BIO-FERTILIZER TECHNOLOGY: A TOOL FOR AGRICULTURE, HORTICULTURE AND FORESTRY SYSTEMS

Abstract

Today our country is having a huge task of feeding about more than 100 million of our people. This task could have been impossible but for the Green Revolution of 1960 which has given reasonable hope for India being self-sufficient in the production of enough food for feeding the increasing population. Chemical fertilizers have been in the forefront of the struggle to increase the world food production. They have become vital for crop production. But the use of costly chemical fertilizers for large scale production of agricultural crops in the fields and fungicides & pesticides for preserving grains bring about physical and chemical alternations to the land, thereby bringing soil pollution. Hence, such soil pollution can be prevented by treating the soil with beneficial microbes instead of chemical fertilizers. As the first living things on the planet, microbes are crucial to preserving the ecosystem's biological balance. Plants, animals, and bacteria have formed a variety of interrelationships over a long period of time that can be classified as associative, antagonistic, commensalistic, mutualistic, pathogenic, or symbiotic. In nurseries and fields, diseases severely damage crops used in agriculture, horticulture, and forestry, reducing biomass production or destroying germplasm collections. Numerous bacterial and fungal diseases target economically significant crop plants. Microbial bio-fertilizers are utilized as biological control agents for a variety of disease-causing organisms because they can stop the spread of harmful organisms and safeguard crops in nurseries and fields. These beneficial microbes are also used for reclamation and rehabilitation of different problem soils such

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as wastelands, saline or salt affected lands, heavy metal contaminated lands, mined out areas, deserts, coastal sand dune and other polluted soils. This paper highlights different kinds of bio-fertilizers and their production and application methods to various crops for enhanced healthy, quality and grain yield.

Keywords: Green revolution, plant microbe interactions, beneficial microbes, Bio-fertilizers

I. BIOFERTILIZERS

Instead of being a source of nutrients on their own like synthetic chemical fertilizers are, potential microorganisms in bio-fertilizers allow and enhance the availability of accessible nutrients in the plant's rhizosphere (1). Bio-fertilizers are beneficial microorganisms and they are involved in break down of organic matter, N_2 fixation, P solubilization, secretion of plant growth promoting substances and enhance availability of mineral nutrients in the soil. They come in carrier-based formulations that are ready to apply to soil, roots, or seeds. Through their biological activity, they increase the availability of vital plant nutrients, support the development of the microflora, and ultimately enhance the health of the soil. In addition to preserving soil structure, the bio-fertilizers work as a biocontrol agent against pathogens that are carried by the soil or by plant roots. Their uses are very much considered as important in growth improvement and establishment of forest tree seedlings.

In the last two to three decades, the use of bio-fertilizers has increased considerably in India as well as other parts of the world (2). Bio-fertilizers are consequently viewed as an appealing and practical biotechnological option in order to increase and restore soil fertility, encourage plant growth, enhance crop output reduce production costs, and diminish the environmental impact associated with chemical fertilization (3, 4). In addition to nitrogen-fixing soil bacteria like *Azospirillum, Azotobacter,* and *Rhizobium*, and nitrogen-fixing cyanobacteria like *Anabaena*, phosphate-solubilizing bacteria like Pseudomonas and mycorrhizal fungi like Arbuscular Mycorrhizal (AM) fungi and Ectomycorrhizal (ECM) fungi, nitrogen-fixing cyanobacteria are also frequently utilized as bio-fertilizers (**Table 1**). Similar to this, bacteria that produce phytohormones (such auxins) and microbes that cause cellulite are also utilized as bio-fertilizers. Additionally, using plant growth-promoting rhizobacteria (PGPR) can be helpful when creating strategies for increasing plant development under both typical and abiotic stress circumstances (5).

Table 1: Types of beneficial microbes and their uses as bio-fertilizers in different crops

S. No.	Microbes/ Bio-fertilizers	Genus	Crop plants being used	Benefits
1	Actinobacteria	*Arthrobacter, Brevibacterium, Cellulomonas, Corynebacterium, Kocuria, Microbacterium, Micrococcus, Mycobacterium, Rhodococcus, Streptomyces, Streptomonospora, Haloglycomyces, Haloactinospora, Actinopolyspora,*	Maize, Pea, Rice, Wheat, Soybean, Sugarcane, Sunflower,	(1) Promote plant vigor by using growth stimulants (2) The capacity to withstand biotic and abiotic stress. 3) Boost nutrition utilization

