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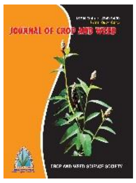

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Review Article

Bio-fertilizer : A sustainable way for soil amelioration

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ABSTRACT

One of the main problems in agriculture due to climatic change is production of enough food on a sustainable basis for a rapidly expanding population. Enhancing soil productivity through nutrient management is a vital method for maintaining food and nutritional security. This is a significant strategy for achieving crop development and productivity and is determined by how readily the nutrients are available to the plant. At present, crop nutrient requirement is mainly supplied through chemical fertilizers. However, perpetual and excessive use of chemical fertilizers to supplement the nutrient requirements of crops witnessed severe deterioration of physical, chemical, and biological characteristics of the soil. Besides, it triggered pressing environmental issues endangering agricultural sustainability. Investigating the latent potential of organic sources as an alternative to chemical fertilizers is required to address this issue. Bio-fertilizer are widely gaining popularity among various organic sources due to their recognized role in improving nutrient use efficiency, reclamation of degraded soil, nitrogen fixation, etc. Microbial bio-fertilizers were reported to enhance the rate of mineralization thus improve soil fertility and biochemical properties of soil. Therefore, it is identified as an ecologically safer and economically viable option that addresses the global demand for green technology in crop production. The primary goal of this study was to investigate how bio-fertilizers might improve soil fertility and promote agricultural sustainability.

***Keywords*: Beneficial micro-organisms, bio-fertilizers, SDG's Soil fertility and sustainable agriculture**

Soil fertility is the most significant factor restricting crop productivity in under developed countries worldwide, particularly among farmers with little resources (Mizik, 2021; Wang, 2022). Understanding the principles of farming practice is necessary in many parts of the world to maintain soil quality, soil health which helps to address the issues of soil loss, deteriorating soil fertility, and declining productivity levels (Sampathkumar *et al.*, 2019). Chemical fertilizers are industrially manufactured products that include known percentage of nitrogen, phosphorous and potassium (Kumar *et al.*, 2019; Sheikh *et al.*, 2022). In spite of this, using insecticides accelerates the process of soil acidification, contaminates air, water, soil and damages plant rhizospheres and makes plants more vulnerable to susceptible pests and diseases (Ammar *et al.*, 2022). To avoid these problems recent endeavour have been made to produce nutrient-rich, high-quality fertilizer to ensure bio-safety and thereby helps in the reduction of chemical fertilizers (Itelima *et al.*, 2018). A bio-fertilizer is a microbial inoculant made of algae, bacteria and fungal organisms used alone or in combination to improve soil health by turning inaccesible nutrients into available form through biological processes (Zainuddin *et al.*, 2022). These bio-fertilizers plays a key role in increasing crop output and soil fertility for sustainable farming, and act as a substitute for chemical fertilizer (Tomer *et al.*, 2016; Kumar *et al.*,2018; Asoegwu *et al*., 2020).

It is an essential component in integrated nutrient management (Bhardwaj *et al.*, 2014) and contains a wide range of beneficial bacteria and fungi, including arbuscular mycorrhizal fungi (AMF), also known as plant growth promoting rhizobacteria (PGPR) and nitrogen fixers (Fasusi *et al.*, 2021) when it is added to the soil it maintain soil environment as it is rich in macro and micro nutrients. For farmers, these fertilizers offer the best value and environmental protection.

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The use of microbial inoculants in agriculture is a long- term procedure that farmers have used for many centuries (Mohammadi and Sohrabi, 2012). It began with a tradition of small-scale compost manufacturing, which clearly demonstrated the effectiveness of bio-fertilizer. The first bio-fertilizer to be produced commercially was "Nitragin" by Nobbe and Hilther in 1895 (Chakraborty and Akhtar, 2021). The discovery of *Azotobacter,* blue-green algae, and numerous other microbes came into use in current situations. Recent applications of *Azospirillum* and vesicular arbuscular mycorrhizae (VAM) were recognized when the culture produces a robust crop yield and speeds up the decomposition of organic wastes and agricultural byproducts through a variety of mechanisms (Singh *et al.*, 2016). Bio-fertilizers are divided into various categories depending on the type or group of microorganisms they contain.

