops. The atmosphere nitrogen gets converted to usable forms in these nodules. Nodulation, plant growth and nitrogen nutrition get improved with the inoculation of appropriate and compatible strains of leguminous crops. Suitable rhizobial inoculation is beneficial for crops such as chickpea, pea, lentil, soybean, groundnut and several forage legumes.

4.2 Azotobacter

Azotobacter is a free living nitrogen-fixing bacterium that can be associated with the rhizosphere of non-leguminous crops. This is mostly employed in cereals, vegetables, fruit crops and other agricultural systems. Along with nitrogen fixing some strains have the capacity to produce biologically active compounds promoting plant growth.

4.3 Azospirillum

Azospirillum is an associative nitrogen-fixing bacterium frequently associated with grasses and cereals. It can colonize plant roots and contribute to nitrogen nutrition while also promoting root development. Its use has been investigated in crops such as maize, wheat, rice, sugarcane and several horticultural crops.

5. Phosphate Solubilizing Microorganisms

Phosphorus is critical for energy transfer, root growth, flowering, fruit formation, and other metabolic activities. Some parts of phosphorus in the soil could be in insoluble forms and may be less available to plants. Phosphate solubilizing bacteria and fungi can make some insoluble forms of phosphorus available in soluble forms through the generation of organic acids, phosphatases and other biochemical substances.

6. Potassium Solubilizing Microorganisms

Potassium plays an important role in enzyme activation, water regulation, photosynthesis and stress resistance. Even though many soils have sufficient amounts of potassium, some potassium could be in insoluble mineral forms, thus less available to plants. Potassium solubilizing microorganisms can solubilize some potassium from minerals through acidification and chelation among other biochemical means.

7. Zinc- and Micronutrient-Solubilizing Microorganisms

Micronutrients such as zinc, iron, manganese and copper are required in small quantities but are essential for plant metabolism. Deficiencies of these nutrients can reduce crop growth and quality. Certain beneficial microorganisms can increase the availability of micronutrients by producing organic acids, siderophores and other compounds.

Microbial inoculants capable of mobilizing micronutrients may therefore have potential in nutrient-deficient soils. Their application can be particularly useful as part of integrated micronutrient- management programmes.

8. Plant Growth Promoting Rhizobacteria (PGPR)

Plant growth promoting rhizobacteria, PGPR for short, are microorganisms which colonize roots and induce plant growth via direct and indirect mechanisms. Key genera include Bacillus, Pseudomonas, Azospirillum, Enterobacter and others.

PGPR may promote plant growth via secretion of compounds such as indole-3-acetic acid and phytohormones, increased nutrient uptake, siderophores production, pathogen suppression and stimulation of defense response in plants. Moreover, some PGPR strains can increase drought, salinity and other abiotic stress tolerances.

9. Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi form symbiotic relationship with roots of many horticultural and agricultural plants. They increase effective soil volume searched for nutrients due to extended mycelium outside the root system. This way, fungi can increase the uptake of immobile nutrients, especially phosphorus, and improve water uptake.

Symbiosis between plants and fungi can improve establishment, nutrient use efficiency and drought tolerance of plants. Moreover, mycorrhization is very helpful in horticulture when cultivating plants in nurseries.

10. Trichoderma and Other Beneficial Fungi

Trichoderma species are widely used as biological agents for managing several soil-borne plant pathogens. They can act through competition, mycoparasitism, production of antimicrobial compounds and stimulation of plant defence mechanisms. Some strains can also promote root development and improve plant growth.

Beneficial fungi such as Trichoderma can be applied to seeds, nursery substrates, soil or planting material depending on the crop and formulation. Their use can contribute to integrated disease-management programmes and reduce dependence on chemical fungicides

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11. Microbial Inoculants in Horticultural Crops

There is high potential for the use of microbial inoculants in horticulture due to their responsiveness to the increased nutrient supply and better root formation. In vegetable seedlings, microbial inoculation can help with increasing the vigor of the seedlings and development of roots and better transplanting. With the crops like tomato, chili, brinjal, cabbage, cauliflower and cucurbits, beneficial microorganisms can be combined with organic manures and fertilizers.

Fruit crops may also be treated with the microbial inoculants both at nursery stage and at the time of planting or establishment of orchards. The mycorrhizal fungi, nitrogen-fixing bacteria, phosphate solubilizing microorganisms and bio control agents can help with the root formation and nutrient uptake. In perennial orchards, the maintenance of organic matter in soils along with the appropriate microbial environment becomes essential. The use of microbial inoculants can also be considered in the protected systems of horticulture. Nevertheless, the different parameters in protected environment, such as temperature, moisture and substrates, require the selection of strains and doses of the microbial inoculants.

