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Increasing nutrient use efficiency in crops through biofertilizers

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Abstract

As modern agriculture relies heavily on synthetic chemical fertilizers, environmental problems have increased, including greenhouse effect, soil erosion, and air and water pollution. In addition, it is important that in a global context sustainable agricultural practices, that is, processes that require less energy and have less impact on the environment, can be used to produce much-needed food for growing populations. As a result, bio fertilizers, which include bacteria, fungi, and algae, have been proposed as they provide possible solutions for large-scale natural, eco-friendly, and economical agricultural practices, while maintaining soil structure. and biodiversity. Microbial bio fertilizers improve plant growth by improving the absorption or availability of plant nutrients, in addition to bringing nutrients to the soil. Bio fertilizers primarily increase nutrition by regulating atmospheric nitrogen, solubilizing phosphorus, and producing chemicals that promote plant growth. Rhizobia and other types of nitrogen-fixing bacteria are used to promote the growth of legumes and other plants. In addition, both blue-green algae (BGA) and Azolla contribute to the nitrogen budget for active farming. Many plants rely on arbuscular mycorrhizal fungus to absorb phosphorus and other nutrients. Phosphorus-solubilizing bacteria that fix atmospheric nitrogen, such as Azotobacter and Azospirillum, can increase the solubility and availability of phosphorus in plants, and consequently plant production. Azospirillum also has other benefits, such as its ability to produce chemicals that promote growth, disease resistance, and drought tolerance. Therefore, using microbial bio fertilizer is a viable option.

Keywords: Biofertilizers, Rhizobia, sustainable agriculture, Azotobacter

Introduction

NUE is an important term for assessing agricultural production systems, and the management of fertilizers, as well as the interaction of soil and plant water, can have a significant impact. As managers try to meet the growing public demand for food, fiber, and fuel, NUE demonstrates the potential for nutrient losses in the environment from agricultural systems. Because nutrients can be stored in the soil, NUE measures are not a measure of nutrient loss, so systems with low NUE may not be harmful to the environment, while those with high NUE may not be harmful.

The Objective of Nutrient Use and Nutrient Use Efficiency

Nutritional use aims to improve crop performance by providing economically viable nutrients to the crop while minimizing nutrient losses in the field and supporting the sustainability of the agricultural system by contributing to soil fertility or other components of soil quality. The NUE mentions some aspects of that operation, but not all of them (Mikkelsen *et al*., 2012) [19]. The most beneficial NUE enhancements are those that have a significant impact on the performance of the complete compression system. As a result, management practices that improve the NUE without compromising productivity or future productivity development opportunities are likely to benefit. If higher NUE searches reduce current or future production, the need to invest in weaker areas will likely increase. Weak areas support systems with low NUE and low water efficiency. At the same time, when nutrient levels rise to their highest level, production increases but at a lower rate, and NUE falls (Barbieri *et al*., 2008) [3]. The source, time, and features of the area, as well as other cultural and soil processes and climates, will affect the rate of decline.

Classification of NUE

1. Agronomic efficiency: Defined as the economic production obtained per unit of nutrient applied. It is calculated by the following equation:

$$\text{Agronomic efficiency} = \frac{(Grain\ yield\ of\ fertilized\ crop\ in\ kg) - (Grain\ yield\ of\ unfertilized\ crop\ in\ kg)}{(Quality\ of\ fertilizer\ applied\ in\ kg)}$$

2. Physiological efficiency: It is defined as the biological production obtained per unit nutrient applied. It is calculated by the following equation:

$$\text{Physiological efficiency:} \frac{(Total\ dry\ matter\ yield\ of\ fertilizedcrop\ in\ kg) - (Total\ dry\ matter\ yield\ of\ unfertilized\ crop\ in\ kg)}{(Nutrient\ uptake\ by\ fertilized\ crop\ in\ kg) - (Nutrient\ uptake\ by\ unfertilized\ crop\ in\ kg)}$$

3. Apparent recovery efficiency: It is defined as the biological production obtained per unit of nutrient applied. It is calculated by the following equation:

$$\text{Apparent recovery efficiency:} \frac{(Nutrient\ uptake\ by\ fertilized\ crop) - (Nutrient\ uptake\ by\ unfertilized\ crop)}{(Quantity\ of\ fertilizer\ applied)}$$

