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Review Article

A Review: Vital Role of Biofertilizers in Plant Growth Enhancement and Maintenance of Soil Health

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Abstract: Biofertilizers are also being used to help farmers change their fortunes. In several developed countries, it has proved to be a promising technology, however in developing countries; the use of bioinoculants is limited by a number of factors. Scientific understanding of bioinoculants and their use can pave the way for their successful application. A biofertilizer is a material that includes living microorganisms that colonise the rhizosphere or the interior of the plant when added to plants, plant surfaces, or soil, and foster growth by growing the supply or availability of primary nutrients to the host plant. Biofertilizers provide nutrients to plants by natural processes such as nitrogen fixation, phosphorus solubilization, and the production of growth-promoting compounds. Biofertilizers use microorganisms to maintain the soil's natural nitrogen balance and increase soil organic matter. Good plants may be cultivated through the use of biofertilizers while still improving the soil's sustainability and protection. Biofertilizers would likely limit the usage of conventional fertilizers and chemicals, but they will not be able to completely eliminate them. Plant-growth enhancing rhizobacteria is a preferred scientific name for these helpful bacteria since they perform several functions (PGPR).
Keywords: PGPR, nitrogen fixation, phosphorus solubilization, microorganisms.

Introduction

Since the last two decades, climate change has become one of the most serious issues for the nation, policymakers, and farmers. The end product of the world's growing population is a transition in climatic conditions. At the same period, increased crop production is needed to ensure food sustainability for the world's growing population. Due to scarce land supplies, farmers must use a large volume of chemical fertilizers and pesticides to obtain full crop yields. Excessive usage of these fertilizers, which are chemically synthesized synthetic compounds including nitrogen, phosphorus, and potassium, pollutes soil, air, and water directly or indirectly (Galloway *et al.*, 2008; Youssef and Eissa, 2014). The continued usage of chemical fertilizers, biocides, and pesticides has a negative impact on the existing micro flora found in the rhizosphere or applied area, including microbes, fungi, cyanobacteria, and protozoa, causing an imbalance in the natural environment (McLaughlin and Mineau, 1995). Their long-term use has a negative impact on the health, texture, and fertility of plants and soil, resulting in environmental degradation as well as human health and well-being. Traditional agricultural practices, on the other hand, depend heavily on the extensive usage of synthetic fertilizers and pesticides for plant nutrition and disease control (Vasile *et al.*, 2015). The benefits of judicious application of these chemical inputs are undeniable, not only for plant development, crop output, and efficiency, but also for the farmers' income. Unfortunately, the increased usage of artificial supplies can end up contaminating water, air, and soil, posing a serious challenge to the natural environment (Rahman and Zhang, 2018). Because of the careless application of agrochemicals and their inability to biodegrade, they accumulate below ground, causing unfavorable changes in soil composition, productivity, and water keeping power (Savci, 2012).

Excessive usage of synthetic fertilizers has also been related to eutrophication of water supplies, the greenhouse effect (Goenadi *et al.,* 2018), and toxic build-up of heavy metals like arsenic, cadmium, and plumbum (Goenadi *et al.*, 2018). It's worth noting that long-term usage of mineral fertilizers will deplete soil nutrients and render crops more vulnerable to disease (Aktar *et al.,* 2009). Organic cultivation is an option to traditional agriculture that helps to reduce crop production's reliance on chemical plant defense inputs. It incorporates environmentally sustainable agronomic methods which, in theory, allows for contamination-free food processing (e.g., possibly poisonous trace elements, leftovers of plant agents) while still ensuring soil quality and biodiversity. Organic fertilizers and toxic pesticides are not permitted (Niggli, 2015). Organic agriculture, one of the fastest growing divisions of agriculture (Brenes-Munoz *et al.,* 2016), is also growing in terms of output and use of ecological produce. From 11 million hectares in 1999 to 57.8 million hectares in 2016, the region of organic farm land has increased dramatically (Willer and Lernoud, 2018).