12. Mechanisms of Plant Growth Promotion

The use of microbial inoculants for increasing the yield of crops depends on many factors. Biological nitrogen fixation helps in increasing the availability of nitrogen. Phosphate and potassium solubilization helps in the increased availability of nutrients, which are present in an unavailable form. The production of plant growth regulators stimulates the growth of roots and shoots. The production of siderophores helps in the uptake of iron by the plants and also prevents iron from being available to specific pathogens. Beneficial microorganisms can synthesize antmicrobial substances, and at the same time, they can compete with harmful microorganisms for nutrients and sites for attachment. Some microbial inoculants induce systemic resistance in the plants so that they can defend themselves against pathogens and environmental stress.

13. Application Methods

The application of microbial inoculants can be done using various techniques based on crops and forms of microbial inoculants. The first method is seed treatment which is the most widely used application technique especially when the microbial inoculants are related to germinating seeds and young roots. Soil application of microbial inoculants can be done by mixing with compost, farmyard manure, or other suitable carriers.

Root dipping can be used for transplanted vegetable and horticultural crops. Seedling roots can be dipped in the microbial suspension before transplantation into fields. The media used in nurseries can also be inoculated with beneficial microorganisms before transplanting into fields. In perennial horticultural crops, microbial inoculants can be applied near the roots either at planting or during orchard maintenance operations. Some of the microbial inoculants can be applied foliarly but its effectiveness will depend on the properties of the microorganism and environmental conditions.

14. Interaction with Organic Manures and Fertilizers

Microbial inoculants require favorable environmental and nutritional conditions for optimal functioning. Organic manures and compost can act as sources of carbon substrates and favorable soil environment for microorganisms. Microbial inoculation does not necessarily mean complete elimination of mineral fertilizers. In many production systems, integrated nutrient management involving organic inputs, biofertilizers and judicious quantities of mineral nutrients may provide more consistent results. The appropriate combination should be determined according to crop requirements, soil-test results and local conditions.

15. Microbial Inoculants and Climate Resilience Agriculture

Changes in climate have led to greater drought, high temperatures, salinity and other types of stresses for plants in many agricultural areas. Beneficial microorganisms could help in increasing plant resistance through enhanced root formation, nutrient uptake, efficient water usage and stimulation of stress response. Mycorrhiza fungi could be beneficial through their hyphal network in water and nutrient uptake, and some PGPR could affect plant hormone and stress response. Therefore, microbial inoculants could be used in climate resilient agricultural system, but they need proper validation for their performances under different climatic conditions since their responses are dependent on the environment.

16. Benefits of Using Microbial Inoculants

The application of microbial inoculants could result in many advantages in agriculture. These inoculants could improve nutrient availability, enhance root formation, improve plant growth, increase nutrient-use efficiency and enhance crop production. Some of these inoculants could also help in reducing diseases pressure through pathogen suppression.

From an environmental perspective, improved nutrient-use efficiency can help reduce unnecessary fertilizer application and associated nutrient losses. Biological approaches to disease management may reduce dependence on chemical pesticides when appropriately integrated into crop protection programmes. Microbial technologies can therefore contribute to sustainable and resource-efficient agriculture.

CONCLUSION

The use of microbial inoculants is among the biological approaches that can help in enhancing soil health, nutrient status, and crop yield. Microbes including Rhizobium, Azotobacter, Azospirillum, phosphate solubilizing bacteria, potassium solubilizing microorganisms, plant growth promoting rhizobacteria, arbuscular mycorrhizal fungi, and Trichoderma can carry out various functions in agricultural ecosystems. They can enhance nutrient cycling, promote roots, inhibit soil-borne pathogens, and increase the tolerance of plants to different environmental stresses. In horticultural productions, microbial inoculants can be efficiently incorporated into nursery practices, vegetable production, fruit orchards, protected crops and integrated nutrient management practices. Nevertheless, the effectiveness of such microbes relies on their quality, compatibility with the crops and soil, environmental factors, mode of application and general farm management practices. Thus, microbial inoculants should not be considered as alternative sources to fertilizers and other agricultural products. Rather, they should be treated as an integral part of a strategy for improving soil health.

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