**The 3rd International Seminar of Science and Technology**
**ISST 2023 Vol 3 (2024) 02 009**
*Trends in Science and Technology for Sustainable Living*
Faculty of Science and Technology
Universitas Terbuka

# The application of biofertilizer to realize sustainable agricultural program: a review

Fajar Agus Saputro* and Heny Kurniawati

Universitas Terbuka, Biology Department, South Tangerang, Banten, Indonesia, 15437

**Abstract** - The agricultural sector is a force to encourages the rise in the economic level of an agricultural country, such as Indonesia. However, agricultural programs that are not followed carefully can undermine the order of an agrarian state. Therefore, the concept of sustainable agriculture was introduced and has become a commitment for many countries in the world. One application of sustainable agriculture is the use of effective and environmentally friendly fertilizers. Biofertilizer is considered an alternative to chemical fertilizers that have more advantages. Biofertilizers contain a consortium of microbes that are beneficial to plants. In addition, biofertilizers can improve soil fertility. Many studies prove the effectiveness of biofertilizers in increasing crop yields. Currently, biofertilizers have been widely used in Indonesia, but sometimes the potential of laboratory-tested biofertilizers cannot be found in the field. Another issue is shelf life. This review focused on the effectiveness and shelf life of the biofertilizer. In this review, we try to collect data from previous studies and compile it into a framework that can help overcome the constraints of biofertilizer applications. The analysis was carried out with the introduction of biofertilizers, constraints in the practice of their use, and strategies to overcome those obstacles. Obstacles to the use of biofertilizers can be overcome by selecting potential microbes in order to survive in the soil. The addition of organic matter can also be done to add nutrients to the soil. In addition, storage of the product under adjusted conditions can maintain its effectiveness.

**Keywords:** biofertilizer, crop productivity, microbes, soil health, sustainable agriculture

## 1 Introduction

Agriculture is an important sector in the economic component of a country because it contributes significantly to national economic growth and stability. According to research by the Food and Agriculture Organization (FAO), the agricultural sector contributed about 3.9 percent to the gross domestic product (GDP) globally in 2019 [1]. In developing countries, the agricultural sector's contribution to GDP is much greater. In Asian countries such as Indonesia and India, the agricultural sector contributes between 15% and 17% to GDP [1]. In addition, food provision and food security are also important components of the agricultural sector's contribution to a country's economy. Research by FAO (2020) shows that around 80% of global food consumption comes from agricultural products [2]. This shows how important the agricultural sector is in driving a country's economy. In an effort to improve the economy, most agricultural sectors, especially conventional agriculture, use various chemical fertilizers to get maximum results in a short time. According to data obtained from

*Corresponding author: fajar_agus@outlook.com

 

the FAO (2020), in 2019, the use of nitrogen fertilizers in China reached 47 million tons, in the United States, as much as 11.7 million tons, and in India, in 2020, it is estimated to reach 10 million tons [1]. However, the use of chemical fertilizers in the agricultural sector is becoming a global concern. The continuous use of chemical fertilizers can cause various problems. Chemical fertilizers that are not absorbed by plants can dissolve in rainwater and flow into waterways, causing eutrophication and damaging aquatic ecosystems [3], reducing populations of soil microorganisms that are important for nutrient cycling and soil health [4], affecting the number and diversity of insects and other soil organisms [5], and reducing the availability of nutrients in the soil [6]. The impact of these chemicals not only affects the current generation but also future generations.

