***Review Article***

**The Role of Biofertilizers in enhancing soil and Productivity - A Review**

**Abstract**

Biofertilizers, which offer a natural and eco-friendly alternative to chemical fertilizers, are essential to sustainable farming methods. Through processes including nitrogen fixation, phosphate solubilization, and the expansion of soil microbial diversity, these microorganism-derived compounds improve soil fertility and promote plant growth. This review explores the definition and significance of biofertilizers, highlighting the differences between chemical fertilizers and biological nitrogen fixation. It categorizes biofertilizers into various types, including nitrogen-fixing, phosphate-solubilizing, and mycorrhizal biofertilizers, and discusses their ecological benefits. The impact of biofertilizers on ecosystem health and soil reclamation of degraded lands is also examined, showing their role in restoring soil structure and fertility. Various application techniques, such as seed inoculation, soil treatment, and foliar sprays, are discussed to maximize their effectiveness. Although biofertilizers have many advantages, such as the effectiveness of costs, sustainability in the environment, and higher crop yields, they also have drawbacks, such as problems with soil compatibility and shelf-life. Finally, emerging perspectives on biofertilizers highlight innovations in biotechnology and their potential to play a pivotal role in climate-smart and resilient agriculture. This review underscores the growing importance of biofertilizers as a sustainable solution for modern agricultural challenges.

 **Keywords-** Biofertilizers, Microbial organisms, Soil health, and Sustainable agriculture.

  **Introduction**

The importance of agriculture in supporting global food security and mitigating nutritional challenges is significant. In this context, the implementation of biofertilizers stands out as a promising method for improving agricultural efficiency in a sustainable manner. (Albahri *et. al.,* 2023). The integration of biological agents as substitutes for chemical fertilizers has resulted in notable enhancements in various crop parameters. In the context of the twenty-first century, challenges such as climate change, food insecurity, and agricultural pollution pose significant threats, adversely affecting plant growth, soil health, and food availability. To tackle these pressing issues, innovative methodologies are required, as numerous stressors—including toxic heavy metals, organic pollutants, emerging contaminants, and a range of biotic and abiotic factors—can hinder nutrient accessibility, disrupt plant metabolic processes, and diminish crop yields and soil fertility. Among the various strategies being investigated to bolster plants' resilience to environmental stressors, nanotechnology, particularly the use of nanoparticles, demonstrates considerable potential in enhancing plant performance under challenging conditions. This technology is set to transform both agriculture and pharmaceuticals, promising a more sustainable, efficient, and resilient system for both sectors. Specifically, nano-fertilizers are anticipated to improve nutrient utilization efficiency in plants through a controlled and sustainable release of nutrients (Sujanya and Chandra, 2011) (Mariyam *et.al.,* 2024) (Pathak *et.al.,* 2024). Bio-fertilizers are crucial for environmental conservation, as they enable a lower dependency on chemical fertilizers in the cultivation of crops in diverse regions. These products are characterized by the inclusion of naturally occurring microorganisms that are artificially multiplied to improve the fertility of the soil and boost productivity of crops (Mazid and Khan, 2014). Chemical fertilizers negatively impact the health of soil, causing a decline in organic matter levels, reduction in the ability to hold onto water, alterations in soil fertility, heightened salinity, compromised nutrient uptake, and disturbances in soil structure and microbial diversity. The enduring nature of these harmful chemicals poses a considerable threat, leading to the pollution of groundwater resources (Savci, 2012). In the pursuit of self-sufficiency, nations have extensively employed chemical fertilizers to enhance agricultural productivity. Nevertheless, the application of these fertilizers has led to significant environmental degradation, as they diminish the soil's water retention capabilities, adversely affect its fertility, elevate soil acidity, and decrease microbial populations, ultimately causing nutritional deficiencies within the soil (Nosheen *et. al.*, 2021). Biofertilizers serve as valuable tools within the agricultural ecosystem by improving soil quality through the addition of essential components such as nitrogen, vitamins, proteins, and enhanced water retention capabilities, thereby mitigating the adverse impacts associated with chemical fertilizers (Mariya and Sripriya, 2023). Soil serves as a crucial foundation for food production throughout human history. However, in recent decades, the widespread adoption of agricultural practices, including the application of pesticides and synthetic fertilizers, which have resulted in significant degradation of soil on a global scale. This degradation has resulted in diminished fertility, primarily due to a decline in the field of biodiversity, reduced retention of water capabilities, along with disruptions in cycles of biogeochemistry. The intricate relationships that exist between plants, soil, and microbes have a significant impact on soil health and plant output. (Harman *et. al.,* 2021).

The Soil microorganisms engage in cooperative interactions both among themselves and with plant roots through various mechanisms, contributing significantly to a range of essential functions that are crucial for maintaining ecological equilibrium within the soil (Kumar *et. al.,* 2021). It has been noted that utilizing Apricot biofertilizers farming alters the microbiological structure and deterioration mechanisms, which might lead to more effective nutrient cycling in soil environments during field cultivation (Baldi *et. al.,* 2021) (Agri *et. al., 2*021). The integration regarding biofertilizers into agricultural practices may provide an effective means to bolster the microbial status of soil, facilitating the activity of the natural soil microbiota and thereby impacting nourishment availability and the degradation of natural materials. (Chaudhary *et. al.,* 2021). The interactions between plants and microorganisms can be classified as beneficial when they enhance plant survival, nutritional quality, and agricultural yield. In contrast, they are deemed detrimental if they hinder growth of plants. Fertility of soil fundamentally connects to the equilibrium between microbes and plant life (Vishwakarma *et. al.,* 2021). Regular use of chemical fertilizers is often deemed unsustainable, as it can adversely affect soil ecosystems. Such practices may lead to a decline in soil biodiversity and an increase in soil acidity, particularly from nitrogen fertilizers that lower pH levels. This change can destabilize soil aggregates, making them more susceptible to erosion, which in turn can lead to a decrease in soil fertility. As a result, even with the continued application of chemical fertilizers, agricultural productivity may suffer over time (Nyalemegbe *et. al.,* 2009).

**Chemical vs. Biological Nitrogen Fixation: A Comparison**

The contribution of biological nitrogen fixation of (BNF) to nitrogen usage in agriculture is significant, comprising 65% of the total consumption. (Burris and Roberts, 1993). In numerous agricultural systems, nitrogen frequently serves as the primary limiting nutrient that influences crop yield. Although nitrogen is abundant in the atmosphere, plants are unable to utilize it in its inert form. The availability of nitrogen is facilitated through fertilizers, which are produced via the atmospheric nitrogen chemically fixed by the Haber-Bosch method. This method necessitates elevated temperatures (ranging from 400 to 500°C) and substantial pressure (approximately 20 MPa), resulting in energy requirements equivalent to 5.5 barrels of oil, 2 metric tons of coal, or almost 875 cubic meters of natural gas to synthesize ammonia in one metric ton. The Dinitrogen is characterized as the diatomic molecule with the highest stability, with two nitrogen atoms connected through a robust triple bond. The energy required to dissociate this triple bond is significant (945 kJ), presenting a considerable challenge in the process of dinitrogen fixation (Dixon and Wheeler, 1986). Global nitrogen cycle indicates that each and every nitrogen atom found in the atmosphere completes a full cycle roughly once every million years. (Postgate, 1990) Atmospheric dinitrogen can be biologically fixed by diazotrophs, which are prokaryotic organisms capable of converting dinitrogen into ammonia. This ammonia becomes accessible to crop plants. In the soil, certain microorganisms facilitate the conversion of ammonia into nitrate, which is subsequently available for plant uptake. The nitrate produced can undergo denitrification processes in the deeper soil layers, resulting in the release of nitrogen gas back into the atmosphere. This sequence illustrates the typical nitrogen cycle. The enzymatic fixation of nitrogen by bacteria occurs at normal pressure and temperature, a procedure referred to as biological nitrogen fixation (BNF). While quantifying the extent of natural nitrogen fixation in the biosphere presents challenges, it is thought to be approximately 10 million metric tons annually, in contrast to approximately 160 million metric tons per year from anthropogenic sources, which is 1.5 times greater than natural fixation. (Galloway *et. al.,* 2008).

**Biofertilizers**

The concept of 'Biofertilizer' in India is specifically associated with fertilizers that provide essential nutrients to crops through microbiological means, although other countries may refer to this concept using different terms. Microbial-based fertilizers, commonly termed biofertilizers, play an essential part of sustainable farming, significantly contributing to the long-term enhancement of soil fertility (Bargaz *et, al,* 2018). Biofertilizers, which are commonly called microbial inoculants, consist of organic products that include specific microorganisms extracted from the root systems and adjacent zones of plants. Evidence suggests that their application can lead to an increase in plant growth and yield by 10% to 40% (Kawalekar, 2013). Biofertilizers are typically utilized in solid or dry formats, which are formulated by incorporating them into appropriate carriers, including lignite, humus, wood charcoal, rice bran, peat, clay minerals, and wheat bran. The use of these carriers extends the durability of the products and simplifies the management of microbiological agents. (Bhattacharjee and Dey, 2014). Biofertilizers consist of organic fertilizers that originate from biological sources, including both plant and animal origins, as well as living or inactive microbiological cells. They possess the ability to increase the accessibility and bioavailability of nutrients, thereby facilitating their uptake by plants (Lee *et. al.,* 2018). Bioinoculants that inhabit the rhizosphere and the internal structures of plants enhance growth when introduced to seeds, plant surfaces, or soil (Rahuwanshi, 2012). Biofertilizers are defined as natural materials that encompass living microbes, such as algae, fungus, and bacteria, or their byproducts. These substances are utilized in agricultural practices by applied to the soil, seeds, or the surfaces of plants to get better soil fertility and stimulate plant development (Alnaass *et. al.,* 2023). In the context of organic fertilizers, specific organisms, including earthworms, play a crucial role in converting these fertilizers into materials that plants can readily absorb. *Plant-growth promoting rhizobacteria* are the most commonly employed bacteria in the production of biofertilizers, as they promote plant growth through the release of potassium (K), nitrogen fixation (N), phosphorus solubilization (P), and hormone production (Lu, *et. al.,* 2020). Advantageous microbes, including various bacteria and fungi, colonize the rhizosphere, which is the soil zone being affected by root exudates, as well as the surfaces of plants, thereby establishing either symbiotic or associative interactions with them (Ayala and Rao, 2002). Biofertilizers operate by enhancing the absorption of nutrients, facilitating the fixation of atmospheric nitrogen, solubilizing phosphates, and mobilizing various other nutrients, which collectively enhance the accessibility of vital nutrients for plant development (Bhardwaj *et. al.,* 2014). Biofertilizers contribute positively to soil health, enhance the physical structure of the soil, and support a diverse microbial community within soil ecosystem. They present an environmentally sustainable alternative to chemical fertilizers, encouraging practices that promote sustainability in agriculture while simultaneously decreasing environmental pollution and lessening dependence on synthetic agricultural inputs.) (Daniel *et. al.,* 2022).

