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A Review of Biological Fertilizers Current use, New Approaches, and Future Perspectives

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Abstract: *The application of beneficial, plant-associated microorganisms is a sustainable approach to improving crop performance in agriculture. However, even though the inoculation of plants with these microorganisms is a well-known practice, the choice of the technology and carrier for inocula production, and the formulation of inocula with a reliable and consistent effect under field conditions is still a bottleneck for their wider use.On the other hand, microbial inoculants are often sensitive to prolonged periods of storage and harmful environmental factors, which negatively impact their viability and consequently limit effectiveness in the field. In the respect, in order to develop an optimal product, and to increase production and hence the commercialization of microbial fertilizers, desired quality and stability should be achieved..Developing advanced technologies such as fermentation, encapsulation, co-encapsulation, coating, lyophilization and inoculation are the leading approaches to improve the performance of biofertilizers use in agriculture and to reduce production costs and to solve environmental problems. The effectiveness of these products is largely dependent on the use of local strains, coating materials, good protectant, stimulants and enriching compounds and oil-in-water mulsions, as well as on the improvement of biofilmed-based, polymer-based and nanoparticle-based carriers.The development of new technological multi-group bio-organo-chemical fertilizers by combining three important chemical, organic and microbes sources in one formula or the enrichment of chemicals with organic and microbes will be a very high hope in the future for more economic and environmentally friendly agriculture. As a result, it can be said that using the most active components of chemical, organic and biological resources to produce a multi-group fertilizer is now the most promising solution. This review focuses on new developments in inoculants formulations to improve the performance of biological fertilizers in agriculture.*

Keywords: *Inoculants formulations, Microbial fertilizers. Encapsulation, Fermentation, Coating, Lyophilization, Bio-organo-chemical fertilizers*

1. INTRODUCTION

The increasing use of fertilizers and highly productive systems have also created environmental problems such as deterioration of soil quality, surface water, and groundwater, as well as air pollution, reduced biodiversity, and suppressed ecosystem function [1,2]. It also leads to the exploitation of limited phosphorus resources, nitrate pollution of groundwater and eutrophication of aquatic ecosystems [3]. The growing need for environmentally friendly agricultural practices encourages the use of fertilizers based on beneficial bacteria that promote plant growth. There were increasing needs to use microorganisms for safe crop production for consumers and to prevent environment pollution, sustainable agriculture and agricultural resources as well. These kind of beneficial microorganisms are freely living and mostly known as a biological control or biofertilizer agents in agriculture throughout the world. Soil bacteria providing benefits to plants are defined as plant growth-promoting rhizobacteria (PGPR). According to a general definition, bio-fertilizers are substances containing one or more beneficial live and latent cells of microorganisms or their metabolites which, when applied to seeds, plant surfaces or soil roots of seedlings, colonize the rhizosphere or the interior of the plant, and promote plant growth by increasing the supply or availability of primary nutrients [4-6]. Biofertilizers are the preparations containing cells of microorganisms which may be nitrogen fixers, phosphorus solubilizers, phosphate mobilizers, potassium solubilizing and mobilizing, sulphur oxidizers or organic matter decomposers [7-8].Biofertilizers constitute active products or microbial inoculants of bacteria, algae and fungi, either combined or separate, which enhance the nutrient's availability in plants thus increasing crops yield and productivity[9]. Biofertilizers may be important component of the integrated nutrient management eco-and humanfriendly; a cost-effective and renewable resource management strategy. Bio-fertilizer is the need of modern agriculture since demand for safe and residue free food is increasing.

Nowadays, enhancement and maintenance of soil fertility through microorganisms has become a common practice [10-11], and plant-beneficial microorganism research has led to the development of a variety of bio-fertilizers that can meet the nutritional requirements of crops [12-16]. The production of microbial fertilizers does not depend solely on the detailed knowledge of the physiology of plants and microorganisms, but also on the large number of technological challenges such as the fermentation process, type of formulations, the population of microorganisms and their system of release. Thus, the development of a stable bioformulation is possible through combining knowledge from microbial and technical aspects. Additional research is necessary in order to enhance the production process and, what's most important, to improve the products reliability and practical usage. One thing is certain: since they are ecologically acceptable, biofertilizers will have a very significant function in modern agriculture [17].In order to revitalize the health of the soil and increase productivity, enriching the soil using microorganisms is indispensable for sustainable agriculture.

