Review Article

The future of biofertilizer use in safe agriculture

***Abstract*:**

An essential part of a nation's economy is agriculture. Chemical fertilizers and pesticides are widely used in intensive agriculture techniques nowadays to boost crop yield and satisfy the growing global population's nutritional needs. Yet, it has been discovered that increasing urbanization, reduced agricultural lands, sharp climate changes, and widespread use of agrochemicals in farming techniques lead to environmental disruptions and public health risks that compromise agricultural sustainability and food security. Agrochemical overuse is also causing agriculture soils to continuously lose their biological and chemical balance, quality, and physical attributes, as well as their biological health. The potential for plant-associated microorganisms to address these issues and play a critical role in plant growth is immense.With their abilities to promote plant growth, plant-associated bacteria hold great promise for resolving these issues and are essential for increasing agricultural production and biomass in both greenhouse and field settings. Improved nutrient availability (i.e., N, P, K, Zn, and S), phytohormone regulation, biocontrol of phytopathogens, and mitigation of biotic and abiotic stresses are some of the advantageous processes of improved plant growth. Microorganisms and plants interact to support sustainable agriculture, and these microbes may be essential ecological engineers that reduce the demand for chemical fertilizers. Among the steps involved in this process are the production of the inoculum, the inclusion of cell protectants such as glycerol, lactose, and starch, an acceptable carrier material, optimal packing, and the most efficient delivery modalities.Bio-fertilizers are some of the best agricultural tools available today. It's a gift from modern agricultural science. On agricultural land, biofertilizers are applied in lieu of traditional fertilizers. Conventional fertilizers contain green manure, compost, and household waste. These are less effective than chemical fertilizers. Farmers so often try to employ chemical fertilizers in the field to encourage crop development. But it's clear that chemical fertilizers are bad for the environment. They can disperse substances that cause cancer and are accountable for soil, air, and water pollution. Furthermore, they can eventually deplete the soil's fertility. Scientists have created biofertilizers in an attempt to reduce pollution and enhance everyone's health organically. The microorganisms in biofertilizer assist the host plants in maintaining physiologic balance, supporting proper development and growth, and obtaining an adequate quantity of nutrients. Living microorganisms are used to create biofertilizers. Only specific microorganisms that aid in the growth and reproduction of plants are used. There are many different kinds of microorganisms used in biofertilizers. being an essential component of farming organically. Since biofertilizer is a fundamental component of organic farming, it is crucial for preserving soil sustainability and fertility over the long term.

Key words: Bio-fertilizers, organic farming, sustainable agriculture, crop growth and VAM

Introduction

For plants to flourish, they need vital nutrients from the soil, such as nitrogen (N), phosphorus (P), potassium (K), and several other minerals (Arya, 2000). Soil productivity is directly impacted by the critical link between phosphate and nitrogen (Hutchinson and Richards, 1921). Although NPK-containing fertilizers are added to the soil to increase crop output, crops do not completely utilize them. Runoff and percolation from the excess fertilizer harm the soil and water supplies during the monsoon season. Water bodies are contaminated by additional nutrients, which causes eutrophication.India, a nation of 1.25 billion people according to the 2011 census, is primarily dependent on agriculture for economic growth. Farmers are under pressure to increase agricultural yields;therefore, they use a lot of chemical fertilizers without adhering to prescribed methods. This careless use degrades the qualities of the soil and pollutes water during the rainy season through runoff. Widespread use of synthetic fertilizers, particularly in paddy fields, may interfere with the development of residing microorganisms (Bishara, 1978), and fish and other creatures are impacted by runoff.Over time, this excessive use has deteriorated soil and contaminated water, which has an effect on public health. Chemical fertilizers are widely used in agriculture, but they are expensive and have bad effects on soils that lead to nutritional imbalances, decreased fertility, and decreased capacity to hold water. These fertilizers seep out of the soil since plants aren't able to absorb them well enough, which makes it necessary to create inexpensive fertilizers that blend in with the environment. Living cells, especially microbes, used as biofertilizers have the ability to fix atmospheric nitrogen into nitrates. By giving the root system nutrients and having the ability to solubilize insoluble salts like phosphate, they promote healthy seed germination by creating fertilizing materials in the soil (Mazid*et al.*, 2014).