The current worrying rate of depletion of the world's natural resources, particularly rock phosphate and petroleum resources, is a major source of concern for the future of agriculture, especially in developing countries (St. Clair and Lynch, 2010) [34]. Sustainable agricultural production, not unexpectedly, is an important global challenge that has aroused the interest of policymakers, industry leaders, and scientists (Seufert *et al*., 2012; Wezel *et al*., 2014) [30, 40]. Efforts to reduce depletion of mineral nutrients are currently a major research problem, but disruption of global biogeochemical cycles, largely due to the use of mineral fertilizers, continues to be a serious problem (Kahiluoto *et al*., 2014) [14].

Bio fertilizers, or microbial injections, are a possible solution to reduce the use of traditional inorganic fertilizers. Many of them can act as biofertilizers by fixing nitrogen (N), assisting in accessing nutrients such as phosphorus (P) and nitrogen (N) from organic fertilizers and soil stock, improving drought tolerance, plant health, and increasing salt tolerance (Vessey, 2003) [39].

Bio fertilizers

Bio fertilizers, also known as bio inoculants, are preparations that contain living or hidden cells from small insects that aid the absorption of plant organisms by interacting within the rhizosphere after being given seeds or soil. It speeds up microbial processes bound to the soil, which increases the availability of nutrients in a way that plants can easily absorb. Bio fertilizers provide a number of other benefits, including cost-effective, environmentally friendly, and renewable supply of plant nutrients, which make them an integral part of integrated nutrient management. Now we cannot announce that bio-inoculants are an effective alternative to chemical fertilizers, but in the near future, scientific insights will allow us to do just that. In addition to genetic modification, current works published in bio fertilizers suggest that bio inoculants play a different role in different plants.

Root growth was observed in wheat following injections with bio inoculant consortia, to name a few examples. Likewise Rhizobium injection improves deaminase activity.

In pulse plants. Fertilizer application of bio fertilizer often has variable effects, which has hampered its widespread acceptance by farmers. Soil conditions, species identification, and host genotype are all possible causes. However, the history of extensive research provides a rich tool for identifying major contributing factors. There have been many updates on viral inoculants, but the results are limited. McGonigle (1988), Lekberg and Koide (2005), and Berruti *et al*. (2016), for example, investigated the potential bio-fertilization of AMF (arbuscular mycorrhizal fungus). Rubin *et al*. (2017) investigated the role of PGPR (rhizobacteria that promote plant growth) in drought conditions.

Objectives

The goal of using bio / microbial fertilizers in seeds, soil, or compost pits to increase the amount and biological / metabolic activity of beneficial microorganisms accelerates certain microbial processes and increases the amount of nutrients obtained through easily digested methods. Although chemical fertilizers increase soil fertility, crop production, and production, the overcrowding / use of chemical fertilizers has caused great concern about soil texture, soil fertility, and other environmental problems. The use of bio fertilizers is economical and environmentally friendly.

Bio fertilizers are an important part of integrated nutrient management because they are an inexpensive, renewable source of plant nutrients that can be used to increase the chemical fertilizer for sustainable farming. In the production of bio fertilizers, several microorganisms are used in their interaction with plant matter. They can be grouped in different ways depending on their nature and function

Table 1: Examples of few groups of biofertilizers

S. No.	Groups	Examples
N2 fixing Bio fertilizers		
1.	Free-living	*Azotobacter, Beijerinkia, Clostridium, Klebsiella, Anabaena, Nostoc,*
2.	Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
3.	Associative Symbiotic	*Azospirillum*
P Solubilizing Bio fertilizers		

1.	Bacteria	*Bacillus megaterium* var. *phosphaticum, Bacillus subtilis Bacillus circulans, Pseudomonas striata*
2.	Fungi	*Penicillium sp, Aspergillus awamori*
Mobilizing Bio fertilizers		
1.	Arbuscular mycorrhiza	*Glomus sp.,Gigaspora sp., Acaulospora sp., Scutellospora sp. & Sclerocystis sp.*
2.	Ectomycorrhiza	*Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp.*
3.	Ericoid mycorrhizae	*Pezizella ericae*
4.	Orchid mycorrhiza	*Rhizoctonia solani*
Bio fertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	*Bacillus* sp.
Plant Growth Promoting Rhizobacteria		
1.	Pseudomonas	*Pseudomonas fluorescens*

