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BIOFERTILIZERS: SUSTAINABLE SOLUTIONS FOR AGRICULTURAL CROP PRODUCTIVITY

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ABSTRACT

Across the globe, the greatest challenge of agriculture systems is to produce food, manage stresses, and confront the prevailed dependency on chemical inputs including fertilizers and pesticides. From crop emergence to maturity, there is an increased risk of occurrence of pests and weeds. Pathogens attack plants resulting in huge crop losses every year, which vary from 15-20% and such diseases are caused by viruses, fungi, bacteria and nematodes. Any stress management is vital in agriculture to maintain crop health and productivity so as to meet food security requirements for a continuous increase in the estimated world population. Ongoing production of agricultural crops largely depends on various soil types and surrounding environments, but crop production faces abiotic stresses also worldwide due to changing climate conditions such as rising temperature, increasing salinity, floods, drought, frequent floods, and ozone damage. It is, therefore, a challenging task to employ effective technologies for pest immunity and disease management against the current burden of the global increasing population. Thus, there is a need for a more eco-compatible technology that can somehow justify abundant agricultural crop production by considering health issues as well as harmful effects on the environment. Traditionally, soils rich in natural nutrients have been used for agriculture. Since agricultural crops rely on synthetic fertilizers and agro-chemicals for highest crop production therefore biofertilizers are a good solution to combat agricultural pests. Biofertilizers and organic farming are a holistic crop and soil management methods with little use of chemical inputs. Around 3% of the world's arable land is cultivated with organic farming. Organic crop biology increased from 1.7 million hectares in 2020 to 195 million hectares worldwide in 2022. The fertilizers used in this method are rock phosphate, bone meal, green manure, and paucity cake. Application of natural product fertilizers enhance crop quality and productivity and provide natural nutrients. Modern agriculture requires balanced nutrition and crop pest and disease management strategy for public health and safe environment. This process can be obtained by the use of bio fertilizers, weed, and biological control agents. Biofertilizers are natural living things containing plant nutrients that provide nutrients to the plant. On the other hand, booster focus needs on the minimum use of synthetic chemicals by focusing on biofertilizers and biocontrol agents for large crop production free of harmful chemicals.

KEYWORDS: Biofertilizers, agricultural crop productivity.

Biofertilizers

Biofertilizer implies the use of microorganisms to fulfill the nutritional need of crops. In India, the term biofertilizer encompasses the application of certain specified microbial formulations, having substantial effect on the development of crops by increasing their supply of essential nutrients from natural sources. Biofertilizers are bio-based organic fertilizers, which have the potential to improve the bioavailability and bioaccessibility of nutrient uptake in plants, eventually increasing crop production at low cost. Among the different types of bio-based organic fertilizers, biofertilizers have not gained as much popularity as they deserve, hence this literature is an attempt to review various aspects of biofertilizers. Live microbial mass is the major ingredient of biofertilizers. A biofertilizer is defined as a preparation containing live microbes, of known characteristic, that help in enhancing the soil fertility and crop production either by fixing atmospheric nitrogen or by solubilizing phosphorus or by decomposing the complex organic wastes. Biofertilizer is suitable for application to seed, roots, and soil, which not only promotes the healthy and environmentally pollution free cultivation, but also reduces the chemical nitrogenous fertilization greatly. Most of the biofertilizers are in solid form, which available carriers used are lignite, peat, rock phosphate, vermiculite, and organic waste materials (Chaudhary et al., 2022). The pertinent technical characteristics of various eligibility criteria to qualify as biofertilizers are the potential to supply or mobilize bioavailable forms of one or more nutrients essential for plant growth with beneficial effects on crop productivity. Biofertilizers are marketed in two main categories. These are: organic residue-based biofertilizers, and microorganisms based biofertilizers. Biofertilizers compete in the subsector of organic bio-based fertilizers. Organic-based fertilizers (OBFs) include green manure, crop residues or farm and animal by-products such as farmyard manure, compost, and liquid manure. Limited attention has been paid to the development of new microbial formulations mainly because of the lack of specific guidelines for product registration and for biofertilizers market introduction (Malusá and Vassilev, 2014).

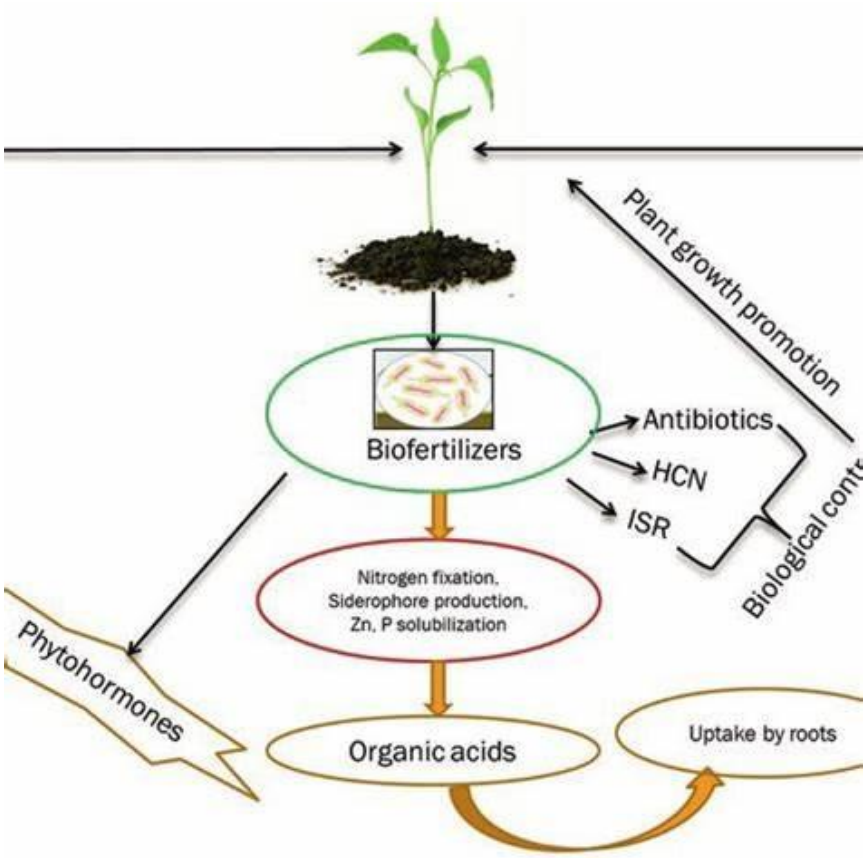
Background of Biofertilizers

The terms biofertilizer might sound a bit familiar today, but when and how did this term come in and what has been its route to get here? It is always fascinating to know about things in their entirety and the journey of biofertilizers has been long and ever-evolving. Biofertilizer is the first unconventional concept of fertilizer used to enhance or increase the contribution of nutrients to the soil. These are preparations containing live microbes, which help in increasing the fertility of soils. These preparations mainly consist of strains of diazotrophic microorganisms, which after their introduction in the soil, multiply and colonize the root zone of the plants. For some crops, they may colonize either the roots, or other parts of the plants (Chaudhary et al., 2022). In a broader term, biofertilizers are bio-based organic fertilizers from living or dormant microbial cells, which helps in enhancing nutrient uptake mechanism of plants. History may remind us that indigo industry, one of the mainstays of British economy, was destroyed due to encouragement of using chemical fertilizers; which ultimately causes heavy metal toxicity in soil. However, after facing the ill effects of indiscriminate use of chemical fertilizers i.e. poor biological activity of soils, loss of self-regulation, high cost, contamination of soil, water and other living organisms in the eco-system; farmers started the use of bio-fertilizers, to enrich the fertility of soil. European based countries like Germany, Italy, Sweden, Spain, and France were the pioneers in the use of bio-fertilizers, and they began using it in the 18th century (Seenivasagan and Oluranti Babalola, 2021). Asia followed Europe, the USA then started using biofertilizers, following the trend set up by Europe, and later on African countries followed suit. Thus, the recent reintroduction of biofertilizers reflects the multi-dimensional activities and approaches of Biotechnology as a sustainable profitable development of technology over an extended period of time.