**Categories of Biofertilizers;**

Different types of biofertilizers can be distinguished by their distinct roles and modes of action. The most commonly used biofertilizers include rhizobacteria that promote plant growth, nitrogen-fixing agents (N-fixers), potassium-solubilizing microorganisms (K-solubilizers), and phosphorus-solubilizing organisms (P-solubilizers) and (PGPR) (Mahdi *et. al.,*2010). Among the mechanisms that define the direct effects on plants are nitrogen fixation, phosphate compound solubilization, micronutrient solubilization, and phytohormone production. (Chaudhary *et. al.,* 2021). One gram of fertile soil may contain as many as 10^10 bacteria, contributing to a biomass of approximately 2000 kg per hectare (Raynaud and Nunan, 2014). Biofertilizer" is an umbrella term that includes a variety of substances, such as nitrogen-fixing microorganisms, phosphorus and potassium solubilizers, mycorrhizae, and diverse microbial consortia. These entities are often known by other labels, including microbial injections, bioinoculants, soil injections, microbial fertilizers, bioenhancers, phytostimulators, and Plant Growth Promoting Rhizobacteria, among others. Despite the attractive prospects offered by biofertilizers, commercially produced microbial-based variants confront numerous obstacles in real-world agricultural situations. These challenges are primarily attributed to the survival rates of these microbial inoculants under fluctuating environmental circumstances, insufficient awareness among farmers, poor formulation quality, and the lack of localized strains that perform effectively. (Mitter *et.al.,* 2020). Soil bacteria can exhibit various morphological forms, including cocci (spherical, 0.5 μm), bacilli (rod-shaped, 0.5–0.3 μm), and spiral configurations (ranging from 1 to 100 μm). The distribution of these bacteria within the soil matrix has an impact on the soil' s and chemical characteristics, the presence of organic matter, phosphorus levels, and agricultural practices. Notably, the development of sustainable agricultural methods in the future depends on the functions of bacteria in nitrogen fixation and plant growth stimulation Additionally, these microbes play a crucial role in facilitating diverse nutrient cycles within the ecosystem.

**Types of Nitrogen-Fixing Biofertilizers;**

The most important factor limiting plant growth is the availability of nitrogen. (Gupta *et. al.,* 2012). Biological fixation of nitrogen is the process by which di-nitrogen (N2) is transformed into a form that can be utilized by plants, primarily ammonium (NH4+). This transformation involves the reaction of N2 with hydrogen ions derived from water. It is important to note that nitrogen fixation is not exclusively a biological process; natural phenomena such as lightning and fire can also convert N2 into nitrate (NO3−). In fact, approximately 1% of the total nitrogen fixed annually is attributed to ammonia produced by lightning (Igarashi and Seefeldt, 2003). Although nitrogen makes up around 80% of the atmosphere in its free form, most plants cannot directly absorb this nitrogen. It takes a certain set of microbes to allow plants to use nitrogen from the atmosphere. These microbes are referred to as biological nitrogen fixers (BNFs) because they transform inert nitrogen dioxide into an organic form that plants can absorb. Although nitrogen makes up around 80% of the atmosphere in its free form, most plants cannot directly absorb this nitrogen. It takes a certain set of microbes to allow plants to use nitrogen from the atmosphere. Biological nitrogen fixers (BNFs) are microorganisms that transform inert nitrogen dioxide into an organic form that plants can absorb. (Reed *et. al.,* 2011). All living organisms, encompassing both eukaryotes and prokaryotes, inherently rely on biological nitrogen fixation (BNF) for their nitrogen supply, whether directly or indirectly. Proteins, nucleic acids, and other organic nitrogenous substances are all synthesized using nitrogen as a basic component. Process of biological nitrogen fixation is energetically demanding, necessitating the consumption of 16 ATP molecules to cleave a single N2 molecule. Furthermore, an additional 12 ATP molecules are essential for the assimilation and transport of NH4+, culminating in a total requirement of 28 ATP molecules. To facilitate the acquisition of 1 g of nitrogen, nodulating plants must supply their bacterial symbionts with 12 g of glucose (Buscot and Verma, 2005). Nitrogen fixation is aided by *blue-green algae*, symbiotic organisms like *Rhizobium*, *Frankia*, and *Azoll*a, as well as free-living bacteria like *Azotobacter* and *Azospirillum*. *Rhizobium*, *Mesorhizobium*, *Azorhizobium*, *Bradyrhizobium*, *Sinorhizobium*, and *Allorhizobium* are among the nitrogen-fixing bacteria that are linked to legumes. *Achromobacter*, *Alcaligenes*, *Arthrobacter*, *Acetobacter*, *Azomonas*, *Beijerinckia*, *Clostridium*, *Bacillus*, *Enterobacter*, *Erwinia*, *Desulfovibrio*, *Derxia*, *Corynebacterium*, *Campylobacter*, *Herbaspirillum*, *Klebsiella*, *Lignobacter*, *Mycobacterium*, *Rhodospirillum*, *Rhodopseudomonas,* *Xanthobacter*, and *Methylosinus*, on the other hand, are those linked to non-leguminous plants. (Meena *et. al.,* 2017). Many genera are known to be separate from the rhizosphere; however, it is *Azospirillum* and *Azotobacter* genera that have been extensively examined for their ability to enhance the yields of legumes and cereals in field conditions (Bhat *et. al.,* 2015). Below, an overview of the principal nitrogen-fixing bacteria is provided.

***Rhizobium***

*Rhizobium* is classified within the bacterial family Rhizobiaceae and serves as a prime illustration of symbiotic nitrogen fixation. This bacterium is capable of fixing atmospheric nitrogen (N2) in both leguminous and non-leguminous crops. According to research, Rhizobium can fix nitrogen at up to 300 kg N/ha/year for a variety of legume species. According to research, Rhizobium can fix nitrogen at up to 300 kg N/ha/year for a variety of legume species. According to research, Rhizobium can fix nitrogen at up to 300 kg N/ha/year for a variety of legume species. According to research, Rhizobium can fix nitrogen at up to 300 kg N/ha/year for a variety of legume species. (Pindi and Satyanarayana, 2012). Within the α-proteobacteria, the *Rhizobiaceae* family includes symbiotic nitrogen-fixing rhizobacteria which infect leguminous plant roots. Establishment of this symbiotic relationship involves intricate interactions between the host and the bacteria, leading to the formation of nodules where *Rhizobia* act as intracellular symbionts (Allito, *et. al.,* 2015). *Rhizobia* is the collective name for the genera *Rhizobia*, *Bradyrhizobia*, *Sinorhizobia*, *Azorhizobia*, and *Mesorhizobia*. Additionally, there are diazotrophs—non-symbiotic rhizobacteria that fix nitrogen in non-leguminous species—that can interact with their host plants in a non-obligate manner. (Verma *et. al.,* 2010). Upon infecting roots of leguminous plants, bacteria induce the development of nodules. Inside these structures, molecular nitrogen undergoes reduction to ammonia, which the plant employs for the manufacturing of vitamins, proteins, and other substances high in nitrogen. Consequently, these root nodules act as ammonia manufacturing sites. (Flores-Félix *et. al.,* 2013). The species of *Rhizobium* enhance growth of non-leguminous plants by causing alterations in root structure and physiological growth processes. Rhizobium application has been demonstrated to enhance crop development by raising nitrogen content, plant height, seed germination rates, and leaf chlorophyll levels. (Sara *et. al.,* 2013). Rhizobium is frequently employed in agricultural practices to secure sufficient nitrogen, with around 80% of biologically fixed nitrogen originating from symbiotic relationships, thereby presenting an opportunity to substitute chemical nitrogen fertilizers (Rubio-Canalejas *et. al.,* 2016).

***Frankia—Casuarina* -**

*Angiosperms* from various genera, including *Hippophae, Discaria, Coriaria, Myrica, Alnus, and Casuarina*, establish symbiotic connections to *Frankia*, an actinomycete. On many plant species in 25 genera and 8 families of dicotyledons, these filamentous, spore-forming actinomycetes create nodules. These plants are all classified as woody trees or shrubs. Such a symbiotic relationship plays a important part in Improving economy of Nitrogen through fixation of nitrogen and is crucial for agroforestry systems as well as for preserving deteriorating land surfaces. It is knownthat *actinorhizal* symbiosis improve temperate forests' fertility in a manner similar to the contributions of woody legumes in tropical regions. Actinorhizal plants thrive in nitrogen-deficient environments, such as eroded slopes and mining waste sites, and they yield commercially valuable shrubs and large trees. In North America, the current grasslands lack a substantial legume presence, indicating that *actinorhizal* symbiosis historically contributed significantly to the enhancement of nitrogen levels in these areas. The actinorhizal nodules consist of groups of altered roots containing Cells infected with *Frankia* found within the cortex. Initially, nodules manifest as swellings, which subsequently develop into lobes at their tips, forming vesicles that serve as the locations for fixing nitrogen. Frankia's capacity for biological nitrogen fixation (BNF) in Coriaria arborea is roughly 90 kg N/ha/year. (Silvester, 1976).

***Anabaena Azollae***

Angios-Azolla serves as a biofertilizer in rice cultivation across various countries, including the China, Vietnam, Thailand, Sri Lanka, and Philippines. Water fern *Azolla* forms a symbiotic interaction with cyanobacterium *Anabaena azollae*. *Azolla* in India is recognized as a valuable biofertilizer for paddy fields, and farmers use it extensively. It grows well in water beds or slow-moving creeks and is applied on crops in between rice plantings. Following a growth period, it is either incorporated into the soil prior to transplanting or allowed to decompose as the canopy of rice develops. Due to its low carbon-to-nitrogen (C: N) ratio, *Azolla* is rapidly mineralized, providing essential nitrogen to the plants. In addition to nitrogen fixation, Azolla effectively suppresses weed growth in wetland rice, offering an economic advantage of rice farming. Azolla has also recently been used as animal feed to increase dairy animals' milk production. It has been demonstrated that applying 15 tons of Azolla microphylla per hectare in conjunction with neem cake increases grain output by 29.2%. (Sundaravarathan and Kannaiyan, 2002). Azolla leaves exhibit a nitrogen composition of 4–5% when calculated based on dry weight, in contrast to a nitrogen content of 0.2–0.4% when considered according to wet weight. These leaves break down quickly, releasing nitrogen that is beneficial for plant growth. The *Azolla-Anabaena* symbiotic system is capable of supplying 1.1 kg of nitrogen daily per hectare, with a single crop of *Azolla* supplying between 20 and 40 kg nitrogen per hectare to rice crops over a period of approximately 20 to 25 days (Setiawati *et. al.,* 2018).