The aforementioned harmful consequences of overloading soil with synthetic agro-chemicals, as well as increased consumer understanding of the importance of protecting the natural environment and human health, prompted researchers to look for alternatives that were just as effective but did not threaten terrestrial habitats (Geiger *et al.,* 2010). An agenda for reducing and preventing water contamination caused by nitrates from crop sources. Agriculture has also benefited from biofertilizers (Council Directive 91/676/EEC, 1991). These microbial strains have exciting agricultural potential because they increase plant growth and development by growing native nutrient (N, P, K, S, Zn) bioavailability and producing antibacterial and/or antifungal substances, and therefore may be used to reduce mycotoxins pollution (Toyota and Watanabe, 2013).

Furthermore, biofertilizers have been shown to increase the activity of indigenous soil microorganisms and accelerate microbial processes in the soil (Raja, 2013), release plant growth stimulants, protect plants from abiotic and biotic stresses, improve soil quality in terms of biological, chemical, and physical properties, and convert complex chemical compounds into easily assimilable compounds (Fragoeiro and Magan, 2008; Raja, 2013). In contrast to conventional pesticides, biofertilizers are an economical, environmentally sustainable, and organic source of plant nutrients; as a result, they are gaining worldwide prominence and value in crop development (Swapna *et al.*, 2016). The aim of this study is to summarize the beneficial effects of rhizosphere microorganisms on agriculturally valuable plants and to highlight the importance of biofertilizers in long-term agricultural sustainability.

Biofertilizer definitions and applications in agriculture

The word "biofertilizer" can be translated in a variety of ways (El-Ghamry *et al.,* 2018). Biofertilizer may be described as seaweed extracts, composed urban wastes, microbial mixtures with unspecified constituents, or mineral fertilizer products enriched with organic compounds, among other things. Surprisingly, science study articles use a wide definition of this word, encompassing anything from green manures to animal manures to plant extracts (Vessey, 2003). The idea of biofertilizer has evolved in tandem with our understanding of the interactions that exist between soil microorganisms and plants. According to Okon and Labandera-Gonzalez (1994), substances that increase the exploitation of nutrients found in soil but do not substitute them (such as mineral fertilizers) should be classified as inoculants rather than biofertilizers. Vessey (2003) described biofertilizer as "a material containing living microorganisms that colonises the rhizosphere or the interior of the plant and promotes growth by raising the supply or availability of essential nutrients to the host plant when applied to plant surfaces, seeds, or soil." This concept of biofertilizer differs from the one suggested by Okon and Labandera-Gonzalez (1994), and it is a contraction of the word "biological fertilizer." Fuentes-Ramirez and Caballero-Mellado (2005) described a biofertilizer as "a substance containing living microorganisms that exert direct or indirect beneficial effects on plant growth and crop field via various mechanisms." According to their description, items containing beneficial microorganisms that are used to kill phytopathogens could be classified as biofertilizers; however they are most often referred to as biopesticides (Fuentes-Ramirez and Caballero-Mellado, 2005).

Similarly, phytostimulators or bioenhancers are microorganisms that promote plant development by synthesising phytohormones, whereas rhizoremediators are microorganisms that may biodegrade organic pollutants (Somers *et al.*, 2004). As a result, not all microbial inoculants can be labelled as biofertilizers (Bhattacharyya and Jha, 2012). From a scientific standpoint, a biofertilizer is a single microorganism that promotes plant growth; however, in the agronomical context, this term refers to a product made up of beneficial strain(s) that are useful for nutrient mobilisation, packaged in a carrier, with features that enable it to be stored at the time specified by the producer, and ready for use. In this regard, biofertilizer may also allow for the inclusion of substances that help microorganisms perform better. Biostimulants extracted from microorganisms (products dependent on dead microbial cells or extracts with microbial origin) should not be used interchangeably with words such as plant or animal manure, intercrop, or fertilizers relating to a mixture of mineral and organic compounds (Malusa and Vassilev, 2014). The primary goal of using biofertilizers is to promote plant development while minimising negative environmental impacts and increasing harvest yields.

Types of biofertilizers

Biofertilizers are broadly classified into various types based on the nature of organisms (Table 1).

