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To,

Dr. Savita D. Mali,
PG Department Of Microbiology
Vivekanand College, Kolhapur.

Subject: Letter of appreciation and thanks...

Respected Sir/Madam,

We hope this letter finds you in the best of spirits. We are writing to express our sincere gratitude for your invaluable book chapter **"Microorganisms - A Key To Sustainable Agriculture And Environment"** in book entitled **"Environmental Conservation, Sustainability and Climate Action"** with **ISBN No. 978-81-987675-1-6.** It has been an absolute pleasure working with you throughout the publication process, and we wanted to take a moment to convey our heartfelt appreciation for your dedication and commitment.

On behalf of VYD Publisher's, we would like to express our profound appreciation for creating awareness among the society on very important burning issue. We look forward to future opportunities for collaboration and wish you continued success in all your future endeavors.

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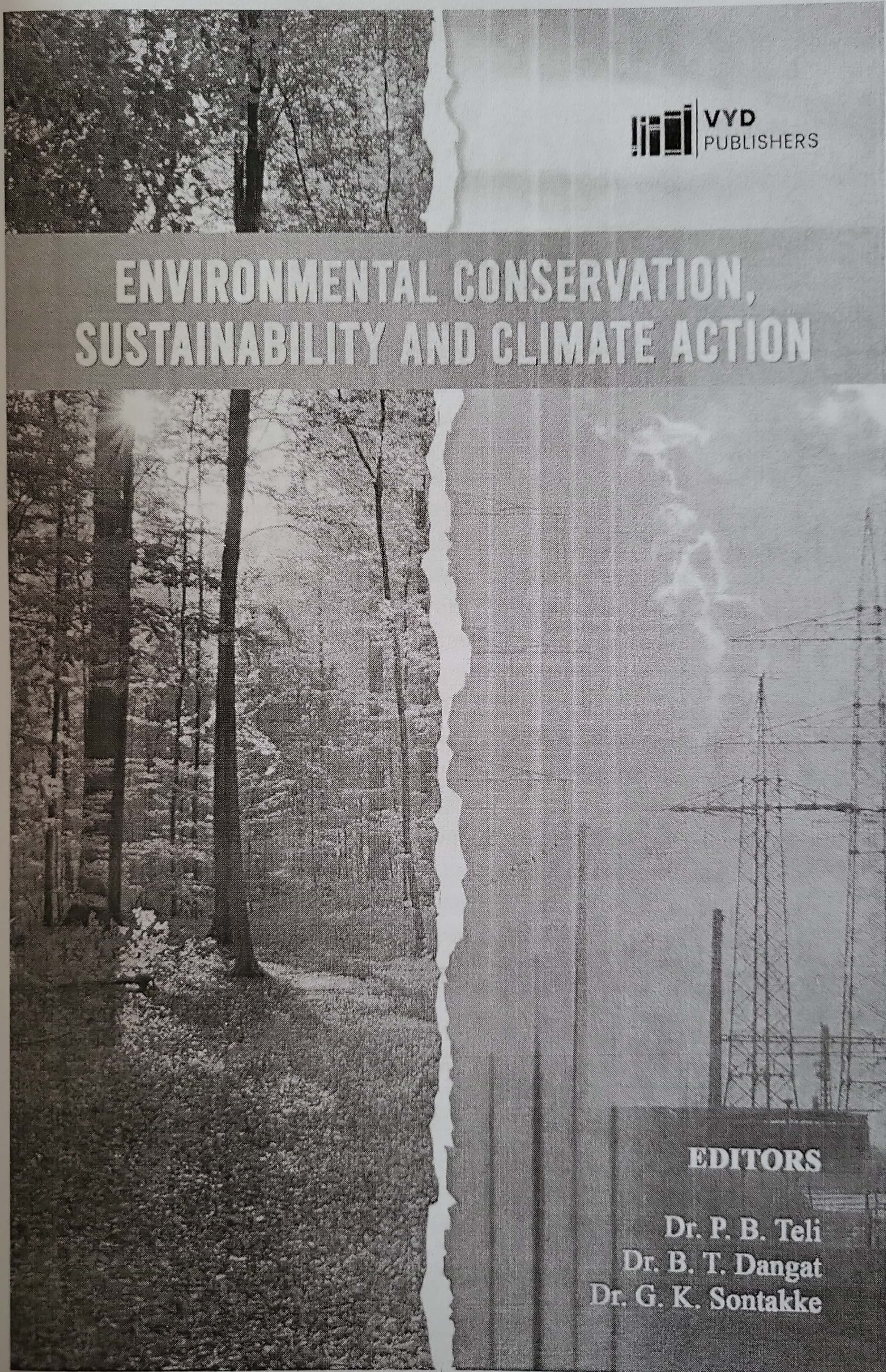