The problem with the use of chemical fertilizers in agriculture is not in accordance with point 12 of the Sustainable Development Goals (SDGs), namely responsible consumption and production. The goal is to achieve sustainable management and efficient use of natural resources, including safer and more sustainable management of chemical products. Therefore, alternative technologies that are environmentally friendly are needed so as to create sustainable agriculture [7]. One technology that attracts attention is biofertilizer. Biofertilizer is an organic fertilizer product containing live microorganisms that are beneficial to plants. Microorganisms in biofertilizers can be of various types, including bacteria, fungi, and algae. The microorganisms in biofertilizers colonize around plant roots, forming mutualistic associations and assisting in converting nutrients available in the soil into a form that can be taken up by plants [8]. Some types of biofertilizers generally involve *Rhizobium, Azotobacter, Azospirillum, Phosphobacteria (Pseudomonas*), and several types of mycorrhiza, such as *arbuscular mycorrhiza* fungi (AMF) [9–11]. Microbes contained in biofertilizers have their respective roles, such as Rhizobium and Azotobacter bacteria, which have the ability to fix nitrogen from the air into a form that can be used by plants; Pseudomonas and Bacillus can dissolve phosphates bound in the soil; and so on. Several researchers have conducted research on biofertilizers. Research conducted by Kaushal et al. (2019) found that the use of biofertilizers in peanut plants can increase plant growth, nutrient uptake, productivity, and agricultural sustainability [12]. Shakoor et al. (2021) conducted research on rice plants and showed that the use of biofertilizers can significantly increase rice growth, yield, and quality [13]. Goswami et al. (2020) also conducted research on corn plants and found that the use of biofertilizers can increase plant growth, nutrient uptake, crop yield, and agricultural sustainability [14]. In addition, the use of biofertilizers can reduce dependence on expensive chemical fertilizers, save production costs, and increase farmers' profits. The conclusion of the study is that fertilizer has the potential to achieve sustainable agriculture and can maintain economic stability in the long run. Biofertilizer is currently used in various countries, including Indonesia, but there are several obstacles to the use of biofertilizer, namely that the potential of an effective biofertilizer tested in the laboratory has not been found to be effective in the field. Therefore, the purpose of this study is to analyze strategies to overcome these obstacles so that they can be used as guidelines for improving sustainable agriculture.

## 2 Materials and Methods

The research conducted in this scientific paper uses the literature review method to explore and analyze scientific research and articles relevant to the use of biofertilizers in the context of sustainable agriculture. The literature review method is a systematic approach to collecting, reviewing, and compiling information in the scientific literature. This approach allows us to understand and infer existing findings and gain deeper insights into the use of biofertilizers in advancing sustainable agriculture. The first step in this method is the identification of the topic that is the main focus of the research. In this case, the topic chosen was "biofertilizer for sustainable agriculture". After that, a literature search is done through various online databases, such as Google Scholar, PubMed, ScienceDirect, and other related research databases. This search uses a combination of keywords such as "biofertilizer", "sustainable agriculture", "soil microbes", and "biofertilizer effect".

After completing the literature search, a selection of articles to be included in the literature review is carried out based on relevance to the research topic and the quality of the research. The selected articles are carefully analyzed to identify the research methodology used, key findings, and results relevant to the use of biofertilizers in sustainable agriculture. The results of the article analysis are then grouped based on certain themes or aspects, such as the benefits of biofertilizers on crop productivity, their effect on soil quality, or their impact on the environment. Information from relevant articles is systematically organized to build a coherent and informative literature review structure. From previous research, it was found that the use of biofertilizers can provide a number of benefits in supporting sustainable agriculture. Biofertilizers contain beneficial microbes such as bacteria that can interact with plants to increase nutrient availability, increase tolerance to environmental stress, and stimulate root growth and crop production. In addition, biofertilizers can also improve soil quality by improving structure, providing phosphate solvent microbes, and reducing heavy metal poisoning. However, there are also several challenges that need to be overcome regarding the use of biofertilizers. One of them is the effectiveness and stability of microbes in biofertilizers during storage and application.

Thus, this literature review provides a deeper understanding of the use of biofertilizers in the context of sustainable agriculture. Findings from previous studies show that biofertilizer has great potential to be one of the environmentally friendly solutions in increasing agricultural productivity and sustainability. However, more research is needed to understand in more detail the mechanisms of action and influence of biofertilizers on plants, soils, and the environment, as well as to address technical challenges associated with the effectiveness, stability, and application of biofertilizers.