***Azotobacter*-**

*Azotobacter*, which is part of the *Azotobacteriaceae* family, is employed for all non-leguminous plants as a biofertilizer, especially those such as rice, cotton, sweet potatoes, sweet sorghums, vegetables, and sugarcane. *Azotobacter chroococcum* is the most common species in cultivated soils, and these organisms are generally found in alkaline and neutral soil settings. (Moraditochaee *et al.,* 2014). Azotobacter is a diazotrophic bacterium that exists independently and is capable of fixing nitrogen. Its diverse metabolic activities contribute significantly to nitrogen cycle (Sahoo *et. al.,* 2014). Azotobacter is responsible for the biosynthesis of important plant hormones, including Vitamin B complex, naphthalene acetic acid, gibberellic acids, and indole acetic acids. These hormones contribute to the suppression of root pathogens, the promotion of root growth, the enhancement of mineral uptake, and the improvement of soil fertility (Sumbul *el. al.,* 2020). It has been noted that Azotobacter is typically not very abundant in the rhizosphere of crop plants or in uncultivated soil. This organism's presence has been observed in the rhizospheres of multiple crop types, including Bajra, rice, maize, and sugarcane, a selection of plantation crops and vegetables (Wani *et. al.,* 2013). Azotobacter possesses the capability to synthesize vitamins like riboflavin and thiamine (Revillas *et. al.,* 2000). Genus Azotobacter is capable of producing antifungal substances and antibiotics that suppress the growth of numerous pathogenic fungi in root area, which plays a significant role in mitigating seedling mortality (Bhosale *et. al.,* 2013).

***Azospirillum-***

The genus *Azospirillum* consists of Gram-negative, aerobic bacteria with the capacity to fix nitrogen that don't form nodules. These organisms are categorized within the *Spirilaceae* family (Mehnaz, 2015). The genus contains a variety of species, including *Amazonian Azospirillum, halopraeferens Azospirillum, and brazilian Azospirillum*; however, the most significant advantageous species are *Azospirillum brasilense* and *Azospirillum lipoferum* (Mishra et.al., 2013). *Azospirillum lipoferum* is a prevalent bacterium found in soil, first identified by *Beijerinck* in 1925. This bacterium is classified as an associative symbiotic nitrogen-fixing organism, known for its manufacturing of substances that promote development, like indole-3-acetic acid (IAA) and gibberellins, which enhance root development. Additionally, *Azospirillum lipoferum* synthesizes significant amounts of plant growth-promoting substances, including pantothenic acid, thiamine, and niacin, which contribute to improved plant growth and yield. Notably, *Azospirillum* exhibits remarkable versatility in its ability to fix atmospheric nitrogen (Dobereiner, 1997). *Azospirillum* forms a symbiotic relationship with a range of plants, particularly those that use the C4 dicarboxylic route (also known as the Hatch-Slack pathway) for photosynthesis, as it thrives and fixes nitrogen in presence of organic salt’s derived from aspartic and malic acids (Mishra and Dash, 2014). Consequently, it is primarily advised for the cultivation of crops such as Pearl millet, sorghum, sugarcane, and maize. These organisms produce growth-promoting chemicals, such as gibberellins, cytokinins, and indole-3-acetic acid (IAA), which aid in root development and the uptake of vital plant nutrients like potassium (K), phosphorus (P), and nitrogen (N).. The inoculation of Azospirillum significantly influences root growth and exudation processes (Trabelsi and Mhamdi, 2013).

***Glucanobacter-***

Acetobacter diazotrophicus, a notable diazotroph, serves as a nitrogen-fixing bacterium located in stems, roots, and leaves of sugar beet and sugercane plants, and introduced through treatment of soil. Furthermore, it produces growth-promoting compounds including indole-3-acetic acid (IAA), which facilitate root development, seed germination, and nutrient absorption. (Gahukar – 2005-06). This organism exhibits a remarkable tolerance for elevated levels of sucrose and thrives endophytically within sugarcane ecosystems. In Presence of hormones that promote growth, specifically indole-3-acetic acid (IAA), released by plants facilitates germination and root development, thereby enhancing nutrient uptake. Consequently, this bacterium is capable of fixing approximately 15 kg of nitrogen per acre on an annual basis. The distribution of different types has also evolved, with phosphate-solubilizing bacteria (PSB) demonstrating significantly superior results compared to Azotobacters, which show moderate performance. The overall quantity of units diminishes the annual capacity, while the decline in rhizobium populations indicates that the production of groundnuts and pulses did not meet anticipated levels. The correlation between capacity and actual distribution, as opposed to mere production, provides a metric for assessing capacity. Furthermore, the relationship between actual distribution and capacity offers insights into the extent of capacity utilization. Notably, the most significant enhancements in straw and grain yield were recorded in wheat plants that received rock phosphate as a phosphorus fertilizer, following inoculation with a combination of Azotobacter, Rhizobium, and vesicular-arbuscular mycorrhizae (VAM). *Gluconacetobacter diazotrophicus* serves as a nitrogen-fixing endosymbiont in sugarcane plants, where it exerts antagonistic effects on *albilineans xanthomonas* by inhibiting synthesis of bacterial polysaccharide known as xanthum. In the case of soybean and cereal crops, these plants can derive as much as 30% of their nitrogen requirements through biological nitrogen fixation (BNF), particularly when provided with sufficient phosphorus, potassium, and trace elements. Among these crops, sugarcane demonstrates the most significant benefit, capable of acquiring up to 150 kg of nitrogen per hectare through BNF (Dobereiner, 1997)

***Cyanobacteria (Blue-Green Algae*)-**

Cyanobacteria that fix nitrogen are most widespread category of nitrogen (N2) fixers found on Earth. This diverse assemblage of prokaryotic organisms, commonly referred to as among the blue-green algae are, includes genera such as *Lyngbya, Oscillatoria, Nostoc, Anabaena, and Aulosira* (Sharma *et. al.,* 2010). *Cyanobacteria* establish symbiotic relationships with various organisms, including ferns, flowering plants, liverworts, and fungi (RoyChowdhury *e.t al.,* 2014). Cyanobacteria's role in soil health is crucial, as they enrich the soil with nitrogen and provide vital nutrients, including growth-promoting and vitamin B complex substances such as Gibberellic acid, indole acetic acid, and auxins, which are instrumental in accelerating plant growth. In submerged rice fields, these microorganisms can fix nitrogen at rates of 20 to 30 kg per hectare, resulting in a yield increase of 10 to 15 percent when applied at 10 kg per hectare. Research findings reveal that integration of blue-green algae a in agricultural systems, especially in context of rice cultivation, enhances the nitrogen supply for plants. (Singh *et. al.,* 2016) (Mishra and Pabbi, 2004). The strains demonstrated the capacity to release bioactive compounds, which contributed to improved plant growth and increased yield. Additionally, a separate investigation revealed that the inoculation of rice with cyanobacteria sourced from rice fields positively influenced both the rice plants and the characteristics of the soil (Roona and Shamina, 2022).

***Phosphate Solubilizing and Mobilizing Biofertilizers***

Plants typically contain approximately 0.2% phosphorus based on dry weight, which is a crucial nutrient for their development and growth. Among the macronutrients, phosphorus is generally least mobile nutrient obtainable by plants in most soil environments. The conversion of insoluble phosphate forms into soluble forms is facilitated by microbes (Prabhu, *et. al.,* 2019) (Kalayu, 2019). Phosphate-solubilizing bacteria (PSB) play a crucial role in transforming phosphate compounds that are insoluble, like as H2PO4 and HPO4, into soluble forms through various mechanisms. These mechanisms include the secretion of acids that are organic, chelation processes, and exchange reactions between ions. Within microbial communities, PSB represent approximately between 1–50% of the total microbial population engaged in phosphate solubilization, in contrast to fungi, which contribute only 0.1–0.5% to these activities (Sharma *et. al.,* 2013). Various microorganisms, including *Bacillus*, *Rhizobium*, *Aerobacter*, *Burkholderia*, *Aspergillus*, and *Penicillium*, are recognized as phosphate-solubilizing bacteria and fungi. The application of Alcaligenes sp. has demonstrated improvements in plant growth parameters through its ability to phosphorous solubilization and indole-3-acetic acid production (IAA) (Abdallah *et. al.,* 2016). The phosphate solubilizing bacteria (PSB) supply not just phosphate but also essential trace elements, including iron and zinc, which significantly promote plant growth. Additionally, these bacteria produce enzymes that are effective in eliminating pathogens, thereby safeguarding plant against many diseases (Anand *et. al.,* 2016).

***Phosphate Mobilizers-***

Microorganisms that facilitate phosphate mobilization are capable of converting the less accessible forms of phosphorus into more available forms (Suther *et. al.,*2017). These microorganisms are advantageous bacterium that proficiently facilitate mobilization of phosphorus that dissolves and phosphorus mineralization in organic compounds, both of which represent forms of phosphorus that are not readily available. Notable examples of phosphorus-mobilizing microorganisms (PMB) include *Bacillus*, *Pseudomonas*, and *Rhizobium* (Kirui *et al.,* 2022). Three distinct processes have been identified in relation to this process. The first mechanism involves the release of phosphatase enzymes by PMB. The second mechanism pertains to the creation of organic acids by PMB. Lastly, PMB may engage in a symbiotic interaction with other fungal mycorrhizae, facilitating the mobilization of soluble phosphorus from areas inaccessible to plant roots through the absorption of soluble phosphate via hyphal structures. (Etesami *et al.,* 2021) (Nassal *et al.,* 2018). A significant benefit of *Arbuscular mycorrhiza* lies in its ability to facilitate the transport of phosphorus to plants, both organic and inorganic. Notable instances of arbuscular mycorrhizal fungi (AMF) encompass *Entrophospora, Paraglomus sp., Glomus sp., and Acaulospora sp.* In comparison, ectomycorrhizal fungi encompass genera like *Boletus, Laccaria,* and *Amanita* species. Additionally, the fungal endophyte *Serendipita* has been shown to enhance potassium levels in maize while also providing protection against stress due to salinity (Haro and Benito, 2019).