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ENVIRONMENTAL CONSERVATION, SUSTAINABILITY AND CLIMATE ACTION

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MICROORGANISMS - A KEY TO SUSTAINABLE AGRICULTURE AND ENVIRONMENT

- *Dr. Savita D. Mali*

Introduction:

World's population is exponentially growing everyday and it is supposed to increase up to 9.7 billion till 2025 (Poveda J., 2021). To feed this population, it is essential to increase the production of food. Thus, there is an urgent requirement to increase the production of crop. Plants need different elements for their growth and these are categorised as macro nutrients and micronutrients. Macronutrients primarily N, P, and K are required in large volume for plant growth. Micro nutrients like Fe, Mn, Cu, Zn, Mo, B, Cl, and Ni are required in less quantity for the growth of plants. Three main macronutrients nitrogen, phosphorous, and potassium are most important for the growth and development of plants (White P. and Brown P., 2010). These nutrients mostly are supplied in the form of chemical fertilizers like urea (N), calcium nitrate (N), ammonium sulfate (N), diammonium phosphate (N and P), muriate of potash (K), etc. (Thomas L. and Singh I., 2019).

These chemicals act as 'fast foods' for plants causing them to grow faster and vigorously. However, at the same time, these chemicals generate harmful impacts on living beings and the environment. Indiscriminate usage of chemical fertilizers is becoming a curse for the ecosystem as it is threatening several troublesome issues such as pollution of water resources leading to eutrophication, increase in soil salinity, global warming, development of acid rain and health problems (Adesemoye A. & Kloepper J., 2009). The toxic chemicals released from fertilizers get absorbed into the plants and finally enter the food chain through vegetables and cereals. However, the largest health risk is when the chemicals flow into groundwater and finally get access into the human body through drinking water. Contaminated water may carry high levels of nitrates and nitrites, causing haemoglobin disorders. Ingestion of phosphate fertilizers can develop chronic kidney diseases. Ammonium nitrate exposure causes eye and skin irritation, nausea, vomiting, etc. (Nganchamung T. et al., 2017).

Chemical fertilizers may cause long-term damage to the land, ultimately making the land less fertile or non-fertile. Moreover, chemical fertilizers are uneconomical because of the production process or because of the need for their importation. Owing to all these negative impacts of chemical fertilizers, it is essential to increase the usage of fertilizers that are economical and made by using natural resources that are safe for mankind and environment friendly. One of the alternatives to chemical fertilizers is microbial inoculants which are cost-effective and can assist to maintain human and environmental health.

Soil microorganisms play an important part in the biogeochemical cycles of nutrients (Hayat R. et al., 2010). A variety of soil microorganisms found in the rhizospheric area of plants, have capability to enhance the yield of crop as well as the nutritional quality of agrarian products (Gouda S. et al., 2018). These useful microorganisms of soil are inclusively called as plant growth promoting microbes (PGPM). A very large quantity of bacteria, fungi, and some algae, and actinomycets were identified beneficial for the growth and development of plants. Bacterial genera (called as plant growth promoting rhizobacteria - PGPR) such as *Azospirillum, Azotobacter, Alcaligenes,* *Arthrobacter, Burkholderia, Bacillus, Enterobacter, Klebsiella, Pseudomonas, Rhizobium, Serratia,* etc. (Bhattacharyya P. and Jha D., 2012), fungal genera (called as plant growth promoting fungi - PGPF) such as *Aspergillus, Alternaria, Penicillium, Pythium, Phoma, Rhizoctonia, Trichoderma, Phytophthora, Rhizopus, etc.*, algae like blue green algae such as *Nostoc, Anabaena, Oscillatoria,* and *Spirulina*, and actinomycetes such as *Frankia, Streptomyces, Nocardia*, and *Micromonospora* have been reported by many researchers contributing for plant development. Plant growth promoting microbes enhance the growth of plants through various direct mechanisms which results into nutrient availability to plants and a number of indirect mechanisms that help plants to manage abiotic and biotic stresses of environment.

Plant growth promoting microbes (PGPM) as bioinoculant for plants

Bioinocualnts are live cultures of beneficial microbes (PGPM) which make available different nutrients to plants in utilisable form. In the 21st century, microbial inoculants which are also referred as biofertilizers are emerging as a viable substitute for sustainable crop production. These are prepared as liquid as well as solid (carrier based) formulations. The production method of biofertilizers includes selection of strain, cultivation of selected strain in suitable nutrient medium, formulation, quality testing, and packaging

Production of bioinoculant

Selection of strain: The plant growth promoting microbial strains having desired characteristics is isolated from soil using selective culture medium. Further the most potent strain is screened from all isolated strains by studying various properties of all strains

Mass production: The selected microbial strain is then cultivated using suitable nutrient medium to achieve high cell densities.