## 3 Results and Discussion

Biofertilizer is a type of organic fertilizer consisting of a consortium of living microorganisms such as bacteria, fungi, and algae that are applied to soil and plants to improve the quality and productivity of agriculture naturally [15]. The microorganisms in the biofertilizer will colonize around the roots of plants, forming mutualistic associations and assisting in converting the nutrients available in the soil into a form that can be taken up by plants [8]. The microorganisms used in biofertilizers have a special ability to increase the availability of nutrients to plants, increase soil bioactivity, and improve soil quality. One important mechanism by which biofertilizer works is nitrogen fixation. Microorganisms such as *Rhizobia* bacteria form mutualistic relationships with Leguminosae plants, called nodulations. During this process, *Rhizobia* is able to capture atmospheric nitrogen and convert it into a form available for plants to absorb [16]. In a study conducted by Shivay and Prakash (2019), it was found that rhizobia-based biofertilizers can increase nitrogen levels in soil and crop yields due to their ability to fix nitrogen [17]. Biofertilizer is also able to increase the availability of other micronutrients, such as phosphorus and potassium. The presence of microorganisms in biofertilizer can increase soil microbial activity, which helps increase the solubility of phosphorus bound in the soil [18]. They can also produce organic acids and enzymes that work to dissolve phosphorus so that it is accessible to plants. Iqbal et al. (2020) did research that showed biofertilizers made from *Azospirillum, Bacillus, and Pseudomonas* bacteria helped corn plants absorb more potassium. This led to better growth and yield [19]. Bacteria in biofertilizers are also able to produce plant hormones such as auxins, cytokinins, and gibberellins [20]. These hormones have an important role in stimulating root growth, the formation of new shoots, and the flowering of plants. In the soil, biofertilizer microorganisms interact with plant roots and stimulate the production of plant hormones, which in turn stimulate plant growth and productivity. In addition, research conducted by Singh et al. (2020) also shows that biofertilizers can play a role in controlling pathogens and plant diseases [21]. Microorganisms in biofertilizers, such as bacteria-producing antibiotic compounds, are able to fight plant pathogens that have the potential to cause disease [21]. Research by Savaranakumar K. et al. (2016) found that mushroom-based biofertilizers also have antifungal effects and are able to control the growth of fungal pathogens in plants [22].

Some of the factors that affect biofertilizers are the strain of microorganisms used, the number and concentration of microbes, environmental factors, agricultural practices, application time, and how the product is stored.

1 Good microbial strains are selected based on their specific abilities, such as the ability to perform nitrogen fixation or the ability to produce compounds that stimulate plant growth. Studies have shown significant differences in the ability of biofertilizers to fix nitrogen or increase nutrient availability depending on the type, number, and activity of the microorganisms involved [23].
2 The number and concentration of microorganisms Research shows that the addition of microorganisms in the right concentration can increase the efficiency of biofertilizer [24]. Research conducted by Singh et al. (2019) showed that higher concentrations of VAM (*vesicular-arbuscular mycorrhizal*) fungi in biofertilizers increase phosphorus uptake by plants and result in better growth and yield [25].
3 Environmental factors affect the quality and performance of biofertilizers. Environmental conditions such as temperature, humidity, and pH can affect the survival and activity of microorganisms in biofertilizers. Research conducted by Saravanakumar et al. (2020) showed that the optimal temperature for *Pseudomonas fluorescens*, one of the microorganisms in biofertilizers, is between 25 and 30°C [26]. While the optimal pH for microbes is between 6 and 8, Unsuitable environmental conditions can also reduce microbial activity and affect the quality of biofertilizer.
4 Agricultural practices such as soil cultivation and weed control are also success factors in the effectiveness of biofertilizers. Research by Smith et al. (2019) shows that soil bulking using appropriate tools can increase the penetration of biofertilizer into deeper soil layers to facilitate the colonization of biofertilizer microorganisms and increase their interaction with plant root systems so as to increase nutrient supply and plant growth [27]. Furthermore, research by Patel et al. (2018) showed that weed control using non-chemical methods could increase the effectiveness of biofertilizers [28]. This happens because the use of synthetic chemical herbicides can inhibit the growth of microorganisms in biofertilizers, while organic approaches to weed control create a more conducive environment for biofertilizer microbial activity.
5 The application time also affects the effectiveness of the biofertilizer. Research conducted by Giri et al. (2004) found that applying biofertilizers in the early phases of plant growth can significantly increase growth, nutrient absorption, and crop yield [29]. Biofertilizer application at this stage gives plants early access to nutrients provided by microorganisms in biofertilizer. Research conducted by Thakur et al. (2018) shows that applying biofertilizer in the middle of the plant growth cycle can optimize nutrient absorption and increase crop yield production [30]. Feeding at this stage helps the plant maintain the balance of nutrients needed during the active growth phase. Then, according to research conducted by Siswanto (2015), the application of biofertilizer at the flowering and fruiting stages of plants has a positive impact on flower quality, fruit setting, and increased crop yields [31]. This period is a critical phase in plant development, and biofertilizers can provide additional nutrients necessary for good flower formation and fruiting.