		Amycolatopsis, Prauserella		
2	Firmicutes	*Alicyclobacillus, Alkalibacillus, Alkalinebacterium, Amphibacillus, Ammoniphilus, Aneurinibacillus Bacillus, Brevibacillus, Exiguobacterium ,Gracilibacillus, Halobacillus, Lysinibacillus, Planococcus, Marinilactibacillus, Oceanobacillus, Paenibacillus, Paraliobacillus, Pontibacillus, Salibacillus, Salimicrobium, Thalassobacillus, Virgibacillus, Salinibacillus, , Sporosarcina Sediminibacillus, Tenuibacillus, , Planomicrobium*	Amaranth (Greens), Apple, Barley, Buckwheat, Maize, Mustard, Oat, Pepper, Rice, Sorghum, Sunflower, Tomato, Wheat	(1) Production of plant growth hormones like indole acetic acids, hydrogen cyanide, gibberellic acid, and siderophore; (2) Solubilization of phosphorus, potassium, and zinc (3) Nitrogen fixation; (4) Biocontrol
3	Proteobacteria	*Alcaligenes, Rhizobium, Albimonas, Allidiomarina, Deleya, Halomonas, Marinobacterium, Pseudomonas, Marinobacter, Aquisalimonas, Microbulbifer, Salicola, Marinospirillum, Methylophaga, Achromobacter, Paracoccus, Pantoea, Enterobacter, Kluyvera,*	Amaranth greens, Barley, Bean, Buckwheat, Cotton, Cowpea, Maize, Millet, Mustard, Oat, Pea, Rice, Soybean, Sunflower, Tomato, Wheat	(1) Promote plant vigor by using growth stimulants (2) Fixation of nitrogen. (3) Nutrient solubilization Four) Biocontrol

		Azospirillum, Methylobacterium, Arcobacter, Oceanibaculum, Fodinicurvata, Altererythrobacter, Glycocaulis, Xanthobacter, Bradyrhizobium, Amorphus, Sinorhizobium		
4	Bacteroidetes	*Flavobacterium, Shingobacterium*	Barley, Millet, Wheat	(1) Attributes promoting plant development
5	Ascomycota	*Trichoderma, Penicillium, Fusarium, Phoma, Aspergillus, Phomatropica, Acremonium*	Agricultural, Horticultural (Fruit) and Forestry crops	(1) Biodegradation (2) Biocontrol
6	Glomeromycota	*Acaulospora, Entrophospora, Gigaspora Glomus, Scutellospora*	Agricultural, Horticultural (Fruit) and Forestry crops	(1) Phosphate-mobilizing (2) Bio-control (3) Plant growth promoting attributes (4) Reclamation of Problematic soils
7	Cyanobacterias	*Asterocapsa, Chroococcus, Aphanothece, Gloeocapsa, Microcystis, Synechococcus, Rhabdoderma, Merismopedia, Aphanocapsa, Coelosphaerium, Leptolyngbya, Pseudanabaena, Komvophoron, Oscillatoria, Lyngbya, Phormidium, Nostoc, Anabaena, Scytonema.*	Beans, Maize, Rice.	(1) Nitrogen Fixation (2) Bioremediation (3) Biocontrol
8	Ascomycota	*Cenococcum,*	Forestry crops	(1) Phosphate-

	and Basidiomycota	*Amanita, Boletus, Boletellus, Hebeloma, Laccaria, Lactarius, Pisolithus, Rhizopogon, Russula, Scleroderma, Suillus, Thelephora, Tricholoma*	(Australian Acacias, Conifers, Casuarinas, Eucalypts, Pines, Sal)	mobilizing (2) Bio-control (3) Plant growth promoting attributes (4) Reclamation of Problematic soils

Advantages of Bio-fertilizers:

1. Eco-friendly.
2. Cost effective.
3. Renewable.
4. Components in INM
5. Sustainability in production
6. Restore natural soil fertility and improve soil health.
7. Make the nutrients available to plants
8. Provide protection to plants against drought and some soil borne diseases. Improves rhizosphere beneficial micro flora by synergistic interaction.
9. Activate the soil biologically. Solve problems such as increased salinity and soil run-off from the fields.
10. Replace the application of chemical nitrogen and phosphorus fertilizers by 25%.
11. Synthesize growth promoting substances and antibiotics for improved seedling growth.
12. No residual toxicity in food products and soil.

II. DIFFERENT TYPES OF BIO-FERTILIZERS

Bio-fertilizer product comprises of the specified microorganism(s) blended in carrier materials like charcoal, vermiculite, talcum powder, etc.

- **Nitrogen Fixing Microbes -** *Azospirillum, Azotobacter, Glucanobacter,* Blue green algae, *Azolla, Frankia, Rhizobium,* etc. Among them, Blue Green Algae, *Azolla* and *Glucanobacter* are of agricultural importance only and others are used in agriculture, horticulture and forestry practices.

- **Phosphate Solubilizing Microbes -** Phosphate Solubilizing Bacteria (PSB) such as *Bacillus megaterium* var. *phosphaticum, Pseudomonas striata* and *Bacillus polymyxa,* Phosphate Solubilizing Fungi (PSF) like *Aspergillus awamori, Pencillium digitatum,* etc.

- **Phosphate Mobilizing Mycorrhizal Fungi**

  i. **Endomycorrhizal fungi –** They are classified into five groups.