Formulation: To prepare solid / carrier based bioinoculant, high count broth is mixed with a suitable carrier. A carrier material is an inert material which supports the growth of the organism. A suitable carrier material such as peat, lignite, charcoal, farm yard manure etc. is selected based on its availability, organic content and moisture holding capacity. The mixture is then incubated at room temperature for 3 to 5 days for acclimatization of culture with the carrier material.

Quality testing and packaging: The prepared bioinoculant is tested for its viability by determining colony forming units so as to ensure the required number of viable cells in the product. Finally, carrier based inoculant is packaged in appropriate containers, such as low-density polyethylene bags.

Application methods of bioinoculant: Different techniques like soil, seed, root and foliar application are employed for bioinoculants (Yang P. et al., 2024). The foliar inoculation method is least used method, while seed inoculation is the most used methods.

Soil inoculation: For soil treatment, bio inoculants are mixed with compost fertiliser and mixture is kept overnight. Then mixture is spread into the soil where seeds are to be sown.

Seed inoculation: In case of liquid formulation, bioinoculant is sprinkled on the heap of seeds and mixed manually. Then seeds are then dried for half an hour and sown immediately. In case of solid formulation, slurry of bioionculant is prepared in water jaggery mixture. The seeds are added into the slurry and mixed well. The seeds are then sown into field after drying for one hour.

Seedling inoculation: This technique applies bioinoculant on the roots of plants hence it is also named as root inoculation technique. In this method, roots of seedlings are dipped into the slurry of bioinoculant for half an hour and then seedlings are planted into the field.

Mechanisms of plant growth promotion by PGPM

Direct mechanisms

Nitrogen fixation: Nitrogen is most essential nutrient for the growth of plants and it is involved in the synthesis of proteins, nucleic acids and other cell constituents. Atmosphere contains 78% of nitrogen. However, plants are unable to utilize the gaseous form of nitrogen. A very large number of soil microorganisms (Table 1) have ability to fix atmospheric nitrogen with the help of enzyme nitrogenase (Church M. Et al., 2008). Many of bacteria, fungi, algae, and actinomycetes have ability to convert atmospheric nitrogen to ammonia which is then readily utilized by plants.

Mineral solubilisation: It includes conversion of insoluble nutrients like P, K, and Zn present in soil to soluble form. Microorganisms carry out this conversion through different mechanisms like production of acids and enzymes.

Phosphorous solubilisation: Phosphorous is another important element for the growth and development of plants. It is essential for synthesis of nucleic acids, proteins, and energy. A very little amount of phosphorous is present in soluble form in soil. A very large number of rhizospheric bacteria and fungi (Table 1) have ability to convert insoluble phosphorous to soluble form and make it readily available for plant uptake (Zhang T., et al., 2019).

Potassium solubilisation: Potassium is one of the key elements essential for growth of plants. It acts as activator for number of enzymes in plants. Like phosphorous, potassium (K) is also present in plentiful quantity in soil. However, only 0.1% K is in soluble form and utilised by plants. Potassium solubilising bacteria and fungi (Table 1) present in all types of soil and convert insoluble K to soluble form of K which is easily taken up by plants.

Zinc solubilisation: Among all micro nutrients, zinc is a rather unique element for plant nutrition. It acts as a cofactor for number of enzymes, thus it is required for optimum plant growth (Javed H., 2012). The zinc requirement of various crops is fulfilled by external supply of soluble zinc in the form of fertilizer. But nearly 96 to 99 % applied soluble zinc get transformed to various unavailable forms (Bapiri A. et al., 2012). Zinc solubilising microorganisms present in the soil convert insoluble zinc to soluble form and thus help plants to satisfy the zinc requirement.

Production of siderophores: Siderophores are low molecular weight compounds having high iron affinity and secreted by microorganisms (Table 1) during iron deficiency. Iron is essential for the growth of all living cells. It acts as a cofactor for number of enzymes as well as involved in DNA, RNA synthesis Though abundant iron is present in the soil, its low solubility under aerobic conditions and neutral pH makes it a limiting element for plants. Siderophores secreted by rhizospheric microorganisms scavenge iron from the environment and form a complex with it. This complex is taken up by the cells as well as it is easily taken up by the plant roots.