Organic farming has emerged as an important priority area globally in view of the growing demand for safe and healthy food and long term sustainability and concerns on environmental pollution associated with indiscriminate use of agrochemicals. Though the use of chemical inputs in agriculture is inevitable to meet the growing demand for food in world, there are opportunities in selected crops and niche areas where organic production can be encouraged to tape the domestic export market. Bio-fertilizers are being essential component of organic farming are the preparations containing live or latent cells of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic micro-organisms used for application to seed, soil or composting areas with the objective of increasing number of such micro-organisms and accelerate those microbial processes which augment the availability of nutrients that can be easily assimilated by plants. Biofertilizers play a very significant role in improving soil fertility by fixing atmospheric nitrogen, in association with plant roots and without it, solubilise insoluble soil phosphates and produces plant growth substances in the soil.Actually, it is being urged for them to utilize the preexisting biological process of nutrient mobilization (Venkatashwarlu, 2008). Numerous writers have examined the role and importance of biofertilizers in sustainable crop production. But as a result of several challenges, Asia's progress in BF production technology has never kept up with expectations.

HISTORY OF BIOFERTILIZERS:

Using a lab culture of Rhizobium sp., Nobbe and Hiltner created "Nitragin," which began the commercial history of biofertilizers in 1895 (Singh et al., 2019). Research on arbuscularmycorrhizal fungi inoculants in the late 1950s shown their beneficial effects on phosphorus (P) uptake and plant growth promotion (PGP) (Koide and Mosse, 2004).

Improvements in multi-omics technology over the last ten years have allowed for more accurate characterization of the structure and function of microbial communities, deepening our understanding of the complexity of the microbiome. These novel techniques are increasingly being used to define soil microbial communities and their effects on plant nutrient uptake as well as other growth-promoting (PGP) characteristics. However, their successful application in the development of innovative biofertilizer technologies is still unfulfilled. Notably, N. V. Joshi carried out the first study on legume Rhizobium symbiosis in India, which began commercial production as early as 1956.

Need of bio-fertilizers:

Synthetic fertilizers have been used carelessly, which has led to soil contamination and pollution, water basin pollution, the eradication of beneficial insects and microorganisms, heightened crop disease susceptibility, and decreased soil fertility. Demand outpaces supply; by 2020, 7.2 million tons of extra nutrients will be needed to meet the anticipated 321 million tons of food grain production. The problem is made worse by the depletion of fossil fuels and the growing cost of fertilizers, which puts small and marginal farmers at a financial disadvantage and increases the gap between the supply and demand of nutrients, endangering sustainable agriculture and posing hazards to the environment. Long-term usage of biofertilizers, on the other hand, offers small-scale farmers an affordable, environmentally responsible, and effective substitute that boosts output while taking care of environmental issues.

Potential characteristic features of certain biofertilizers:

Biofertilizers are natural, organic, low-cost, low-polluting fertilizers that need less application and are considered a safe substitute for chemical fertilizers in ecological preservation (Gahukar, 2005–06). They use microbes to produce growth-promoting chemicals like vitamins and hormones, solubilize phosphates, and fix atmospheric nitrogen (Yojana, 1992). Several studies support the benefits of biofertilizers for crops and soil, hailed as the most secure way to maintain soil fertility. Due to their reliance on cyanobacteria and nitrogen-fixing bacteria, these agents—dubbed "Microbial inoculants" by Subha Rao (1982)—usher in a new era of agricultural techniques by increasing microbial processes in the soil. Among common biofertilizers, Azotobacter, Azospirillum, Rhizobium, and blue-green algae excel as nitrogen fixers, while Bacillus megatheriumvarphosphaticum, Aspergillus awamori, and Penicillium digitatum stand out as proficient phosphate solubilizers.

Nitrogen fixers *Rhizobium*:

Rhizobium is a symbiotic bacterium that only grows in conjunction with legumes and can fix nitrogen at a rate of 50–100 kg/ha. It is a member of the Rhizobiaceae family of bacteria. It is beneficial for oil-seed legumes like soybeans and groundnuts, forage legumes like lucerne and berseem, and pulse legumes like chickpeas, red grams, peas, lentils, and black grams. The capacity of Rhizobium to nodulate leguminous crops successfully depends largely on the strains' compatibility with the particular legumes in question. It invades these legumes' roots, producing tumor-like growths known as root nodules that act as hubs for the synthesis of ammonia.