S.No.	Groups	Examples
N_2 Fixing Biofertilizers		
1	Free-living	*Azotobacter, Beijerinckia, Clostridium, Klebsiella, Anabaena, Nostoc*
2	Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
3	Associative symbiotic	*Azospirillum*
P Solubilizing biofertilizers		
1	Bacteria	*Bacillus megaterium* var. *phosphaticum, Bacillus subtilis, Bacillus circulans, Pseudomonas striata.*
2	Fungi	*Penicillium* sp., *Aspergillus awamori*
P mobilizing biofertilizeres		
1	*Arbuscular mycorrhiza*	*Glomus* sp., *Gigaspora* sp., *Acaulospora* sp., *Scutellospora* sp. and *Sclerocystis* sp.
2	Ectomycorrhiza	*Laccaria* sp., *Pisolithus* sp., *Boletus* sp., *Amanita* sp.
3	Ericoid mycorrhizae	*Pezizella ericae*
4	Orchid mycorrhizae	*Rhizoctonia solani*
Biofertilizers for Micro nutrients		
1	Silicate and Zinc solubilizers	*Bacillus* sp.
Plant Growth Promoting Rhizobacteria		
1	Pseudomonas	*Pseudomonas fluorescens*

Plant growth promoting rhizobacteria

Biofertilizers are artificially maintained soil microorganism cultures that can be used as microbial or soil inoculants to increase plant and soil viability and productivity. In other words, a biofertilizer or microbial fertiliser is a substance made up of living microorganisms and a mixture of biodegradable substances that is applied to seed, plant surfaces, or colonises the interior part of the plant by various means such as rhizospehere, intercellular spaces, and increases the availability of primary nutrients to the host plant, resulting in increased growth and yields (Vessey, 2003). It is also regarded as one of the most important factors in the development of an integrated nutrient management scheme with minimal environmental effects (Malusa *et al.*, 2016). The commercial history of biofertilizer begins in 1895 with Nobbe and Hiltner's invention of "Nitragin," a Rhizobia laboratory community, accompanied by the detection of Azotobacter and then blue green algae (Ghosh, 2004; Das *et al.*, 2015). Instead of artificial fertilisers, beneficial plant microbiome interactions provide a potential long-term alternative for improving agricultural output (Timmusk *et al.*, 2017). Biopesticides and biofertilizers are natural-based chemicals that are commonly used to improve soil fertility and as a biocontrol agent (Miranda, 2012). Currently different group of microorganisms have been identified, which belongs to bacteria, fungi, and protozoan kingdoms, these colonize rhizosphere or the internal plant tissues and used as biofertilizers for the enhanced agriculture production (Vessey, 2003; Lucy *et al.*, 2004; Smith and David, 2008) (Figure 1).

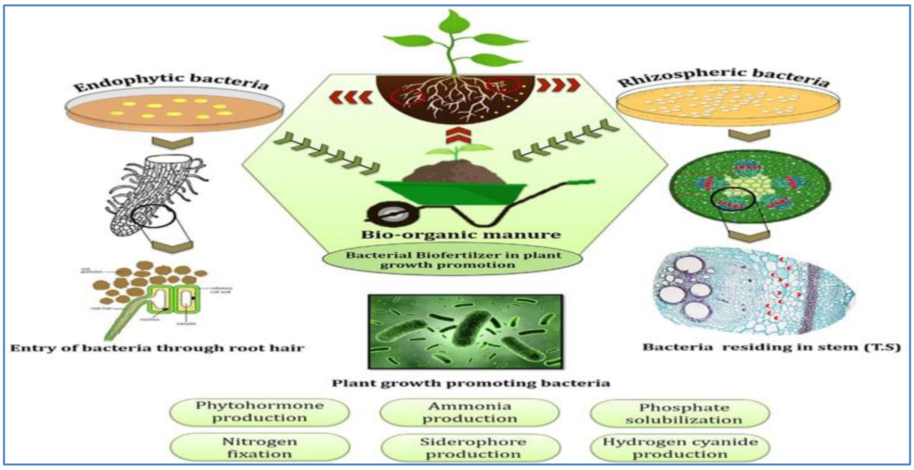

Figure 1. A schematic view of plant growth promoting bacteria (rhizospheric and entophytic) and their role in plant growth promotion.

