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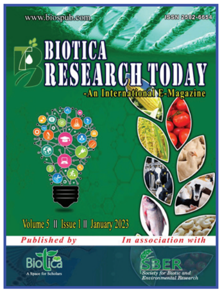

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Biofertilizers and Its Role in Ecorestoration: An Overview

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Abstract

Plant nutrients are very important for the proper and healthy production of food. Today, the soil management practices are totally dependent on the chemical-based fertilizer, which not only affect the humans and the other organisms but also causes damage to the ecosystem or to the environment. Thus, biofertilizer has been discovered or identified as a better alternative for increasing the productivity of the crop. The inoculation of this type of fertilizer over a field makes the soil fertile and thus makes it suitable for sustainable farming. The discovery of the beneficial microorganisms as biological inoculants has increased the potential of the agriculture sector to grow a good productive crop. Thus, the use of biofertilizers increases the soil fertility, crop production, tolerance to all types of stresses, *etc*.

Introduction

In agriculture, various biotic and the abiotic components ensures the fertility of soil and affects the agriculture production worldwide. With the increase in the human population, urbanization and industrialization; the demand for food has also increased. The precious non-renewable resource of soil is constantly in danger due to negative anthropogenic activities. The intensification of agricultural land use and adoption of modern agricultural techniques have resulted in the accumulation of organic and inorganic contaminants in the soil that are alarmingly increasing day by day. These contaminants not only negatively affect the health of the soil and plants but also have a direct or indirect negative impact on organisms that depend on them (Pandey *et al.,* 2022). For proper availability of food sources various chemical fertilizers are been in used. These chemical fertilizers however help to increase the crop productivity but on the other hand damages the environment, *i.e.*, soil, water and air, and this damage to the environment affects all living organisms (Tiwari *et al.,* 2020). The excessive use of chemical fertilizers increases the soil salinity, diminishes the soil fertility, reduces the soils water holding capacity and also causes the inconsistency in the soil nutrients.

It is necessary to address both reducing climate change and increasing food security. Unexpected environmental changes have had a significant impact on human diet and health (Kanwal *et al.*, 2019). Food crops are depleting macro- and micro-nutrients proportionately, and soils that can be conserved by either conventional agricultural practices or organic farming are being depleted proportionately (Tiwari *et al.,* 2020). Therefore, a shift to a cost effective and an eco-friendly use has occurred that protects the environment and also helps to increase the fertility of soil without causing any damage to the soil. This method involves the use of biofertilizers in contrast of the chemically based fertilizers.

Biofertilizers or the microbial inoculants are live microbial formulations (bioformulations) that are used to improve the soil fertility and also help in plant growth and development (Rai *et al.*, 2014). Various bacteria, archaea and fungi are used as biofertilizers. The biofertilizers of the microbial origin are a good option for sustaining the productivity in an effective manner (Al-Taey and Majid, 2018) and they have been advanced to use the naturally occurring nutrient mobility mechanisms that promotes the soil fertility and hence results in improved crop production (Al-Tawaha, 2011). PGPR (Plant Growth Promoting Rhizobacteria) can also be used as microbial inoculants to increase the soil quality and its fertility (Singh *et al.,* 2016). This type of biofertilizer can work with a direct as well as with an indirect mechanism. Direct mechanisms is involved in the promotion of nitrogen fixation, potassium and phosphorus solubilization, plant-nodule formation, production of siderophores and plant hormones; while the indirect mechanism involves the activation of ISR (Induced Systemic Resistance) and many more.

Thus, the yield for any crop will only increase when a specific plant-microbe interaction is known. However, the use of biological fertilizers is at its primary level in agriculture and various advances in the field of biotechnology, microbiology and molecular biology will definitely increase the use of biofertilizers in the future. Biofertilizer use in agriculture can be increased by carrying out various researches on microbial strains development and thus can make the process of formation of biofertilizers a cost-effective and an eco-friendly process. A key feature for sustainable agriculture is the utilization of such biological inoculants that make the soil fertile without disturbing the microbial indices in the soil (Al-Tawaha *et al.,* 2018).

Different Types of Biofertilizers

1. Bacterial Biofertilizers

Bacterial Biofertilizers are the live cells of the bacteria that are used as biofertilizers. These microbes contain one of a unique gene called the “Nif gene”, that is responsible for the nitrogen fixation. There are two different methods of applying the bacterial biofertilizers- Bacterization and Green manuring.

However, Bacterization (Rocha *et al.,* 2019) is a widely used technique for applying the bacterial suspension. Here, the seeds are treated with the bacterial suspension usually either of species *Bacillus, Azotobacter* and *Rhizobium.* This treatment then helps to improve the growth of host plant due to the secretion of growth promoting substances and secondary metabolites.

2. Rhizobial Biofertilizers

It is a type of biofertilizer that contains the symbiotic Rhizobium bacteria (Kebede, 2021). This bacterium enters into the host plant root hair and results in the nodule formation and thus fixes atmospheric nitrogen.

