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Biofertilizers: A Potential Solution to Improved Soil Biology in the Desert

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Introduction

Biofertilizers are soil biological supplements containing microorganisms in organic media that potentially impact plant growth by improving nutrient availability. These organisms can mobilize nutrients like nitrogen and phosphorus by converting them from organic or complex forms (organic nitrogen, calcium-bound phosphates) into more labile inorganic forms (nitrate-nitrogen or orthophosphates) that are readily available to plants. These organisms can also produce chemicals (biomolecules) that promote plant growth. By contributing to improved soil and plant health, biofertilizers may reduce the need for supplemental synthetic fertilizers, which further contributes to soil and environmental health. Excessive use of synthetic fertilizers can lead to increased soil salinity, greenhouse gas emissions, and water pollution. Therefore, effective use of biofertilizers may promote long-term, eco-friendly, sustainable farming practices in arid desert regions by providing ecosystem stability, and minimizing pollution (Giri et al., 2019), as depicted in Figure 1.

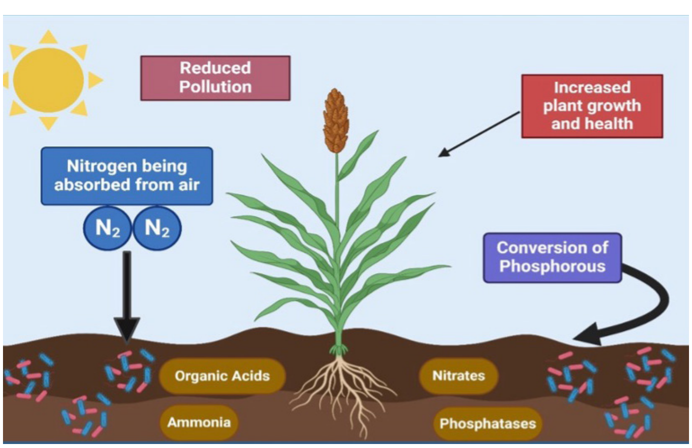

Figure 1. Role of biofertilizers in enhancing plant and soil health.

Why desert soils need biofertilizers

Agriculture in desert soils presents numerous challenges that must be addressed to achieve sustainable crop production, however, biofertilizers can impart resiliency in desert agroecosystems. Soil organisms, especially microbes (e.g., fungi, bacteria), struggle to thrive and proliferate in arid environments because of extreme soil moisture conditions (frequent droughts), low soil organic carbon (SOC), extreme temperatures, and high salinity. These conditions contribute to reduced microbial activity in desert soils that adversely impact nutrient availability to crops (Naorem et al., 2023), and may subsequently hinder crop production. While biofertilizers should not be considered a silver bullet for all problems related to soil management and crop production issues, they may help manage some of the most common issues desert agriculture faces due to the declined activity of essential soil microorganisms that carry out nutrient cycling to support plant nutrition.

Different Types of Biofertilizers Used in Commercial Agriculture

There are different groups of commercially available biofertilizers that can be used for agricultural purposes (Figure 2). **Nitrogen Fixing Biofertilizers**: These biofertilizers contain microorganisms such as *Rhizobia* (bacteria) that reside in the roots of legume plants (alfalfa, peas, beans) and maintain a symbiotic relationship. These bacteria can transform atmospheric nitrogen into plant-accessible forms, in exchange, plants provide essential carbohydrates to the bacteria residing in root nodules (Figure 3). **Phosphate Solubilizing Biofertilizers**: Arid soils are generally highly alkaline (pH above 8), which promotes the stability of insoluble phosphorus complexes in soil, making phosphorus unavailable