Nitrogen-fixing microbes

The process of converting atmospheric nitrogen into ammonia through diazotrophic microbes is known as biological nitrogen fixation (BNF). BNF allows for complete nitrogen replenishment and constant nitrogen regulates plant growth and yield. Chemical fertilizer causes increased nitrogen oxide release, water eutrophication and acidification of soils. Although, biologically stable nitrogen is stable and less abundant in immersion and melting. Nitrogen fixation is highly limited to bacteria and archaea, which make up a large proportion of diazotrophic organisms. Nitrogen fixation groups include green sulfur bacteria, firmibacteria, actinomycetes, cyanobacteria and all components of proteobacteria. However, only methanogen can fix nitrogen in the middle of archaea. Different types of bacteria are able to make nitrogen fixes with different physiologies including: aerobic (for example, Azotobacter), anaerobic (Clostridium), facultatively anaerobic (Klebsiella) or heterotrophs; anoxygenic (Rhodobacter) or oxygen (Anabaena) phototrophs; and chemolithotrophs (Leptospirillum ferrooxidans). Diazotrophs live in different areas of soil and water, and the contribution of diazotrophic bacteria varies from 20kg-300kg N / ha / year. Diazotrophic bacteria can develop contact with grass, symbiotic relationships with termites, cyanobacterial symbioses, actinorhizal association with woody plants and symbiosis with vegetables leading to the formation of root nodules.

Symbiotic nitrogen-fixing microbes

Symbiotic fusion with legumes is made up of the species Mesorhizobium, Azorhizobium, Allorhizobium, Rhizobium and Sinorhizobium (composed Rhizobium) (Sindhu and Dadarwal, 1997) [33]. The variety of Rhizobium forms nodules on certain legume-eating plants, which contribute to improved growth, increased plant nutrition and improved soil fertility. Another important factor in nitrogen fixation is the formation of leghemoglobin in nodules, which helps maintain the low oxygen concentration required for the activity of nitrogenase-sensitive nitrogenase (Marchal, and Vanderleyden, 2000). Rhizobium nitrogen fixation process makes legumes less dependent on chemical fertilizers compared to legume-free plants (Goyal *et al*., 2021) [10].

Free-living nitrogen fixing bacteria

Azotobacter is one of the leading organisms among living diazotrophic bacteria (Aasfar *et al*., 2021). Different types of *Azotobacter* have been differentiated from neutral to alkaline soils and are commonly found in the rhizosphere of non-legume plants including cotton, wheat, rice and vegetables (Sindhu and Lakshminanaryana, 1982; Jain *et al*., 2021) [33]. The cultivated soil is mainly occupied with *Azotobacter chroococcum* and Azotobacter insignis, A. beijerinckii, A. macrocytogens and A. vinelandii, capable of processing up to 2–18mg N / g of carbon used in the cultural environment (Moraditochaee *et al*., 2014; Smercina *et al*., 2019). Some of the Azotobacter compounds have been found to act as potential biocontrol agents and have been reported to release bioactive compounds such as phytohormones, which promote the absorption of minerals by promoting root growth.

Chaudhary *et al*. (2013) [7] reported that injecting salt-tolerant Azotobacter varieties caused a significant increase in the amount of nitrogen, biomass and grain yields of wheat varieties WH157 in clay pots containing salty soil under pot-top conditions. The highest increase in plant growth restrictions was achieved after injecting with Azotobacter strain ST24 at a fertilizer dose of 120 Kg N / ha.

Associative nitrogen-fixing microbes

Azospirillum is commonly used as a biofertilizer in wetlands in many countries including Italy, Mexico, Belgium, Africa, USA, Pakistan, France, Germany, Uruguay, Australia, Argentina and Brazil. Azospirillum species are associated with plant roots and include various compounds involved in promoting plant growth, such as IAA, gibberellins and cytokinin. To date, approximately 17 different types of Azospirillum have been identified, although Azospirillum brasilense and *Azospirillum lipoferum* are the most widely studied (Rodrigues *et al*., 2015). Azospirillum alone fixes nitrogen up to 20-40 Kg / ha / year in non-legume plants. Azospirillum species alter root morphology in plant genetic function and further support plants under stress conditions by modeling osmosis and cell wall expansion.