Table 1 Microorganisms promoting plant growth

Characteristic	Type of microorganism	
	Bacteria	**Fungi**
Nitrogen fixers (Symbiotic and Non symbiotic)	*Rhizobium, Azotobacter, Azospirillum,*	Arbuscular mycorrhizal fungi
Phosphate solubilizers	*Klebsiella, Burkholderia, Enterobacter*	*Aspergillus, Fusarium, and Penicillium*
Potassium solubilizers	*Bacillus, Klebsiella, Enterobacter*	*Aspergillus, Penicillium*
Zinc solubilizers	*Acetobacter, Bacillus, Pseudomonas*	*Aspergillus, Penicillium, and Fusarium*
Siderophore producers	*Bacillus, Rhizobium, and Enterobacte*	*Aspergillus,* Arbuscular mycorrhizal fungi
Plant growth hormone (indole acetic acid, gibberellins, cytokines) producers	*Acetobacter, Bacillus, Pseudomonas*	*Fusarium, Trichoderma*

Production plant growth hormones

Many plant growth promoting microbes are known for their ability to produce phytohormones (Table 1) such as auxins, gibberellins, and cytokinins (Gupta et al., 2015), which play an important role in boosting plant growth and development. Indole acetic acid (a type of auxin) is primarily produced in the rhizosphere and is involved in promoting root elongation, root hair formation, and lateral root development, which collectively increase the plant's ability to absorb water and nutrients.

Gibberellins are involved in promoting seed germination, stem elongation, and flowering. Cytokinin is another class of phytohormones produced by plant growth promoting microbes that play a vital role in cell division, shoot initiation, and leaf expansion. These phytohormones interact with auxins to regulate various aspects of plant growth and development, including delaying leaf senescence and enhancing chlorophyll production (Chaudhary P., 2022).

Indirect mechanisms

Production of antibiotics: The major challenge in front of plant pathologists is to protect plants from soil borne plant pathogens and control of pest. The management of plant diseases and pest involves application of fungicides, bactericides, insecticides, etc. However, applications of these chemicals result in environmental pollution and resistance among pathogens.

Antibiotics are low molecular weight substances that are produced by one type of organisms and inhibitory to other organisms. Plant growth promoting microorganisms (PGPM) like *Bacillus* and *Pseudomonas* are reported to produce antibiotics which inhibit the growth of plant pathogens (Wang Y., 2024). Besides this, these antibiotics also appeared to have insecticidal, antiviral, and antihelminthic properties. Due to these properties, such microorganisms protect plants from pathogenic organisms and pests.

Reduction in heavy metal content of soil: /Hyper accumulations of poisonous metals like cadmium, lead, arsenic, and mercury in soil result in extraordinarily decrease in crop productivity. A variety of bacteria and fungi present in soil have been reported to reduce toxicity of heavy metals through various mechanisms like bio absorption, precipitation, oxidation, reduction, etc. (Sharma and Archana, 2020)

Decrease in salinity of soil: Agriculture sector is facing a big problem of saline soils in many areas of world. Saline soils are exerting tremendous impact on agro-economy. Various studies identified the importance of PGPR to enhance growth and productivity in salt stressed plant for sustainable agriculture (Venkateswarlu et al., 2008). Halo tolerant plant growth-promoting rhizobacteria (HT-PGPR) can reduce soil salinity by improving plant tolerance to salt stress and promoting soil health

Production of enzymes: Some PGPR are appeared to produce variety of enzymes which play an important role in plant development. These enzymes include chitinases, proteases, glucanases, cellulases, urease and catalase; most of which are effective against fungal pathogens. These hydrolytic enzymes cause the lysis of the phytopathogens.

Soil bioremediation: A variety of pollutants in the form of chemical pesticides, chemical fertilizers, heavy metals, hazardous waste, industrial waste are getting added in huge quantity into the environment through various human activities. These pollutants are posing a serious threat to soil, water, and air ecosystem. Plant growth promoting microbes play an important role in bioremediation of pollutants. It has been reported that these microbes can solubilize and degrade various kind of pollutants including herbicides, hydrocarbons, and explosives, etc. (Singh A. & Cameotra S., 2013) and thus help to maintain a sustainable environment.

Conclusion:

Thus, microbial bio inoculant is a boon for farmers and plays an indispensable role in maintaining long term fertility of soil. In a changing climate and unexpected weather patterns farmers face crop failures which lead to food instability and economic loss to farmers. Usage of plant growth promoting microbes as bioinoculants could help farmers to get stable crop yields and alleviate the effects of climate-related pressures. Bioinoculants are natural, organic, biodegradable, environment-friendly and cost-effective in nature. Further, the microbes present in the bio inoculants not only provide nutrients to plants in suitable form but also help plants to manage abiotic stress created in the environment.

Similarly, the plant growth promoting microbes protect plants from biotic stress such as pathogens and pest and hence also function as bio control agents. Microbial inoculants also improve the physical properties, fertility and productivity of soil, reducing the need for chemical fertilizers while maintaining high crop yield. This makes bio inoculants a powerful tool for sustainable agriculture and a sustainable environment. Thus microbial inoculants are one of the key answers and have to be taken into account to establish a sustainable farming system that will feed the entire world while making a profit and improving both human and environmental well-being.

Bio inoculants do not have any disadvantages. However, they have limitations regarding their shelf life. Hence, agronomists have to work and develop formulations that increase the shelf life of the bioinoculant organism so that these could be used widely by farmers.

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