***Plant Growth Promoting Rhizobacteria-***

Collection of bacteria that live freely in the rhizosphere, inhabiting the roots of plants and encouraging favorable development effects in plants is known as plant growth-promoting rhizobacteria (PGPR) (Beneduz *et. al.,*2012). PGPR functions as a biofertilizer, encompassing a diverse array type bacteria found in soil that inhabit rhizosphere, are associated with the rhizoplane on the root surface, and exist as endophytes within the intercellular spaces (Vandana et al., 2021). Plant growth-promoting bacteria (PGPB) encompass a variety of bacteria that exist independently and establish specific symbiotic connections to plants. This category also includes bacterial endophytes capable of colonizing certain areas of plant tissue, as well as Cyanobacteria (Farrar *et. al.,* 2014). Enhancement of plant growth is facilitated by range of mechanisms utilized by plant growth-promoting rhizobacteria (PGPR). These mechanisms include nitrogen fixation, the mineralization of macro- and micronutrients, the secretion of exopolysaccharides, the production of phytohormones, synthesis of siderophores, emission of hydrogen cyanide to inhibit phytopathogen proliferation, and the production of antibiotics, among others (Gouda et al., 2018) (Numan et al., 2018). Plant Growth-Promoting Rhizobacteria (PGPR) encompasses various genera, including but not limited to *Bacillus, Frankia, Pseudomonas, Rhizobium, Micrococcus, Streptomyces, Xanthomonas, Enterobacter, Cellulomonas, Serratia, Arthrobacter, Alcaligenes, Azotobacter, Acinetobacter, Actinoplanes,* and *Thiobacillus* (Yadav *et. al.,* 2017).

**Impact of Biofertilizers on Ecosystems-**

Despite the extensive application of biofertilizers in agriculture over recent decades, there remains a significant lack of detailed information regarding their colonization and ecological dynamics. Furthermore, mechanisms underpinning their relationships with vegetation and resident microorganisms’ communities continue to intrigue researchers. A critical factor influencing the effectiveness of biofertilizers in native environments is indigenous microflora present in rhizosphere. This competitive group, characterized by a wide variety of species, can significantly impact both the survival of biofertilizers and their capacity to encourage plant growth (Hibbing *et. al.,* 2010). Moreover, the practice of bacterizing seeds and seedlings, as well as implementing soil amendments, can significantly impact the structure of the indigenous microflora. This impact must be carefully considered in relation to safety of bacterial introduction into the environment (Dey *et. al.,* 2012). It is essential to carefully consider the non-target effects of microbial biofertilizers, which encompass their impact on organisms on organisms beyond intended pathogens, their cycles of biogeochemistry, alterations in texture of soil, and modifications to soil properties such as water retention, porosity, and overall fertility, as well as their role in erosion prevention (Pereg and McMillan 2015). Several studies conducted over extended periods are essential for drawing conclusions regarding the efficacy and risk factors associated with bioinoculants. Consequently, it is evident that further comprehensive study is necessary to evaluate long-term effects of biofertilizers on non-target organisms prior to deeming these "safe" bioinoculants for commercial use. Furthermore, the impact of biofertilizers not on target communities has been examined through both culturally dependent and independent methodologies, encompassing both physiological and genetic assessments. While the evaluation of microbial community compositions via both cytochemical and plating techniques provides valuable framework for investigating the influence of biofertilizers on resident microorganisms, the integration of advanced technology is imperative for a thorough examination of their effects on soil function and microflora. Although DNA serves as a dependable marker for assessing diversity and potential of community, recent advancements in extraction of messenger RNA (mRNA) from soil present a significant opportunity to enhance evaluation of risk and efficiency studies involving biofertilizers. Furthermore, an mRNA-based strategy would offer insights into actual biofertilizer functional diversity at a given period points within the studied system. Therefore, it is crucial to employ high-throughput methods with greater resolution alongside traditional techniques for a comprehensive analysis of risk assessment, diversity, and efficacy of biofertilizers before to their introduction into ecosystem. (Sharma *et. al.,* 2012).

**Impact of Biofertilizers on Plants-**

The relationship between elevated photosynthesis and enhanced plant growth is evident, as nearly 90% of biomass from plants is produced through absorption of CO2 in the photosynthetic process (Long *et. al.,* 2006). The application of advantageous microorganisms, specifically endophytes that can synthesize growth hormones like indole-3-acetic acid (IAA) and ACC deaminase, has been shown to enhance potassium absorption in plant tissues while simultaneously reducing ethylene concentrations, thereby contributing to adaptability to stress in different plant species (Chaudhary *et. al.,* 2022a). Inoculating plants with biofertilizers such as *Bradyrhizobium* *sp*. *IRBG 271*, *Rhizobium sp*. *IRBG 74*, and *R. leguminosarum* resulted in a notable rise in the single-leaf photosynthetic rate in comparison to uninoculated control. IRBG strain, in particular, showed greatest improvement in activity of photosynthetic, with an increase of 14% compare to control group (Peng *et. al.,* 2002). Biofertilizers functioning as endophytes demonstrate a range of associations with their host plants, which can be classified as mutualistic, parasitic, or symbiotic. These organisms colonize tissues of plants in a manner that does not lead to disease, ultimately offering advantages to vegetation (Chaudhary et al., 2022b). The endophytes can gain benefits of mutualistic relationships, as they obtain nourishment from their host plants and propagate through the transmission of host seeds. Additionally, they facilitate the absorption of essential nutrients like nitrogen, magnesium, zinc, and phosphorus from soil, which they subsequently supply to host plant, thereby promoting its growing and overall survival (Bamisile *et. al.,* 2018). In the previous study was noted that under heat stress, Pseudomonas sp. increased plant growth by promoting the production of heat shock proteins (HSPs) and reducing reactive oxygen species (ROS). Additionally, Paenibacillus sp. contributed to the growth of Phaseolus vulgaris by facilitating the synthesis of  hydrogen cyanide (HCN), siderophores, and indole-3-acetic acid (IAA) in conditions of salinity stress (Gupta and Pandey, 2019). Shukla *et. al.,* (2012) Research indicates that the application of Trichoderma harzianum to rice plants leads to improved root growth and offers a protective effect against drought stress. Pseudomonas putida inoculation enhanced production of abscisic acid, salicylic acid, and flavonoids thereby providing protection to soybean plants against stress from drought (Kang *et. al.,* 2014). Pseudomonas species inoculation has been shown to enhance the resilience of maize plants against drought stress, resulting in increased sugar content and biomass in the treated specimens. This protective effect is attributed to dehydrin protein upregulation and elevated the proline levels (Sandhya *et. al.,* 2010). Gond *et. al.,* (2015) Studies have shown that inoculating tropical corn with Pantoea agglomerans under conditions of stress from salt (0–100 mM) significantly enhances both plant growth and tolerance, a phenomenon linked to aquaporins' upregulation. Similarly, Bacillus megaterium has been found to influence aquaporin gene regulation in maize during salt stress, thereby enhancing root growth and leaf water retention.

**Impact of biofertilizers on heavy metals remediation-**

Metals constitute a natural component of soils, with several of them serving as essential micronutrients for plant development. Nevertheless, ongoing human activities, widespread agricultural practices, and the swift pace of industrialization have resulted in major environmental problems brought on by the discharge of pollutants, such as organic contaminants, toxic waste, and heavy metals (Shinwari *et. al.,* 2015). Heavy metals constitute a major group of inorganic pollutants that are capable of dissolving in water and accumulating in soil environment, primarily because of their persistent and non-degradable characteristics (Akhtar *et. al.,* 2013). Harmful heavy metals present in various states of valence encompass lead (Pb), copper (Cu), nickel (Ni), mercury (Hg), chromium (Cr), cadmium (Cd), zinc (Zn), and arsenic (As). While these metals are essential micronutrients for plants, excessive accumulation can be detrimental to most plant species. Elevated concentrations of heavy metal ions in surroundings are swiftly utilized by plant roots and subsequently transported to the shoots and leaves, resulting in stress that disrupts metabolic processes, inhibits growth, and may ultimately lead to plant mortality (Mehes-Smith *et. al.,* 2013). Additionally, elevated levels of soil-borne heavy metals diminish fertility of soil and have a detrimental impact on the microorganism community (Lenart and Wolny-Koładka, 2013). The remediation heavy metals from soil presents significant challenges because their non-biodegradable nature. Detoxification can only be achieved through alterations in their oxidation state. Generally, heavy metals exhibit greater toxicity in their oxidized forms compared to their reduced counterparts (Wuana and Okieimen, 2011). Various techniques, such as biological, physical, and chemical methods, have been employed to eliminate pollutants from metals. However, bioremediation stands out as the most effective strategy for removal due to its cost-efficiency and ease of application, particularly when contrasted with physiochemical detoxification technologies, which tend to be costly and detrimental to soil properties ((Lim *et. al.,* 2014). Selection of rhizobacteria that promote plant development (PGPR) includes *Achromobacter chroococcum* and *Achromobacter xylosoxidans*, Bacillus subtilis, Bacillus megaterium, Bradyrhizobium, various Pseudomonas species, *Brevibacillus species*, *Rhizobium, Sinorhizobium, Ralstonia metallidurans, Pseudomonas putida, Pseudomonas aeruginosa, Kluyvera ascorbata, and Mesorhizobium species*, *Ochrobactrum and Variovox paradoxus species,* *Psychrobacter species*, and *Xanthomonas species*. These microorganisms are integral to the bioremediation processes addressing heavy metal contamination (Shinwari *et. al.,* 2015). It is well established that the presence of heavy metals in the environment causes stress in plants, which subsequently triggers the synthesis of ethylene hormone. Elevated concentrations of this hormone can adversely affect plant growth (Hossain *et. al.,* 2012). Among the several strategies that plant growth-promoting rhizobacteria (PGPR) employ for plant defense, the generation of 1-aminocyclopropane-1-carboxylate (ACC) deaminase is particularly significant, as it helps to reduce the concentration of ethylene, a hormone that induces stress in plants ((Singh *et. al.,* 2015). By producing ACC deaminase, PGPR offer a vital line of defense for host plants, helping them to address stress responses that arise from toxicity of heavy metal. Moreover, PGPR further mitigate metal toxicity through generation of microbial siderophores (Radzki *et. al.,* 2013). PGPR can aid in diminishing metal toxicity by utilizing biosorption mechanisms, which involve the binding of heavy metals to microbial cells. This process can occur through both metabolically dependent and independent pathways ((Dary *et. al.,* 2010).