Alen'kina and Nikitina, (2021) [29] examined the effect of lectins from two species of Azospirillum brasilense Sp7 (epiphyte) and *Azospirillum brasilense* Sp245 (endophyte) on the germination and growth of a wheat plant under abiotic pressure. A lectins of A. brasilense Sp7 and Sp245 produce adverse effects of mimic stress, heavy metals (CuSO4, CoSO4, ZnSO4, Pb (CH3COO) 2), hypo- and hyperthermic stress, salt in the water and drought in a different way, causing descent. in the germination of wheat seeds. In both varieties of Azospirillum, the most remarkable effect was seen in the exposure to heavy metals. Therefore, the stimulating effect of lectins was demonstrated by the length and number of roots of the wheat plants. Lectin for endophytic strain showed higher efficacy compared to epiphytic type lectin.

Phosphate-solubilizing/mobilizing microbes

Phosphorous is an important macronutrient needed for plant growth and development. The soil has a good phosphorus content of up to 400-1200mg / Kg of soil. But the solubility of soluble or inorganic phosphorus available i.e., orthophosphate is very low, which is why low levels of phosphorus in the soil cause a decrease in crop yields. Generally, phosphorus is present in the form of tricalcium, dicalcium phosphate and minerals. The process of solubilization and mineralization in the soil i.e., the conversion of organic phosphate form into inorganic form is carried out by phosphate-solubilizing bacteria. PSB produces organic acids such as citric acid and gluconic acids, which dissolve organic reservoirs phosphates. Also, PSB secretes phytases and nucleases enzymes to form mineral organic reservoirs phosphates. PSBs are also best known for producing secondary metabolites such as IAA and siderophores, which promote plant growth. Interestingly, the ability to produce indole acetic acid was associated with improved phosphate solubilizing activity of rhizobacteria and the addition of L-tryptophan to growth sources was found to increase the P-solubilizing activity of PSB. IAA larger than 20μg mL − 1.

Ditta *et al*. (2018) [8] showed that PSB injection into chickpea resulted in an increase of 23%, 13%, 17% and 15% of the total number of nodules per plant, shoot length, number of pods per plant and grain yield, respectively in chickpea. In addition, there has been a steady increase in soil aggregate (37%) and phosphorus content of 2.35 times in rock phosphate. Also, the nitrogen, phosphorus and protein content has been improved in grasses and chickpeas namely 11%, 42% and 16%, respectively.

Potassium-solubilizing microbes

Potassium is ranked third as the essential plant nutrients behind nitrogen and phosphorus. Potassium is found in abundance in the soil but only a small portion (1-2%) of it is found in plants. Therefore, a system of potassium refillation in soil solution is needed to obtain adequate nutrients for plant crops. Like other nutrients, potassium also contributes to plant growth and development, and if not provided in the required quantity, plant growth will slow down with undeveloped roots and low yield. Potassium also affects important physiological processes such as starch production, root growth and stomatal movement. When potassium is deficient, root growth is slow and poorly developed, seeds will be small and infection will lead to reduced yields.

Ding *et al*. (2021) use 50 and 100% recommended dose with or without potassium solubilizing bacteria (PSB) and 40kg of humic acid (HA) ha $^{-1}$ in faba beans (Vicia faba L., cv. Giza 843) plants planted in horizontal soil. Potassium efficiency (KUE) (40%) was found in soils treated with HA and PSB. The high growth and yield of faba bean plants was observed with the use of humic acid and PSB in plants fertilized at 50% of the recommended dose. Chlorophyll and leaf carbohydrates increased by 36 and 50%, respectively, in addition to control, as a result of HA and PSB application. Adding half of the K requirements of faba bean in the form of 40kg of HA and PSB has resulted in an increase of 14% and a 19% increase in seed and grass yield compared to complete mineral fertilization without inoculation.