- Arbuscular Mycorrhizal (AM) fungi - *Acaulospora, Entrophospora, Gigaspora, Glomus, Scutellospora*, etc.
- Ericoid Mycorrhizal fungi
- Arbutoid Mycorrhizal fungi
- Monotropoid Mycorrhizal fungi
- Orchid Mycorrhizal fungi

ii. **Ectomycorrhizal fungi -** *Amanita, Boletus, Boletellus, Hebeloma, Laccaria, Lactarius, Pisolithus, Rhizopogon, Russula, Scleroderma, Suillus, Thelephora, Tricholoma*, etc.

- **Potassium Mobilizing Microbes -** *Frateuria aurentia*

1. **Nitrogen Fixing Microbes*:*** All plants associated microenvironments, especially the rhizosphere are colonized in high abundances by different microbes (6). A group of bacteria called the plant growth-promoting rhizobacteria (PGPR) actively colonize plant roots and boost plant growth and yield. There is evidence that the PGPR, which are members of the genera *Azospirillum, Azotobacter, Pseudomonas, Xanthomonas, and Rhizobium*, generate auxins that aid in promoting plant growth. PGPR promote plant growth by (i) Production of phytohormones (ii) Synthesis of antibiotics, (iii) Asymbiotic N_2 fixation against plant pathogenic microorganism by production of siderophores (iv) Solubilisation of mineral phosphate and other nutrients (7). These beneficial microbes *viz*., AM fungi and PGPR are associated with many crops including tree species grown in saline soils and other habitats (8, 9,10).

- ***Azospirillum***: *Azospirillum* is a general root colonizer of nitrogen fixing rhizosphere bacteria and it fixes nitrogen under microcephallic conditions (11). They are frequently associated with roots and rhizosphere of a large number of various agriculture crops and cereals. It fixes atmospheric nitrogen asymbiotically and contributes to plant nitrogen nutrition; it can improve the plant nutrient uptake and offers protection against pathogens. They are also very versatile in carbon and nitrogen metabolism. Not just nitrogen fixation is a big advantage *Azospirillum* can provide to plants. Additionally, they have the capacity to boost the quantity of root hairs on the root system, which is crucial for aiding the plant in absorbing nutrients and more water from the soil. Plant growth hormones (auxins) produced by *Azospirillum* encourage the plant to create more roots, which strengthens the plant's overall structure. More food and biomass are produced by stronger plants. Recently, a study on diversity status of PGPR in the rhizosphere of thirty six different medicinal plants in Kanyakumari district, Tamil Nadu revealed that all the medicinal plants had association of different PGPR organisms with population density of 1,718 colonies of *Azotobacter*, *Azospirillum*, Phosphobacteria, Actinomycetes and soil fungi (12) and all these isolates had excellent performance with IAA production and phosphate solubilisation abilities under *in vitro*.

  Crops for which it is intended: All non-leguminous vegetable crops, agriculture crops, horticulture crops and forestry crops.

- ***Azotobacter*** **:** Azotobacter is a free-living bacterium that uses nitrogen gas from the atmosphere to synthesize the proteins in its cells. On cell lysis, the cell protein is then mineralized in the soil, helping to increase the amount of nitrogen available to agricultural plants. There are four important species of *Azotobacter viz*., *A. chroococcum, A. agilis, A. paspali* and *A. vinelandii* of which *A. chroococcum* is most commonly found in our soils. In Indian soils, there are just 10,000 to 1 lakh *Azotobacter* bacteria per gram of soil. A study on the diversity status of PGPR in soil from various salt-affected areas in Tamil Nadu and Pudhucherry, South India, revealed a total of 51 PGPR isolates, of which 16 strains of *Azotobacter* spp. were recorded. These strains were then screened for their effectiveness in producing plant growth hormone (IAA) and phosphate solubilization under in vitro conditions (8). It was discovered that Azotobacter chroococcum produced the most IAA (36 g/mL). Population of *Azotobacter* is mostly influenced by other microorganisms present in soil. There are some microorganisms, which stimulate the *Azotobacter* population in soil thereby increasing the nitrogen fixation by *Azotobacter.* Besides nitrogen fixation, *Azotobacter* also produces Thiamine, Riboflavin, Nicotin, Pyridoxin, Indole Acitic Acid and Gibberellin. It also improves seed germination to a considerable extent and controls plant diseases due to antifungal antibiotics produced by *Azotobacter.*

  Crops for which intended: All non-leguminous vegetable crops, agriculture crops, horticulture crops and forestry crops.