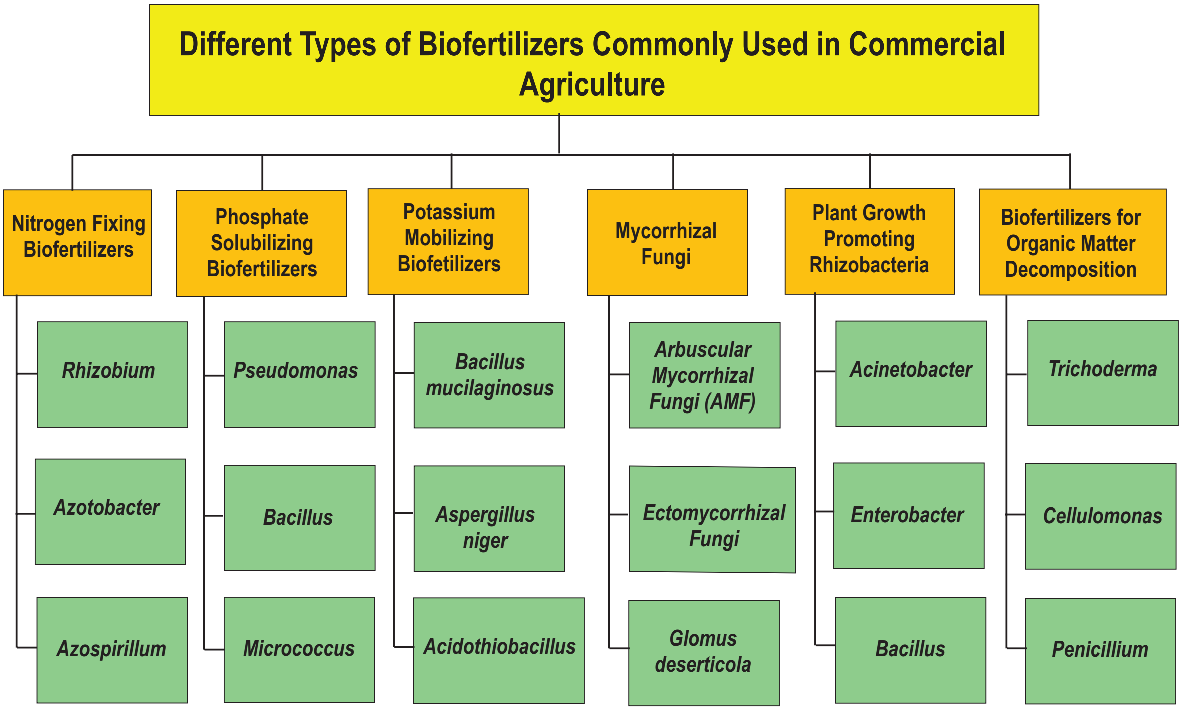

Figure 2. Different types of biofertilizers commonly used in agriculture

for plant uptake. Phosphate-solubilizing biofertilizers include microorganisms known as *Phosphate Solubilizing Microorganisms* (PSMs) such as bacteria (*Pseudomonas, Bacillus, Micrococcus*) and fungal groups (*Penicillium, Aspergillus*) that convert insoluble phosphorus to soluble, crop-available forms. **Mycorrhizal Fungi:** Arbuscular mycorrhizal fungi (AMF) create intricate networks with the roots of higher plants (Figure 3). This network increases the surface area of the roots, allowing plants to absorb more water and nutrients (particularly phosphorus) using this extended root surface. This may help plants stay healthy by resisting disease, nutrient deficiencies, and surviving dry conditions. **Plant Growth Promoting Rhizobacteria (PGPR):** These are beneficial bacteria that live in the rhizosphere (root zone) that colonize plant roots and promote plant growth by a variety of methods, such as growth hormone production, minimizing abiotic stresses (heat stress, salinity stress), and protection against diseases. When applied as biofertilizers, these beneficial bacteria (*Pseudomonas, Azospirillum, Azotobacter, Bacillus*) support plant development and ultimately, crop production. **Biofertilizers for Biomass Decomposition:** These biofertilizers contain microorganisms that break down resistant organic matter from crop residues, in turn replenishing the soil with crop-available nutrients. They enhance soil structure, water retention, and fertility (Fasusi et al., 2021).

Figure 3. Symbiotic root nodules on alfalfa roots (left) while arbuscular mycorrhizal fungi (right) act as ‘root extensions’ in grapevines to collect nutrients from the soils

Challenges for Adoption in the Desert Agroecosystems

Despite the promising benefits of biofertilizers in desert agriculture, their implementation faces several obstacles. One key concern is the lack of accurate recommendations and application guidelines derived from thorough scientific studies and data on their efficacy in arid and semi-arid environments, which makes it difficult for farmers to make essential decisions. Additionally, a vast diversity of biofertilizers is available on the market, which makes it difficult for growers to know which product to select.

Figure 4. The soil health research and extension team is conducting biofertilizer trials in upland cotton in the University of Arizona Agricultural Experimental Stations

Moreover, biofertilizers in arid environments may not always result in considerable production improvements due to harsh soil conditions that limit the activity of beneficial microbes (Fasusi et al., 2021), and, therefore, their efficacy. The University of Arizona led soil health research and extension teams are running experiments on different groups of biofertilizers in desert environments of Arizona, and will publish results in subsequent Extension publications.

Potential for Biofertilizers in the Desert Southwest

Biofertilizers can enhance crop production in arid soils by promoting soil biology that solubilizes nutrients and balances nutrient cycling in the rhizosphere. For example, the desert soils of Arizona are alkaline with a high pH of 8.0 or more, and at this pH, phosphates are found in insoluble complexes and are not available for plant uptake. Biofertilizers derived from phosphorus-solubilizing *Bacillus* have shown improved growth and yield on various crops (Giri et al., 2019); similar microorganisms may result in phosphorus being more available to crops grown in high-pH soils of the desert. Also, mycorrhizal fungi can increase plant nutrient uptake including phosphorus by increasing overall root surface area (Fasusi et al., 2021), and can potentially improve soil fertility in arid desert environments. Arizona also produces legumes like alfalfa that can potentially fix nitrogen in symbiosis with nitrogen-fixing *Rhizobia* if an adequate population is present in the soil or supplied through nitrogen-fixing biofertilizers. Moreover, biofertilizers in arid environments can promote a balanced rhizosphere supplemented with beneficial microbial communities for sustainable agricultural production.

Current Research on Biofertilizers in the United States

Farmers in the US are interested in biofertilizer use and the total number of commercially available biofertilizers has increased exponentially in recent years (Santos et al., 2024); however, there are still large research gaps. For example, most research has been focused on nitrate-fixing biofertilizers, and research has shown that inoculating legumes with rhizobia bacteria can increase plant growth and yield (Barbosa et al., 2022). Recently published research from Texas reported the effects of mycorrhizal fungi colonization on soils with corn and cotton production, which demonstrated how cultural practices can enhance the availability and survival of mycorrhizal fungi (Thapa et al., 2022). However, research is lacking in arid desert ecosystems. Currently, a team of researchers from the University of Arizona Sanyal and Norton Labs is testing the impacts of biofertilizers on cotton production in low desert environments. After the first year of data collection, there were no significant ($P<0.05$) differences in soil health indicators, plant nutrient uptake, or seedcotton yield; more research outcomes will be published in the subsequent extension articles. A second year of research will be conducted to collect more data and perform more robust statistical analyses.

Conclusion

Biofertilizers represent possible solutions for improving soil health in the desert southwest. Their contribution to soil biology is well reported and suggests promising benefits to soil health and crop production in arid environments. However, more research should be conducted on these products to determine their sustainability in arid production systems.

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