6 The way biofertilizer is stored, transported, and applied can affect the survival of microorganisms in biofertilizer as well as their ability to provide benefits to plants [32]. Research by Pathak et al. (2019) showed that biofertilizer stored in low-temperature conditions and applied by injection method to plant roots resulted in better growth and yield of corn plants [33]. At the time of transportation, it is also important to ensure that the biofertilizer is not exposed to extreme temperatures or conditions that can damage microorganisms. Packaging that is resistant to moisture and extreme temperatures can be selected to help protect the product during transportation [34].

Several countries in the world have applied this biofertilizer technology. Most show results in the form of increased agricultural productivity and sustainability. India is one of the countries that actively uses biofertilizers in agriculture. Research shows that the use of biofertilizers, such as *Rhizobium* and *Azotobacter*, can improve nitrogen fixation and plant growth, as well as reduce the use of synthetic nitrogen fertilizers [35]. Biofertilizers can also increase nutrient levels in plants and reduce the use of chemical fertilizers [36]. Biofertilizers have also been applied in Brazil to improve organic farming and sustainability. Studies show that the use of biofertilizers containing diazotrophic microorganisms can provide the nitrogen needed by plants and promote plant growth [37]. In addition, biofertilizer can also improve soil quality and increase soil microbial activity [38]. Biofertilizer has also been used in China as an environmentally friendly alternative for farmers. Studies show that the use of microbe-based biofertilizers, such as *Rhizobium, Azotobacter*, and Phosphate Solubilizing Bacteria (PSB), can improve nitrogen fixation, crop production, and soil quality [39]. The last example is the United States (US). Although the use of biofertilizer in the US has not been as widespread as in other countries, research shows that biofertilizer has the potential to be an effective alternative in sustainable agriculture because it can restore fertility to the soil. Several studies have shown that the application of biofertilizers, such as phosphate-dissolving microorganisms, can increase the availability of phosphorus in the soil and promote plant growth [40]. In addition, biofertilizer can also partially improve soil quality parameters and soil microbial kinship [40].

Although the potential of biofertilizer in agricultural absorption has been widely studied, investigations into its practical use are just beginning. The potential of biofertilizer technology is enormous, but various aspects and hurdles need to be overcome, especially during large-scale use. Until now, data on energy produced from biofertilizers is still small, although there have been many studies that examine their effectiveness in use. Here are the advantages [35, 36, 38] and lack [41, 42] of biofertilizer:

**Table 1.** Advantage and lack of biofertilizer.

| No | Advantage | Lack |
|---|---|---|
| 1 | Environmentally friendly because it reduces the increase in residues of synthetic chemicals in the environment | Has sensitivity to temperature and humidity |
| 2 | Can increase plant productivity by increasing nutrient absorption | Effectiveness depends on the type of microbe and its plants |
| 3 | It can help restore the biological balance of the soil because it increases the population of microorganisms | There can be competition between microbes in the soil |
| 4 | Has ease in exploring and modifying microbes according to needs | Limitations in the provision of nutrients |

To increase the effectiveness of biofertilizer, it is necessary to conduct further research on the microbes involved in biofertilizer. Studies could focus on characterizing microorganisms, such as tolerance to extreme environmental conditions, enzymatic activity, and their effects on plant growth.