**Impact of Biofertilizers on Pesticide Remediation-**

Nematicides, herbicides, fungicides, and insecticides are employed to manage or suppress diseases of plants. Application of pesticides is vital for contemporary agricultural methods, serves as a vital tool for effective pest management. Nonetheless, the overuse and prolonged application of these chemicals can have detrimental impacts on the environment and present serious hazards to human health and plant life, as they can infiltrate the tissues of living organisms, leading in relation to bioaccumulation (Kumar and Puri, 2012) (Aktar *et. al.,* 2009). Bioremediation practices for the remediation of pesticide pollution have emerged as a topic of significant interest, attributed to their environmentally sustainable approach, cost-effectiveness, and efficacy in eliminating pollutants from ecosystems (Nawaz *et. al.,* 2011). Currently, the study of bacterial strains that can degrade pesticides is emerging as a promising avenue for addressing the negative consequences associated with pesticide use. Numerous study has been conducted on plant growth-promoting rhizobacteria (PGPR), highlighting their significant roles in horticulture, forestry, agriculture, and environmental sustainability. As a result, potential of PGPR in the bioremediation of pesticides has been thoroughly investigated (Shaheen and Sundari 2013). This has been observed that certain microbes., including *Gordonia, Klebsiella, Paenibacillus, Pseudomonas, Serratia, Bacillus, Enterobacter, Azospirillum,* and *Azotobacter*, are able to diminishing toxicity of pesticide (Shaheen and Sundari, 2013). Beyond these strains, *Actinomycetes* exhibit noteworthy potential for biodegradation and biotransformation of pesticide compounds. Microbes are primarily utilize enzymatic degradation as the main mechanism for pesticide degradation. This process encompasses three significant enzyme systems: Esterases, mixed function oxidases (MFO), and hydrolases during initial stage of metabolic, followed by glutathione S-transferases (GST) system in the later stage (Ortiz-Hernández *et. al.,* 2013). Moreover, This has been observed several enzymes that catalyze an extensive range of reactions, variety of processes, such as oxidation and hydrolysis, the inclusion of amino groups to nitro groups, dehalogenation, the transformation of nitro groups into amino groups, ring cleavage and the substitution of oxygen for sulfur, and the metabolism of side chains, which have been found to alleviate toxicity posed by pesticides (Ramakrishnan *et. al.,* 2011). The analysis of multiple reports suggests that the Plant Growth-Promoting Rhizobacteria (PGPR) use offers a promising method for decreasing pesticide residues in soil in an environmentally sustainable manner.

**Impact of Biofertilizers on Parasitic Nematodes in Crops -**

El-Haddad *et. al.,* (2011) demonstrated that various biofertilizers made of bacteria, specifically nitrogen-fixing bacteria such as four strains of Paenibacillus polymyxa, phosphate-solubilizing bacteria like Three strains of B. megaterium and potassium solubilize bacteria including Three strains of Bacillus circulans were individually applied to plants of tomato affected by root-knot nematode M. incognita in potted sandy soil. The study revealed that all the biofertilizers made of microorganisms exhibited notable nematicidal properties, with B. circulans KSB2, B. megaterium PSB2, and P. polymyxa NFB7 showing most significant reduction of nematode populations compared to the control group that was not inoculated. Furthermore, the application of these biofertilizers resulted in enhanced length of shoot (cm), an increased number of leaves on per plant, as well as greater dry weight of shoot (g) and dry weight of root (g) in tomato plants, in contrast to those affected by nematodes that did not receive biofertilizer inoculation. Khan *et. al.,* (2012) demonstrated that Chilli (*Capsicum annuum* L.) plant growth, yield, and quality affected by nematode infestation were significantly enhanced through inoculation with biological nitrogen-fixing agents, specifically *Azotobacte*rand *Azospirillum*. Ismail and Hasabo (2000) investigated effectiveness of six new commercial biofertilizers from Egypt, including blue-green *algae*, *phosphorine*, *serealin*, *nitrobien*, *rizobacterin*, and *microbien*, in combating M. *incognita* in the sunflower cultivar Giza 101. All biofertilizers that were tested demonstrated a significant decline in nematode populations. The most effective treatment in suppressing these populations was rizobacterin, with phosphorine and nitrobien following closely behind. It has been documented that bacteria similar to biofertilizers commonly release a range of compounds, including alcohol, hormones, phenolic chemicals, fatty acids, hydrogen sulfide, enzymes, and volatile compounds, which play a role in curbing the development of plant-parasitic nematodes (Youssef and Eissa, 2014). These products might exhibit hazardous effects on nematodes, or they could indirectly change rhizosphere environment, which may contribute to a reduction in population of nematode (Youssef and Eissa, 2014).

**Impact of Biofertilizers on Degraded Land Soil Reclamation -**

The process of Exploiting mineral resources in considerable degradation of soil, modifies microorganisms communities, and adversely affects vegetation, culminating in the destruction of extensive land areas. The gradual proliferation of these altered landscapes threatens productivity of agriculture and forests while also upsetting the natural equilibrium of ecosystem. This has been consistently noted that during different mining operations, nutrients are leached away due to heightened rates of erosion, which ultimately undermines soil productivity (Sheoran *et. al.,*2010). A variety of beneficial microbes frequently utilized in agricultural practices encompasses species such as *Streptomyces, Pseudomonas, Bacillus, Azospirillum, Mycorrhizae, Rhizobia,* and *Trichoderma*. These microorganisms play a crucial role in decomposition of organic matter within the soil, thereby enhancing the availability of essential macronutrients, including Calcium, magnesium, sulfur, potassium, phosphorus, and nitrogen, as well as micronutrients such as Zinc, manganese, molybdenum, iron, copper, chlorine, and boron for crop plants (Imran *et, al.,* 2015). It has been documented that biofertilizers significantly contribute to soil fertility, enhance crop productivity, and improve profitability. Beneficial microorganisms are essential for the breakdown of organic materials within soil, thereby increasing the availability of essential macronutrients such as calcium, magnesium, sulfur, potassium, phosphorus, and nitrogen, along with micronutrients including zinc, manganese, molybdenum, iron, copper, chlorine, and boron for crop plants (Adhikari *et. al.,* 2001). In a state of vulnerability, reclamation serves as the process that reinstates the ecological integrity of areas affected by mining activities. The effective reclamation of mine spoil dumps depends on the establishment of a thriving indigenous microbial community, which plays a vital role in forming soil structures that facilitate growth of plant and in generating essential plant nutrients through various biogeochemical cycles (Kumar *et. al.,* 2013). The procedure of reclaiming a location for mining presents significant challenges, as these locations not only experience a decline in fertility and productivity but also lose their capacity to sustain Plant and microbial communities (Chaubey and Prakash 2014). Biofertilizers are applied to enhance soil fertility through the processes of atmospheric Phosphate solubilization and nitrogen fixation, and creation of substances that encourage the development of plants (Marschner 1995). Maintenance of ecosystem balance and productivity is significantly influenced by various factors. The restoration of degraded land ecosystems can be partially achieved through the implementation of tree plantations and use of organic amendments, which increase soil fertility and productivity. Mining activities lead to the severe acidification of soils at mining sites, adversely impacting plant growth. The introduction of organic amendments can elevate the pH levels of these soils, thereby improving not only the pH but also the overall water-retention capacity , quality of soil , and facilitating a gradual release of nutrients (Diacono and Montemurro 2010). The application of bioinoculants plays a significant role in mitigating detrimental effects of soil salinity by enhancing physicochemical characteristics of the soil, which in turn leads to increased agricultural yield (Jiménez-Mejía *et, al.,* 2022). Consequently, one can assert that the upkeep of effective soil reclamation depends on the presence of leguminous plants in the plant community and the healthy operation of the microbial community in areas affected by mining. It has been observed that the integration of three bacterial biofertilizers—*Pseudomonas*, *Bacillus lentus*, and *Azospirillum brasilense*—leads to an increase in antioxidant enzyme expression and chlorophyll content in leaves experiencing stress, which in turn fosters the establishment of a more advanced photosynthetic system within plant (Heidari and Golpayegani 2012). Application of biofertilizers is instrumental in improving soil quality through the provision of nutrients and the establishment of a natural environment in the rhizosphere. This practice helps mitigate nutrient leaching and overspill, while also facilitating effective crop residue management. Furthermore, the use of microbial inoculants can lead to a decrease in quantity of chemical fertilizers required and enhance the efficiency of those that are utilized (Puneet *et.al.,* 2012).

**Emerging Perspectives on Biofertilizers-**

The incorporation of diverse biofertilizers into agricultural practices represents a burgeoning area of research and application in contemporary agriculture. Certain bacterial strains are currently being utilized effectively in several developing nations, and their adoption is anticipated to increase over time (Weekley *et. al.,* 2012). A significant proportion of biofertilizers produced exhibit effectiveness tailored to particular crops, soil types, and environmental conditions. Plant growth and development are affected by various biotic and abiotic factors within soil ecosystem (Bramhachari *et. al.,*2018). Biofertilizers' prospects in agriculture presents significant opportunities for transformative change. These environmentally friendly alternatives, which utilize beneficial microorganisms, are set to play a crucial role in tackling urgent worldwide concerns like environmental sustainability, mitigation of climate change, and the reduction of dependence on expensive and harmful agricultural inputs. The establishment of strong regulatory frameworks and standards, along with broad acceptance and adoption by farmers and stakeholders, will be essential for the effective integration of biofertilizers into conventional agricultural practices. With ongoing innovation, collaboration, and investment, biofertilizers are likely to become a fundamental component of improving food security, encouraging environmental care, and fostering sustainable agriculture, and strengthening resilience of farming communities globally (Kumar *et. al.,* 2024).

**Conclusion-**

Biofertilizers present a promising alternative to chemical fertilizers in improving soil fertility and crop yield, aligning with the global shift towards sustainable agricultural practices. The review highlights that biofertilizers, like as nitrogen-fixing bacteria, phosphorus-solubilizing microbes, and Mycorrhizal fungus, offer several environmental and economic benefits. They improve soil health by enriching microbial diversity, enhancing nutrient availability, and reducing the reliance on synthetic fertilizers, which can have detrimental effects on both environment and health of human.

Integrating biofertilizers in systems of agriculture not only increases crop productivity but also contributes to the reduction of soil erosion, water contamination, and greenhouse gas emissions, making them an integral component of sustainable farming. Additionally, biofertilizers support soil organic matter, leading to long-term improvements in soil structure and fertility, which are critical for maintaining agricultural productivity over time.

However, the widespread adoption of biofertilizers faces challenges such as lack of awareness, inconsistent product quality, and limited research on their effectiveness under diverse environmental conditions. Despite these challenges, advancements in biotechnology, along with government support and farmer education, are gradually paving the way for biofertilizers to become a mainstream solution in sustainable agriculture.

Overall, biofertilizers hold great potential in addressing the dual challenge of enhancing agricultural productivity while conserving and restoring soil health. As the world moves towards more sustainable farming practices, biofertilizers will play a significant part in ensuring food security, protecting environment's resources, and mitigating Climate change's effects. Therefore, continued research and innovation in this field are vital to unlocking the full potential of biofertilizers in the future.