Rhizobium works in symbiotic relationships with legumes and some non-legumes, such as Parasponia, to fix atmospheric nitrogen. Rhizobium population in the soil is dependent on legume crops; when they are absent, the population of Rhizobium in the soil declines. In order to accelerate nitrogen fixation and replenish the population of efficient Rhizobium strains close to the rhizosphere, artificial seed inoculation is frequently required. For each legume to produce functional nodules, a specific species of Rhizobium is required. In bacteroids, leuhaemoglobin promotes nitrogen fixation and, in the presence of phosphorus and molybdenum, converts atmospheric nitrogen into ammonia. This helps the bacteroids utilize oxygen (Gahukar, 2001). Without leghemoglobin, nitrogen fixing is not possible. Due to rhizobial symbiosis, introducing rhizobial culture into fields can boost the yields of pulse crops (Dubey, 2001). Rhizobium can be found in the roots of groundnuts, beans, and grams.It can increase crop productivity by up to 20% and fix about 15-20 kg N/ha. Higher magnesium content was noted by Kumudha (2005) as a result of Rhizobium inoculation. The symbiotic characteristics of the wild-type strain R. ciceri 18-7, the mutant M126, and the complemented mutant M126 (C4) were investigated by Bhaskar and Kashyap (2004). These characteristics included the nitrogenase activity, total nitrogen content, nodule number, and fresh and dry weight of the injected plants, in addition to the acetylene reduction assay.

***Rhizobium species* suitable for different crops**

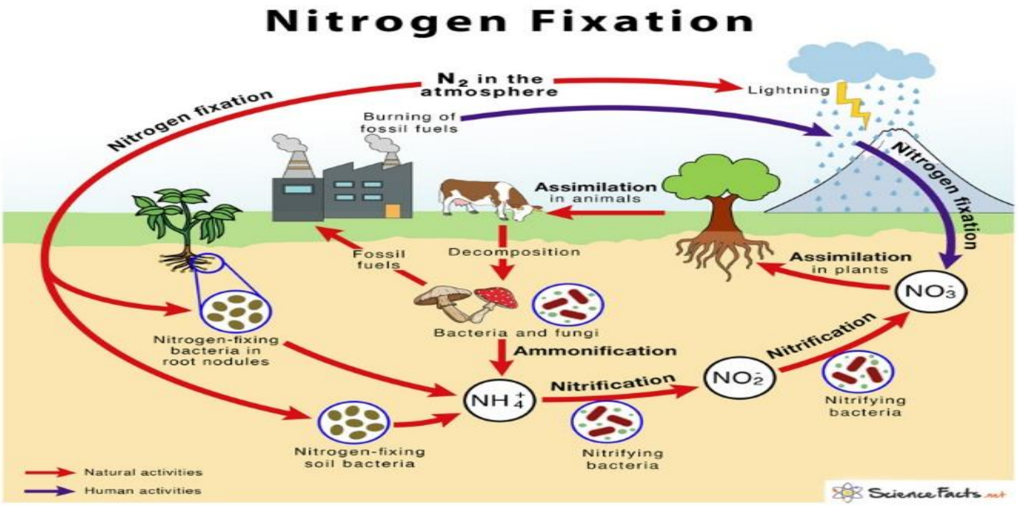
S. No.	*Rhizobium sp.*	Crops
1	*R. legumenosarum*	Pea, Lentil, Vicia
2	*R. trifoli*	Berseem
3	*R. phaseoli*	Bean group
4	*R. lupini*	*Lupinus, Ornithopus*
5	*R. japonicum*	Soybean
6	*R. meliloti*	*Melilotus,* Lucerne
7	*Cowpea miscellany*	Cowpea, Gram, Ground nut etc..

Azospirillum:

Azospirillum and other members of the Spirilaceae family display heterotrophic activity and associative interactions. They are distinguished by their ability to fix nitrogen, which averages

20–40 kg/ha, as well as by the compounds they produce that control growth. Although this genus has many species, such as A.amazonense, A.halopraeferens, and A.brasilense, A.lipoferum and A.brasilense are largely connected with the global spread and benefits of inoculation. Many plants, particularly those that use the C4-dicarboxylic acid route for photosynthesis, such maize, sugarcane, sorghum, and pearl millet, have symbiotic interactions with Azospirillum species.