Zinc solubilizing microbes

Among micronutrients, zinc deficiency is a deficiency of the most widely distributed nutrients. Zinc deficiency (Zn) not only has a negative effect on plants but also on human health. Zinc deficiency is ranked 5th for human-related deaths in developed countries. Zinc is involved in the synthesis of chlorophyll, enzymes, proteins and metabolic reactions. Plants with zinc deficiency produce symptoms such as chlorosis, low membrane integrity and leaf size, delayed shoot growth, reduced grain yield, pollen formation, root growth, water absorption and transport and increased risk of heat, light and fungal diseases. In wheat, Zn deficiency causes deformed growth and leaf blight. Therefore, it is very important to deal with zinc deficiency as a major concern among other micronutrients.

Sulphur oxidizing microbes

Macronutrient sulfur is needed by plants in high amounts as it is part of macromolecules such as amino acids (cysteine, cystine and methionine) and is involved in regulating various enzymes such as superoxide dismutase, ascorbate peroxidase, monodehydro -ascorbate reductase, dehydro-ascorbate reductase. and glutathione reductase. Sulfur deficiency causes chlorosis with low lipid content and low plant growth and yield (Saha *et al*., 2018). The soil is made up of organic and inorganic sulfur and the process of converting organic sulfur into plant-based sulfur (i.e., SO42−) is a form formed by sulfur-oxidizing (SOB) compounds including Xanthobacter, Alcaligenes, Bacillus, i -Pseudomonas Thiobacillus sp., Thiobacillus thioparous and T. thioxidans. Sulfur-oxidizing microorganisms also show other activities that promote plant growth.

Application of Microbial Biofertilizers

Biofertilizers are commonly marketed as network-based inoculants, have the advantage of being relatively inexpensive and easy to manufacture. Breeding germs, processing materials, mixing materials and culture culture, and packaging are steps to produce more fertilizers. Proper biofertilizer-carrying containers should be inexpensive, readily available, and easy to carry; non-toxic and organic in the structure (staying indestructible); and be able to hold high water. Peat / lignite clay soils, vermiculite, coal, compressed mud, farm manure, and soil compounds are some of the common materials used in the construction of high quality fertilizers. This, however, may have its drawbacks such as short shelf life and high temperature tolerance. As a result, the liquid formations of Rhizobium, Azospirillum, Azotobacter, and Acetobacter have been created, which, although more expensive, have the advantages of simplicity, higher cell count, longer shelf life, no contamination, storage up to 45 ° C., and improved soil efficiency (Ngampimol and Kunathigan 2008). However, microbial biofertilizers are used for seed treatment, immersion of seedling roots, and soil compaction.

How do Biofertilizers Work

Biofertilizers are efficient in delivering a wide range of nutrients to soils in an environmentally responsible and well-balanced manner. Biofertilizers capture nitrogen from the atmosphere and transform it into plant-useable forms in the soil. They also convert phosphates that are insoluble to plant-available forms. They produce hormones and antimetabolites, which encourage root growth. These fertilizers also help to adjust a soil's fertility, promoting soil life. The use of biofertilizers increases nitrogen cycling in the soil and initiates a process known as "biological buffering," which helps to alleviate soil stress. Microbes used as biofertilizers in the soil can boost host immunity and protect crops from pests and illnesses, lowering pesticide consumption.

Biofertilizers help to increase nutrient levels or by; (i) influencing plant bodies, thereby altering the formation of root exudates, (ii) contributing to the dissolution and availability of nutrients, (iii) increasing interactions with other soil bacteria (Sindhu and Suneja, 1997; Adesemoye and Kloepper, 2009; Fitter *et al*., 2011; Miransari, 2011a; Miransari, 2011b) [33, 1, 20, 21]. Bacteria make nutrients through acidolysis, oxidoreduction, chelation or by releasing compounds such as oxalate, gluconate, citrate, catechol, lactate and pseudobactin (Marschner and Rengel, 2007; Uroz *et al*., 2009; Parmar and Sindhu, 2019) [18, 36, 25]. Arbuscular mycorrhizal fungi are often associated with terrestrial vegetation and increase the availability and absorption of water and minerals, restoring carbon dioxide to the plant (Javaid, 2009; Kumar *et al*., 2021) [12, 15]. The host plant provides a suitable environment or habitat for the growth of fungal spores into the fungal hyphae, thus forming the mycorrhizosphere. Thus, there are large numbers of microorganisms in the rhizospheric region, which play an important role in the extraction of phosphorus, potassium and zinc from various soluble chemicals in the soil (Sindhu *et al*., 2014) [32]. The application of genetically modified insecticides has been found to promote root growth and germination, improved nutrient uptake and increased seed yield of different plants under potty as well as in the field under different agricultural and environmental conditions.