3. Azotobacter Biofertilizers

This type of a biofertilizer is recommended for the use in non-leguminous plants like cotton, millet, wheat, paddy, tomatoes, *etc*. It is a heterotrophic bacterium that derives its energy by degrading the plant residues (Wani *et al.,* 2016). It fixes atmospheric nitrogen to some extend and also produces vitamins, gibberellic acids and IAA for proper growth of plant.

4. Azospirillum Biofertilizers

It is a type of fertilizer that contains *Azospirillum* bacteria which have the ability to colonize into the plant roots and helps in fixing atmospheric nitrogen. *Azospirillum* is an associative nitrogen fixer. It fixes about 20-40 kg N ha^{-1} under microaerophilic conditions (Rashid *et al.,* 2016). It also synthesizes IAA, leading to the growth of plant and is also supposed to increase the biotic and abiotic stress tolerance capacity in plant. This culture is prepared by transferring a full loop of bacteria in an Okon’s Medium containing ammonium chloride and incubating it for 3 days at 35 °C.

5. Cyanobacteria as Biofertilizer

Cyanobacteria are the asymbiotic nitrogen fixers. The process of nitrogen-fixation occurs inside specialized structures called the heterocysts. Various others nitrogen fixers are *Azolla, Nostoc, Anabaena*, *etc*. They all have the ability to utilize CO_2, water and nutrients to convert the solar energy into biomass (Pathak *et al.,* 2018).

6. Azolla Biofertilizers

Azolla is a fast-growing aquatic fern that forms a symbiotic relationship with cyanobacterium Anabaena *azollae* and thus allows in the fixation of nitrogen. It enhances the rice production by 30-60 kg N ha^{-1} and also increases the nitrogen mineralization in waterlogged soil.

7. Phosphate-Solubilizing (Bacteria) Microorganisms

These are the group of beneficial microorganisms including *Pseudomonas, Bacillus, Penicillium* and *Aspergillus* (Molds) that are capable of converting the insoluble form of organic and inorganic phosphorus into a soluble form of phosphorus (Kalayu, 2019) that can be easily used by the plants. This microorganism converts this insoluble form of phosphorus to a soluble form of phosphorus by the help of organic acids such as formic acid, glycolylic acid and acetic acid.

8. Mycorrhizal Biofertilizers

This type of a biofertilizer contains spores of mycorrhiza fungus, this fungus is one of a beneficial fungus that symbiotically associates with the plant roots and also increases the absorption of phosphorus along with other nutrients from the soil, thus supporting the growth and development of plant and increases their yield. Here, the fungus can form either a sheath like the ectomycorrhizae, arbutoid, ecto-endomycorrhizae and monotropoid mycorrhizae or can either penetrate inside the host cells as arbuscular, orchid and ericoid mycorrhizae.

Biofertilizers can also be classified on the basis of their function and nature. Some of them are stated in the Table 1.

Table 1: Type of biofertilizers with some of the examples

Sl. No.	Type of biofertilizer	Examples	
1	PGPR	Pseudomonas	*Pseudomonas florescens*
2	Nitrogen fixing biofertilizer	Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
3	Nitrogen fixing biofertilizer	Associative Symbiotic	*Azospirillum*
4	Nitrogen fixing biofertilizer	Free-living	*Azotobacter, Clostridium, Anabaena, Nostoc*
5	Biofertilizers for Micro-nutrients	Silicate and Zinc solubilizers	*Bacillus* sp.
6	Phosphate Solubilizing Biofertilizers	Bacteria and fungi type	*R. leguminosarum, M. mediterraneum, B. japonicum, Bradyrhizobium* sp., *Penicillium* sp., *Aspergillus awamori*

Microorganisms play crucial roles in the nutrient cycling, structure-building, and plant-soil interaction processes that take place in soil. These responsibilities are essential for reestablishing ecosystem function and biodiversity when it comes to ecosystem restoration. However, the soil microbial community plays an important role in restoration (Pandey *et al.,* 2021a,b). Beside different types of biofertilizers, the demand for their use in much less, thus, by highlighting some of the advantages of these biological inoculants over the chemical fertilizers, an idea to spread the knowledge about their usefulness or an initiative can be made for their proper use by a large population. Figure 1 shows some of the leading advantages that prove that biological fertilizers are best for maintaining soil fertility and also best for the maintenance of sustainable agriculture.