The use of PGPB as a biofertilizer has been shown to be a healthy and effective way to boost crop yields (Premachandra *et al.*, 2016; Vejan *et al.*, 2016). Several bacterial genera, including *Azotobacter*, *Bacillus*, *Klebsiella*, *Enterobacter*, *Arthrobacter*, *Burkholderia*, *Bacillus*, *Pseudomonas*, *Azotobacter serratia*, and others, have been used as biofertilizers in recent decades, as reported by various writers, and these isolates have been dubbed PGPB (Kloepper *et al.*, 2004; Saharan and Nehra, 2011; Kumar *et al.*, 2014).

Bacteria that fix nitrogen in a symbiotic relationship

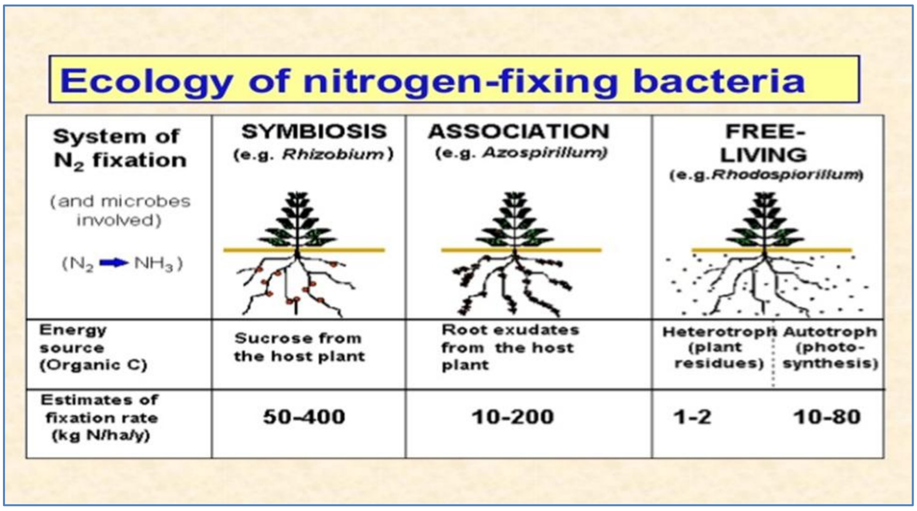

Figure 2. Ecology of nitrogen fixing bacteria (Mani, 2014)

The most important restricting factor for plant growth is nitrogen (Gupta *et al.*, 2012). To repair this nitrogen and make it accessible to the plant, a specific community of microbes is needed. Biological nitrogen fixers are microorganisms that fix nitrogen in the environment (BNFs). They convert inert N_2 into plant-usable organic form (Reed *et al.,* 2011) (Figure 2).

Rhizobia

Rhizobia are the most effective bio-fertilizers that repair atmospheric nitrogen by producing root nodules that function as nitrogen-fixing mini-factories in legume plants. Symbiotic nitrogen fixation is a molecular conversation between a legume and a Rhizobium that results in the formation of a new tissue (nodule) on the root plant. The Rhizobium enzyme nitrogenase fixes nitrogen in the atmosphere with the aid of nodulins (legume plant proteins) and transfers it to the plant for successful symbiosis. Depending on the legume species, host Rhizobium genotype, agro-climatic factors, and their relationship, the legume-Rhizobium connection will contribute up to 360kgN/ha/yr. Inoculating legume crops with Rhizobium bio-fertilizer improves nodulation, nitrogen fixation, and production. According to nodulation surveys, the majority of legume crops grown in India need inoculation every season. A bottleneck in achieving higher yields from Rhizobium inoculation tends to be competition between ineffective native strains and effective inoculant strains.

Symbiosis of Frankia and Casurania (non-leguminous tree)

Actinorhizal plants are non-leguminous trees that have nodulated with Frankia. Filamentous spore-forming actinomycetes in 25 genera and 8 angiosperm families develop nodules. This form of symbiosis has the potential to improve nitrogen economy by N_2 fixation while also assisting in the stabilisation of eroding land surfaces. The actinorhizal nodules in the cortex represent a cluster of transformed roots of Frankia contaminated cells. Swelling first appears in nodules, and then grow into vesicles, which are the sites of N_2 fixation. With Alunus and Croatia plants, nitrogen fixation in Frankia is about 90-200 kg N/ha/yr. *Anabaena azollae* is a cyanobacterium that establishes a symbiotic relationship with the water fern *Azolla* and is used as a bio-fertilizer in rice cultivation. This partnership will fix 30-100 kg of nitrogen per hectare per season in the rice ecosystem. *Azolla*, in addition to nitrogen fixation, is considered to kill weed populations in wet land rice, providing an added economic benefit to rice cultivation. It's also been used in livestock feed to boost milk output recently.