On organic acid salts like malic and aspartic acid, these bacteria fix nitrogen. Azotobacter enters root tissues and coexists peacefully with plants, despite the fact that they colonize roots without leaving behind visible nodules. Azospirillum are aerobic bacteria that are gram-negative, free-living, associative symbiotic, and do not form nodules. They are found in a wide range of dicots and monocots, such as corn, sorghum, and wheat (Tarrand et al., 1978 and Elmerich, 1984), and they are involved in the fixation of nitrogen in a number of cereals (Balandreau, 1983 and Vose, 1983).According to studies, they can effectively increase nitrogen fixation to 20–40 kg/ha and cereal crop yields by 10%–15%. Different A. brasiliense strains are injected into wheat seeds to improve plumule, radicle length, and germination (Tien et al., 1979; Gunasekaran and Purushothaman, 1980). According to Okon and Labandera – Gonzalez (1994), nitrogenase activity or the synthesis of plant growth promoters may be the source of Azospirillum's growth-promoting properties. Azospirillumbrasiliense (strain Sp7) and Azospirillumlipoferum (strain C2) have been shown in field studies to have a favorable effect on grain yield and dry matter in a variety of rice types. Sp7 has been shown to have better grain and straw yields than C2. (Ray and others, 2004).



Azotobacter:

A. chroococcum is the most common species in arable soils. It is an aerobic, free-living, heterotrophic bacterium that belongs to the Azotobacteriaceae family and grows well in neutral or alkaline soils. A. macrocytogenes, A. beijerinckii, A. insignis, and A. vinelandii are a few other noteworthy species. Their population in soil usually lies between 104 and 105 g-1 because of the low amount of organic matter and the presence of microorganisms that are hostile. Even though they are rare, Azotobacter plays a vital role in maintaining the health of the soil because they produce antibiotics that inhibit the growth of harmful fungus in the root zone, which reduces the mortality of seedlings.

Azotobacter have been found in a variety of crop plants, including rice, maize, sugarcane, bajra, vegetables, and plantation crops, although being generally sparse in the rhizosphere. According to Jain (1998) and Gohukar (2001), these adaptable bacteria are well-known for secreting vitamin-B complex, gibberellins, napthalene, acetic acid, and other advantageous compounds that inhibit specific root diseases and improve plant nutrient uptake. Notably, the presence of a native Azotobacter population is a prerequisite for the effectiveness of Azotobacter inoculation in soil. Additionally, Azotobacterindicum grows well in the acidic soil present in the roots of sugarcane plants, and Azotobacter species such as those found in Paspalumnotatum roots play a major role in nitrogen fixation by providing 15–93 kg of nitrogen per hectare annually (Dobereiner et al., 1973). They can be applied by seed, seedlings, or soil treatment to a variety of crops, such as vegetables, flowers, cereals, and millets.

Blue Green Algae and Azolla:

Cyanobacteria as a source of Biofertilizers for sustainable agriculture (Deepali*et al.*, 2020).These phototrophic organisms, which are classified into eight groups, generate auxin, indole acetic acid, and gibberllic acid. Due to their abundance in paddy fields, they are also known as "paddy organisms" and fix 20–30 kg N/ha in submerged rice fields. A vital component needed in significant amounts for the cultivation of lowland rice is nitrogen (N). Lowland rice mostly gets its nitrogen from the soil and from related organisms' BNF (Biological Nitrogen Fixation).

In order to attain food security through sustainable agriculture, the 50–60% N demand is satisfied through a combination of soil organic N mineralization and BNF by free-living and rice plant-associated bacteria. More and more, BNF is needed to meet the requirement for fixed nitrogen instead of using industrial nitrogen fixation. Anabaena azollae, a cyanobacterial symbiont that is heterocystous, is found in the leaves of Azolla, an aquatic fern that floats freely on the water's surface. Azolla fixes atmospheric nitrogen in paddy fields by collaborating with cyanobacteria that fix nitrogen. Additionally, when it grows and immediately after being tramped, it releases organic nitrogen into the water. Many nations, including Bangladesh, China, India, the United States, and Sri Lanka, employ aszolla as a biofertilizer.

It raises the production of paddy crops by 10–20% and fixes 40–60 kg N/ha in a month (Kumar, 2004). Azolla reduces weed growth in rice fields and adds nitrogen, phosphorus (15–20 kg/ha/month), potassium (20–25 kg/ha/month), and organic carbon, among other nutrients. In addition, it is vulnerable to extreme heat (>400°C) and drought (Gahukar, 2005–06). Potassium traces are also absorbed by azolla from irrigation water. Before planting rice, as well, aszolla can be utilized as green manure. Species of Azolla are metal-tolerant and can be used in close proximity to places contaminated by heavy metals.