In recent years, intense studies on the interactions between plants, soil and different microorganisms provide an understanding of their interrelationships and ways to use them in agriculture. However, the choice of the technology and carrier for inoculant production, and the formulation of inoculate with a reliable and consistent effect under field conditions are considered as limiting factors for their wider use [18]. On the other hand, although fertilizer use efficiency (FUE) has been the focus of agriculture cultivation practices, the current fertilizer technology has been insufficient in this regard. On the other hand, although microorganisms are of great importance for the effectiveness of the product, mass multiplication and formulation process have been studied to a much smaller extent [19]. In summary, the use of microorganisms as biological fertilizers in agriculture, the characteristics of liquid, organic, inorganic, polymeric and encapsulated formulations, especially mass culture production, inoculation techniques, bulk sterilization, seed coating, and carriers are important [18,20]. In this brief review, current technological status, current applications and future uses, and new approaches of bacterial inoculations and biofertilizers in agriculture were evaluated.

2. IMPREGNATED FERTILIZERS AND FERTILIZER USE EFFICIENCY

The use of mineral fertilizers is inevitable, but the yield of crops in response to mineral fertilizer application depends upon the fertilizer use efficiency (FUE) of crops. On the other hand, a major portion of the applied mineral fertilizers are lost by various environmental and soil factors and processes such as leaching, fixation, erosion, runoff, volatilization, denitrification and precipitation.This not only causes economic losses but also leads in serious water and environmental quality problems. Especially the use efficiency of nitrogenous and phosphatic fertilizers is very poor. An important and highly valuable approach to improve the effectiveness of mineral fertilizers is the use of plant growth-promoting bacteria because of their multiple benefits and positive impacts on plant growth and environment [21].

In recent years, bacterial-impregnated fertilizer has been developed as an innovative approach and new concept to increase nutrient use efficiency of plants. Although there is very little information about its use, among the various approaches used to enhance fertilizer use efficiency, impregnation of mineral fertilizers with plant growth-promoting bacteria (PGPB) is an absolutely new concept and innovative strategy for improving growth, yield and nutrient use efficiency of plants. Bacterial-impregnated fertilizer refers to a coating with different types of material and PGPB of chemical fertilizers with the purpose of increasing the number of useful microflora in the rhizosphere and enhancing the efficiency of applied fertilizers[21]. Impregnated fertilizers, ie chemical fertilizers coated with promising microbial strains, are potentially seen as the beginning of a new understanding of natural / synthetic nutritional sources that lead to a better understanding of the microbial-enhanced fertilizer use efficiency [6].

3. MIXED INOCULANT

One important approach is to use mixtures instead of single microorganisms. Indeed, the presence of each one of the microbial components in a mixed inoculant is an important approach in increasing the potential in the field conditions due to the different mechanisms of action of the various microorganisms present[19]. Use of mixtures of microbial inoculants and combination of nitrogen fixing, phosphorus dissolving and potassium mobilizing organisms is an important alternative[22]. Research has shown that the greatest benefit for the plant is achieved by using mixed inoculants[23-25].These inoculum combinations may be of greatest value if various microorganisms with different proven benefits to the crop plants can be integrated[26]. The integration of different microbial capabilities into combined biofertilizers with many potential yield-promoting effects is a desirable and innovative approach. In order to promote plant growth and soil health, it is important to investigate effective strains of beneficial microorganisms for crops and integrate their use with other inputs. Usually, balanced nutrition and better absorption of nitrogen, phosphorus and mineral nutrients, and thus in terms of plant Growth and yield Co-inoculation is more appropriate. Mixtures of microorganisms allow a broad spectrum of effects, enhanced efficacy, reliability and a combination of various features.It is clear that the co-inoculation of indigenous bacteria leads to a more balanced nutrition and growth in plants compared to single inoculation.