Asymbiotic fixation

Azotobacter, *Derxia*, and *Beijerinckia*, which are present in soil, are the most effective asymbiotic/free living nitrogen fixing bio-fertilizers. *Azotobacter*: Owing to the presence of numerous readily utilisable carbon compounds, *Azotobacter* is a possible bio-fertilizer in the rhizosphere of leguminous and non-leguminous crops. Bean growth and yield are thought to benefit from these free living nitrogen fixers. They are considered to release growth-promoting compounds such as indole acetic acid (IAA), gibberellic acid, and have fungistatic function in addition to fixing nitrogen. *Azotobacter* inoculation has been shown to increase yield in cereals such as maize, pearl millet, wheat, and sorghum. Under natural field conditions, *Azotobacter* inoculation reduces the nitrogen demand of fertilisers by 10 to 20%. Cyanobacteria, also classified as blue green algae, include *Anabena*, *Nostoc*, *Aulosira*, and *Tolypothrix*, both of which are exceptional N_2 fixers. Cyanobacteria are unicellular colonial microbes with the potential to divide into distinct cell groups in certain filamentous organisms: a) Vegetative cells: natural photosynthetic cells contained in ideal growing conditions b) Akinetes: climate-resistant spores produced in stressful environments. Heterocysts: thick-walled cells that contain the nitrogenase enzyme, which is needed for N_2 fixation. Heterocysts are specialised systems capable of fixing N_2.

Bacteria that dissolve phosphate

To transform insoluble forms of phosphate to soluble forms, microorganisms are needed (Phosphate solubilizing microorganisms) (Kalayu, 2019). The phosphate solubilizing mechanism involves many bacteria and fungi organisms (Antoun, 2012). These transform insoluble forms of phosphate, such as

HPO4 and H2PO4, into soluble forms via a variety of mechanisms, including organic acid production, chelation, and ion exchange reactions (Sharma *et al.*, 2013). Phosphate solubilizing bacteria supply phosphate as well as other trace elements including Te and Zn, allowing plants to expand more quickly. They often provide the enzyme that kills pathogens, shielding the plant from diseases caused by bacterial strains. Phosphate solubilizers include bacteria like *Pseudomonas*, *Bacillus*, *Rhizobium*, and *Enterobacter*, as well as fungi like *Penicillium* and *Aspergillus* (Phosphate solubilizing microbes) (Anand *et al.*, 2016) (Figure 3).

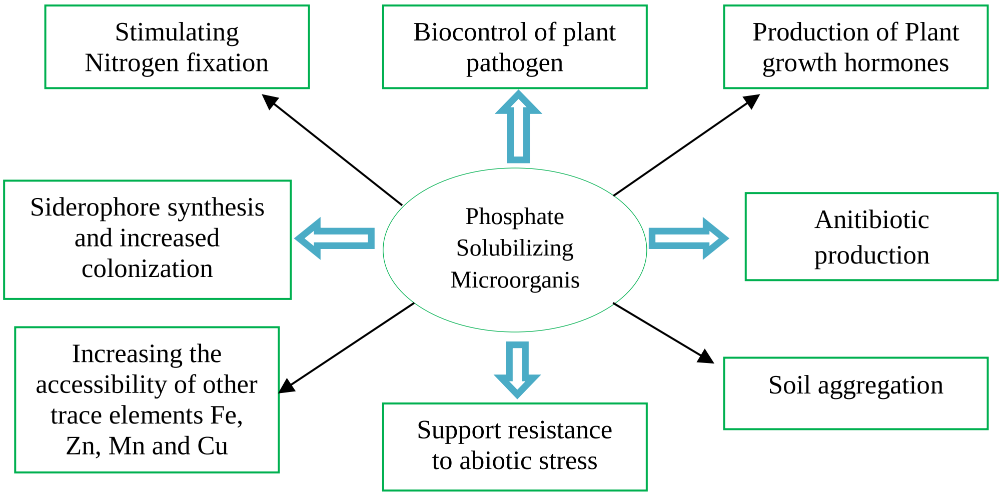

Figure 3. Role of phosphate solubilizing bacterial in plant growth and development (Krishnaraj and Dahale, 2014)