Table 1: Classification of bio-fertilizers

Bio-fertilizers	Group	Example	Mechanism	References
Nitrogen fixing	Bacterial Symbiotic	*Rhizobium Azospirillum spp.,*	Increases Soil Nitrogen levels by fixing atmospheric nitrogen and making it available to plants.	Nosheen *et al.*, 2021
	Free Living	*Azotobacter Klebsiella* spp.,		
Phosphorus mobilizing	Mycorrhiza	*Arbuscular mycorrhiza, Acaulospora* spp.,	Phosphorus moves from the soil to the root cortex and helps in root development.	Nosheen *et al.*, 2021
Potassium solubilizing	Bacteria	*B. edaphicus, Arthrobacter spp., and B.circulanscan*	Produces organic acids that dissolve potassium silicate ions so that plants can get them.	Etesami *et al*., 2017
	Fungi	*Aspergillus niger*		
Potassium mobilizing	Bacteria	*Bacillus* spp.	They transport potassium from inaccessible soil forms.	Jha, 2017
	Fungi	*Aspergillus niger*		
Phosphorus solubilizing	Bacteria	*Pseudomonas striata, Agrobacterium Micrococcus*	Turning insoluble P in the soil into soluble forms, organic acids are secreted, lowering the pH of the soil.	Nosheen *et al*., 2021
	Fungi	*Aspergillus awamori, Trichoderma spp., Penicillium spp.,*		
PGPR	Plant Growth Promoting Rhizobacteria	*Pseudomonas* spp. *Enterobacter, Streptomyces, Xanthomonas, Erwinia*	Produce hormones and increase nutrient availability and increase yields.	Nosheen *et al*., 2021

Importance of bio-fertilizers in improving soil fertility

Bio-fertilizers are necessary to restore soil fertility and texture thus improving soil health and in increasing crop yield (Kawalekar, 2013; Ramteke *et al.,*2023). A good carrier material such as peat soil lignite, vermiculite, charcoal, farm yard manure are used to produce good fertilizer (Kannan and Moorthy, 2022; Thomas and Singh, 2019). It enhances the water holding capacity, nutrients and vitamins present in the soil (Asoegwu *et al.*, 2020). The microorganisms in the bio-fertilizers contribute to the increased availability of phosphorus and nitrogen in the soil (Subbarao, 1984). These microbial inoculants are economical and environmentally friendly (Mohammadi and Sohrabi, 2012; Riaz *et al.*, 2020). They aid in the growth and survival of other beneficial micro-organisms. It protects crops from soil-borne diseases. Bio-fertilizer serves as a buffer against sudden changes in soil pH (Patra *et al*., 2021).Calcium carbonate can counteract the carrier material's acidic character because it is an acidic substance. Blue green algae can regulate the salinity of the soil. It increase the quantity of accessible phosphorous, zinc, and iron in soil in addition to nitrogen (Mekki and Ahmed,2005). They can, at most, reduce the application of chemical fertilizers in agronomic and pest-free environments. They support chemical fertilizers in order to meet the soil's integrated nutritional demand. Indole acetic acid (IAA), gibberellic acid, and other substances that promote growth are produced in response to several bio-fertilizers. They function as antagonists and reduce the occurrence of soil-borne plant infections, aiding in disease bio-control.

Bio-fertilizers as a sustainable tool

Sustainable agriculture is creating safe, high-quality agricultural products in an effective way that improves the social and economic circumstances of farmers, the environment, and people's health and welfare (Adegbeye *et al.*, 2020). Use of fertilizers, pesticides, and other inputs that benefit plants while causing no or little environmental harm is crucial for a sustainable agricultural system (Gomiero *et al*., 2011). Using microbial inoculants is one of the potential techniques to reduce the use of chemical fertilizers and pesticides. Now a days environmentalists are pushing for a shift to organic farming and bio-fertilizers in the market and society to maintain environmental imbalance (Umesha *et al.*,2018). By utilising beneficial bacteria in sustainable agricultural production, there will be a major emphasis on ecologically friendly and safe practices in the coming decades (Das *et al*.,2022). When introduced to the soil ecology, these micro-organisms represent an extensive range of naturally occurring bacteria that enhance the soil's physico-chemical characteristics, microbial biodiversity, and overall health. The number of mycorrhizae, *Azotobacter*, *Azospirillum*, rhizobium, cyanobacteria, phosphorus and potassium-solubilizing microorganisms, and others increased in the soil during no-tillage (Yadav and Sarkar, 2019).