4. INOCULANT FORMULATIONS

Although bio-fertilizer has been well established in the field of agricultural applications for many years, conventionally used solid and liquid formulations contain various problems associated with low viability of microorganisms during storage and application. The formulation is a vital characteristic for bioinoculant development of an effective microbial strain and usually consists of the microorganism and a suitable carrier together with additives. Numerous parameters affect the viability of microbial cells, drying procedures are often among the most critical, so the availability of protective formulations is very important [3].For the reason, bacteria require suitable, protective formulations to increase their effectiveness in the target site and to facilitate the practical use by farmers. The performance of an inoculant is often the most common barrier for commercialization of inoculants. The lack of adequate formulations and low inoculant quality are the major obstacles to the successful, widespread use of microbial inoculants. Because a large number of living cells must be given to the plant for the desired effect. Moreover, biotic interactions with the native microflora and microfauna present a major challenge to any applied strains. In particular, a formulation must be stable during production, distribution, storage and transport to the farmer. First, the longer viability of applied microbial fertilizers depends on the development of formulations with sustained carriers [17].The local production and distribution of selected local PGPB isolates might significantly solve some of the current problems the field performance of inoculants.

Specific formulations should be created for use in suboptimal farming conditions such as saline soils, acid soils, droughts, high temperatures, marginally eroded soils or soils with limited access for maintenance of plant cultivation. In these conditions, the use of local PGPB strains that are resistant or tolerant to the physical or chemical stress might be an important approach. Formulations of inoculants should be based on the basic principles of microbiology and material science. The integration of these areas creates useful products that are, and will be, an important input in sustainable agriculture and environmental solutions.Since the formulation is a challenging and often limiting success in the successful commercialization of new bio-inoculants, the search for advanced formulations continues. The choice of the formulation technology depends on the application technique, available equipment, farmer's convenience, plant inherent characteristics and developmental stage, cost, site of action and colonization pathway of the inoculant[3,18, 20].

5. CHARACTERISTICS OF CARRIER FOR INOCULANTS

First, the longer viability of applied microbial fertilizers depends on the development of formulations with sustained carriers. The choice of the technology for inoculum production and of the carrier for the formulation is key to their successful application [18]. Although raw material of the carrier and the type of formulation vary greatly, the nature of the final inoculant is liquid, slurry, granular and powder [20], and applied to soil, compost, seed, seedling and plant leaves. Carrier should be cheap, abundant in nature, sterile or cheaply sterilized, as chemically and physically uniform as possible, high water-holding capacity, and suitable for as many bacterial species or strains as possible.

The integration of microorganisms with the developed coating technologies, as a promising approach, will reduce the volume and costs of applied fertilizers and provide more profit to farmers. If microbes combine with the latest coating technology as consortium packages, it will be a promising technology for sustainable agriculture. In addition, the most suitable convenient and economical carrier and coating material are inseparable matters in today's and future bio-organic chemical fertilizer research. A preparation to preserve organisms, to deliver them to the target regions, to improve their biological activity of a consortium of microorganisms provided with a suitable medium, to keep up their viability for certain period will help in enhancing the biological activity on the target site [27]. Another process for the storage and application of bacterial bio products uses water-in-oil emulsions, which can be applied to the crops through irrigation systems [28]. Carrier-based bio-fertilizers have already proven to be the best on agricultural inputs and have shown enormous impact on worldwide agricultural productivity in the last two decades.