Biofertilizers that solubilize and mobilise potassium

Behind nitrogen and phosphorus, potassium is the second most plentiful and essential nutrient in plants. While potassium is plentiful in soil, only 1-2 percent is accessible to plants, while the remainder is present as mineral K, which plants cannot use (Park *et al.*, 2009). Examples of potassium solubilizing biofertilizers include *Bacillus* species and *Aspergillus niger*, *Arthrobacter* species, *Cladosporium*, and *Sphingomonas aminobacter*, both of which have differing capacity for K solubilization. *B. edaphicus* and *B. mucilaginosus* have been shown to help in solubilization and mobilisation. When *B. mucilaginosus* was inoculated into soil, it increased oil content and groundnut biomass by 35.4 and 25%, respectively, while also increasing K and P supply (Sugumaran and Janarthanam, 2007). A recent study found that rising potassium supply increased K absorption in tea plants in mica waste-treated soil by a potassium solubilizing strain *Bacillus pseudomycoides* (Pramanik *et al.*, 2019) (Figure 4).

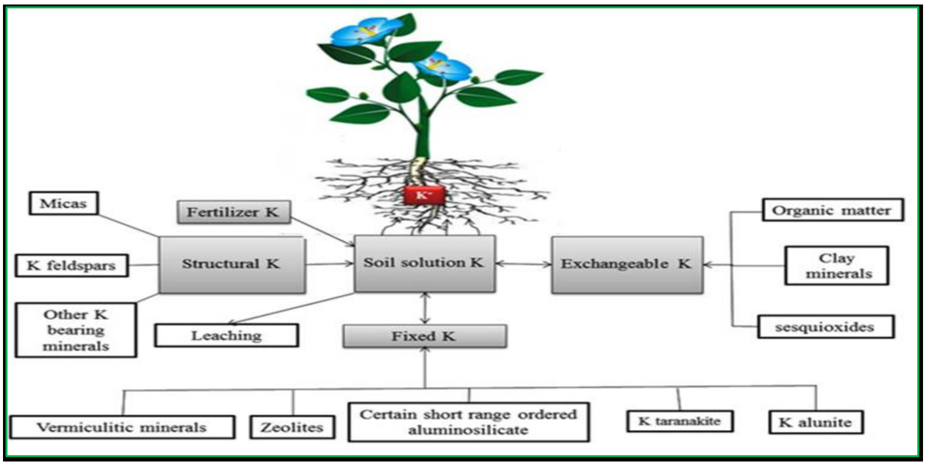

Figure 4. Interrelationships of various forms of soil K (Sparks and Huang, 1985)

Biofertilizers that oxidise sulphur

Plants need sulfur as a micronutrient as well. Sulfur has been seen to play an important role in enhancing the biological and physical properties of soil. Sulfur is well-known for its ability to protect soil from elevated pH levels. Sulfur also improves the production of nitrogen and phosphorus fertilisers, as well as the ability of crops to absorb micronutrients, according to previous research (El-Halfawi *et al.,* 2010).

According to a recent analysis, inoculating *Thiobacillus* with elemental sulphur improves elemental sulphur oxidation, resulting in increased nutrient abundance in soil and, as a consequence, increased plant development (Pourbabaee *et al.,* 2020).

Biofertilizers that solubilize zinc

Zinc is an important micronutrient available in tissues at relatively low concentrations (56-100 mg/kg) for plant growth and reproduction. Zinc deficiency in wheat can cause yellowing of the leaves and stunted development (Kamran *et al.,* 2017). Zinc availability in soil has been confirmed to be increased by Mycorrhiza, *Saccharomyces* species, and several Rhizobacteria genera such as *Pseudomonas* species and *Bacillus* species. These bacteria use chelated ligands and oxidoreductive structures to solubilize zinc (Raj, 2007) (Figure 5).