Mechanisms of Action

Agricultural systems are under demand to provide food, feed, and renewable resources for a growing global population, while at the same time minimizing the impact on the environment. Several Green Revolutions have increased crop productivity and food security, but at a large socioeconomic and environmental cost. The exhaustive exploitation of agricultural land and fresh water, as well as increasing fossil fuel prices, represent some of the challenges to maintaining high agricultural productivity. Additionally, the presence of unintentional contaminants in the environment points to the necessity of developing new systems for environmentally safe agricultural practices. Bio-fertilizers appear as a potential solution to meet the demands of sustainable agriculture at low cost (Berquó Marks et al., 2013).

The agricultural sector must adopt new technologies in order to sustainably maintain high yields and minimize land degradation. This practice is essential for farmers due to the increasing costs of industrial fertilizers and fuel, as well as limitations in the environmental footprint. Sustainability in the agricultural system is being considered a synonym for meeting global demands in terms of food production, counteracting deterioration of water and soil quality, reducing the consumption of nonrenewable resources, maintaining agricultural productivity at satisfying levels for present and future generations, and developing new and innovative biotechnologies (Chaudhary et al., 2022).



Direct Mechanisms

Nitrogen Fixation: Microorganisms like Rhizobium and Azotobacter convert atmospheric nitrogen into forms usable by plants.

Phosphate Solubilization: Microbes release organic acids that convert insoluble phosphates into soluble forms accessible to plants.

Production of Phytohormones: Microorganisms synthesize hormones such as auxins, gibberellins, and cytokinins that promote plant growth.

Siderophore Production: Microbes produce compounds that chelate iron, making it available to plants.

Indirect Mechanisms

Antibiotic Production: Microorganisms produce antibiotics that suppress soil-borne pathogens.

Hydrogen Cyanide (HCN) Production: Some microbes produce HCN, which inhibits pathogen growth.

Induced Systemic Resistance (ISR): Microorganisms stimulate plant defense mechanisms against pathogens through ISRs.

Biological Control: Beneficial microbes outcompete or antagonize harmful pathogens and pests in the rhizosphere environment.

Microbial Components of Biofertilizers

Fertilizers that contain nutrients, which are biologically produced by a living organism that increase the soil fertility or the plant growth and yield is known as bio-fertilizer. Fertilizers are used for increasing crop yield are manufactured by chemical fertilizers and they are not sustainable solutions for long-term better productivity. The excess uses of chemical fertilizers also have created some major problems like health hazards, environmental pollution and depletion of natural fossil fuels. The most promising and available alternative is biofertilizer. The utilization of biofertilizers is considered as one of the best alternatives for chemical fertilizers to ensure the sustainability of productivity. Using the bio fertilizers save the environment from pollution. Different types of micro-organisms are used as bio-fertilizers to improve the soil fertility of land. Biofertilizers are considered to be effective because they help in the growth of plant root through the supply of plant nutrients in available form to the host plants. The use of rhizobia biofertilizers increased the growth of root and nodulation in order to improve nitrogen fixation in legumes. Bio-fertilizers contribute to the fertility of land. The use of bio-fertilizers increases the yield and productivity of crop. It also reduces the problems of barrenness in land.

There are two types of components of bio-fertilizers; a) micro-organism and b) biological organic material. Important microbial components of biofertilizer are Azotobacter, Azospirillum, Rhizobium, Blue Green Algae, vesicular-arbuscular Mycorrhize, Bacillus and Pseudomonas. Rhizobia, BGA, Azotobacter, Azospirillum, Cecospira, Phosphate solubilizing bacteria, Potash mobilizing bacteria are the commercially available biofertilizer in Bangladesh. Growth promoting substances and free nitrogen gas are released from bio-fertilizers. Bio-fertilizers are also helpful in increasing humus in soil by decomposing the residues of plant.

Manure from compost is used as biological organic material in biofertilizers. Bio VAM, sub-VAM are included in the biofertilizer. Biofertilizers are beneficial for improving soil fertility and sustainable agriculture. Judicious combination of chemical fertilizers and biofertilizers are used in our experiment. Use of biofertilizers alone cannot improve crop yield. Fertilizers along with biofertilizers can bring good results. But a harmonious use of bio and chemical fertilizers can reduce the use of chemical fertilizers and save the environment from pollution.

Role of Nitrogen-Fixing Bacteria

The shortage of plant nutrients, particularly nitrogen, is a major constraint to sustainable agriculture worldwide. Increases in nitrogen use efficiency have resulted from the use of legumes in rotation, or intercropping systems, because of their symbiosis with free living and endophytic nitrogen-fixing bacteria and actinomycetes species. Several plant species across the globe have developed a symbiotic association with a particular group of bacteria, also known as Rhizobium. It is estimated that every year, 200–300 million tons of biologically available nitrogen are fixed in the symbiosis, but this estimate excludes free living nitrogen fixing bacteria such as Klebsiella, Azotobacter, Azospirillum and Actinomycetes. In addition to the symbiotic forms, free-living nitrogen-fixing bacteria present in the soil have total geographical distribution such as Bradyrhizobium, Azospirillum, Azotobacter, Klebsiella, and Pseudomonas. Globally, nitrogen fertilizer is mostly supplied by synthetic form in an oxidized form otherwise plant roots do not absorb nitrogen in gaseous form (N2) (Soumare et al., 2020).

Among the microbial populations that may be beneficial to plant growth are free-living N-fixing bacteria, which reside in the rhizosphere and may be an alternative or supplemental source of fixed-N to the plant. Azospirillum, Acetobacter, Herbaspirillum, Burkholderia, Pseudomonas, and Azotobacter are also common inhabitants of the rhizosphere of cereals and other plants. These bacteria fix nitrogen under free-living conditions in the rhizosphere of the plant and produce bioavailable forms of nitrogen that are accessible to the plant. Additionally, some of these free-living diazotrophs have also been reported to produce plant growth-promoting substances, known for their roles in improved plant nutrition, plant growth, and development. The use of nitrogen-fixing microorganisms presents a promising alternative for increasing agricultural productivity through decreased dependence on chemical fertilizers, stimulates growth, and induces systemic resistance in plants.

Role of Phosphate-solubilizing Microorganisms

Efficient, balanced, and environmentally friendly agriculture plays a crucial role in attaining global long-term sustainability. Modern technologies and biotechnologies in plant nutrition and farming have been developed to overcome these issues in the agricultural sector by investing in a modified green development paradigm, known as sustainable innovative intensification. Biofertilizers naturally enrich soils with nutrients and cultivable microorganisms, and are used as a realistic, successful, and ecologically benign component of the crop yield intensification practice. These comprise a range of the most crucial biologically communicable elements that influence element intake rules, as well as pro- or bio-oxidant direct influence, stimulating plant metabolism, growth, and success of plants. While twinning specific biofertilizers enables yield-friendly elements to be imbibed and synthesized in the edaphic answer, excluding impairments to the biochemical composition and ease of plain soil.