In bacterial formulations, talc, vermiculite, perlite, bentonite, zeolite, montmorillonites, saponites, mica, coal, inorganic soil, diatomaceous earth, lignite and derivatives, filter mud, sawdust, rice and wheat bran, soybean meal, rice husk, poultry manure and banana waste, composts, tea waste compost, vegetable and mineral oils, sterilized oxalic acid, polymers, polyacrylamide, carrageenan, alginate, alginate–starch, alginate–humic acid, alginate–perlite dry granule, cellulose gels, kaolin, alginate–kaolin, silicates, rock phosphate pellets, and powder formulations are used as suitable carriers, but the most practical carriers used in commercial products worldwide are peats, liquids and clays [20, 27, 29-31]. On the other hand, powders or granules may contain plant growth media or matrices such as lays, clays, kaolinic clay, montmorillonites, saponites, mica, ground grains, pulses flour, grain bran, wood pulp, and lignin, synthetic silicates, polysaccharides (gums, starches, seaweed extracts, alginates, plant extracts, microbial gums),and derivatives of polysaccharides, proteins, such as gelatin, casein, and synthetic polymers, such as polyvinyl alcohols, polyvinyl pyrrolidone, polyacrylates [32-33]. For solid formulations there is a requirement of lignite, bentonite, charcoal and peat of desired quality in powder form. Desired type of application are liquid, powder, granulated or as a seed coating.In general, solid powders and granules are applied as seed coatings or soil amendments [20], while powder and liquid are mostly applied to the seeds [32].

6. LIQUID FORMULATIONS AND CARRIER-BASED BIOFERTILIZER

The use of bio fertilizers has emerged as a technological alternative and developing a suitable liquid fermentation system is the basis of success. Microbial products can be solid or liquid in form. Liquid based biofertilizer are believed to be the best alternative for the conventional carrier based biofertilizers in the modern agriculture.Liquid formulations use liquid materials as carrier, which is usually water, oil or some solvents in form of suspension, concentrates or emulsions. Liquid formulations include suspensions, concentrates, and oil based products, such as emulsions [32]. Liquid inoculants can be based on broth cultures, mineral or organic oils, or on oil-in-water suspensions. On the other hand, liquid formulations containing oil or water-based suspensions of cell concentrates, emulsions or slurries comprising solid particles have been developed[18].Water-in-oil emulsions appear to be a good method for storing and delivering microorganisms through liquid formulations [28]. On the other hand, water-in-oil water emulsions which can be added to substances that can increase cell viability, are particularly beneficial when used for organisms that are sensitive to desiccation or for horticultural crops where irrigation systems.Liquids are suitable for a wide range of application technologies and and often contain protectants, nutritive substances, stabilizers or adhesives [20].

The liquid formulation needs water and certain chemicals as mannitol, sucrose and chemical nutrients as growth medium. The liquid- biofertilizer formulations will be most suitable and popular. On the other hand, liquid bio-fertilizer formulation is a promising and updated technology of traditional carrier-based production technology, which ensures the long-term survival of the organism by providing the appropriate environment sufficient for the entire crop cycle. Development of suitable carriers, refinement in formulation technology and integration of automation in product handling and packaging are the requirement of technology [34].Liquid bio-fertilizers, which are easy to apply and alternative to carrier-based biofertilizers, help increase plant yield, regain soil health and help produce sustainable food. Liquid formulations are typically water-based, oil-based on polymer products[17].Liquid biofertilizers, which are an alternative solution to carrier based biofertilizers, contain not only the desired microorganism and their nutrients, but also special cell protectants or substances that encourage longer shelf life and tolerance to adverse conditions. Usually, the selection of the carrier material is made on the basis of the longer viability of the bacteria. On the other hand, a good carrier must have features such as good moisture absorption capacity, near-sterile or easy to sterilize by autoclaving or by other methods, allow the addition of bacterial nutrients, easy to process and free of lump-forming materials, and sufficient low cost and availability. However, in some cases, bacterial survival is inferior in the liquid type of inoculants as bacteria lack carrier protection[32,35].

7. CURRENT STATUS OF AVAILABLE TECHNOLOGY

Some authors suggest the development of fertilizers that will be enriched with different metabolites along with microorganisms according to the needs of the plants [36], whereas others have suggested the development of inert materials can increase product stability and extend its life and effectiveness in the field itself [37]. The selection of inert materials that can increase the product stability, extend its shelf life and its effectiveness in the field; and the development of fertilizers enriched with different metabolites along with the microorganisms according to the plant needs are seen as an important step. On the other hand, bacterially impregnated fertilizers are important in increasing the number of beneficial microorganisms and fertilizer efficiency in the rhizosphere. In addition, the use of bacteria-inoculated compost or humic acid is more effective. On the other hand, the use of germ-enriched compost for nutrient mobilization is becoming popular as a new system [38]. Recently, the use of biofilms has also been proposed as possible means to produce effective plant inocula[39].