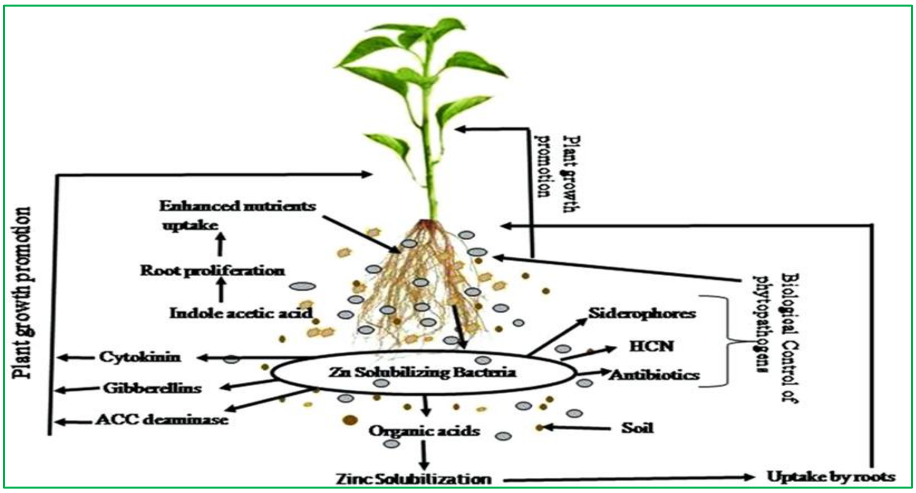

Figure 5. Biofertilizers that solubilize zinc (Kumar *et al.,* 2019)

Mycorrhizal Fungi

A symbiotic relationship between plant roots and some fungi is referred to as mycorrhiza. Depending on the form of plant and fungus involved in the mycorrhiza relationship, the fungi colonise the plant root either intracellularly or extracellularly. The relationship between a host plant and a fungus can be defined as reciprocal in the sense that the host plant provides the fungus with carbohydrates required for its metabolic activities, and the fungus provides the host plant with nutrients and water required for its development. As a result, the fungus-host plant relationship is a mutually advantageous symbiotic relationship (Basu *et al.,* 2018). Mycorrhizal fungi aid in the absorption of water and nutrients from the soil, such as phosphorus, which is important for plant growth and productivity. In mycorrhiza Glomus versiformis hyphae, the inorganic phosphate transporter (Pi) was found to improve phosphate absorption from the soil to the host plant (Parihar *et al.,* 2019).

Mycorrhizal fungi can also help to detoxify organic and inorganic soil toxins that can damage plant productivity. Mycorrhizal fungi are divided into two categories: mycorrhizal fungi and mycorrhizal fungi. Endomycorrhiza is found in more than 86 percent of plant organisms, with hyphae penetrating plant root cortical cells and forming intracellular arbuscules; ectomycorrhiza is found in trees and shrubs, with hyphae not penetrating plant root cells and forming intracellular arbuscules (Averia *et al.,* 2017) (Figure 6).

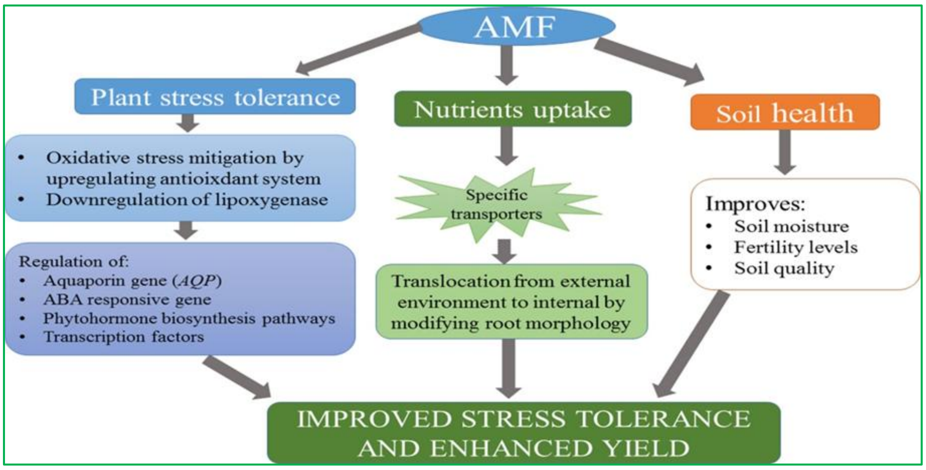

Figure 6. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation (Begum *et al.*, 2019).