Potential use of biofertilizers in sustainable crop production

Biofertilizers are considered a viable and sustainable biotechnological method to increase yield, improve and restore soil fertility, promote plant growth, reduce production costs and the environmental impact associated with chemical fertilization (Aguado-Santacruz G, 2012, Vassilev 2015, Ronga D 2019 and Thomas L.2019) [2, 37, 28, 35].

Several microorganisms are commonly used as organic fertilizers, including nitrogen-fixing bacteria in the soil (e.g. Azotobacter, Rhizobium), nitrogen-fixing cyanobacteria (e.g., Anabaena), solubilizing phosphate bacteria (e.g., similarly, bacteria. The producer of phytohormones (eg auxins) and those cellulite microorganisms are also used as biofertilizers. In addition, the use of bactericidal plants can be helpful in developing strategies that facilitate plant growth under normal and stressful conditions.

Applications of Bio fertilizers

Following are the important applications of bio fertilizers:

Seedling root dip

Rice crops are suitable for this method. Seedlings are planted in a water bed with bio fertilisers for 8-10 hours. For transplanted crops, this procedure is employed. In 40 litres of water, two packets of the inoculant are blended. An acre's worth of seedlings is soaked in the mixture for 5 to 10 minutes before being transplanted.

Seed Treatment

To prepare the slurry, mix one packet of inoculant with 200 mL rice kanji. The hectare seeds are stirred in the slurry so that they are evenly covered with an inoculant and dried in the shade for 30 minutes.

Main field Application

Four packets of inoculant are mixed with 20 kg of dried and light yard manure and dispersed on a large hectare field just before planting.

Table 2: Different microbial bio fertilizers available in market and their application

Microbial biofertilizers	Trade names	Application
Azospirillum lipoferum, *Azospirillum brasilense*, and different strains of Azospirillum	Bio spirillum, Green Plus, Bio-N, Azo-S, ROM, and Spironik	For normal and acidic soils and dry soils For paddy and other crops
Azotobacter chroococcum, different strains of Azotobacter (non-symbiotic)	Bioazoto, Bhoomi Rakshak, Kisaan Azotobacter culture, and Azonik	For all crops like wheat, sorghum, barley, maize, paddy, mustard, sunflower, sesamum, cotton, sugarcane, banana, grapes, papaya, watermelon, onion, potato, tomato, cauliflower, chilly, lady finger, rapeseed, linseed, tobacco, mulberry, coconut, spices, fruits, flowers, plantation crops, and forest plants
Gluconacetobacter diazotropicus	Sugar-Plus	For sugarcane
Rhizobium strains (symbiotic, nitrogen fixing)	Biobium, Rhizo-Enrich, Kisaan Rhizobium culture, Rhizoteeka, Green Earth Reap N4, and Rhizonik	Pulses (gram, peas, lentil, moong, urd, cowpea, and arhar), oil legumes (groundnut and soyabeans), fodder legumes (barseem and lucerne), and forest tree legumes (subabul, shisam, and shinsh)
Phosphorus-solubilizing and Phosphorus-mobilizing microbes like Bacillus megaterium, mycorrizhal fungi, etc.	Biophos, Get-Phos, MYCORISE, Kisaan P.S.B. culture, MycoRhiz, Reap P, and Phosphonive	For all crops
Potassium-mobilizing or potash bacteria like *Bacillus mucilagenosus*	BIO-NPK, Bharpur, BioPotash, Potash-Cure, and Green Earth Reap K	For all crops
Sulfur-solubilizing microbes like *Thiobacillus thioxidans*	Biosulf, Sulf-cure, Sulphonik, S Sol B ®, Siron, and MicroS109	For cereals, millets, pulses, oilseeds, fiber crops, sugar crops, forage crops, plantation crops, vegetables, fruits, spices, flowers, medicinal crops, aromatic crops, orchards, and ornamentals
Zinc-solubilizing microbes	Biozinc, Zinc-Cure, Zinc activator, Zinc extra, and MicroZ-109	For crops like paddy, wheat, pulses, citrus, pomegranate, ginger, etc.
Silica-solubilizing microbes	BioSilica, Silica-Cure, and Silica-109	For crops like cereals, sugar cane, onions, leafy greens, legumes, cucumber, pumpkin, and gourd