- ***Frankia*** **(Actinorhizal Bio-fertilizer)**
- A gram-positive actinobacterium called *Frankia* fixes nitrogen and coexists symbiotically with actinorhizal plants. It may establish symbiotic nitrogen-fixing partnerships with more than 220 species of woody dicotyledonous plants, also known as actinorrhizal plants, which are found in eight families of angiosperms and include species of *Alnus* and *Casuarina*. The symbiotic interaction between *Frankia* and actinorhizal plants leads to the development of a nodule, a perennial root organ that contains actinobacteria and fixes nitrogen. Important ecological and economic advantages of the Frankia-actinorhizal plant symbiosis include soil stabilization, land reclamation, crop protection, and the production of wood for fuel and construction. (13). The application of Frankia as a bio-fertilizer to Casuarina and other actinorhizal plants significantly increases plant growth, biomass, shoot and root N content, and survival rate after transplanting in fields. It has been reported that association of soil microbes, particularly Frankia, with actinorhizal plants can mitigate the negative effects of abiotic and biotic stresses. However, the selection of efficient Frankia strains is crucial for the development of actinorhizal plantations on degraded locations (14). Therefore, using effective Frankia strains is crucial for better crop establishment and output.

  Crops for which it is intended: *Casuarina* spp., *Alnus* spp.

- ***Rhizobium*** **(Nitrogen Fixing Symbiotic Bacterial Bio-fertilizer):** *Rhizobium* is a genus of nitrogen-fixing gram-negative soil bacteria that endosymbiotically associate with the roots of leguminous plants, such as common bean (*Phaseolus vulgaris*) and other flowering plants, to fix nitrogen. It is employed as a bio-fertilizer because of its capacity to colonize plant roots, fix atmospheric nitrogen, and improve nitrogen nutrition in the soil and rhizosphere of host plants. This bacterium infiltrates plant cells to form root nodules, where they convert atmospheric nitrogen into ammonia using nitrogenase enzyme. In return, the plant gives the bacterium organic chemicals produced during photosynthesis. All rhizobia have this beneficial interaction, with the genus Rhizobium serving as a typical example (15), and they are also capable of solubilizing phosphate (16). Examples of symbiotic nitrogen fixing *Rhizobium* bacteria are *Rhizobium leguminosarum* in pea plants; *Rhizobium phaseoli* in beans; *Rhizobium japonicum* in soybeans and *Rhizobium lupini* in Lupins. *Rhizobium* bio-fertilizer can be applied to plant surfaces, seeds, or soil to provide nutrients to the plants. In addition to nitrogen fixation, *Rhizobium* also contributes to the improvement of soil productivity and fertility, drought stress, salt stress and thereby creating an environment conducive to plant growth.

Crops for which it is intended: All leguminous plants of agriculture crops such as Beans, Soybeans, Chickpeas, Peanuts, Lentils, Lupins, Peas, Alfalfa, and Clover and forestry crops like species of *Acacia, Adenanthera*, *Albizia, Caesalpinia, Dalbergia, Erythrina*, *Gliricidia, Leucaena, Pongamia*, *Pterocarpus*, *Sesbania*, *Tamarindus*, etc.

2. **Phosphate Solubilizing Microorganisms (PSM):** This group comprises the Phosphate Solubilizing Bacteria (PSB) and the Phosphate Solubilizing Fungi (PSF). The PSB include *Bacillus megatherium* var. *phosphaticum, Bacillus polymyxa, Bacillus subtilis, Pseudomonas striata,* etc. and PSF include *Aspergillus awamori, Penicillium digitatum, Penicillium bilaji*, yeast (*Saccharomyces* sp.) etc. The bacterium secretes certain organic acids like fumaric acid, succinic acid, acetic acid, lactic acid, etc. There are many earlier studies reported on the distribution of PSB on various host plants including tree crops (17) and they have isolated twenty three different PSB from the rhizosphere region of *Tectona grandis* in Andhra Pradesh, Kerala and Tamil Nadu. They screened the efficacy of all these strains on growth improvement of Teak plants. They screened the efficacy of all these strains and found that the isolates of *Bacillus subtilis* and *Pseudomonas flourescens* showed increased plant growth with good siderophore production and phyto hormone production as compared to uninoculated (control) plants. In a similar manner, 35 PSB isolates from the rhizosphere of Ailanthus excelsa in Tamil Nadu, India, were examined for their effectiveness in producing IAA and solubilizing phosphate under in vitro conditions (18). It was discovered that all of the PSB isolates produced high levels of IAA, and some of the isolates were able to do so to a greater extent than others. In a different study, 45 PGPR isolates from *Gmelina arborea*'s rhizosphere in Kerala and Tamil Nadu, India (19), including *Azotobacter* spp., *Azospirillum* spp., and PSB, were tested for IAA production and phosphate solubilization effectiveness *in vitro*. The best isolates were chosen for nursery inoculation. Similar to this, PGPR diversity status in various salt-affected locations was investigated in Tamil Nadu and Pudhucherry, South India, and a total of 51 PGPR isolates were discovered (20 It was discovered that a high rate of P solubilization efficiency (SE) was found, with *Bacillus megaterium* indicating a SE of 140% and *Bacillus subtilis*, a SE of 120%, making both the isolates as strong phosphate solubilizers. A total of 18 isolates of PSB were isolated and screened for their efficiency of plant growth hormone (IAA) production and P solubilization under in vitro conditions. The insoluble tricalcium phosphate and rock phosphate in the soil are broken down by these organic acids, making them available to the crop plants. Therefore,

using PSM as bio-fertilizers boosts the plants' ability to absorb P and enhances agricultural yield.