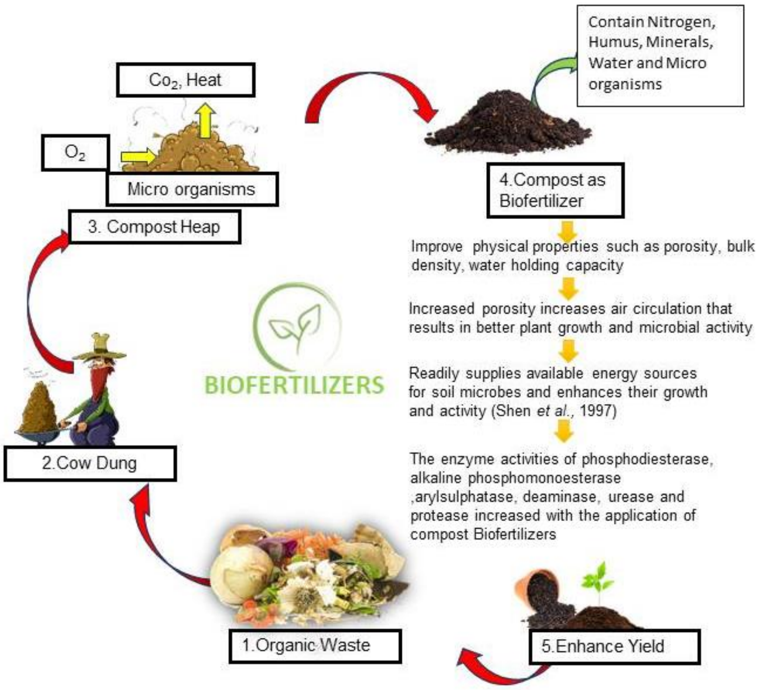


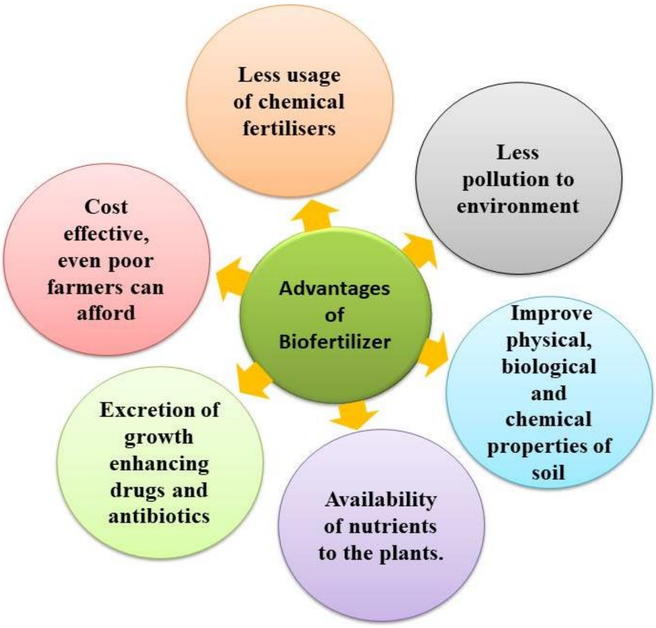
Fig. 1: Pathway of bio-fertilizers and their mode of action

Pathway of bio-fertilizers in soil

The amount of organic waste and animal dung are decomposed to improve soil microorganisms such as nitrogen and phosphate solubilizing bacteria, as well as many decomposing fungi which helps in improving the amount of humus and minerals (Singh *et al.*,2020). The bacteria such as *Azotobacter*, cellulosing fungi use low molecular weight organic acids like citric and gluconic acids to covert insoluble form into soluble form (Soumare *et al.*, 2022; Duarte *et al.*, 2022). These solubilized and mineralized molecules are absorbed by plants, which significantly enhances plant growth and agricultural yield by improving physical properties of soil and better aeration to the plant. Microbes also help in break down organic stuff such as dead plants, farmyard waste, cattle waste, etc. to improve the fertility status of soil.

Advantages of bio-fertilizers

Due to quick action and faster nutritional release, inorganic fertilizers have gained enormous popularity globally. However, plenty research has been made on the drawbacks of inorganic fertilizers, and reported, the drawbacks cannot be ignored (Gilbert, 2012; Guo, 2021). The usage of inorganic fertilizers contributed to a vast array of issues and accompanied environmental degradation (Sharma *et al.*, 2021). Bio-fertilizers serve as food sources that are regenerative and support soil health. They replace chemical fertilizers by 25% to 30% and boost grain yield by 10 to 40% (Ajeng *et al.*, 2020; Daniel *et al.*, 2022). They regulate the soil's C:N ratio and breaks down plant residues. They aid in enhancing the soil's structure, water-holding capacity and soil texture without affecting soil fertility and plant growth. They are categorized as non-pollutants, cost-effective and environmentally friendly (Pal *et al.*,2015). They mobilize and solubilize nutrients for the soil and plant, respectively. Utilizing bio-fertilizer does not cause the problem of excessive application, or does not the use of particular expertise (Kuila and Ghosh, 2022). Bio-fertilizers have a history of due to the delayed release of nutrients, they have long-term impacts. They distribute their nutrients to plants over the course of more than one season, slowly and consistently (Kothari and Wani, 2021). As a result, regular use of bio-fertilizer increases soil fertility overall by causing nutrients to accumulate in the soil (Hafez *et al.*, 2021). Additionally, it has been discovered that bio-fertilizers can aid in the management of plant diseases such pythium root rot, rhizoctonia root rot, frost wilt, and parasitic nematodes (Gupta *et al.*, 2015). Bio-fertilizers contain many including trace elements which are often absent in inorganic fertilizers.