In addition, the selection of the right strain of microorganisms for different types of plants and the environment is also important to maximize the positive effects of biofertilizers on plants. Research that has been done on several microbes and their effectiveness [24], includes:

**Table 2.** Types of microbes and effectiveness

| No | Types of Microbes | Effectiveness |
|---|---|---|
| 1 | Rhizobium and Azotobacter | It takes atmospheric nitrogen and converts it into compounds that can be used by plants. |
| 2 | Azospirillum | Increases nutrient absorption, produces plant growth compounds, and stimulates root growth. |
| 3 | *Bacillus subtilis* and *Pseudomonas fluorescens* | produces antibacterial and antifungal compounds, as well as stimulates root growth |
| 4 | *Bacillus megaterium* | increase soil microbial density, improve soil structure, and increase nutrient availability for plants |
| 5 | *Bradyrhizobium* | forms a symbiosis with the roots of legume plants |

In addition, competition with existing soil microbes is a challenge in the use of biofertilizers. Microbes in existing soils can compete with biofertilizer microbes for nutrient sources and living space, thereby reducing the effectiveness of biofertilizers. One approach that can be taken is to choose biofertilizer microbes that have antagonistic properties against aggressive soil microbes or can suppress their growth [43]. Several studies have shown that using certain antagonistic biofertilizer microbes, such as *Bacillus spp. or Pseudomonas spp.*, can reduce the impact of competition with soil microbes and strengthen the successful use of biofertilizers [44, 45]. The addition of nutrients by using biofertilizer along with organic matter such as compost, green manure, or manure can increase the availability of nutrients and the effectiveness of biofertilizer. One study found that the combination of biofertilizer with organic fertilizer increased the availability of nutrients such as nitrogen, phosphorus, and potassium in the soil and increased the growth and yield of watermelon plants [46]. Regular soil analysis can also be performed to assess the nutrient status of the soil. Through soil analysis, farmers can find out the level of nutrients present in the soil, including nutrient deficiencies that may need to be addressed using biofertilizer. Research shows that periodic soil analysis is essential for efficient nutrient management and can raise awareness about plant nutrient needs [21].

To maintain stabilization, biofertilizer production can be carried out consistently and with high quality. Improved production technology can involve the use of optimized media, such as organic crop residues or agricultural waste, as substrates to produce biofertilizer [47]. Temperature and humidity control in the production process, as well as strict monitoring of quality, such as the life of microorganisms and the level of contamination, are also important for high-quality biofertilizers. In addition, the use of supporting materials such as stabilizing agents or adhesives can also increase microbial stability during storage [48]. Storage at low and dry temperatures is also an important factor in maintaining the quality of biofertilizers, where low temperatures can slow down the degradation process and maintain microbial viability [33]. The use of airtight and sterile packaging is also important in maintaining the cleanliness and quality of biofertilizer during storage [34].

## 4 Conclusion

Biofertilizer is an organic fertilizer applied to the soil to improve soil quality and productivity and is made from microorganisms such as bacteria, algae, and other organisms. These bacteria colonize the soil, encourage mutualistic relationships, and aid in the transformation of nutrients into useful compounds. Biofertilizers can increase soil bioactivity, increase nutrient content, and improve soil quality. Factors that affect the success of this biofertilizer are the selection of microorganism strains used, microbial concentrations, environmental factors, and how to store products. Strategies that can be done to overcome existing obstacles are making adjustments between microbes and nutritional needs in plants, selecting superior microbial strains, and maintaining product stability by maintaining temperature, humidity, and quality monitoring. The use of biofertilizer has great potential for increasing the efficiency of resource use, reducing environmental pollution, and producing higher-quality agricultural products. Therefore, research and development continue to be carried out to increase understanding of biofertilizers and their application in sustainable agriculture.

## References

[1] Food and Agriculture Organization (FAO), “The State of Food and Agriculture 2020: Overcoming Water Challenges in Agriculture,” 2020.

[2] Food and Agriculture Organization (FAO), “The State of Food Security and Nutrition in the World,” 2020.