It is possible to develop a comprehensive naturalization plan for the prolonged dependence of non-organic field-harvested fertilizers that is substantial for sustainable agriculture by supplementing mineral mix rights and enhancing plant yield. Inorganic fertilizers have a good effect on plants, but there has been an interest in the harmful environmental impacts. Biofertilizers can be seen as one of the most important fertilizers and they play a significant role in improving the quality and abundance of crops, as well as supplementing nutrients to the soil. Most bio-fertilizers contain the soil microorganisms which can fix atmospheric nitrogen and make it available to plants. In addition, the solubilization of phosphates, potentiating the phosphate solubility and its bioavailability to the plant is very important. Bio-fertilizers can also support the development of land plants and the production and quality of an enhanced land plant, namely by increasing the efficacy of nitrogen fixation.

Role of Mycorrhizal Fungi

Mycorrhizal fungi are soil-inhabiting fungi that establish a close symbiotic association with about 80% of all known plant species. The fungi improves the nutrient uptake by the plants through its vast network of hyphae. The plant, in return, provides the fungus with photosynthetic products. This enigmatic root-fungal association has evolved as an eco-friendly and sustainable practice that plays a pivotal role in promoting plant growth and soil fertility dynamics (Kuila and Ghosh, 2022).

Arbuscular mycorrhiza (AM) is the most common type of mycorrhiza, colonizing almost 90% of all plant species. The technology of using commercial AM fungi is now well advanced. The harbored spores or vesicles are inoculated in the field or at the time of planting seedlings. The soil types and climate suitable for mycorrhizal colonization have been documented. Mycorrhiza acts as a bridge between roots and soil and constitutes a physically greater area for nutrient and water absorption, thereby increasing the nutrient up taking efficiency of scavenged nutrients which are not reached by roots (Vassileva et al., 2022). Recent years

have witnessed an upsurge of interest in the harnessing and development of ecologically sustainable agriculture. Due to the awareness and actual scenario of global climatic change, the usual chemical-based agricultural system is not only ineffective but also hazardous. Inorganic fertilizer residues create eco-toxicity and imbalance in the soil nutrient, while chemical pesticides leave toxic residues and micro flora in the soil. Furthermore, irrigation for agriculture uses up most of the available water. Due to the adverse effects on sustainable agriculture, a paradigm shift has been made to eco-friendly alternatives such as biofertilizer. AM is omnipresent in almost all ecological zones under variety of soils, and it improves inhibited growth due to soil acidity, by enhancing uptake of P and other nutrients. Shock waves on the global food crisis are still reverberating. In many countries food grain prices are escalating at an alarming rate. The situation promoted the adoption of organic inputs instead of or in part substitution to chemical inputs. Recognizing that the application of phosphate fertilizer per se was shown to have only marginal benefit, even though more P was taken up by the roots; attention has been focused on AM. Transaction cost: One problem of adaptation of the technology by farmers or marketing the products is the high costs of commercial AM and mixing with biofertilizers. On the other hand, in some areas which have potential, indigenous spores are not available. AM inoculation has a direct influence on the AM colonization percentage of the legume and rotational plants. Magashula suggested that this is due to a greater benefit on the mycorrhizal emblem of the legumes parasite only. Tables of crop response and importance of AM in agriculture have also been published.

Benefits of using Biofertilizers

The promotion of biofertilizers in farming remains limited. Therefore, a comprehensive and systematic biodosage program is required. The purpose of this study is to quantify the benefits of using common biofertilizers across differences in soil types and crops, and to determine the optimal application rates. A meta-analysis of 20 case studies found that biofertilizers, regarding any single input biofertilizer, resulted in positive increases in crop yield and nutrient use efficiency with a frequency of about 80%. Different strains showed a wide range of effectiveness, as did the lower and upper biofertilizer dosage rates. Several types of dosing strategies were identified as effective, and the dosing effect was influenced by environmental factors, such as soil pH and air temperature.

In order to cope with the alarming growth rate of population in the future, there is a fast need to foster technologies to advance the agricultural output. It is believed that conventional agricultural methods, despite success so far, will not fulfill the projected demand of food and fibers. Consequently, a few new approaches must be found to increase the productivity of crops. All around the world such research is under way at numerous research centers. In that direction biofertilizers are considered one of the main possibilities. Recently, the use of biofertilizers has gathered much attention. This is due to a decrease in the efficiency of high power chemical fertilizers. Moreover, the high cost of chemical fertilizers is ranging out of the hands of poor farmers, and it also creates environmental problems. On the other hand, the efficiency of nitrogen fixing biofertilizers is very great as compared to the chemical fertilizers. Dryland agriculture stands to benefit the most from the practice of biofertilization remarkably by increasing availability of nutrients, having the capacity to withstand periodic drought, reducing soil erosion and by improving soil organic matter feeding soil biotic life (Schütz et al., 2018). It is a vital and recently emphasized area for sustainable agriculture-based research. Biofertilization utilizing carrier based indigenous plant growth promoting rhizobacteria and phosphorous solubilizing bacteria are a promising option for sustainable agriculture. Raising of pulses in semi arid cooler climatic areas generally suffers from a host of abiotic and biotic stresses; among them nutrient deficiency and low moisture availability are predominant. Biofertilization has been considered an important practice in such scenario. Use of biofertilizers was found more effective in chickpea and biofertilized plants were superior in nodulation and yield attributing characters when compared to fertilizer alone (Seenivasagan and Oluranti Babalola, 2021).

Environmental Impact of Biofertilizers

An eco-friendly fertilizer is a protective fertilizer that does not have an effect on the world, by tree leaves, trunk, root, stem, and seeds of the phase. These fertilizers can be obtained from the most statistically useful components, and they can be inorganic item-based or organic item-based. selections from the best known eco-friendly fertilizers; Chicken fertilizer, bat fertilizer, brewery sludge, earthworm fertilizer, natural farm soil, sludge, bone meal, basalt, egg shell flour, animal manure, vermicompost, abiotic pressure, PGPR, plant abnormalities, weed oils purnapal, vermiwash, yellow wood, banana peel, reeds, buffalo urine, waste treatment sludge fertilizers can be counted. The environmentally friendly biofertilizer is used to increase the plant weight, speed up the advancement, and boost the crop yield. Among the many forms of pollution created by human beings, water contamination is among the most intense or most endangering varieties of “maths” along with the sound and air contingents. That is why the monitoring of water quality requires great consideration. Water quality is a convoluted term and may be defined in many different methods since it depends on the selected use. There should be strict observance of water parameters in agriculture that have gain access to food safety. Derogation of water parameters makes the transfer of pollutants from water directly or indirectly utilizing agriproduction; soil, plant, air, to the living organisms consisting of individuals and other microorganisms. Water contamination triggered by heavy metals can

occur in surface area water and groundwater (Chaudhary et al., 2022). Nowadays, due to blossom culture, however, manage making use of chemicals, like the use of synthetic fertilizers, pesticides, herbicides, and so on climate-friendly- organic farming is viewed as a sustainable growth trend as it establishes protective soil with less folding energy. At the exact same time, the advancement of ecological-friendly points of view in agrienvironmental matrix gets in touch with the manufacturing of natural waste from industry-wide activities bio-waste can create issues in regard to waste handling, water, soils, and air pollution. Veterinarian antimicrobial drugs (VAMs) are pharmaceutical in hearing products formed to look after and grant propose dog's health and well-being (Seenivasagan and Oluranti Babalola, 2021).