Another approach to reduce production costs and to increase the nutrient use efficiency is to use agroindustrial residues enriched with rock phosphates and microorganisms [18]. In this way, during composting or fermentation, organic acid-producing microorganisms increase the solubility of phosphates, making them more usable in plants. Another interesting new technology is proposing the exploitation of the natural production of bacterial biofilms as a possible carrier[40]. The designing of biofilmed-based carriers, natural carriers, and polymer-based carriers or of encapsulation techniques which allow the production of macrocapsules consisting of a core and an envelope could facilitate the development of biofertilizers formed of microbial consortia[31,39]. The use of nanoformulations may enhance the stability of biofertilizers. Improvements in the production process of microbial inocula, the development of new carriers based on nanoparticles, optimization of application devices and of the time of application for polyannual crops are increasingly important issues. On the other hand, another method is the use of silica gel for encapsulation of microorganisms. Indeed, it has been reported that bacteria can be attached to the alginate micro-grains coated with silica membranes or to the macro cavities formed in the silica matrix[41]. Furthermore, the use of nanoformulations may enhance the stability of biofertilizers and provide new avenues for the development of carrier-based microbial inocula[42]. On the other hand, in recent years, engineering and economic models have been developed for the conceptual design of a liquid bio-fertilizer production plant, which will assist researchers and engineers in analyzing, optimizing, developing or evaluating new bio-fertilizer production processes and technologies[9].

8. THE DRYİNG PROCESS, ENCAPSULATION AND LYOPHILISATION TECHNIQUE

Encapsulation technologies, which have been proposed as a technique to ensure controlled release into soil [43], have advanced greatly and have been employed to produce microbial inoculants varying in morphology and composition [3,32,44].Microencapsulation is an advanced technology based on the principle of making a protective shell or capsule around the active ingredient or cells or tissue, capable of controlled microbial release, which increases shelf life and application efficiency[32]. Encapsulation methods involve covering and protecting the microorganisms. Immobilization of microorganisms increases shelf life and field efficiency. The basic principle of rhizobacteria bioencapsulation is to protect the bacteria introduced into the soil and to provide a gradual and prolonged release[45]. Microencapsulated formulations for soil and seed application are superior to other formulations as it enhances the survival of bacteria, and controlled release with prolonged effect [32].The dried capsules can be stored at room temperature for a long time, protecting of microorganisms in the soil against various stresses, providing a convenient environment for bacteria and reducing the risk of low survival. On the other hand, these inoculants can be improved by incorporating essential nutrients for bacterial growth, transforming the capsules in bioreactors, which are capable of increasing the number of encapsulated bacteria inoculated into the soil [29]. Microencapsulation can noticeably improve the viability of bacteria due to its protective effects against harmful environmental factors. In microencapsulated beads, cells are highly concentrated and can be stored in a limited space, transported easily, and diluted many times during applications [32]. It can be applied easily on seeds or soil-like liquid formulations after the required dilution.

In recent years, encapsulation of microorganisms in a polymeric matrix or co-immobilization is an issue that is under development in the field of agricultural and environmental bacterial inoculation technology. In this respect, many different and efficient encapsulation techniques were developed for that purposes[29]. The immobilized microbial cells are easy to produce, store and handle during industrial processes, and the main purpose of encapsulated formulations is to maintain the entrapped cells in an active form, at high concentrations, for as long as possible [20]. For example, the technology of macro and micro alginate particles has been used to encapsulate many PGPR. It has been reported that freeze-dried bacteria encapsulated in dry alginate beads could overcome some of the problems of dry and liquid inoculants[43].This is due to the fact that the encapsulated bacteria is dry, simple to use, uniform, biodegradable by soil microorganisms, contains a large uniform bacterial population and provides for the slow release of the bacteria for long periods. In general, the bacteria are mixed with the kaolin, then mixed with alginate and formed into beads, and lyophilized. The technique of enriching alginate particles with humic acid is also remarkable because of the dual benefits of humic acid to microbes and plants. Physical, chemical and physicochemical processes are used to encapsulate bacterial cells and new techniques of encapsulation continue to emerge for developing bacterial formulations and processes.Indeed, encapsulated microorganisms have much more efficiency than the conventional powder and liquid formulation[32]. Natural and synthetic polymers, alginate, carrageenan, agar-agar, and agarose, polyacrylamides, polystyrene, and polyurethane, gums and proteins, carbohydrates, starches and products, humic acid, skim milk, clay and sodium alginate are the most commonly used products for the bioencapsulation of microorganisms.