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 **References**

1. **Albhari, G., Alyamani, A.A., Badran, A., Hijazi, A., Nasser, M., Maresca, M., and Baydoun, E. (2023).** Enhancing essential grains yield for sustainable food security and bio-safe agriculture through latest innovative approaches. *Agronomy*, **13**(07):1709.
2. **Sujanya S. and Chandra, S. (2011).** Effect of part replacement of chemical fertilizers with organic and bio-organic agents in ground nut, (*Arachis hypogea* L.). *Journal of Algal Biomass Utilization*. **2** (4): 38– 41.
3. **Mariyam, S., Upadhyay, S.K., Chakraborty, K., Verma, K.K., Duhan, J. S., Muneer, S., Meena, M., Sharma, R.K., Ghodake, G., and Seth, C.S. (2024).** Nanotechnology, a frontier in agricultural science, a novel approach in abiotic stress management and convergence with new age medicine-A review. *Science of the total Environment,* 912:16097.
4. **Pathak, H.K, Chauhan, P.K., Seth, C.S., Dubey, G., and Upadhyay, S.K. (2024)** Mechanistic and future prospects in rhizospheric engineering for agricultural contaminants removal, soil health restoration, and management of climate change stress. *Science of the total Environment,* 927: 172116.
5. **Mazid, M. and Khan, T.A. (2014).** Future of Bio-Fertilizers in Indian Agriculture: An Overview. *International Journal of Agricultural and Food Research*, 3, 10-23.
6. **Savci,S. (2012).** An Agricultural Pollutant: Chemical Fertilizer, *International Journal of Environmental Science and Development,* Vol. 3, No. 1.
7. **Nosheen, S., Ajmal, I., and Song., Y. (2021).** Microbes as Biofertilizers, a Potential Approach for Sustainable Crop Production. *Sustainability*, 13, 1868.
8. **Maria, J.S., and Sripriya, P. (2023).** Biofertilizers: an advent for eco-friendly and sustainable agriculture development.*Vegetos*, **36** (4): 1141-1153.
9. **Harman, G., Khadka, R., Doni, F., and Uphoff, N. (2021).** Benefits of plant health Productivity from enhancing plant microbial symbionts. *Frontiers in Plant Science*, 11:610065.
10. **Kumar, S., Kumar, S., and Mohapatra T. (2021).** Interaction Between Macro‐ and Micro-Nutrients in Plants, *Frontiers in Plant Science*, 12:665583.
11. **Agri, U., Chaudhary, P., and Sharma, A. (2021).** In vitro compatibility evaluation of agriusable nanochitosan on beneficial plant growth -promoting rhizobacteria and maize plant. *National Academy Science Letters,* **44**(6): 555-559.
12. **Baldi, E., Gioacchini, P., Montecchio, D., Mocali, S., Antonielli, L., Masoero, G., and Toselli, M. (2021).** Effect of Biofertilizers Application on Soil Biodiversity and Litter Degradation in Commercial Apricot Orchard, *Agronomy,* **11**(6): 1116.
13. **Chaudhary, A., Parveen., H., Chaudhary, P., Khatoon, H., and Bhatt, P. (2021).** Rhizospheric Microbes and Their Mechanism in “Microbial Technology for Sustainable Environment”, eds. P. Bhatt, S. Gangola, D. Udayanga, and G. Kumar. *Springer,* <https://doi.org/10.1007/978-981-16-3840-4_6> .
14. **Vishwakarma, K., Kumar, N., Shandilya, C., Mohapatra, S., Bhayana, S. and Varma, A. (2020).** Revisiting Plant-Microbe Interaction and Microbial Consortia Application for Enhancing Sustainable Agriculture: A Review. *Frontiers in Micribiology*, 11:560406.
15. **Nyalemegbe, K.K., Oteng, J.W., and Brempong-Asuming, S. (2009).**Integrated Organic-Inorganic Fertilizer Management for Rice Production on the Vertisols of the Accra Plains of Ghana. *West African Journal of Applied Ecology*,**16**(1):23-33.
16. **Dixon, R.O.D. and Wheeler, C.T. (1986).** Nitrogen fixation in plants. Glasgow: Blackie & Son, Ltd, (New York Chapman and Hall).
17. **Galloway, J., Raghuram, N., and Abrol, Y.P. (2008).** A perspective on reactive nitrogen in a global, Asian and Indian context. *Jstor,* **94** (11): 1375-1381.
18. **Postgate, J. (1990).** Trends and Perspectives in Nitrogen Fixation Research. *Advances in Microbial Physiology*, 30: 1-22.
19. **Burris, R.H. and Roberts, G.P. (1993).** Biological Nitrogen Fixation. *Annual Review of Nutrition ,* 13: 317-35.
20. **Kawalekar, J.S. (2013).** Role of biofertilizers and biopesticides for sustainable agriculture. *Journal of Bio Innovation,* **2** (3): 73-78.
21. **Bhattacharjee, R. and Dey, U. (2014).** Biofertilizer, a way towards organic agriculture: A review. *African Jpournal of Microbiology Research,* **8** (24): 2332-2343.
22. **Lee, L.H., Wu, T.Y., Shak, K.P.Y., Lim, S.L., Ng, K.Y., Nguyen, M.N., and Teoh, W. H. (2018).** Sustainable approach to biotransform industrial sludge into organic fertilizer via vermicomposting: A mini‐review. *Journal of Chemical Technology and Biotechnology*. **93**(4) : 925-935.
23. **Raghuwanshi, R. (2012).** Opportunities and Challenges to Sustainable Agriculture in India. *NEBIO***,** 3, 78-76.
24. **Alnaass, N.S., Agil, H.K, Alyaseer, N.A., Abubaira, M. and Ibrahim, H.K. (2023).** The Effect of Biofertilizers on Plant Growth and its Role in Reducing Soil Pollution Problems with Chemical Fertilizers. *African Journal of Advanced Pure and Applied Sciences (AJAPAS),* **2** (3): 387-400.
25. **Lu, H., Wu, Z., Wang, W., Xu, X. and Liu, X. (2020).** Rs- 198 Liquid Biofertilizers Affect Microbial Community Diversity and Enzyme Activities and Promote Vitis vinifera L. Growth. *BioMed Research International Volume,* Article ID 8321462.
26. **Ayala, S. and Rao, EP. (2002).**Perspectives of soil fertility management with a focus on fertilizer use for crop productivity.*Current Science****.*82**(7):797-807.
27. **Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y. and Dhiba, D. (2018.)** Soil Microbial Resources for Improving Fertilizers Efficiency in an Integrated Plant Nutrient Management System. *Frontiers in Microbiology*, 9:1606.
28. **Bhardwaj, D., Ansari, M.W., Sahoo, R.K. and Tuteja, N. (2014).** Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories*, 13:66.
29. **Daniel, A.I., Fadaka, A.O., Gokul, A., Bakare, O.O., Aina, O. Fisher, S., Burt, A.F., Mavumengwana, V., Keyster, M. and Klein, A. (2022).** Biofertilizer: The Future of Food Security and Food Safety*. Microorganisms*, **10** (6): 1220.
30. **Mahdi**, **S.S., Hassan, G.I.,** **Samoon, S.A., Rather, H.A., Dar, S.A. and (2010).** Bio– Fertilizers in Organic Agriculture. *Journal of Phytology*, **2**(10):42-54.
31. **Raynaud, X. and Nunan, N. (2014).** Spatial ecology of bacteria at the microscale in soil. *PLoS ONE*, **9**(1): e87217.
32. **Mitter, E.K., Tosi, M., Obregón, D., Dunfield, K.E. and Germida, J.J. (2021).** Rethinking Crop Nutrition in Times of Modern Microbiology: Innovative Biofertilizer Technologies. *Frontiers in Sustainable Food System,* 5:606815.
33. **Igarashi, R.Y. and Seefeldt, L.C. (2003).** Nitrogen Fixation: The Mechanism of the Mo-Dependent Nitrogenase. *Critical Reviews in Biochemistry and Molecular Biology,* **38**(4): 351-84.
34. **Gupta, G., Panwar, J., Akhtar, M. S. and Jha, P. (2012).** Endophytic Nitrogen-Fixing Bacteria as Biofertilizer. *Springer, Dordrecht,* 11: 183-221.
35. **Reed, S.C., Cleveland, C. and Townsend, A.R. (2011).** Functional Ecology of Free-Living Nitrogen Fixation: A Contemporary Perspective. *Annual Review of Ecology Evolution and Systematics,* **42**(1): 489-512.
36. **Meena, V.S., Mishra, P.K., Bisht, J.K., and Pattanayak, A. (2017).** Agriculturally Important Microbes for Sustainable Agriculture. Volume 2:Applications in Crop Production and Protection; *Springer*: Berlin/Heidelberg, Germany.
37. **Bhat, T.A., Ahmad, D. and Ganai, M. (2015).** Nitrogen Fixing Biofertilizers; Mechanism and Growth Promotion: A Review. *Journal of Pure and Applied Microbiology,* **9**(2): 1675-1690.
38. **Buscot, F. and Varma, A. (2005).** Microorganisms in Soils: Roles in Genesis and Functions. *Springer Science Business Media*: Berlin/Heidelberg, Germany, Volume 3, p. 422.
39. **Pindi, P.**K.**and Satyanarayana, S.D.V. (2012).** Liquid Microbial Consortium- A Potential Tool for Sustainable Soil Health. *Biofertilizers & Biopesticides,* 3:4.
40. **Allito, B.B., Nana, E.M. and Alemneh, A.A. (2015).** Rhizobia strain and legume genome interaction effects on nitrogen fixation and yield of grain legume: a review. *Molecular Soil* Biology, **6** (4):1–6.
41. **Verma, J.P., Yadav, J., Tiwari, K.N. and Lavakush, Singh, V. (2010).** Impact of plant growth promoting rhizobacteria on crop production. *International Journal of Agriculture Research,* **5**(11): 954-983.
42. **Flores-Félix, J.D., Menéndez, E., Rivera, L.P., Marcos-García, M., Martínez-Hidalgo, P., Mateos, P.F., Martínez-Molina, E., Velázquez, M.d.l.E., García-Fraile, P., Rivas, R. (2013).** Use of Rhizobium leguminosarum as a potential biofertilizer for Lactuca sativa and Daucus carota crops. *Journal of Plant Nutrition and Soil Science*, **176**(6): 876–88.
43. **Sara, S., Morad, M., Reza, C.M**.**(2013).** Effects of seed inoculation by Rhizobium strains on chlorophyll content and protein percentage in common bean cultivars (Phaseolus vulgaris L.). *International Journal of Biosciences,* **3**(3): 1–8.
44. **Rubio, A., Celador-Lera, L., Cruz-González, X., Menéndez, E. and Rivas, R. (2016).** Rhizobium as potential biofertilizer of Eruca Sativa. *In Book Biological Nitrogen Fixation and Beneficial Plant-Microbe Interaction; Springer: Berlin/Heidelberg, Germany*, pp. 213–220.