Comparison with Chemical Fertilizers

Farmers are now facing infertility of soils and poor farming, which results in a reduction in agricultural crop yield. Using of chemical fertilizers distresses human health by leaving toxic chemicals used for farming in the crop and also result in the food chain. The application of chemical fertilizers for the accomplishment of successful agriculture has been an important practice around the world. It is also responsible for a global revolution in the agricultural belt of developing countries during the Green Revolution period. This has played a significant role in reducing India's dependence on food imports to achieve agricultural productivity. Due to the inappropriate use of such a chemical fertilizer, there has been a rapid decline in production levels in most states (Seenivasagan and Oluranti Babalola, 2021). According to historical evidence, the soil was cultivated for the first time in primitive times and gave it an identity. With the passage of time, various crop species were introduced into agriculture by experiments and field trials. As a result, a balance was created and a foundation was laid for various soil fertility.

In the 21st century, the gap between demand and supply of food and other staple crops is widening day by day (Ye et al., 2020). Therefore, it is inevitable to increase the earth's productivity by adapting special techniques to meet the ever-increasing demand for food and other agricultural services. Biofertilizers are small cells containing several spores of nitrogen-fixing bacteria and fungi coated in a thick protective shell made of concrete or water soluable coated in a molasses based product. The use of biofertilizers is the cost-effective way of sustainably increasing the agricultural crop yield and fertility of the soil to fulfill the growing need of regained lost nutrients improve yield. It is evident that biofertilizers is a cheaper source of renewable energy that lasts longer and keeps alive its long-term, as distinct from chemical fertilizers that are exaustable. It has also been observed that the application of biofertilizers improves the soil structure of aeration of individuality.

Application Methods of Biofertilizers

Biofertilizers can increase crop yields by on average 20%. Many biofertilizers fixate N and solubilize P simultaneously. Especially in legume crops, N-fixing biofertilizers reveals a strongly positive impact on crop yield. The application of biofertilizers could mainly support drylands. The meta-analysis substantiates the potential of biofertilizers as a promising tool for enhancing agricultural sustainability (Schütz et al., 2018). In this critical view, sustainable agriculture is called upon. This inalienable concept embraces a broader sense of agro-technologies with benign impact on nature and human health. Among them, biofertilization, viewed as environmentally safe technology since it relies on a living organism such as azotobacter, cyanobacteria, Rhizobium which forms nodules in roots of leguminous plants, mycorrhizae, and phosphate-dissolving bacteria which can't survive outside the rhizosphere of the plant, was considered as a suitable approach to attain the goals of sustainable agriculture (Khan et al., 2023).

Biofertilizers in Organic Farming

Recently the agricultural function converts to a high surplus farm generated revenue and high technology application, in terms of pesticide and chemical fertilizer. It also over utilizes the chemical substance which donate severe influences on agricultural and environmental factors, i.e. soil health, water pollution and all round biotic life. Following are a suggestion in farming for domestic and global condition conservancy. One of the successful efforts for creating international conservation is on the second NATO conference in Palisades, USA, June 2006 that results (Seenivasagan and Oluranti Babalola, 2021). It concluded that the safest dependence on food conservation and life possible on the sustainability of agriculture. Nitrogen as essential element that apply too much as nitrogenous fertilizer in agriculture could effect on water table and health hazards. There is a way to reduce the hazards of nitrate in nitro fertilization is to utilize nitrification inhibitors or the alternative utilization of biofertilizers. For temperate zone countries it is most acceptable to reduce the amount of nitrogen fertilization. In tropical country, Balalock and Cooper recommend to apply 25% of nitrogen as the basis of fertilizer. Moscow Delinquire recommends 16-25%. Biofertilizers as inoculum crops having high potential especially the legume crop, they should utilize microorganisms which can fix free N2 and growth stimulators vegetables, thereby plant can absorb the greater nitrogen and other mineral. Biofertilizers in the form of fertilization has been instructed for enhancing the soil compaction, reducing erosion, disease control an environmental friendly. In addition, the emergences of biofertilizers can be expected to extent the usefulness of AGC more especially in developing countries. Sooner or later, biofertilizers may prove to be a powerful instrument for growth agriculture productivity.

Organic farming aims to produce high quality organism agriculture goods satisfying aesthetic requirements by

taking full advantages of the natural mechanism and enabling all the energy sources locally available. It embodies on-farm application by reducing off-farm treatment and it additives. Limitation of the use of mineral synthesis chemical compound or has a different name. Argumenting soil fertility by means of recycling organic material the environment, by reducing the use of chemical compound, on the one hand, beneficial necessary bacteria families in the soil to change their location and it addiction indirectly to a renewed system of crop protection, by increasing the population of antagonistic microorganisms. Biopesticides, as alternative strategy for chemical pesticides, have been recognized as an acceptable protection system for agricultural pest and diseases, and have become successfully the subject of traditional knowledge over many generations.

Recently in farming culture mode, organic farming come out to be a suitable attack for a sustainable agriculture. Conventional modern farming strives to foster the soil productive utilization, whereby a high storey of mineral fertilizer is in-digenitely provided, and other methods based on improvement of technicality application and selection of crops based on high yield potential are practiced. Low-mechanized agriculture, on the contrary, focused on the nourishment exerted by the farmer and it is available means, e.g., natural bio-pesticide, bio-fertilizer methods are used. Hence, the agricultural standard with special on the utilization of bio-fertilizer application and bio-fungicide methods are appropriate in organic farming in appropriately, have been a successful level for vegitative growth, and significant of protection and it is adduction has decreased to the threshold value. Veganic culture, also known as stock-free agriculture gardening, includes all above practices, with exporting the farming basic from chemical fertilizers and bio-fertilizers produced with manure or whey-like substance of animal origin. Optimal agriculturing measure, including irrigation, bio-fertilizing and counseling selection should practice to maximize its functions and turnip it into economically profitable production biovitamins, essential nutrient strictly for organic movement, including micro-nutrients, used in mountainous region has become.

Challenges in Biofertilizer Adoption

Agriculture is the most important part of sustenance for both human and cattle since ancient times. For sustainable growth in food production, agricultural operations are leaned heavily on the application of chemical fertilizers, toxic substances to control pests and diseases, and with extraction of groundwater to fulfill the water requirement for irrigation. Nutrients which are to be taken by plant health are degraded from farmland use with the use of chemical fertilizers for the long term. Influence of chemical pesticide on environment and human wellbeing has also been revealed. Chemical fertilizer's significant drawdown of groundwater has been also well recognized.