Crops for which PSM is intended: All non-leguminous vegetable crops, agriculture crops, horticulture crops and forestry crops.

3. **Mycorrhizal Fungi (Fungal Bio-fertilizer):** Mycorrhiza, which refers to the advantageous relationship between particular soil fungus and host plant roots, is defined as "Fungus Root" in the dictionary. Mycorrhizal colonizations are recognized to be highly advantageous for the host plants' nutrient intake from inadequate soils, particularly phosphate and nitrogen. There are different kinds of mycorrhizal fungi. Among them, the most widespread and relevant to agriculture, horticulture and forest trees are ecto and endomycorrhizal fungi.

   - **Functions of Mycorrhizal fungi**: Numerous advantages of mycorrhizal connections are received by the host plants. The main one is nutrient acquisition, and they make it easier for the host plants and the soil to exchange nutrients. The uptake of water, inorganic phosphorus, mineral or organic nitrogen, and amino acids is aided by the mycorrhizal fungi. The mycorrhizal fungus in turn provide the host plants carbon. Both organisms gain enormous benefits from this interaction. In regions where drought is frequent, the mycorrhizal fungi considerably expand the surface area of the plant's root system. This is also advantageous where the soil is deficient in nutrients. These plants have an advantage over others that lack this symbiotic association due to their increased surface area, which allows them to outcompete plants without mycorrhizae for nutrients. The mycorrhizal fungi also act as biological control agent against soil and root borne pathogens and offer the roots of the plant a little more protection.

   - **Ectomycorrhizal Fungi**: Ectomycorrhzial (ECM) fungi are symbiotic group of fungi, predominantly belong to Basidiomycetes and some are Ascomycetes. More than 7000 species of fungi form ECM (21), many of them with important commercial tree species such acacias, birch casuarinas, eucalypts, oak, pine, poplars, sal, spruce, etc. (22, 23; 24). The reproductive structures (fruiting bodies) of the macromycetes of ECM fungi are known as mushrooms when they grow in the soil and like truffles, when they grow underground. Few examples of these ECM fungi are *Amanita muscaria, Boletus* spp*., Boletellus* spp*., Laccaria laccata, L. fraterna, Pisolithus albus, P. tinctorius, Russula parazurea, Scleroderma citrinum, Suillus brevipes, Suillus subluteus, Thelephora terrestris, Tricholoma* spp., etc. The Hartig net acts as the interface for the metabolic exchange between the fungus and the host plant roots. The mobilization, absorption, and transport of soil nutrients and water to the roots of host plants are all directly facilitated by the mycorrhizal mangle, which is coupled to fungus filaments that extend into the soil (extraradical mycelium).

     Crops for which the ECM fungi are intended: Acacais, Birch, Casuarinas, Eucalypts, Oak, Pine, Poplar, Sal, Spruce, etc.

   - **Endomycorrhizal Fungi:** One of the main mycorrhizal forms that differs from ECM fungi in structure are endomycorrhizal fungi, also known as endomycorrhizae. The hyphae of endomycorrhizae not only grow inside the roots of the host plants, but also penetrate the root cell walls and become encased in the cell membrane, in contrast to ECM fungi, that forms a network of hyphae around the root cells. As a result, the symbiotic interaction between the fungi and the hoar plant becomes more invasive. A larger surface area of contact between the fungi's hyphae and the plant is produced by the penetrating hyphae. This makes it easier for nutrients to be transferred between the two species. The endomycorrhizal fungi have further been classified into five major groups: arbuscular, ericoid, arbutoid, monotropoid, and orchid mycorrhizae (25).

- **Arbuscular Myocorrhizal (AM) fungi:** The AM fungi are the group of endomycorrhizal fungi and it is the most prevalent and distributed in varied ecosystems. They occur in almost all families of flowering plants. Hence, plants with AM fungi are common in most habitats. Majority of AM fungal species belong to the sub-phylum Glomeromycotina, of the phylum Mucoromycota (26). Four orders of AM fungi, namely, Glomerales, Archaeosporales, Paraglomerales, and Diversisporales, have been identified in this sub-phylum that also include 25 genera (27). The important AM fungal genera are: *Acaulospora, Glomus, Gigaspora, Scutellospora, Entrophospora,* etc. The AM fungi produce single, thick walled spores which are present in the crop rhizosphere. Unlike the ECM fungi, AM fungi cannot be grown on synthetic medium. They are obligate symbionts and they require living host root system for their mass multiplication.