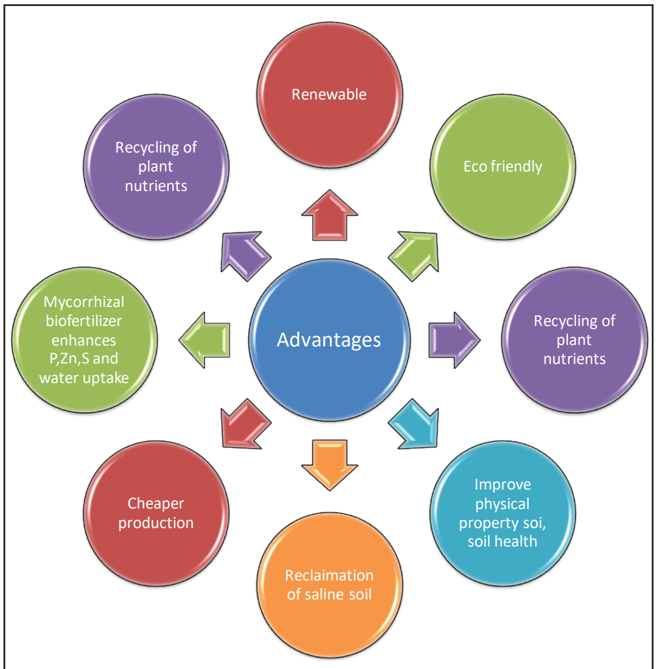

Figure 1: Various advantages of biofertilizers

Biofertilizers and Climate Change

The ecosystem is threatened by a number of significant problems, the most significant of which are climate change, habitat loss, species extinction, and the daily conversion of natural ecosystems for human land uses, which is one of the leading threats and leaving a lasting legacy on ecosystem. Climate change has led to various alterations in temperature and rainfall patterns and this change has a damaging impact on agriculture. Its causes an increase in the elevation of greenhouse gases that has resulted in increase in temperature, droughts, floods, heat waves and uncertainty of monsoons. Thus, to overcome these unfavorable climatic conditions, it becomes necessary to apply the techniques of genetic engineering and plant breeding to make such crops that can bear the stress conditions. However, these techniques require an expertise and are also time consuming, thus, an alternative for this is the use of biofertilizers. Microorganisms are an essential component of life on Earth and have a significant influence on processes like the biogeochemical cycles for nitrogen, carbon, and sulphur.

Soil microbial communities in agricultural systems have been so transformed by decades of fertilization, tilling, and pesticide usage that it is believed that they have reached an alternate stable state (Docherty and Gutknecht, 2019). The live microbes that are used as biofertilizers are mostly free-living bacteria, fungi and arbuscular mycorrhizal fungi. These bio-inoculants ensure making a plant to maintain or to bear the abiotic stress conditions like drought, salinity, *etc*.

Plant growth promoting rhizobacteria (PGPR) mostly influences the ability of plant to bear abiotic and biotic stresses (Backer *et al.,* 2018). These groups of bacteria are found in the rhizospheric region of the plant roots and thus show a positive effect on the growth and development of the plant. They do so by producing various phyto-hormones like auxin (Omer *et al.,* 2004; Gupta *et al.,* 2015), cytokinin, and gibberellins (Gupta *et al.,* 2015; Kumar *et al.,* 2015) and also enable the nutrient consumption from the environment. PGPR also helps in the elimination of pathogenic microbes by inducing the plants immunity. On the other half, they help in iron sequestrations and also decrease the level of ethylene concentrations that gets accumulated in plant under stress conditions (Morgan and Drew, 1997).

Biofertilizers in Eco-Restoration

In natural contexts, microbial diversity is ubiquitous. Although microbes are essential to ecosystem health and human survival, many of these "tiny living animals" have been completely disregarded in harsh environmental conditions. Regarding the role of microorganisms in sustainable development, little is known about the potential contribution of Himalayan microbial diversity to the national economy, investments in capital, and improvements in the quality of life (Pandey *et al.,* 2021a,b).

Biofertilizers can play a role in eco-restoration efforts by helping to improve the health and fertility of the soil in damaged or degraded ecosystems. By providing plants with the nutrients, they need to grow and thrive, biofertilizers can help to support the regrowth of vegetation and promote the recovery of damaged ecosystems. In addition, the use of biofertilizers can help to reduce the need for synthetic fertilizers, which can have negative impacts on the environment if used excessively. Overall, biofertilizers can be an effective tool for promoting the health and vitality of ecosystems and supporting the efforts to restore damaged or degraded areas. Microorganisms play crucial roles in the structure, interaction, and cycling of nutrients in soil.

These functions are essential for restoring the function and biodiversity of the ecosystem. However, it is unclear if the soil microbial population could play a significant role in facilitating restoration. Since microorganisms are crucial to the health of the soil, they could play a significant role in any programme aiming at restoring an ecosystem.

Conclusion

Biofertilizers are an effective applicant that are applied as bioinoculants in soil and enhances the soil fertility and also helps in maintaining the plant growth and development. They are mostly used in organic farming and are one of the best, environment friendly, cost-effective alternatives of chemical fertilizer. With intensive research and development, many new bioinoculants are been developed to improve the plant growth. The relationships between plants and the phytomicrobiome are ancient and represent the result of a very long co-evolution. Evolution is random and thus at times, surprisingly new relationships that are beneficial to plants have been developed or discovered. It is thus also stated that the microbiome in the plant shows or have potential for many more sustainable crop management practices. Thus, the best way out of all to maintain the best management practices is the use of the biological inoculants or the biofertilizers. These biological fertilizers use different mixture of microbes as a consortium or may involve a single type of a strain for maintaining proper soil fertility.

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