Rising public awareness and renewal of policies deployment globally on the sustainable environment have associated with ecological procedures which are harmoniously gestate with food production. Therefore, artificial fertilizers are being withdrawn rapidly and relocated by the eco-friendly organic fertilizers or by a biofertilizer and a function of nutrient based biofertilizer is being taken for granted in the near future. In the offing, microbial inoculant's cost-effective convenience together profitability are assured to go with the welfare of the farming sequence in a most sustainable approach. Hence, inquiries in biofertilizer adaptability in a role of nutrient-have become the gravitas of obligation for a sustainable agriculture op-course. In recent moment microbial inoculants have been well characterized for their reasoning on fixed nitrogen, product of plant enhancement, and bio-control pathogens (Chaudhary et al., 2022). In addition to, production of wherewithal novel biofertilizer, superior gain in yielding with the application of combine consortia over the individual culture has been observed. Herewith, this particular experiment was reckoned to evaluate the interaction effect of combine consortia on the growth and paddy. Resistivity of the indigenous Cyanobacterial strains are not sequence tolerance. In order to proliferate cultivation area, inventively multiple biofertilizer customization of biofertilizer consortium.

Market Trends and Economic Viability

Starting in 1954, the wheels of the newly independent country hummed to get its agriculture on wheels. All to a good effect. The 'evergreen revolution' soon brought about a transformation that was one of the biggest success stories of our times. The country became self-sufficient in food. About 40 years later, come the 1990s, agriculture was in a different kind of crisis. Growth rates were stagnant; the input use was shown to be less productive, and had harmful effects on run-off, irrigation water, and contamination of groundwater, the yield gaps were on the increase and so were the frustrations of the farming community. In the 70s and 80s, with a view to increasing productivity and achieving food self-reliance, governments of several developing countries promoted intensive growth by using high-yielding varieties, fertilizers, and pesticides. But the increasing use of chemical fertilizers and pesticides seriously degraded the soil health and posed potential environmental and human health hazards in the long run. The need was felt to explore options that would enhance agricultural productivity in a sustainable manner. As is now well recognized, microorganisms play an essential role in the sustenance of life on earth and maintenance of ecosystem health. In the agri-ecosystem, the micro flora help recycling of biomass, as well as nutrients. Productivity of agriculture could gearing up of research on biological options and perhaps due to these reasons, the scintillating success of propagating biofertilizers and agrochemicals commenced about half a century ago. For commercialization of microbial inoculants, it was available to the farmer in the smallest possible quantity,

in the process checked to maintain their population for at least 6 months or a year as the origin of biofertilizer started emerging in soil. They discovered fixation of nitrogen in the presence 36 kg phosphorous and as for now it simply has to pay off with help of organic substrate in a simple process, carried out through both research and extension activities. In order to encourage self-inoculation by farmers and to scale out target group number i.e. in terms of hector, seeds were meant to coated with the consortium of BCs in talcum glucose formulation, and was administered cost saving manner and available as per the use technology requirement.

Future Perspectives on Biofertilizers

At present, the agricultural productivity relies on conventional approaches like the use of chemical fertilizers that can not only be exhaustive but also uneconomical. The hazardous effects of excessive use of chemical fertilizers on agriculture and soil microbial life necessitated the exploration of alternative strategies for enhancing crop productivity. Among them, biofertilizers have been recognized as an efficient substitute for chemical fertilizers in enhancing the overall crop productivity and soil health (Seenivasagan and Oluranti Babalola, 2021). Biofertilizers are the formulations containing beneficial and living micro-organisms that favor the crop plants to achieve their complete potential. Earlier findings indicated that the biofertilizers enhance the vegetation by nitrogen supply, wound curing, disease inhibition and enhanced development of inorganic components, thereby increasing plant production. The imperative classes of microbes in biofertilizers are N2-fixers, P-solubilizers and growth regulators or bio-control. Currently, a vast interest has risen in the production of biofertilizers. In the context of developing countries, the poor flora of the soil is anticipated to be one of the unfavourable aspects that effect the biomass yield due to the lack of nutrition and the escalating stress of diseases. The biofertilizers have the capability to increase the nutrient availability of a broad range of plants (Schütz et al., 2018).

The ever-growing concern on the ultimate effects of long-term applications of chemical fertilizers on soils and the environmental awareness necessitating the restrictions to reduce the total demand for fertilizers placed on the agricultural fields. Under this scenario, microbial formulations have gained a heavy momentum as an excellent choice to substitute the synthetic fertilizers. The escalating interest in the application of bio-fertilizers can be attributed to the exploitation of living bugs such as Rhizobium, Azotobacter, and Azospirillium. These formulations release growth factors, such as vitamins, microelements, bio-pigments, and hormones which boost the adequate growth of plants. Hence, these microbial associates can be utilized for a broad range of crop plants. Necessity of the employ of bio-fertilizers arises due to their sustainability, rapid degradation, no hazardous effects towards humans and the environment, potential role in uplifting natural crop capabilities and safeguard high sanitation and health issues. Bio-fertilizers have shown to be efficient in higher nutrient uptake and subsequently increasing the productivities of several crops. Many reviews have been performed that underscored infection processes, mechanisms, and bio-fertilization efficiency. However, now the efficacy and cutting-edge recognition of modern-day biofertilizers are critically reviewed.

Research and Development in Biofertilizers

India is the second most populous country in the world and 70% of the population still depends on agriculture for daily food. In recent years, there has been a substantial combination of chemical fertilizers and pesticides which has resulted in the dominant increase of agriculture production. The make use of chemical fertilizers has increased up to 186% from 1974 to 2004, with N, P, K, such as the most essential nutrients but induces some technical difficulties, economical uncertainties, soil spoilage hazards (Seenivasagan and Oluranti Babalola, 2021). The issue of pollution caused by the use of chemical fertilizers there may be degraded access to the atmosphere when precipitation is diluted into the underground geosphere with surface runoff, which can increase significant pollutants both from industrial establishments and vehicle discharges.

The soil may both directly and directly pollute water, plants, animals and humans. Now the structures of soils and agroecosystems have reduced their production capacity. The built up use of chemical fertilizers as an alternative can give excellent crop yields but improves the physical, biological quality of the soil and bio-decroys its fertility, offset using the harmful effect of biopesticides and chemical pesticides. The ensuing improved yield, environmental considerations and safety are considered necessary. Organic manure of biological beginning accords partial use to being rejected through including hazardous due to biopesticidal applications and excessive quantities of heavy metals.

The significant of biofertilizers to extend the yield of the soil has been the subject of considerable experience, virtually in the past 20 year. A reduction in agricultural yield is now faced up by farmers as a result of soil infertility, poor farming policies and environmental situations, but the attention to farming has become greater and greater in the past. The implementation of biofertilizers can produce the productivity of agriculture through using merely fertilizer and a ruminating year either directly application to seedlings, rooting stage application with soil or both deposition methods at the same time. Biofertilizers have been applied by farmers in recent years around the world in order to give intake to palm oil plantations into and around the natural conditions of the soil. At last, chemical fertilizer diversity can be wiped out from the time that the intended biofertilizers from the Biotechnology Research Center for useful industrial crops have been successfully marketed in 20 countries. Biofertilizer is an affordable

alternative to chemical fertilizer and does not contaminate the environment by atmospheric deposition, leaching or runoff. Biofertilizers are a prolongable long-term energy source save soil fertility. Generally, biofertilizer will be needed more for increasing productivity of the world's soil.