- **Arbutoid Mycorrhizal fungi:** Arctostaphylos and Arbutus are plant genera that have arbutoid mycorrhizae. Basidiomycetes make up the majority of the fungi that forms arbutoid mycorrhizal connections. In arbutoid mycorrhizal connections, the host plant's roots are encased in a fungal sheath or mantle, which is comparable with the structure of ECM linkages. A Hartig-net-like structure is also inserted by the fungus into the outer cortical cells. Through the mantle, nutrients are drawn up by the host plant's roots from the earth. The sheath can also be used as a storage space for extra nutrients and in low nutrient levels, the fungi releases the nutrients that have been stored into the plant. The main difference between arbutoid fungus and ECM fungi is that the arbutoid fungi's hyphae actually enter the plant root's outer cortical cells. As the hyphae coil up inside the cells, nutrients can get from the fungi to the plant and vice versa.

- **Monotropoid Mycorrhizal fungi:** Arbutoid mycorrhizae were once thought to be the group that included monotropoid mycorrhizae. Arbutoid mycorrhizal hyphae, as opposed to monotropoid mycorrhizae, can enter the host plant's cell walls and grow into substantial structures. These mushrooms often form symbiotic relationships with pine, spruce, and fir trees in the coniferous forests where they are most frequently found. They can, however, also establish monotrophoid mycorrhizal relationships with other trees, including beech, oak, and cedar. Monotropoid mycorrhizae produce a dense sheath around the roots of the host plant and a Hartig-net that encircles the outer epithelial layer of the root cells, similar to arbutoid mycorrhizae. Individual hyphae may then be able to penetrate the outer cortical cells thanks to the Hartig-net. These cells' walls are not penetrated by the hyphae; instead, they bend to provide space for the growing hyphae. It is known as a "fungal peg" when this type of growth occurs. These growths greatly increase the surface area of the cell, making it easier for nutrients to move between the fungal growth and the host plant. A membranous sac will eventually expand from the fungal peg into the cell's cytoplasm as a result of the fungal peg eventually bursting. The contents of the fungal peg fill the sac, but they never directly contact the cell's cytoplasm. It is believed that the fungal peg's burst causes a spike in nutrients to aid seed development.

- **Orchid Mycorrhizal fungi:** In general, when an orchid is in its seedling stage of life, it is not photosynthesizing. At this stage, the orchid is dependent on the mycorrhizal fungi to provide the nutrients, particularly carbohydrates, needed for the seedling's growth. In many cases, orchid seeds need to develop a relationship with a mycorrhizal fungus in order for them to begin to sprout. The mycorrhizal fungus can begin to develop a relationship with the seedling once the seed coat has split open as a result of water absorption and root hairs have appeared. The hyphae enter the embryonic cells and form peloton-shaped hyphal loops. Even if the orchid grows older, it still depends on the mycorrhizae for phosphorus and nitrogen as well as nutrients like carbohydrates.

4. **Potassium Mobilizing Bio-fertilizer:** Potash-mobilizing bacteria are capable of mobilizing the elementary potassium or mixture of potassium from the soil in a readily available form for the plant use. Seventy percent of insoluble potassium is made available to the crop plants within 25 days of the K mobilizing bio-fertilizer application to soil.

   Advantages of Potassium mobilizing bio-fertilizer: The potassium-mobilizing bacteria have the following advantages:

   - Enhances potassium nutrients to the crop plants.
   - Improves resistance to diseases in crop plants.
   - Resistant to a wide range of soil pH and temperature.
   - Suitable to all leguminous & non-leguminous crops, all vegetable crops, agriculture crops, horticulture crops and forestry crops.
   - Improves crop growth and yield by 20-30%.
   - Compatible with all other microbial bio-inoculants (bio-fertilizers).

   Crops for which intended: Potassium Mobilizing Bio-fertilizer can be applied to all leguminous & non-leguminous crops, all vegetable crops, agriculture crops, horticulture crops and forestry crops.

III. USE OF BIO-FERTILIZERS IN AGRICULTURE, HORTICULTURE AND FORESTRY CROPS

Numerous researchers have examined all microbial bio-fertilizers, including mycorrhizal fungi and PGPR, in a wide range of crops, including beet, beans, cotton, carrots coffee, coconut, corn, cucumber, oats, rice, sugarcane, sunflower, flax, tobacco, tea, wheat, potato, brinjal, pepper, peanut, tomato, sorghum, black pepper, strawberries, soybeans, , pines, Additionally, they interact both positively and negatively with the natural soil microbiota, take part in numerous ecological processes, and help plants grow by enhancing their ability to withstand biotic and abiotic stresses and supplying them with nutrients by fixing atmospheric nitrogen and solubilizing essential soil nutrients.