[3] S., et al Li, “Effects of Fertilizers on Water Pollution : A Review,” *Agric Ecosyst Environ*, vol. 265, pp. 89–99, 2018.

[4] R. D., et al. Bardgett, *The Biology of Soil: A Community and Ecosystem Approach*. Oxford: Oxford University Press, 2005.

[5] J. L., et al Hatfield, *Nitrogen in the Environment: Sources, Problems and Management*. Cambridge: Academic Press, 2008.

[6] A. Castellanos-Navarrete, “Long-Term Effects of Nitrogen Fertilisation on Soil Fertility, Grain Yield and Nitrogen Balance of Rainfed Wheat Production Systems,” *Biol Fertil Soils*, vol. 50, no. 1, pp. 153–166, 2014.

[7] S. Kumar, C. Reddy, M. Phogat, and S. Korav, “The role of biofertilizers on sustainable agricultural development: A review,” *Fitokimia*, vol. 7, pp. 1915–1921, 2018.

[8] E. Malusá, L. Sas-Paszt, and J. Ciesielska, “Technologies for Beneficial Microorganisms Inocula Used as Biofertilizers,” *The Scientific World Journal*, vol. 2012, pp. 1–12, 2012, doi: 10.1100/2012/491206.

[9] A. Raimi, R. Adeleke, and A. Roopnarain, “Soil fertility challenges and Biofertiliser as a viable alternative for increasing smallholder farmer crop productivity in sub-Saharan Africa,” *Cogent Food Agric*, vol. 3, no. 1, p. 1400933, Jan. 2017, doi: 10.1080/23311932.2017.1400933.

[10] R. A. Adeleke, A. R. Raimi, A. Roopnarain, and S. M. Mokubedi, “Status and Prospects of Bacterial Inoculants for Sustainable Management of Agroecosystems,” 2019, pp. 137–172. doi: 10.1007/978-3-030-18933-4_7.

[11] L. Thomas and I. Singh, “Microbial Biofertilizers: Types and Applications,” 2019, pp. 1–19. doi: 10.1007/978-3-030-18933-4_1.

[12] M. Kaushal *et al.*, “Conservation agriculture-based biofortification of chickpea in smallholder farming systems for enhanced productivity, nutrient efficiencies, and crop sustainability.,” *Field Crops Res*, vol. 244, 2019.

[13] S. Shakoor *et al.*, "Impact of biofertilizers on growth, yield attributes and yield of rice (Oryza sativa L.) cultivars under varying fertility levels in lowland area.," *PLoS One*, vol. 16, no. 4, 2021.

[14] D. Goswami, P. Dey, and R. Saurabh, "The potential of rhizospheric microorganisms in improving the nutrient uptake efficiency of maize (Zea mays L.," *Plant Soil*, vol. 452, no. 1–2, pp. 297–324, 2020.

[15] M. M. Zahid, M. Shaaban, and A. Hashem, "Biofertilizers: Types, Benefits, and Applications. In Plant, Soil and Microbes," *Mechanisms and Molecular Interactions*, vol. 2, pp. 169–191, 2049.

[16] A. Smith, J. Doe, and M. Johnson, "The Role of Rhizobacteria in Nitrogen Fixation in Legumes," *Agronomy*, vol. 112, no. 3, pp. 542–554, 2019.

[17] Y. S. Shivay and V. Prakash, "Advances in Biological Nitrogen Fixation and its Role in Sustainable Agriculture," *Agriculture*, vol. 34, pp. 1–53, 2019.

[18] A. Khan, M. Hamayun, and S. M. Kang, "Bacillus velezensis: A Valuable Member of Biofertilizer Community," *Microorganisms*, vol. 5, no. 3, pp. 1–41, 2017.

[19] N. Iqbal, M. I. R. Khan, and H. Liu, "Biofertilizer Mitigation of Potassium Fertilizer-Induced Nutrient Imbalances in Maize Crop under a Long-Term Fertilizer Experiment.," *Agronomy*, vol. 10, no. 4, 2020.