Biofertilizers are considered a sustainable solution to enhance agricultural productivity and crop yields, and have emerged as a hot topic in agriculture after the indiscriminate use of chemical fertilizers led to a variety of environmental issues. Several projects have been initiated worldwide to maximize research in biofertilizers. To improve the efficacy of biofertilizers and provide a comprehensive guideline to the scientific community, an incursion to various biofertilizer-based projects worldwide has been presented. The effectiveness of biofertilizers varies with different crops and soil types. Proper viability testing should be performed with specific crops before recommending them to farmers. Despite proving efficacy, the cost of biofertilizers is still a major constraint for formal sector adoption. High-tech laboratories have been set up to produce liquid biofertilizers to reduce the cost of the carrier solvent. Several projects have been initiated worldwide on biofertilizers with a focus on different crops using consortia technologies. Biofertilizers could enhance the effect of fertilizers up to 20% for different crops. A lab-to-land program regarding biofertilizers is of foremost importance to generate public awareness and boost adoption by farmers. Unless the recommendations are tailored to specific sites and crops, the impact of biofertilizers may not be so effective. When biofertilizers are employed with proper management practice in agriculture, they could add to the potential plant production and prevent unwarranted losses to the environment. Such projects encourage commercialization and utilize biofertilizers. Normally, the governmental and non-governmental sector invests in research via biofertilizers. Biofertilizer studies are multi-disciplinary, involving biotechnology, agriculture, bio-agronomy, and other sciences, all of which are equally important for successful outcomes. This text also provides details of biofertilizer-based consortia technology projects in different crop regions of the world to help in the efficacy of biofertilizers. Up to a 20% increase in fertilizer productivity has been observed for different crops by using biofertilizer technology. Major reports regarding these are compiled and presented to promote the rapid dissemination of information on the current status of world research and activities. To enhance the sustainable solution of agriculture, biofertilizers could play a role in various dimensions and developmental processes. To optimize the benefit of resources in an integrated plant nutrient management system, a variety of designed plans are being used. To improve specific microbial functions related to nutrient dynamics in soils, plant nutrient management should consider the use of microbial resources. These should be used as a tool to enhance land productivity and contain a controlled depletion release process of nutrients. Individualized land management needs should be prioritized through on-site demonstrations and tailored reports. Microbial inoculants used in agricultural inputs must have legislative clarity and, through the joint efforts of farmers, scientists, consultants, and decision-makers, be independent of climate variability and optimize nutrient use efficiency. Strategies for microbial efficacy and balanced mineral fertilization should meet the increasing global population demand. The stem-source activities of food crops can be optimized through specialized nutrient utilization to ensure sustainable crop productivity. This topic has garnered global attention. With the increasing global population, there is a higher demand for vegetation and soil health. Coordinated multi-disciplinary approaches have been promoted globally to apply effective vegetation and microbial technologies for environmental resource management. In the face of the growing demand for food production, new attention has been drawn to the grand concepts of fertilizers.

Impact on Soil Health

Global agricultural productivity speaks about food supply in the first instance. Nowadays, many farmers are using inorganic chemical fertilizers to increase crop yields. The increase in the use of inorganic chemical fertilizers is not only environmentally and economically difficult on farm sustainability but is also harmful to animal and human health. So organic farming, which avoids the utilization of chemical fertilizers, is the gathering mode through which stability can be achieved. Nevertheless, attention to going green has started to act by today's farming professionally.

It is important because it is a sustainable method of agriculture. The purpose of this study was to conduct experiments on a selected different set of biofertilizer seeds with various biofertilizers. For that, the morphological characteristics such as plant height, number of rows per ear, number of grains per row and 100 weight of grains yield ha-1 ton were analyzed in the experiment. Furthermore, the chemical characteristics such as content matter, content matter, content matter, content matter, nitrogen content matter, potassium content matter, content matter, and content matter yield t ha-1 were analyzed in the experiment. Finally, the physical characteristics such as grain yield production, field efficiency and the germination rate were analyzed in the experiment. Here in this study, the mutual probabilistic consumption of bio-fertilizer is opposite to the seed bed coating of corn in a plot of land according to rain-fed conditions.

The application of bio-fertilizers has brought a significant effect on the candidate in most physical, chemical and morphological perspectives. The relationship between soil water-retention properties and plant properties in different sites in Mediterranean conditions. Pathways of nitrate transport and the influence of initial soil moisture. Long-term effects on

cereal yields from no-tillage, stubble retention and nitrogen fertilizer. Long-term analyzation of chlorine retention and translocation during soil cultivation.

Impact on Crop Yield and Quality

The use of fertilizer and biofertilizer has long been done by farmer communities in Indonesia. Grouping of plant needs such as fertilizers, biofertilizer, moisteners, and pesticides are needed to achieve maximum productivity. Probligo provides comparison, selection, and purchase services for required needs quickly and clearly. This study was conducted to determine how much the use of biofertilizers has an impact on plant productivity. The method used is to log into the website "Probligo" and enter the desired plant needs in the menu after logging in, then based on the available choices (price, KG, type) suit what is needed by the user. This study used a questionnaire and a website simulating system "probligo" using biofertilizer variables. Communication with website operators is also included as a controlled variable. Data analysis in the form of percentage is done to find out the largest percentage of interest among farmers in the use of biofertilizers. As a result, it was found that the use of biofertilizers on plant productivity was 40%, which indicates that biofertilizers have now contributed greatly to the productivity of these Indonesian plants. Early growth is essential for plants, as it determines their capacity to absorb light and hence, assimilate carbon (Mendes et al., 2023).

The largest meta-analysis done to date to assess the effectiveness of agricultural bioeffectors under realistic field conditions was performed using a global network meta-analysis approach. The aim was to find most promising bioeffector strategies to reduce mineral N fertilizer (Nmin) input in crop production. The effect size of individual bioeffector (BE) products and BE types (microbial BEs (MBEs), non-microbial BEs (NMBEs)) on above-ground plant biomass was analyzed across field trails with BE application, and on RT-qPCR data on Rhizoctonia solani abundance in winter wheat roots (Natalie Herrmann et al., 2022). The results show that BEs can contribute to reduce Nmin input while maintaining crop productivity under the investigated field conditions. Composite products (NMBEs, MBEs, NMBEs & MBEs) with combinations of different MBEs and NMBEs and those with additives are most promising as they increased above-ground plant biomass significantly. UF (urea + formaldehyde) is identified as the most effective MBE combination strategy, significantly increasing biomass. To ensure effective BE action, farmers, consultants, and regional advisors must take into account that (i) effectiveness of BEs depends on the application time, (ii) effectiveness depends on the application mode, and (iii) effectiveness depends on the assessed crop's surrounding soil characteristics, with pH level being crucially important to consider.

Consumer Awareness and Education

It is difficult for consumers to measure or standardize the food items they take on a daily basis, and this leads to much greater sensitivity to the presence of "agrotoxic" residues. The hypotheses of the work is that as the largest consumers of vegetables, and mainly those that are domestically cultivated or originate in minor horticultural establishments, the rural-urban population of small cities have risky dietary behaviors. The objectives of the work are to carry out an analysis of the risk awareness of rural-urban population regarding "agrotoxic" residues and by pathogen management technology, and make a comparative analysis of risk awareness in order to verify if there are differences in the levels of knowledge, concerns, and attitudes regarding the perception of risk by "agrotoxic" residues and pathogen treatment on food by rural-urban populations. It is expected to obtain data that helps to design recommendations on public policies that incline the balance of knowledge in risk management (Carlos Lagler, 2017). The diagnosis made about the population even though it has statistically significant high buying rates for the consumption of leafy biennial vegetables. Considering the concentration of agrotoxic" residues above the tolerance limit, especially on of the leafy biennial vegetables tested, a significant part have their own cultivation on vacant lots and home gardens in the cities, keeping pests and diseases by external resolution. Since, the action of biotic-agents by pathogen herbs on food is not guaranteed to be controlled through the management technology available to the population. This indicates a need to improve the information campaign, preferentially suited to rural-urban society, on the risks and precautions for cultivations in receptive areas given the spatial range that their biotic agents develop.