1. **Agriculture Crops:** Soybeans are the most significant example of the usage of bio-fertilizers in crop production. Inoculating the seeds with specific *Bradyrhizobium* spp. strains *such B. japonicum, B. diazoefficiens, and B. elkanii* is the primary method used to produce soybeans. When *Pseudomonas putida, Microbacterium laevaniformans, and Pantoea agglomerans* were combined with *Pseudomonas putida or P. putida*, it significantly increased biomass and facilitated the growth of potato tubers, according to research on the effectiveness of PSB organisms (29) in enhancing potato yield. The larger supply of phosphorus from the bacteria to the growing potato plants made it possible for the yield to be better. P. agglomerans considerably increased potato growth and yield among various PSB by about 20–25%. With AM bio-fertilizer inoculation and rising P levels up to 75% P_2O_5 dose, there was a noticeable improvement in the soil's available N and P status, while the maximum P buildup was achieved with the sole administration of 100% P_2O_5 dose in wheat crops. Overall, it was recognized that the use of AM fungal bio-fertilizer is advantageous in agro-ecosystems with minimal inputs of nutrients or low soil P (30). Numerous researchers in India have reported on similar types of studies on a variety of agricultural products.

2. **Horticulture Crops:** AM fungi are probably the most ubiquitous soil microbe that can colonize 80% of terrestrial plant species With The majority of soil microbes that can colonize 80% of terrestrial plant species are presumably AM fungus. AM fungi are undoubtedly the most prevalent soil microorganisms, with the capacity to colonize 80% of terrestrial plant species, including various horticulture (fruit) crops. In India and other countries, the AM fungal colonization has been shown to have a number of beneficial effects, such as increased seedling survival, improved growth, increased fruit yield and quality, uniformity of fruit crops, earlier and increased flowering, and induced resistance to abiotic and biotic stresses in various fruit crops, such as Apple, Litchi, Orange, Strawberry, Tamarind, etc. (31, 32, 33, 34, 35, 36, 37). *Tamarindus indica's* root colonization, external hypha count, and spore count all increased after soil inoculation with an AM fungal bio-fertilizer (31). There was shown to be an extremely substantial link between AM fungus and mandarin orange growth (33). The frequency of occurrence and level of colonization of AM fungus directly affect the growth of the apple tree's shoot extension (34). When AM fungi and Azotobacter chrococcum were used in various treatment combinations, Raj and Sharma (35) found that apple seedlings in solarized soil had longer shoots than those in untreated plots (35). A previous study found enhanced fruit yield of litchi trees on treatment with 150g Azotobacter + 100g AM fungi/tree and farm yard manure (FYM) (36). Similar kind of studies were reported on various horticulture crops by many researchers in India and elsewhere/

3. **Forestry Crops:** Different bio-fertilizers are used in forestry crops. Several studies by researchers all over the world evaluated the efficacy of mycorrhizal fungi (both ectomycorrhizal and AM fungi) and PGPR to various forestry crops and medicinal plants such as *Acacais, Ailanthus, Albizia, Bamboos, Cadamba, Casuarinas, Gmelina, Melia,* Neem, Red Sanders, Sissoo, Sandal, Teak, etc. (38, 39, 40, 41, 42, 43, 44, 45, 46).

Efficacy of different bio-fertilizer and organic products such as compost and vermicompost on the growth of *Tectona grandis* clones was studied and it was found that the plantlets grown with mixed inoculum of bio-fertilizers (AM fungi, *Azospirillum* and PSB) and 10g or 15g of vermicompost showed more shoot height, root length, collar diameter, shoot and root biomass, volume index and quality index (39). This was followed by the treatment with AM fungi + phosphate solubilizing bacteria + 10g or 15g of vermicompost. Treatment with triple combination of bio-inoculants and 15g compost also showed better growth performances. In general, the application of combination of bio-inoculants and biomanures showed significantly higher and better growth performances of the tissue culture raised plantlets of teak when compared to the uninoculated (control) plantlets during different period of the observation (39).

Tectona grandis and Phyllanthus emblica planting propagules (stumps) produced in a nursery were influenced by the application of bio-fertilizers (Azospirillum, PSB, and AM fungi), and it was found that seed germination was greatest in the Azospirillum treatment, followed by its combination with PSB and AM fungi. After 5 months, combinations of AM fungi + Azospirillum, AM fungi + PSB, and AM fungi + PSB + Azospirillum yielded the highest height of seedlings (40, 41). The use of AM fungus in combination with Azospirillum was determined to be the optimal treatment to produce high-quality teak planting propagules in nurseries based on the profit index.

The impact of different combinations of native dominant AM fungi *Glomus aggregatum* and PGPRs *viz., Bacillus coagulans* and *Trichoderma viride* on the growth, primary metabolites and phytochemical parameters of the medicinally important natural dye yielding plant *Indigofera tinctoria* by subjecting them to pot culture study and results of the study indicated that dry matter content of *I. tinctoria* was higher in *G. aggregatum* + *B. coagu*lans treatment whereas plant height, protein and amino acid contents were higher in G. *aggrega*tum coinoculated with *B. coagulans and T. viride* (42). Chlorophyll, carotenoid, lipid and phenol contents were higher in triple inoculation of *I. tinctoria* than the other treatments. It was also recorded that the inoculation of efficient AM fungi in combination with the two PGPRs had positively influenced the growth and phytochemical constituents of *I. tinctoria* whereas *B. coagulans* and *T. viride* as individual inoculations did not show any significant results *viride* (43, 44).