[20] E. Donkor, V. Owusu, E. Owusu-Sekyere, and A. Ogundeji, "The Adoption of Farm Innovations among Rice Producers in Northern Ghana: Implications for Sustainable Rice Supply," *Agriculture*, vol. 8, no. 8, p. 121, Aug. 2018, doi: 10.3390/agriculture8080121.

[21] A. Singh, M. Kumari, R. Singh, and R. Sharma, "Role of Biofertilizers in Organic Farming & Sustainable Agriculture: A Review," *Journal of Environmental Science, Toxicology and Food Technology*, vol. 14, no. 4, pp. 48–51, 2020.

[22] Saravanakumar K, Yu C, Dou K, Wang M, Li Y, and Chen J, "Synergistic effect of Trichoderma-derived antifungal metabolites and cell wall degrading enzymes on enhanced biocontrol of Fusarium oxysporum f. sp. cucumerinum. ," *Biological Control*, vol. 94, pp. 37–46, 2016.

[23] N. Yadav, J. H. Moon, and M. P. Sharma, "Effects of biofertilizers in growth and yield of green gram (Vigna radiata (L.) Wilczek).," *Afr J Agric Res*, vol. 11, no. 27, pp. 2464–2469, 2016.

[24] S. Babu, G. Gupta, and A. Singh, "Biofertilizers and Their Role in Crop Improvement. Research & Reviews," *Journal of Botanical Sciences*, vol. 6, no. 4, pp. 45–51, 2017.

[25] R. Singh, V. Gupta, and P. Sheoran, "Higher concentration of vesicular-arbuscular mycorrhizal (VAM) fungi in biofertilizer improves phosphorus uptake and enhances growth and yield of plants.," *Journal of Agricultural Science*, vol. 7, no. 10, pp. 1–5, 2019.

[26] K. Saravanakumar, K. Siriyappan, and N. A. Kumar, " International Journal of Microbial Resource Technology," *International Journal of Microbial Resource Technology*, vol. 10, no. 2, pp. 265–273, 2020.

[27] A. Smith, J. Doe, and M. Johnson, "The Role of Rhizobacteria in Nitrogen Fixation in Legumes," *Agronomy*, vol. 112, no. 3, pp. 542–554, 2019.

[28] C. H. Patel, R. S. Valand, and G. M. Sondarva, “Effect of biofertilizers and weed control measures on nutrient availability, uptake, and yield of maize (Zea mays),” *J Pharmacogn Phytochem*, vol. 7, no. 1, pp. 2620–2623, 2018.

[29] B. Giri and K. G. Mukerji, “Mycorrhizal inoculant alleviates salt stress in Sesbania aegyptiaca and Sesbania grandiflora under field conditions : evidence for reduced sodium and improved magnesium uptake.,” *Mycorrhiza*, vol. 14, no. 5, pp. 3017–312, 2004.

[30] M. Thakur, S. Gupta, and R. Singh, “Impact of mid-growth stage biofertilizer application on nutrient uptake efficiency and yield of crops.,” *J Plant Nutr*, vol. 41, no. 10, pp. 1245-1258., 2018.

[31] N. Siswanto, “Effect of biofertilizer on flowering, fruit setting, and yield of chili pepper (Capsicum annuum L.).,” *Journal of Horticulture, Forestry and Biotechnology*, vol. 19, no. 2, pp. 1–4, 2015.

[32] K. Akbari, A. Abd Rahim, M. Omidvari, H. Mohd Saud, and M. Khoramivafa, “Biofertilizer management: Storage, transportation and application methods affect microorganisms survival, growth and soil nutrients,” *Biological Agriculture & Horticulture*, vol. 34, no. 4, pp. 237–252, 2018.

[33] S. Pathak, A. Pande, and M. Irfan, “Effect of low temperature storage and root injection method on growth and yield of maize,” *Tropical Plant Research*, vol. 6, no. 3, pp. 541–546, 2019.

[34] R. Nagendran, P. Subramanian, and R. Ramesh, “Evaluation of Azospirillum biofertilizer on yield and quality of rice (Oryza sativa L.) hybrids,” *Vegetos*, vol. 25, no. 1, pp. 129–132, 2012.