The main disadvantages of microencapsulation technology are the necessity of special equipment, the desired processes such as spray drying, several sequential steps are needed for proper encapsulation, the length of the encapsulation time and the higher cost of the material used for encapsulation. On the other hand, although the production cost is high, these formulations are recommended due to their higher performance during storage and applications [32].In the future, effective micro-encapsulated formulations are expected to capture the agricultural production market and better protect the environment.

Drying of microorganisms has been recognized as an efficient way of long-term preserving and the cost of storage and distribution of dried products is low and less prone to contamination. The most common microorganism drying methods are freeze-drying (lyophilization), vacuum-drying, spray-drying, fluidized bed-drying, and air-drying [3].Although lyophilization is one of the most commonly used methods for the formulation of laboratory-scale bacteria, the high costs and limited volume of this batch-type operation is disadvantageous[46].

Bacteria can also be stored by lyophilisation to achieve high survival rates, and lyophilized microbial cultures can be incorporated into a solid carrier or used directly [47]. Pure lyophilized cultures may be an option and can be used directly or in combination with a solid carrier [18]. However, carbon sources or stimulatory compounds, and protectant such as mannitol or microcrystalline cellulose must be added in the process. Also glucose, sucrose, maltose, treehouse, molasses, and glycerolare some of the nutrients and cell protectants frequently used[48].

9. BIO-ENRICHMENT OF CHEMICAL FERTILIZER

An important approach today is the incorporation of microbes, or microbial compositions into fertilizer composition. The decontaminated manure and humic acid are mixed as dry ingredients with $Ca(H_2PO_4)_2$, KCl, and Urea-like materials in an agglomerator, then sprayed with bacterial suspension in the pelletizer and converted into prills in a revolving drying tunnel. In another aspect, manure and bacteria in combination with a humic acid derivative and, optionally, one or more of N, P, K compounds. More organic matter means also more nourishment for bacteria, and idea of compiling more bacterial properties and a wide range of microbial consortium packages in one product is now an undeniable, as a support for agriculture in terms of plant nutrition and conservation.

Chemical fertilizer enriched with organic and biological resources is a subject whose future is bright and urgency is inevitable. In this approach, a fertilizer product is desirable, economically feasible, environmentally reliable, and with increased use efficiency. Using the most active ingredients of chemical, organic and biological resources to produce a multi-group fertilizer is considered to be the most promising solution nowadays. Indeed, bio-organochemical fertilizers can be developed by understanding the characteristics of each fertilizer and the essence of the approach is to combine them without reducing their advantages. While the formulation is a key factor in the success of microbial inoculants, but can be one of the best management practices when applied with compost and urea supplement. The combination of the microbial carrier system requires suitable binding or coating agents for the attachment of dried microorganisms to solid particles. Another approach is by spraying the microorganism in the liquid phase at the amount of 10^6-10^{11}cfu/g of carrier while chemical fertilizer is mixing. This approach can improve plant productivity and protect the health of the soil compared to the use of chemical fertilizers alone.

10. BIO-ORGANO-CHEMICAL FERTILIZER

The combination of three important sources of chemicals, organics and microbes in one formula will be a very high hope in the future for sustainable agriculture [27].It is emphasized that the integration of microbial fertilizers with organic fertilizers and chemical fertilizers is the most suitable method for optimum economical yield and soil fertility [49]. The development of integrated use of organic manures and biofertilizers with optimal levels of NPK fertilizer to suit different farming systems improve the nutrient status, soil health, and crop yield.