Modified from Singh *et al*. (2014), Biotech International Limited (2018) [5], National fertilizers limited (2018), Biocyclopedia (2018) [4], Indiamart (2018) and International Panaacea Limited (2018)

Table 3: The different constraints in bio fertilizer technology

Bio fertilizer technology constraints	Examples
Technological	▪ Use of microbial strains and inefficient carriers ▪ Low quality and short shelf life of microbial injections ▪ Lack of qualified staff
Infrastructural	▪ Lack of suitable production facilities such as machinery, space, warehouse, etc.
Financial and marketing	▪ Lack of adequate funding ▪ Minimum return on product sales ▪ Lack of the right inoculant ▪ Lack of retail space or market network for manufacturers
Environmental	▪ The need for seasonal bio fertilizer ▪ Soil signs ▪ Short-term cropping activities
Human resources	▪ Lack of proper training in production methods ▪ Uncertainty about the quality of the product produced ▪ The problem of acquisition and ignorance of the technical benefits of farmers ▪ Ignorance of the natural compensation caused by the constant application of chemical fertilizers

Recent advancements in bio fertilizer

Several innovations have emerged in recent years to improve the nutrients and growth dynamics of soil and plant for improved crop production, such as the employment of specialized microorganisms for plant inoculation, best technology, and appropriate carrier material for inoculum purposes. Furthermore, contemporary approaches include artificial selection of microbiomes, mixed inoculants, PGPR as bio fertilizers, usage of biofilms as bio fertilizers, Nano bio fertilizers, and bio-organo-chemical fertilizers to cut bio fertilizer costs and ensure long-term production.

PSM Inoculants

Injecting PSM can improve phosphorus efficiency in the agricultural sector. They were found to be involved in the synthesis of inorganic phosphates and minerals. Pseudomonas putida, Pseudomonas fluorescens CHAO, and Tabriz Pseudomonas fluorescens, respectively, produced 51 percent, 29 percent, and 62 percent P. Similarly, compared to untreated plants, Glomus fasciculatum and Azotobacter led to the vaccination of N take, K with a mulberry leaf. Similarly, after injecting wheat with phosphate-solubilizing Pseudomonas and Bacillus, better phosphorus detection and grain production were recorded. PSM improves the availability of P while maintaining soil biological structure. When access to chemical fertilizers is limited, this applies. PSM is not intended to capture and can be used on a variety of plants. PSM has improved the growth, production, and quality of a variety of crops, including walnuts, apples, corn, rice, mustard, palm oil, aubergine and chile, soybeans, wheat, beans, sugarcane, peas, peanuts, peanuts and legumes, and potatoes, according to several studies. When sprayed on plant plants, PSMs have been proven to increase P absorption, growth, and yield. Many PSMs, including Bacillus megaterium, Bacillus circulans, Bacillus subtilis, and Pseudomonas striata, have been shown to be effective biofertilizer fertilizers or regulatory agents.

PGPR as bio fertilizer

Plant growth promoting bacteria (PGPB) are important for increased crop output because they contain regulators and transporters that help plants absorb specialized nutrients and grow faster. Researchers believe that using these PGPB as a bio fertilizer for the development of a wide range of crops in a wide range of environmental and climatic circumstances has enormous potential (Gouda *et al.*, 2018) [9]. These include both symbiotically related and free-living bacteria that invade plant roots. These bacteria interact with plants in the same way, but having different properties. Plant growth-promoting bacteria, used as a bio fertilizer, not only improve nutrient availability for plant absorption, but also protect plants from pathogens, resulting in improved plant growth and development. Bacteria like Bacillus megaterium, Anabaena, Azolla, Bradyrhizobium, Bacillus polymyxa, Rhizobium, and Sinorhizobium are important for plant growth and development (Olanrewaju *et al* 2017) [24].