45. **Silvester, W.B. (1976**). ‘Ecological and economical significance of the non- legume symbioses. *In 1st Int. symposium on nitrogen fixation*. *(eds. W.E. Newton and C.J. Nyman*). Washington state univ. press, Washington, pp. 489–586.
46. **Sundaravarathan, S. and Kannaiyan, S. (2002).** ‘Influence of Azolla and Sesbania rostrata application on changes *In microbial population and enzymes in rice soils’. Biotechnology of Biofertilizers (ed. S. Kannaiyan)*. pp. 251–225).
47. **Setiawati, M.R., Damayani, M., Herdiyantoro, D., Suryatmana, P., Anggraini, D. and Khumairah, F.H. (2018).** The application dosage of *Azolla pinnata* in fresh and powder form as organic fertilizer on soil chemical properties, growth and yield of rice plant. *AIP Conference Procedings,* **1927**(1): 030017.
48. **Sahoo, R.K., Ansari, M.W., Dangar, T.K., Mohanty, S. and Tuteja, N. (2014).** Phenotypic and molecular characterisation of efficient nitrogen-fixing Azotobacter strains from rice fields for crop improvement. *Protoplasma*, **251** (3): 511–523.
49. **Sumbul, A., Ansari, R. A., Rizvi, R., and Mahmood, I. (2020).** *Azotobacte*r: A potential bio-fertilizer for soil and plant health management. *Saudi Journal of Biological Sciences* **27** (12): 3634–3640.
50. **Moraditochaee M, Azarpour E, Bozorgi HR (2014)**. Study effects of biofertilizers, nitrogen fertilizer and farmyard manure on yield and physiochemical properties of soil in lentil farming. *International Journal of Biosciences*, **4**(4):41–48.
51. **Wani, S.A., Chand, S. and Ali, T. (2013).** Potential use of *Azotobacter chroococcum* in crop production: an overview. *Current Agriculture Research Journal,* **1**(1): 35–38.
52. **Revillas, J., Rodelas, B., Pozo, C., Martínez-Toledo, M. and González-López, J. (2000).** Production of B-group vitamins by two Azotobacter strains with phenolic compounds as sole carbon source under diazotrophic and adiazotrophic conditions. *Journal of Applied Microbiology*, 89, 486–493.
53. **Bhosale, H., Kadam, T. and Bobade, A. (2013).** Identification and production of Azotobacter vinelandii and its antifungal activity against Fusarium oxysporum. *Journal of Environmental Biology,* 34: 177–182.
54. **Mehnaz, S. (2015).** Azospirillum: a biofertilizer for every crop. In Plant microbes symbiosis: applied facets, *Springer India* 297–314.
55. **Mishra, D.J., Singh, R., Mishra, U.K. and Kumar, S.S. (2013).** Role of bio-fertilizer in organic agriculture: a review. *Research Journal of Recent Sciences*, 2:39–41.
56. **Mishra, P. and Dash, D. (2014).** Rejuvenation of Biofertilizer for Sustainable Agriculture and Economic Development. *The Journal of Sustainable Development*,**11**(1):41–61.
57. **Trabelsi, D. and Mhamdi, R. (2013).** Microbial inoculants and their impact in microbial soil microbial communities: a review. *Biomed Research International*, 1:11.
58. **Dobereiner, J. (1997).** Biological nitrogen fixation in the tropics: Social and economic contributions. *Soil Biology and Biochemistry*. **29**(5–6): 771–774.
59. **Gahukar RT (2005-06).** Potential and use of bio-fertilizers in India. Evermans' Sci., XL: 354-361.
60. **Sharma, N.K., Tiwari, S.P., Tripathi, K., and Rai, A.K. (2010).** Sustainability and cyanobacteria (blue-green algae): Facts and challenges. *Journal of Applied Phycology*, **23** (6:) 1059–1081.
61. **RoyChowdhury, D.E. Paul, M.A. and Banerjee, S.K. (2014).** A review on the effects of biofertilizers and biopesticides on rice and tea cultivation and productivity. *International Journal of Science, Engineering and Technology*, **2** (8):96–106.
62. **Singh, J.S., Kumar, A., Rai, A.N. and Singh, D.P. (2016)**. Cyanobacteria: A Precious Bio-resource in Agriculture, Ecosystem, and Environmental Sustainability. *Frontiers in Microbiology,* 7:529.
63. **Mishra, U. and Pabbi, S. (2004).** **Cyanobacteria:** A potential biofertilizer for rice. *Springer,* 9: 6–10.
64. **Roona, P.P., and Shamina, M. (2022).** The Cyanobacterial Application as Biofertilizer for Sustainable Paddy Cultivation: An Overview. *Journal of Plant Science and Research***, 9**(1): 216.
65. **Kalayu, G. (2019).** Phosphate Solubilizing Microorganisms: Promising
Approach as Biofertilizers,*International Journal of Agronomy,*1–7.
66. **Prabhu, N., Borkar, S. and Garg, S. (2019).** Phosphate solubilization by microorganisms: Overview, mechanisms, applications and advances. *Advances in Biological Science Research: A Practical Approach*, 11: 161–176.
67. **Sharma, S.B., Sayyed, R.Z., Trivedi, M.H. and Gobi, T.A. (2013).** Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus*,, 2: 587.
68. **Abdallah, R.A.B., Trabelsi, B.M., Nefzi, A., Khiareddine, H.J., Remadi, M.D,, (2016)** Isolation of Endophytic Bacteria from Withania somnifera and Assessment of their Ability to Suppress Fusarium Wilt Disease in Tomato and to Promote. *Journal of Plant Pathology & Microbiology,* **7**(5): 1000352.
69. **Anand, K., Kumari, B. and Mallick, M. A. (2016).** Phosphate solubilizing microbes: An effective and alternative approach as biofertilizers. *International journal of Pharmacy and Pharmaceutical Sciences,***8**(2):37-40.
70. **Suthar, H., Hingurao, K., Vaghashiya, J., and Parmar, J. (2017).** Fermentation: A process for biofertilizer production. In Microorganisms for Green Revolution; *Springer*: Berlin/Heidelberg, Germany, pp. 229–252.
71. **Kirui, C. K., Njeru, E. M., and Runo, S. (2022).** Diversity and phosphate solubilization efficiency of phosphate solubilizing bacteria isolated from semi-arid agroecosystems of Eastern Kenya. *Microbiology Insights,* 17:15.
72. **Etesami, H., Jeong, B. R., and Glick, B. R. (2021).** Contribution of arbuscular mycorrhizal fungi, phosphate–solubilizing bacteria, and silicon to P uptake by plant.*Frontiers in Plant Science,* 12, 699618.
73. **Nassal, D., Spohn, M., Eltlbany, N., Jacquoid, S., Smalla, K., and Marhan, S. and Kandeler, E. (2018).** Effects of phosphorus-mobilizing bacteria on tomato growth and soil microbial activity. *Plant Soil*, 427:17–37.
74. **Haro, R., and Benito, B. (2019).** The Role of Soil Fungi in K+ Plant Nutrition. *International Journal of Molecular Sciences***, 20**(13):3169.
75. **Vandana, U.K., Rajkumari, J., Signa, P., Satish, L., Alavilli, H., Sudheer, P.D.V.N., Chauhan, S., Ratnala, R., Satturu, V., Mazumder, P.B. and Pandey, P. (2021).** The Endophytic Microbiome as a Hotspot of Synergistic Interactions, with Prospects of Plant Growth Promotion. Biology **10** (2):101.
76. **Gouda, S., Kerry, R. G., Das, G., Paramithiotis, S., Shin, HS. And Patra, J.K. (2018**). Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiological Research*, 206, 131–140.
77. **Numan, M., Bashir, S., Khan, Y., Mumtaz, R., Shinwari, Z.K., Khan, A. L., Khan, A. and Harrasi, A.A. (2018).** Plant Growth Promoting Bacteria as an Alternative Strategy for Salt Tolerance in Plants: A Review. *Microbiological Research*, 209, 21–32.
78. **Beneduzi, A., Ambrosini, A. and Passaglia, L.M. (2012).** Plant growth-promoting rhizobacteria (PGPR): Their potential as antagonists and biocontrol agents. *Genetics and Molecular Biology*, 35, 4, 1044–1051.
79. **Farrar. K., Bryant, D. and Cope-Selby, N. (2014).** Understanding and engineering beneficial plant–microbe interactions: plant growth promotion in energy crops. *Plant Biotechnology Journal,*12(9):1193–1206.
80. **Yadav, A.N., Verma, P., Singh, B., Chauahan, V.S., Suman, A. and Saxena, A.K.S (2017).** Plant growth promoting bacteria: Biodiversity and multifunctional attributes for sustainable agriculture. *Advances in Biotechnology & Microbiology,* **5**(5):555671.
81. **Weekley, J., Gabbard, J. and Nowak, J. (2012).** Micro-level management of agricultural inputs: emerging approaches. *Agronomy,* **2**(4):321–357.
82. **Bramhachari, P.V., Nagaraju, G.P. and Kariali, E., (2018).** Current Perspectives on Rhizobacterial-EPS Interactions in Alleviation of Stress Responses: Novel Strategies for Sustainable Agricultural Productivity BT - Role of Rhizospheric Microbes in Soil: Volume 1: *Stress Management and Agricultural Sustainability. In V. S. Meena. Springer Singapore, Singapore,* pp. 33–55.
83. **Kumar, A.**, **Saharan,** **B.S., Parshad, J., Gera, R., Choudhary, J. and Yadav, R. (2024).** Revolutionizing Indian agriculture: the imperative of advanced biofertilizer technologies for sustainability. *Discover Agriculture,* 2:24.
84. **Hibbing, M.E., Fuqua, C., Parsek, M.R. and Peterson, S.B. (2010).** Bacterial competition: surviving and thriving in the microbial jungle. *Nat Rev Microbiol,* **8**(1):15–25.
85. **Dey, R., Pal, K.K. and Tilak, K.V. (2012).** Influence of soil and plant types on diversity of rhizobacteria. *Proceedings of the National Academy of Sciences* *India Section B: Biological Sciences*, **82**(3):341–352.
86. **Pereg, L. and McMillan, M. (2015).** Scoping the potential uses of beneficial microorganisms for increasing productivity in cotton cropping systems. *Soil Biology and Biochemistry,* 80:349–358.
87. **Sharma, S., Gupta, R., Dugar, G. and Srivastava, A.K. (2012).** Impact of application of biofertilizers on soil structure and resident microbial community structure and function. *In Bacteria in Agrobiology: Plant Probiotics Springer Berlin Heidelberg* 65–77.
88. **Sheoran, V., Sheoran, A.S. and Poonia, P**. **(2010).** Soil reclamation of abandoned Mine land by revegetation: a review. *International Journal of Soil, Sediment and Water,* **3**(2):13.