Constraints in bio-fertilizer technology

- In rural and remote areas, it is difficult to sell bio-fertilizer to a retailer as it acts more slowly than chemical fertilizer (Yadav and Sarkar, 2019)
- It is very difficult to store bio-fertilizers due to the changes in temperature and humidity changes, it should not be exposed to extreme temperatures before use (Sahu and Brahmaprakash, 2016).
- The nutrient content is less in bio-fertilizer when compared to inorganic fertilizers, which is the major limitation of bio-fertilizers which leads to cause deficiencies in cultivated plants. Additionally, using nutrient-rich waste materials to create bio-fertilizer, including palm wastes and wood ash which is rich in potassium and helps to reduce deficiency symptoms. Phosphorus addition to wastes enhances the bio-balance of fertilizers and reduces N losses (Tan and Lagerkvist, 2011)
- Lack of carrier and storage material for inculation of microbes.
- Bio-fertilizer should be kept at room temperature or in cold storage areas out of the sun and heat.
- The materials such as peat, lignite, charcoal, farmyard manure, soil, and rice bran should be used to increase the shelf life
- Farmers are not aware of the benefits of using bio-fertilizers and the harm that cause due to continual use of inorganic fertilizer to the ecosystem (Kumari, 2019).
- Another issue is a lack of sufficient human resources and trained workers. Due to inadequate and unskilled farmers not receiving knowledge required for the application of bio-fertilizers.
- The utilisation of bio-fertilizers is impacted by soil properties as salinity, acidity, dryness, and water logging.

Future scope

As bio-fertilizers is safe for the environment and can help to ensure the sustainability of agriculture, these are the perfect substitute and answer to many problems that exist in current agricultural system (Kuila and Ghosh, 2022). It has ushered in a new era in the production of field grains and raised the possibility of a second green revolution despite several challenges linked to its production, consumption, applications, and commercialization (Conway, 2019). Furthermore, because this fungus is essential for soil conservation and agricultural management, there is a need for extensive research and development on bio-fertilizers and a good culturable strategy for its growth in the laboratory (Mahanty *et al*., 2017). Many other microbes' potential for usage as bio-fertilizers has yet to be thoroughly investigated (Igiehon and Babalola, 2017). Therefore, hunting for such helpful microbes is necessary to preserve agriculture. The usage of bio-fertilizer has several restrictions because it can be impacted by soil native bacteria and ecological factors (Carvajal-Muñoz *et al*., 2012). To receive the best response from bio-fertilizer in all environmental circumstances and soil types, the focus should be shifted to overcoming these constraints in the future. Inadequate amounts of nutrients especially phosphorous have built up in soils if the farmers' unknowingly apply the chemical fertilizers during intensive agricultural operations, renderings the soil dead (Kombiok *et al*., 2012). Because of this, there is a considerable need to develop research interest on effective and long-lasting bio-fertilizers for crop plants, which allow for a large reduction in the use of inorganic fertilizers to prevent further pollution issues (Puglia *et al*., 2021). It entails conducting short-, medium-, and long-term research projects that bring together the expertise of soil microbiologists, agronomists, plant breeders, plant pathologists, nutritionists, and economics.

CONCLUSION

Fertilizers are used to help feed the growing population since the population is growing. Given that the population is expanding, fertilizers are utilised to assist production of food. In response to the "Green Revolution," the production of food grains has increased. But over time, it became clear that chemical fertilizers have a lot of negative side effects, such as polluting the air, water, and soil, spreading plant illnesses, and breeding new pests which ultimately lower the productivity of the arable land. These elements have made it difficult for agriculture to remain sustainable in the long run and developed bio-fertilizers as a potential alternate remedy for the sustained agriculture production. To advance bio-fertilizer technology, it is crucial to thoroughly understand the ecology and dynamics of soil microbes in addition to external and internal elements. The creation of new technologies for effective production systems with advantageous and modified microbes, better handling systems, and extended storage shelf-life would undoubtedly improve the widespread acceptance and use of bio-fertilizers as a sustainable alternative to the current agriculture production system.

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