Phosphate solubilizers:

Numerous research have looked into the solubility of various insoluble inorganic phosphate compounds, such as rock phosphate, hydroxyapatite, dicalcium phosphate, and tricalcium phosphate. This capacity is shared by the bacterial genera Aerobacter, Flavobacterium, Burkholderia, Pseudomonas, Bacillus, Rhizobium, Microccocus, Achromobacter, and Agrobacterium. Large populations of bacteria that solubilize phosphates are seen in both soil and plant rhizospheres. They include both anaerobic and aerobic bacteria, with the latter being more prevalent in buried soils. Phosphate-solubilizing bacteria are frequently found in much larger concentrations in rhizosphere soil than in non-rhizosphere soil. Soil contains higher concentrations of bacteria and fungi belonging to the genera Pseudomonas and Bacillus.

Originally developed by scientists in the USSR, "phosphobacteria" are bacterial fertilizers that contain Bacillus megatherium var. phosphaticum cells. They increase crop productivity by approximately 10 to 20% and can be applied to both lowland and highland rice (Cooper, 1959). In order for crops to use the phosphate in the soil, they release it. Numerous soil bacteria can solubilize inorganic phosphates directly or indirectly, notwithstanding their metabolic activities

(Arya, 2000). In addition, they produce other organic acids such as fumaric acid, lactic acid, citric acid, and succinic acid. They produce hormones called GA and IAA that promote plant development. The phosphate-solubilizing action of the soil is aided by these organic acids.

Phosphates can also be dissolved by phosphate-solubilizing fungi, which include Aspergillus niger, Aspergillus awamori, and Penicilliumdigitatum. Research on microbial management and Plant Growth-Promoting Rhizobacteria (PGPR) has also been conducted. Under this nomenclature, two examples of microbial pesticides include Pseudomonas fluorescens and Bacillus species. Diazotrophs, such those in the genus Pseudomonas, allow vetiver to grow and survive in the absence of nitrogen and phosphate, especially in unproductive soil, according to Sipirin's (2000) research. A 2003 study by Chakraborti et al. discovered that Bacillus pumilus TR24, Bacillus spp. TR16, Ochrobactrumanthropi TR9, and Serratiamarcescens TR10 have antagonistic power against root infections of tea plants. According to Paul et al. (2003),discovered that Pseudomonas fluorescens applied to the black pepper rhizosphere led to improved nutrient absorption and simple mobilisation of vital nutrients in the rhizosphere microrganism.

Phosphate absorbers:

Mycorrhizas, which show fungi growing on plant roots, are the product of symbiosis between particular root-inhabiting fungi and plant roots. Different fungi are adapted to different plant species, including flowers, trees, vegetables, and fodder crops. Mycorrhizas function as biocides and biofertilizers (Kumudha, 2005). They take up nutrients from the soil, such as zinc, iron, sulfur, phosphorus, and manganese, and give them to the plant. They can withstand greater soil temperatures better and add a substantial 30–40% improvement in crop output.

Mycorrhizal fungi also create chemicals that promote plant growth, which helps seedlings inoculated with them grow faster. Both lowland and highland rice have mycorrhiza, which helps the rice absorb the phosphorus it needs. Ectomycorrhiza and Endomycorrhiza are the two most prevalent types of mycorrhizas; they differ in the way that the fungus are arranged and their structural makeup. Higher plants, such as gymnosperms and angiosperms, have ectomycorrhiza in their roots, which needs a pH of 5–6 to thrive well. Overuse of inorganic fertilizers and shadowing inhibits ectomycorrhizal fungal development, resulting in stunted growth and chlorosis of leaves. Alternatively, crop plant roots are frequently home to Endomycorrhiza

(VAM fungi), which enter cortical cells and spread intracellularly by secreting enzymes. VAM fungal hyphae improve phosphorus and other nutrients' absorption.

According to Anandraj*et al*. (2001), VAM also promotes the growth of black pepper and offers protection against Melvidogyne incognita, Radopholussimilis, and Phytophthoracapsici. According to Kumudha (2005), VAM inoculation was successful in causing chlorophyll coloring. According to Trappe and Fogel (1977), greater phosphorus uptake may also be the cause of increased nitrogen uptake in VAM. This might lead to an increase in the activity of NAD-dependent enzymes, which could then boost nitrate reductase activity. In addition to improving water intake, VAM fungus help plants tolerate heavy metals.

The term Mycorrhiza signifies "fungus roots," representing a symbiotic association between host plants and a specific group of fungi in the root system. In this association, the fungal partner benefits from obtaining its carbon requirements from the host's photosynthates, while the host benefits by acquiring essential nutrients like phosphorus, calcium, copper, and zinc, which are otherwise inaccessible, through the fine absorbing hyphae of the fungus. These fungi are associated with the majority of crops, with exceptions including crops/plants belonging to certain families like Chenopodiaceae, Amaranthaceae, Caryophyllaceae, Polygonaceae, Brassicaceae, Commelinaceae, Juncaceae, and Cyperaceae.