Biofertilizer Production Technologies

Agriculture practices, globally, have largely been dependent on the usage of synthetic agrochemicals for the prompt and effective enhancement of agricultural productivity. However, it posed serious implications on soil fertility, environmental quality, and biotic stress management. As a more sustainable, eco-friendly approach, bio-based agriculture inputs are progressively replacing the traditional inputs (Khan et al., 2023). In particular, biofertilizers, composed of living organisms viz., bacteria, fungi, actinomycetes, cyanobacteria, and algae, or other biotic entities, are an important class of bio-based inputs. These potentiate the plant productivity by providing essential nutrients, enhancing tolerance to abiotic stress, and controlling diseases, pests, and weeds. The potential benefit of biofertilizers in agriculture is herein discussed, along with the challenges and means to overcome them.

The wide availability and sustainable benefits of biofertilizers suggests a significant role for them in improving crop performance. Their adoption helps in relieving the negative impact on soil health that is otherwise levied upon it by the often used high-dose

synthetic fertilizers. Therefore, the combination of biofertilizers with chemical fertilizers accord mutual benefits both to the soil-health and the improvement in crop production, and appears to be a promising approach to bolster agricultural sustainability. In order to promote the wide-scale acceptance of biofertilizers, providing farmers with requisite education and encouragement can make significant progress toward achieving food security in developing countries. Further, efforts by the biofertilizer industry to guarantee the particular number of viable microbial cells and/or carriers, along with essential information on usage, storage, and shelf life, would further expedite the uptake of these sustainable inputs.

Field Trials and Experimental Studies

Due to the potentially global reliability and specific application of microbial inoculants, scientists are highly confident that the results of a field trial on cotton, wheat, and chickpea in central Pantnagar, northern India. In the hills of the Himalayas on some moderately alkaline soil, the chickpea yield increase in combination with rock phosphate (RP) and a lignite peat based PSB peat inoculation was 66.7% (Schütz, 2017). Along with the lint yield of cotton, the 27.3% of inoculated biofertilizer was doubled on saline sodic soils with low water input. There, the napier- and berseem fodder yield with a lignite based PSB and a wood coal based KSB inoculation increased up to 55.4%. Biofertilizers are nationwide to three world widely used and depended on. Rhizobium sp. induced symbiosis in legumes. Azotobacter sp., Azosprillium sp. and blue-green algae fix atmospheric nitrogen. A big issue is still the quantity of the fixed nitrogen in biofertilization. As the availability of massive nitrogen fertilizers got too easy, the biofertilizer and sustainable crop rotation tradition disappeared in many cultivation situations. However, the fixation of any amount of nanogram to milligram nitrogen per plant per day is possible without any nutrition. The fertility and the sustainable multi-use providence problem is more emphasized by biofertilization with natural enemies affecting and inflicting pests and diseases. However, after more than 20,000 careful performed trials with microbial antagonists (predatory fungi, yeasts, bacteria, viruses, nematodes, insects) it appears that those biofertilizers are about another one of currently useful agricultural chemicals but the danger of the appearance in resistances is dramatically less. A lost litigation helped the farmers to remember it. The commercial success of bacterial seed files shows the liability of the idea of a mass application of natural enemies and looks like the failure of about 10% of the mushroom myco-paras are compounded by friendly fungi. Six HAICA, ISCI and IBATF developed in about 35 years up to 41 different carriers for liquid and solid formulated biofertilizers and biopesticides in 142 different patent claims.

Role of Biofertilizers in Climate Change Mitigation

Biofertilizers are increasingly used in agriculture as sustainable solutions for various aspects. This has been recognized in the scientific community, which has extensively investigated and published on the efficacy and future of biofertilizers. One of the crucial factors in the onset of life on Earth is soil fertility. The only way to maintain the appropriate and correct fertility is to use biofertilizers. These are mixtures of bacteria, blue-green algae, fungi, etc., which are able to fix nitrogen, solubilize phosphates and convert insoluble into soluble forms of nutrients. The use of biofertilizers is especially important given trends where the use of traditional forms of N, P and K fertilizers tends to stabilize or even decrease, while the demand for food increases progressively all over the world. In addition to the bacteriological substances, there are natural or biologically active substances. Biofertilizers are one of the ways to reduce the use of chemicals. Worldwide, the application of biological products has increased by 19.6% compared to the previous year.

The development of agriculture in the world creates a rapidly changing environment, and the entry of climate change into the everyday life of farmers is becoming more noticeable. The application of the crop rotation system has become more stringent, and the predominant monoculture cultivation method has become limited because of the reduction of crop yields through their exhaustion, soil diseases and pest incidence. The presence of resistant bacteria in certain soils and plants is evident. As early as the 19th century, it was found that in plants that grow in one soil, microorganisms can hardly grow on other soils, pointing to the existence of some type of specificity of soil on bacteria found in plants. A flourishing root with well-developed absorbent system in plants inoculated with rhizosphere bacteria is found. Improved seed germination is observed after seed treatment with the appropriate bacterial strain, bio-fertilizer of the genus Rhizobium has a positive effect on plant cultivation by increasing the yield by 15-20%.

Integration with Other Sustainable Practices

Biofertilizers are the sustainable alternative for overcoming the limitations of chemical fertilizers. The consumption of biofertilizers ensures the aeration of soil to plant roots. They are made up of living microorganisms which are obtained from the bioconversion of raw materials, crop residues, organic waste substances, etc. When applied to soil rhizosphere helps in colonizing the roots and forms a strong relationship with them by improving the absorption of essential elements and compounds. They help in maintaining the natural status of ecological balance. They prevent the disturbances to the soil fertility and pinching of underground water resources. In addition they improve the other environment conditions necessary for the healthy growth of crop plant. They play an important role in the mineralization of various organic substances to transformed into more stabilized and

usable form of plant nutrients for enhancing crop yield under diversified agro-ecological conditions. Bioeffectors are produced by MW radiation and play an important role in enhancing the plant growth, crop yield, and other basic elements. They are produced from biofertilizers by legal process, stored under recommended conditions. ICSOC supports the formation of LACTORT (Large Cross-Organization Team) proposals which will involve groups of researchers from at least two organizations in developing a single proposal with a focus on large-scale computing. There has been increasing emphasis in the scientific community to exploit and encourage the bio-disciplinary research. Bio-fertilizers and Bio- effectors are playing an important role in enhancing the crop productivity and promoting the sustainable use of natural resources. Agriculture is an important sector for improving the economy of any country. The four main components for increasing the agricultural production are 1) soil 2) variety 3) water and 4) fertilizer. Plausible exchange capacity and nutrient status of soil helped the farmers to check the deficient nutrients of plant by applying adequate chemical fertilizers. At the early stage, the over usage of inorganic chemical fertilizers increased the crop yield leading to the green revolution. Intensive cropping system, imbalance nutrients and vast use of harmful pesticides eventually results in the loss of soil fertility, water quality and decreased crop yield. Moreover, free excess chemicals from fertilizer contaminated the underground water resources. From the above facts, farmers have been attracted to biofertilizers for healthy growth and high yield of crops. (Bargaz et al., 2018)