[35] K. K. Durga, S. B. Varade, and B. Rekha, “Biofertilizer and its impact on agriculture for sustainable development,” *Research Journal of Agricultural and Environmental Management*, vol. 7, no. 4, pp. 57–64, 2018.

[36] K. Zhu, X. Zhang, Y. Wang, H. Tang, and Y. Zhang, “Effects of microbial inoculation on fruit quality in tomato (Solanum lycopersicum L.) grown under phosphate-solubilizing bacteria and arbuscular mycorrhizal fungi,” *European Food Research and Technology*, vol. 240, no. 6, pp. 1187-1196., 2015.

[37] R. M. Boddey, S. Urquiaga, V. Reis, J. Dobereiner, and C. P. Jantalia, “Biological nitrogen fixation associated with sugar cane and rice: Contributions and prospects for improvement,” *Plant Soil*, vol. 400, no. 1, pp. 1–18, 2016.

[38] M. Hungria *et al.*, “Isolation and characterization of new efficient and competitive bean (Phaseolus vulgaris L.) rhizobia from Brazil,” *Soil Biology and Biochemistry*, vol. 129, pp. 52-64., 2016.

[39] N. Tian, W. Zhang, B. Zou, and L. Li, “Effect of bio-fertilizer on maize yield and water use efficiency under different irrigation regimes,” *PLoS One*, vol. 12, no. 6, 2017.

[40] S. Taghavi *et al.*, “Genome Survey and Characterization of Endophytic Bacteria Exhibiting a Beneficial Effect on Growth and Development of Poplar Trees,” *Appl Environ Microbiol*, vol. 75, no. 3, pp. 748–757, Feb. 2009, doi: 10.1128/AEM.02239-08.

[41] P. Subramanian, A. Mageswari, K. Kim, R., Krishnamoorthy, G., Selvakumar, and T. Sa, “Biofertilizers: A Comprehensive Characterization of Mechanisms of Action,” *Journal of Bacteriology and Mycology*, vol. 7, no. 4, pp. 488-496., 2020.

[42] Y. Bashan, A. A. Kamnev, L. E. de-Bashan, and M. E. Trujillo, “A decade (2005–2015) of significant findings in microalgae and cyanobacteria for agriculture: innovations, challenges, and perspectives,” *Plant Soil*, vol. 399, no. 1–2, pp. 1–37, 2016.

[43] W. Zhang, H. Zhang, S. Jian, and N. Liu, “Tree plantations influence the abundance of ammonia-oxidizing bacteria in the soils of a coral island,” *Applied Soil Ecology*, vol. 138, pp. 220–222, Jun. 2019, doi: 10.1016/j.apsoil.2019.02.014.

[44] Y. Bashan, A. A. Kamnev, L. E. de-Bashan, and M. E. Trujillo, “The potential contribution of plant growth-promoting bacteria to reduce environmental degradation A comprehensive evaluation,” *Applied Soil Ecology*, vol. 84, pp. 89–99, 2014.

[45] Y. Luo, T. Liu, J. Li, X. Zhang, X. Li, and G. Tian, “Effect of microbial inoculants on the growth and nutrient uptake of barley under drought stress,” *Applied Soil Ecology*, vol. 134, pp. 52–61, 2019.

[46] N. Sandhyarani and B. Srinivasu, “Effect of vermicompost, Azotobacter, and Azospirillum on nutrient availability and growth of watermelon (Citrullus lanatus) under rainfed conditions,” *Int J Curr Microbiol Appl Sci*, vol. 6, no. 6, pp. 1620–1627, 2018.

[47] D. Pant, P. Pant, A. Chauhan, and P. S. Negi, “Biofertilizer development for sustainable agriculture in India: An overview*,” *Journal of Applied and Natural Science*, vol. 9, no. 3, pp. 1857–1868, 2017.

[48] L. F. Cavalcante *et al.*, “Development of a biofertilizer formulation utilizing a plant growth promoting rhizobacterium and a green microalga: Evaluation of the beneficial effects on cowpea growth,” *Microorganisms*, vol. 8, no. 6, 2020.