Ailanthus excelsa, Gmelina arborea, Melia dubia, and Neolamarckia cadamba are four fast-growing native tree species. Different bio-fertilizers like AM fungi and PGPR have been tested individually and in combinations on seed germination and survival of seedlings of these species against the plant pathogenic fungus, *Fusarium oxysporum*, which causes root rot in nurseries. The study's findings revealed that application of Additionally, the application of all four bio-inoculants together with *Fusariu*m in all four tree species produced the highest percentage of seed germination, which was followed by AMF + Azo + *Fusarium* in *Ailanthus excelsa, Gmelina arborea* and *Neolamarckia cadamba* and AMF + Azoto + *Fusarium* in *Melia dubia* (43, 44). Similarly, potential AM fungi have been identified for the growth of neem and studied various plant growth parameters after inoculation includes plant height, collar diameter, AM spore population, root colonization and phosphorous uptake ability and inoculation of AM bio-fertilizer consortia had increased the plant height up to 41% against the control and the phosphorus uptake was found to be increased in all AM fungi treated plants (47). Similar kind of studies was reported on various forestry crops by many researchers in India.

IV. CONSTRAINTS IN BIO-FERTILIZERS PRODUCTION AND USAGE

1. Use of ineffective strain.
2. More demand and less production.
3. Lack of knowledge on its importance and usage methodology.
4. Mutation during fermentation.
5. Quality control – lack of quality assurance.
6. Short shelf life of the product.
7. Non availability of good quality carrier material.
8. Lack of standardization in packaging.
9. Under performance in real life due to handling errors.

V. FUTURE PROSPECTS OF BIO-FERTILIZERS

Sustainable horticultural and agricultural products are in growing demand. As a result, in the years to come, there will be a major increase in the use of eco-friendly beneficial bacteria for food production, such as bio-fertilizers. In accordance with Development Sustainable Goal 12 established by FAO: "Ensure Sustainable Consumption and Production Patterns," government agencies and business will promote the increase in market value in order to improve awareness among farmers and consumers about the benefits of utilizing bio-fertilizers. Another approach to enhancing Rhizobacteria's growth-promoting traits is genetic alteration. Because of this, it's conceivable to identify PGPR genes and use them in transgenic or gene-editing procedures by taking advantage of certain plant-microbe interactions (48). Examples include the possibility that certain strains of the *Agrobacterium*, may promote plant growth on non-susceptible plant hosts (49, 50). These genes include those for phloroglucinol production and nitrogen fixation. Fertilizers based on nanotechnology *i.e.* nano fertilizers are non-toxic, increase nutrient use efficiency, and lower production costs. Longer PGPR release to the target cell will be made possible by the conjugation of gold, aluminum, and silver nanoparticles in the encapsulating of nano bio-fertilizers. (50).

VI. CONCLUSION

The energy expenditures of N fertilizers and the diminishing sources of P, together with a dwindling arsenal of insecticides and water restrictions, make current levels of high intensity agriculture unsustainable. Sustainable food production has proven to be effective when using bio-fertilizers. Numerous scientific studies confirm the advantages of PGPR in the development and production of a wide range of crops. The most significant species of mycorrhizal fungus, specifically Arbuscular Mycorrhizal (AM) fungi, are species of *Rhizobium, Azotobacter, Azospirillum, Bacillus, and Pseudomonas* and mycorrhizal fungi *viz*., Arbuscular Mycorrhizal (AM) fungi and Ectomycorrhizal (ECM) fungi. The tropical forests are being rapidly consumed at the rate of 14 to 18 m ha per annum due to shifting agriculture and over use of wood for paper, timber and fuel. In future, both agriculture and forestry will face challenges on the ecological, climatic and economic fronts. The increasing soil degradation, imbalances in regional productivity and environmental concerns are some of the issues for development of future research and development strategies for evolving sustainable resource management. This calls for developing innovative technologies which ensure better sustainable returns per unit area, at the same time do not degrade the environment. Bio-fertilizer technology can play an important role in production of low cost quality seedlings for afforestation reforestation programmes in forestry as well as healthy and quality yield in agriculture, horticulture and vegetable crops. Tree seedlings have evolved a beneficial mutual dependency upon mycorrhizal fungi for normal infections. Interactions between the host plants, mycorrhizae and soil largely determine the mycorrhizal effect on plant growth which is further conditioned by the variability in abiotic and biotic factors. A better understanding of the interrelationships among these various factors is needed and also is aimed at finding appropriate technology for large scale commercial multiplication and inoculation techniques of mycorrhizal fungi and PGPR bio-fertilizer inocula.

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