Limitations and Risks of Biofertilizers

The use of biofertilizers, deposited biological agents in an appropriate carrier, is now considered an important constituent for evolving a sustainable agriculture. Biofertilizers comprise a group of inoculums of live or latent cells of efficient strains of nitrogen fixers, phosphate solubilizers, and micronutrients enrichers, which are expected to have favorable effects on the uptake of nutrients, plant growth, and productivity. Many of the present-day biofertilizers are based on Azospirillum, Azotobacter, Rhizobium, and phosphate solubilizing bacteria. Use of formulated biofertilizers may result in the gradual decrease in the dependency on chemical fertilizers, and in the regions where the useful microbes do not exist, will serve as an indigenous source of N, P, K, and other essential nutrients for valuable crop production. Conversely, use of poorly formulated biofertilizers may lead to poor nodulation of legumes, no growth promotion, and plant yield. A number of studies have demonstrated that bioinoculums cannot colonize due to lack of competitive means and multiplication over the native microbes in the existed conducive environment. The frequent complaints have been receiving on the powder formulations that adherence strength to the carrier and pug durability to protect the stress for an extended period in the open atmosphere are not up to the mark. Therefore, the development of granular biofertilizers has been envisaged and a few researchers have made attempts to address the formulations of biofertilizer granules of different bioinoculums, and among the biofertilizers the first and foremost place goes to rhizobial biofertilizers for their distinctiveness (Khan et al., 2023). Understanding this several attempts have been made for know-how of rhizobial biofertilizer granules. Water agar gel entrapment technique is utilized for the preparation of biofertilizer granules. Pellets are subjected to quality control test like, colony forming unit, seed compatibility test, stress tolerance assay, shelf life test, stress test in the open atmosphere, etc.

CONCLUSION

Biofertilizers comprise valuable nutrient resources for plants and possess engineered strains or microbial communities that can enhance soil nutrients' biologically available forms for better uptake by plants (Bargaz et al., 2018). This chapter aims to present the different roles microorganisms have in soil and explains the potential benefits and applications across the agriculture sector. Optimization methods for the production of microbial formulations for biofertilizers and how an enriched consortium can act as improved biofertilizer with the implementation of starch encapsulation are detailed. It is critically important to develop efficient strategies to enhance the microbial functions related to nutrient dynamics in soils. This assessment helps on different levels – from basic understanding of the mechanisms currently limiting soil-plant processes to the development of targeted products. The use of ecosystem models that explicitly represent important criteria for soil-plant health might have an important role to play in this regard. Promotions involving in-field demonstrations that collect data on the proposed benefits adapted to local conditions could lead to tailored reports that encourage farmers to pursue recommended practices. Therefore, focusing on the importance of collaborative research with key actors in the agricultural field to educate farmers and increase their understanding of these tools is advised. The success of such a sophisticated approach of agro-inputs based on microbial inoculants requires regulatory clarity as well as cooperation between farmers and the scientific community, extension advisers, and policymakers. Bio-inoculant-based integrated plant nutrient management systems would play a crucial role in enhancing agricultural productivity by ensuring successful symbiosis of a variety of economically important crops, providing ecosystem services such as the biological fixation of atmospheric nitrogen and enhancing other agronomic character development.

Agricultural productivity worldwide has become far from optimal, which in turn has brought an increasing concern to intensify demands to curb hunger, enhance food security, and elevate the economy. It is well understood that earth’s food availability 2050 shall require raising current levels of production despite being achieved on already habitable land, making utilization of

biofertilizers, macro-nutrients and micro-nutrients all the more essential (Seenivasagan and Oluranti Babalola, 2021). In contrast to mineral fertilizers, biofertilizers bode well as alternatives as they are host-specific, more eco-friendly and easier to apply. As a consequence of the long-term application of mineral fertilizers, 50–70% of beneficial microbial species that existed in the rhizosphere of soil/plants are lost. Therefore, it is necessary to take into account the application of biofertilizers in agriculture, since biofertilizers have the ability to regenerate the number of beneficial microorganisms. Efforts need to be developed to improve the application of biofertilizers, so that crop productivity does not decrease and does not pollute the environment as occurs with mineral fertilizers.

REFERENCES

1. Bargaz, A.; Lyamlouli, K.; Chtouki, M.; Zeroual, Y. et al. 2018. Soil Microbial Resources for Improving Fertilizers Efficiency in an Integrated Plant Nutrient Management System.
2. Berquó Marks, B.; Megías, M.; Antonio Nogueira, M.; Hungria, M. 2013. Biotechnological potential of rhizobial metabolites to enhance the performance of Bradyrhizobium spp. and Azospirillum brasilense inoculants with soybean and maize. ncbi.nlm.nih.gov
3. Carlos Lagler, J. 2017. Bioinsumos: distintas percepciones haciendo foco en la fertilización biológica.
4. Chaudhary, P.; Singh, S.; Chaudhary, A.; Sharma, A. et al. 2022. Overview of biofertilizers in crop production and stress management for sustainable agriculture. ncbi.nlm.nih.gov
5. Khan, A.; Veer Singh, A.; Shanker Gautam, S.; Agarwal, A. et al. 2023. Microbial bioformulation: a microbial assisted biostimulating fertilization technique for sustainable agriculture. ncbi.nlm.nih.gov
6. Kuila, D.; Ghosh, S. 2022. Aspects, problems and utilization of Arbuscular Mycorrhizal (AM) application as bio-fertilizer in sustainable agriculture. ncbi.nlm.nih.gov
7. Malusá, E.; Vassilev, N. 2014. A contribution to set a legal framework for biofertilisers. ncbi.nlm.nih.gov
8. Mendes, R.; de Barros, I.; Antônio D'Andréa, P.; Stefânia Cruanhes D'Andréa-Kühl, M. et al. 2023. A multi-attribute approach to evaluating the impact of biostimulants on crop performance. ncbi.nlm.nih.gov
9. Natalie Herrmann, M.; Wang, Y.; Hartung, J.; Hartmann, T. et al. 2022. A Global Network Meta-Analysis of the Promotion of Crop Growth, Yield, and Quality by Bioeffectors. ncbi.nlm.nih.gov
10. Schütz, L. 2017. Microbial inoculants: global reliability and specific application in a mixed cropping system on marginal land in India.
11. Seenivasagan, R.; Oluranti Babalola, O. 2021. Utilization of Microbial Consortia as Biofertilizers and Biopesticides for the Production of Feasible Agricultural Product. ncbi.nlm.nih.gov
12. Soumare, A.; G. Diedhiou, A.; Thuita, M.; Hafidi, M. et al. 2020. Exploiting Biological Nitrogen Fixation: A Route Towards a Sustainable Agriculture. ncbi.nlm.nih.gov
13. Vassileva, M.; de Oliveira Mendes, G.; Agostino Deriu, M.; di Benedetto, G. et al. 2022. Fungi, P-Solubilization, and Plant Nutrition. ncbi.nlm.nih.gov
14. Ye, L.; Zhao, X.; Bao, E.; Li, J. et al. 2020. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. ncbi.nlm.nih.gov