Zinc solubilizers:

Many bacteria are known to act as bio-fertilizers, mainly providing major nutrients. These include nitrogen-fixing bacteria like Rhizobium, Azospirillum, Azotobacter, and BGA, phosphate-solubilizing bacteria like B. magaterium and Pseudomonas striata, and phosphate-mobilizing Mycorrhiza. However, a variety of different microbes found in soil possess the ability to change micronutrients including zinc, iron, and copper. For example, bacteria that can solubilize zinc, such as B. subtilis, Thiobacillusthioxidans, and Saccharomyces sp., have the potential to be used as bio-fertilizers to supply this micronutrient. According to research, Bacillus sp., a type of bacteria that solubilizes zinc, can function as a biofertilizer for zinc. This is particularly useful in soils that have a high concentration of native zinc or when mixed with less expensive zinc compounds that are insoluble, such as zinc oxide (ZnO), zinc carbonate

(ZnCO3), and zinc sulphide (ZnS). This presents a financially advantageous substitute for zinc sulphate.

Benefits from Biofertilizers:

They improve crop production by up to 10–40% and nitrogen fixation by 40–50 kg, and they are economical, pollution-free, and ecologically benign. Additional biofertilizers are not required after 3–4 years of continuous use since parental inoculums continue to support growth and multiplication. In addition, they produce compounds like IAA, amino acids, and vitamins that promote plant growth, while also improving the pH, texture, and other qualities of the soil.

Precautions:

1. Because they are living things, handling them needs to be done carefully.
2. Use biofertilizers prior to their expiration date.
3. Because they are species-specific, a specific agricultural plant should utilize a specific biofertilizer.
4. Apply the recommended amount of biofertilizer.
5. Direct sunlight should be avoided when handling them.

Potential role of bio-fertilizers in agriculture:

Several studies have established the critical role that the incorporation of bio-fertilizers, especially N-fixers, plays in improving soil fertility, impacting yield-related characteristics, and ultimately raising total yield. Additionally, their application lessens the need for chemical fertilizers and improves the soil biota. When Rhizobium is injected into plants in temperate settings, it has been shown to improve characteristics like the number of pods per plant, the number of seeds per pod, and the weight of 1000 seeds, which increases yield when compared to untreated controls.

Similarly, in lowland rice production, the combination use of Azospirillum and BGA has shown to significantly improve yield-related factors such as Leaf Area Index (LAI) and all other relevant features. Since phosphate fertilizers fix in acidic and alkaline soils—which are common in India, where over 34% of land is affected by acidity and over seven million hectares by salinity/alkalinity—it is well known that the efficacy of phosphate fertilizers is noticeably low (15–20%). For these reasons, it is essential to inoculate these soils with phosphate-solubilizing bacteria (PSB) and other beneficial microbial inoculants in order to restore and maintain functional microbial populations. This helps to increase the availability of macro- and micronutrients and solubilize chemically fixed phosphorus, which eventually makes it easier to achieve high and sustainable yields for a variety of crops.

Environmental Limitations for Application of Bio-fertilizer:

1. The absence of appropriate carrier resources is a limitation.
2. Two important issues are farmers' ignorance and market-level restrictions.
3. Quality assurance is hampered by the limited resource generation for the production of biofertilizer.
4. Seasonal and erratic demand adds to the difficulty of the circumstance.
5. A lack of experienced workers and environmental and soil conditions are contributing contributors to the problem.
6. The population of native microorganisms, improper inoculation methods, and fermentation-related mutation.

Conclusions:

An important aspect of organic farming is the use of bio-fertilizers, which are crucial for preserving soil sustainability and fertility over the long term. By fixing atmospheric di-nitrogen (N=N), releasing fixed macro- and micronutrients, or changing insoluble P in the soil into forms that plants can use, they increase the availability and efficiency of these nutrients. Ten million tons of plant nutrients are currently missing between crop clearance and chemical fertilizer supply. Over-reliance on chemical fertilizers is not a sustainable long-term approach, given their expense and environmental impact. This is a result of the financial resources required to establish and maintain fertilizer production facilities, both domestic and international. In this situation, using organic manures, or biofertilizers, becomes a practical way for farmers to increase yield per unit area.

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