89. **Kumar, S., Chaudhuri, S. and Maiti, S.K. (2013**) Soil dehydrogenase enzyme activity in natural and mine soil-a review. *Middle-East Journal of Scientific Research,* **13**(7):898–906.
90. **Chaubey, O.P. and Prakash, R. (2014).** Bio-reclamation of degraded ecosystem. *International Journal of Bio-Science and Bio-Technology,* **6**(4):145–154.
91. **Diacono, M. and Montemurro, F. (2010).** Long term effects of organic amendments on soil fertility: a review. *Agronomy for Sustainable Development,* **30**(2):401–422.
92. **Jiménez-Mejía, R.,** **Medina-Estrada, R. I.,** **Carballar-Hernández, S.,** **Orozco-Mosqueda, M.**, **D, C.,** **Santoyo, G. and Loeza-Lara, P.D.**  **(2022).** Teamwork to survive in hostile soils: use of plant growth-promoting bacteria to ameliorate soil salinity stress in crops. *Microorganisms,* **10** (1): 150.
93. **Imran., Naveed, S., Khan,A. A., and Khattak, I. (2015).** Impact of phosphorus levels and seed rates on growth and yield of late sown maize on high elevation in Swat, Pakistan *Pakistan Journal of*  *Agriculture*  *Research,* **28** (4): 406–13**.**
94. **Adhikari, B. H., Gauli, R.C. and Bhadur, B.C. (2001).** Effects of manures and fertilizers on the grain production of maize in rotation with cowpea in an acid Soil. *Sustainable Maize Production System for Nepal Proceeding of a Maize Symposium* (Nepal), 160-162.
95. **Marschner H. (1995).** Mineral nutrition of higher plants. 2nd ed. London: Academic Press.
96. **Long, S.P., Zhu, X.G., Naidu, S.L. and Ort, D.R. (2006).** Can improvement in photosynthesis increase crop yields?. *Plant, Cell and Environment,* **29**(3): 315–330.
97. **Peng S, Biswas JC, Ladha JK, Gyaneshwar P, Chen Y (2002).** Influence of rhizobial inoculation on photosynthesis and grain yield of rice. *Agronomy Journal,* **94**(4):925–929.
98. **Heidari, M. and Golpayegani, A. (2012).** Effects of water stress and inoculation with plant growth promoting rhizobacteria (PGPR) on antioxidant status and photosynthetic pigments in basil (*Ocimum basilicum* L.). *Journal Saudi Society of Agricultural Sciences,* **11**(1):57–61.
99. **Chaudhary, P., Singh, S., Chaudhary, A., Sharma, A. and Kumar, G. (2022a).** Overview of biofertilizers in crop production and stress management for sustainable agriculture. *Frontiers in Plant Science,* 13:930340. doi: 10.3389/fpls.2022.930340.
100. **Chaudhary, P., Chaudhary, A., Bhatt, P., Kumar, G., Khatoon, H., Rani, A., Kumar, S. and Sharma, A. (2022b).** Assessment of Soil Health Indicators Under the Influence of Nanocompounds and Bacillus spp. in Field Condition. *Frontiers in Environmental Science,* 9:769871. doi: 10.3389/fenvs.2021.769871.
101. **Bamisile, B. S., Dash, C. K., Akutse, K. S., Keppanan, R., and Wang, L. (2018).** Fungal endophytes: beyond herbivore management. *Frontiers in Microbiology,* 9:544. doi: 10.3389/fmicb.2018.0054.
102. **Gupta, S. and Pandey, S. (2019).** ACC Deaminase Producing Bacteria With Multifarious Plant Growth Promoting Traits Alleviates Salinity Stress in French Bean (*Phaseolus vulgaris*) Plants. *Frontiers in Microbiology,* 10:1506. doi: 10.3389/fmicb.2019.01506.
103. **Shukla, P. S., Agarwal, P. K., and Jha, B. I. (2012).** Improved salinity tolerance of Arachis hypogaea (L.) by the interaction of halotolerant plant-growth-promoting rhizobacteria. *J. Plant Growth Regul.*, 31, 195–206. doi: 10.1007/s00344-011-9231-y.
104. **Kang, S.-M., Radhakrishnan, R., Khan, A. L., Kim, M.-J., Park, J.-M., and Kim, B.-R. (2014).** Gibberellin secreting rhizobacterium, Pseudomonas putida H-2-3 modulates the hormonal and stress physiology of soybean to improve the plant growth under saline and drought conditions. Plant Physiology Biochemistry, 84: 115–124.
105. **Sandhya, V., Ali, S. Z., Grover, M., Reddy, G., and Venkateswarlu, B. (2010).** Effect of plant growth promoting Pseudomonas spp. on compatible solutes, antioxidant status and plant growth of maize under drought stress. *Plant Growth Regulation*, 62: 21–30.
106. **Gond, S. K., Torres, M. S., Bergen, M. S., Helsel, Z., and White, J. F. (2015**). Induction of salt tolerance and up-regulation of aquaporin genes in tropical corn by rhizobacterium Pantoea agglomerans. *Letters in Applied Microbiology,* **60** (4): 392–399.
107. **Chauhan, P., Singh, A., Singh, R.P. and Ibrahimd, M.H. (2012).** Environmental Impacts of Organic Fertilizers Usage in Agriculture. https:// [www.reasearcgate.net/publication/286235139\_Environmental\_impacts\_of\_organic\_fertilizers\_usage\_in\_agriculture](http://www.reasearcgate.net/publication/286235139_Environmental_impacts_of_organic_fertilizers_usage_in_agriculture).
108. **Shinwari K.I., Shah, A., Afridi, M.I., Zeeshan, M., Hussain, H., Hussain, J., Ahmad, O. and Jamil, M. (2015).** Application of plant growth promoting rhizobacteria in bioremediation of heavy metal polluted soil. *Asian Journal of Multidisciplinary Studies* **3**(4): 179-185.
109. **Akhtar, M.S., Chali, B. and Azam, T. (2013).** Bioremediation of arsenic and lead by plants and microbes from contaminated soil. *Research in Plant Sciences,* **1**(3):68–73.
110. **Mehes-Smith. M., Nkongolo, K. and Cholewa, E. (2013).** Coping mechanisms of plants to metal contaminated soil. *Environmental change and sustainability*, 978–953.
111. **Wuana, R.A. and Okieimen, F.E. (2011.**) Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *Communications in Soil Science and Plant Analysis*, 42: 111-122.
112. **Lenart, A. Wolny-Koładka, K. (2013).** The effect of heavy metal concentration and soil pH on the abundance of selected microbial groups within Arcelor Mittal Poland steelworks in Cracow. *Bulletin of Environmental Contamination Toxicology,* **90**(1):85–90.
113. **Lim, K.T., Shukor, M.Y. and Wasoh, H. (2014).** Physical, chemical, and biological methods for the removal of arsenic compounds. *Biomed Research International*, 2014:9.
114. **Hossain, M.A., Piyatida, P., da Silva JA. and Fujita, M. (2012).** Molecular mechanism of heavy metal toxicity and tolerance in plants: central role of glutathione in detoxification of reactive oxygen species and methylglyoxal and in heavy metal chelation. *Journal of Botany*, 2012:87875.
115. **Singh, R.P., Shelke, G.M., Kumar, A. and Jha, P.N. (2015).** Corrigendum: Biochemistry and genetics of ACC deaminase: a weapon to “stress ethylene” produced in plants. *Frontiers in Microbiology*, 6:1255.
116. **Radzki, W., Manero, F.G., Algar, E., García, J.L., García-Villaraco, A. and Solano B.R. (2013)** Bacterial siderophores efficiently provide iron to iron- starved tomato plants in hydroponics culture. *Antonie Van Leeuwenhoek*, **104**(3):321–30.
117. **Dary, M., Chamber-Pérez, M.A., Palomares, A.J., Pajuelo, E. (2010).** “In situ” phytostabilisation of heavy metal polluted soils using Lupinus luteus inoculated with metal resistant plant-growth promoting rhizobacteria. *Journal of Hazard Materials,* **177**(1-3):323–330.
118. **Aktar, W., Sengupta, D. and Chowdhury, A. (2009).** Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology,* **2**(1):1–12.
119. **Kumar, M. and Puri, A. (2012).** A review of permissible limits of drinking water. *Indian journal of occupational and environmental medicine*, **16**(1):40-4.
120. **Nawaz, K., Hussain, K., Choudary, N., Majeed, A., Ilyas, U., Ghani, A., Lin, F., Ali, K., Afghan, S., Raza, G., and Lashari, M.I. (2011).** Eco-friendly role of biodegradation against agricultural pesticides hazards. African Journal of Microbiology Research, **5**(3):177–183.
121. **Shaheen, S. and Sundari, K.S. (2013).** Exploring the applicability of PGPR to remediate residual organophosphate and carbamate pesticides used in agriculture fields. *International Journal of Agriculture Food Science & Technology,* **4**(10):947–954.
122. **Ortiz-Hernández M.L., Sánchez-Salinas, E., Dantán-González, E. and Castrejón-Godínez, M.L. (2013).** Pesticide biodegradation: mechanisms, genetics and strategies to enhance the process. Biodegradation-life of science. *Intech-publishing, Rijeka*, pp. 251–287.
123. **Ramakrishnan, B., Mallavarapu, M., Venkateswarlu, K., Sethunathan, N. and Naidu, R. (2011).** Mixtures of environmental pollutants: effects on microorganisms and their activities in soils.  *Reviews of Environmental Contamination and Toxicology,* 211:63–120.
124. **El-Haddad, M.E., Mustafa, M.I., Selim, S.M., El-Tayeb, T.S., Mahgoob, A.E.A. and Abdel Aziz, N.H. (2011**). The nematicidal effect of some bacterial biofertilizers on Meloidogyne incognita in sandy soil. *Brazilian Journal of Microbiology*, **42**(1):105–113.
125. **Khan, Z., Tiyagi, S.A., Mahmood, I. and Rizvi, R. (2012).** Effects of N fertilization, organic matter, and biofertilizers on the growth and yield of chilli in relation to management of plant-parasitic nematodes. *Turkish Journal of Botany,* **36**(1):73–78.
126. **Ismail, A.E. and Hasabo, S.A. (2000).** Evaluation of Some new Egyptian commercial biofertilizer, plant nutrient and a biocide against *Meloidogyne incognita* root knot nematode infecting sunflower. *Pakistan journal of Nematology,* **20**(1/2): 39- 49.
127. **Youssef, M.M.A. and Eissa, M.F.M. (2014).** Biofertilizers and their role in management of plant parasitic nematodes. A review. *E3 Journal of Biotechnology and Pharmaceutical Research,* **5**(1):001-006.