Biofertilizers help plants develop faster

Rhizobium leguminosarum, *Rhizobium* spp. IRBG 74, and *Bradyrhizobium* spp. IRBG 271 have been shown to improve plant biomass, yield, and chlorophyll content as compared to uninoculated plants in recent studies (Verma *et al.*, 2019). Similarly, some Rhizobia strains will boost inoculated plants' surface area, photosynthetic rate, water uptake capability, yield, and stomatal conductance (Pathak *et al.*, 2016). Its use has also been linked to the impact of biofertilizer in rising plant growth and yield for increased food output. On two forage rice genotypes, the impact of a biofertilizer made from a plant growth-promoting *Bacillus pumilus* strain TUAT-1 was recently evaluated. As opposed to non-inoculated rice, biofertilizer made from *Bacillus* species improved rice production (Win *et al.*, 2018) has published on the use of biofertilizer to improve maize growth and yield production. As compared to an uninoculated control, biofertilizer formulated with phosphate solubilizing bacteria was found to improve maize growth and yield.

Soil fertility maintenance

Bio-fertilizers are the product of the most advanced microbial technologies needed to promote environmentally friendly, organic agriculture. When added to seed, plant surfaces, or soil, bio-fertilizers include living microorganisms that speed up microbial processes, increasing the supply of nutrients for quick assimilation by plants (Pooja Sharma *et al.*, 2012). It is essential to start a national movement to protect soil health and increase soil productivity (Swaminathan, 2004). Since no single source will provide the appropriate amount of plant nutrients, it is necessary to combine all sources of plant nutrients to provide balanced nutrition to the crops (Arora, 2008). Natural manures, as well as artificial fertilisers, are used in integrated nutrient management (INM) schemes. Because of the favourable agroclimatic conditions in the NEH area, a variety of organic sources are available for use in agriculture. These sources can decrease soil nutrient mining and increase total soil fertility by improving the soil's physico-chemical and biological conditions. The lack of P availability due to fixation as the Fe/Al complex is a major crop development issue in the area. Biofertilizers such as phosphorus solubilizing bacteria (PSB)/*Azotobacter* could help improve potato P and N nutrition. Organic manures' positive results are manifested over time as a rise in soil organic matter and humus. Soil organic matter and humus have many functions: they provide a slow-release supply of plant nutrients to crops, they improve water holding ability to sustain the soil's water regime, and they operate as a barrier against changes in soil pH (Upadhayay and Singh, 2003).

Conclusion

Biofertilizers are a promising tool in agricultural environments as a secondary, organic, and environmentally beneficial supply of plant nutrients. Biological fertilisers are thought to be a vital factor in sustaining soil fertility and crop production at a reasonably high level, which is essential for farming to be sustainable Biofertilizers can also aid in mitigating the risks associated with the increasing global population's demand for food and the widespread chemicalization of agro-ecosystems. Biofertilizers are becoming an increasingly important aspect of modern crop production, thanks to a shift in agricultural practices that stresses the use of biological inoculants in the coming years. While many rhizosphere microorganisms are known to promote plant growth in a variety of ways, only a few have been formulated as biofertilizers. As a result, modern strategies that allow for broader use are needed to achieve organic farming goals. Because of their low side effects and profitable agricultural production, using PGPB as a biofertilizer and biocontrol agent is a sustainable approach for agriculture. Microbial inoculants or PGPB are currently used in the management of salinity, drought, and other biotic and abiotic stresses, in addition to biofertlizers and biocontrol. Farmers, industries, and researchers will now use these PGPB strains to improve salinity resistance, heavy metal tolerance, and xenobiotic degradation. This PGPB strains are also used in the manufacture of bioactive compounds, which aid in drug development and disease control.

Conflicts of interest: The authors declare no conflicts of interest.

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