Nano bio fertilizer

Nano-bio fertilizer is a hybrid fertilizer that combines nanotechnology and bio fertilizer to improve agricultural efficiency and yield. The synergistic action of nanomaterials and microbial fertilizers aids soil moisture retention and nutrient uptake by plants (Kumari & Singh, 2019) [16]. Other fertilizers have major drawbacks, such as field instability due to changes in environmental conditions, temperature, and pH, poor shelf life, reduced microbial strains, only short-term efficiency, and the need for a large amount of fertilizer to cover a large area, among others, which can result in poor growth and yield (Akmakç, R. (2019). Farmers profit from the usage of nano bio fertilizer because it improves field performance, reduces costs, and increases production (Mala *et al.*, 2017) [17]. Nano bio fertilizers are not only good for the environment, but they also improve the efficiency of the indigenous microbial population by utilizing critical nutrients like potassium, nitrogen, and phosphorus. This will increase the activity of microbial enzymes, which will help to improve soil fertility.

Biofilm bio fertilizer

Biofilms have recently been used to make a breakthrough in the production of bio fertilizers. Biofilms are microbial communities that are adhered to surfaces, which can be biotic or abiotic, and are embedded with a biological component that helps the biofilm maintain its structural integrity and sustainability (Junaid & Khan, 2018) [13]. Quorum sensing allows microbial species to communicate with one another. The primary goal of developing biofilm bio fertilizer is to address issues with biotic and abiotic soil components, as well as to make the indigenous microbial population more resistant to diseases and inhibitors (Parween *et al.*, 2017) [26]. Biofilm is formed on the plant surface or within the plant, and it is beneficial for PGPR nitrogen fixation and crop productivity. Biofilms also aid in Zn solubilisation and chelating agent synthesis (Igiehon & Babalola, 2017) [11]. Biofilms allow microbial species in a community to share genetic information and organic resources. Multiple microbial strains in a biofilm are explored to be a more resistant and sustainable strategy than a biofilm composed of a single microbial species. When compared to microorganisms that are single or do not form biofilm, bacterial-fungal biofilms have much higher nutrition absorption and resistance to environmental stress (Velmourougane *et al*., 2017) [38].

Applications of biofilm bio fertilizer

Biofilm bio fertilizer can be used in a variety of ways to improve ecosystem performance and resilience. This includes increased soil microbial activity due to lower BFBF requirements than chemical fertilizers, as well as improved soil biodiversity and quality restoration. Biofilm bio nutrient gives plants resilience to heavy metals, drought, stress, pH, temperature, and disease assault. Biofilm bio fertilizer also aids in land preservation and reduces negative health effects. It also helps farmers have a longer shelf life by increasing agricultural output under various environmental circumstances (Mitter *et al*., 2021) [22].

Conclusion

- Bio fertilizers are an important part of organic farming in modern agricultural practices as they can be used instead of chemical fertilizers, linked to a variety of environmental hazards. Bio fertilizer can repair and make atmospheric nitrogen available in soil and root systems, dissolving phosphate (from soluble forms such as tricalcium, iron, and aluminum phosphates), filtering phosphates into soil layers, producing hormones and antimetabolites to maintain root growth, and organic rot. the issue of mining. Increased harvest yields, improved soil structure (by influencing soil compaction for better water relations), increased nutrient efficiency, non-polluted water sources, and drought tolerance to plants (by improving leaf water and turgor capacity, maintaining stomach function, and increasing root development.).
- They also reduce the use of chemical fertilizers, which lead to sustainable non-environmental damage.
- In addition, it is expected that advanced knowledge of PGPR interactions, as well as bioengineering of microbial communities to improve the performance of biofertilizers in field conditions, will assist in the development of sustainable, environmentally friendly agricultural techniques, and intelligent agricultural technologies to provide timely solutions in the short and long term to increase crop production and sustain the soil in a sustainable manner.

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