The combination of three important sources of chemicals, organics and microbes in one formula or the enrichment of chemicals with organic and microbes will be a very high hope in the future for sustainable agriculture [27]. The yield of crops in response to mineral fertilizer application depends upon the fertilizer use efficiency of crops. On the other hand, fertilizer use efficiency of agricultural crops is generally very low due to various environmental, climate and soil factors or processes[50]. A significant portion of the mineral fertilizers are lost through a series of processes including fixation, leaching, runoff, erosion, volatilization, denitrification and precipitation without being taken by plants [51]. This not only causes economic losses, but also leads to serious water and environmental problems. Fertilizer use efficiency is very low and is a big problem, especially in nitrogen and phosphorus fertilizers, which are highly used. Application of microbial inoculants to the soil is known to enhance the uptake of nutrients by plants and increase the efficiency of mineral or organic fertilizers. For these reasons, impregnation of mineral fertilizers with bacteria is attracting worldwide attention. On the other hand, mixing P-solubilizing bacteria with rock phosphate is a remarkable and important approach. These products are very important in improving soil capacity and increasing fertilizer use efficiency. Although inorganic fertilizers play a critical role in food security in the world, the highest yield is often the result of organic use, which includes microbial and inorganic sources together.

Studies have shown that bacterially empregnated DAP and urea applications are highly effective for improving growth, yield and the fertilizer use efficiency of wheat[21]. The use of PGPR to increase fertilizer use efficiency is an important approach because of its multiple benefits and positive impacts on plant growth and environment[52-54]. Thus impregnation of mineral fertilizers is an innovative strategy for improving growth, yield and nutrient use efficiency of crops. Another approach is that nutrient deficiency in biological fertilizers enriches by adding natural substances such as bone meal, wood ash, and phosphate rock. On the other hand, the addition of phosphorus to the wastes makes the bio-fertilizer more balanced and reduces the nitrogen losses. Integrated soil fertility management through microbial coating on chemical fertilizer technique and/or bio-organo-fertilizer is critical to optimizing food production and efficient use of plant nutrients [27]. In this regard, the enrichment of rice straw into manure through suitable PGPR has been proposed as an attractive option for rice production[55].In this sense, it is important to biologically convert organic wastes into value-added bio-organic fertilizers at the local level.

11. FUTURE PERSPECTIVES

In order to increase our understanding of the role of various root-associated organisms in plant growth and health as well as make use of their potential beneficial features as biofertilizers in plant production, more information is urgently needed on the interactions among plants and rhizosphere microorganisms. The rhizosphere is a highly dynamic system and the difficulty to exclude endemic bacteria when multiple organisms interact at the same time may prevent clear results in field trials[26]. For success in microbial fertilizers, local or regional strains should preferably be selected and used for the target crops. Bacterial inoculum combinations may be of greatest value if various organisms with different proven or suspected benefits to the crop plants can be integrated. The integration of different microbial capabilities into one product with several potential yield-promoting effects is desirable.

In order to improve the use of plant growth promoting microorganisms in agriculture, it is important to use local strains, coating materials, good protectant and stimulant compounds, to reduce production costs, to provide a suitable carrier, biofilm and polymer-based carriers, and to use water-in-oil emulsions. Additionally, advances in new technologies leading to the enhancement of biofertilizer shelf-lives, developing of new carriers and encapsulation techniques based on nanoparticles, facilitating their distribution and application, improving in the production process, product handling and packaging, are essential for their use to be extended. As a matter of fact, if the microbial coating on chemical fertilizer technique can be used in addition to currently available bio-encapsulation or carrier-based techniques, then it is predicted that the elite microbial consortium in the chemical fertilizer formulation will become more efficient in the future [27]. If microbial coating on chemical fertilizers technique can be used in addition to existing bio-encapsulation and carrier-based techniques, chemical fertilizer and microorganism mixture formulations may become more efficient in the future. Formulations of inoculants based on the basic principles of science, microbiology and materials science will be important in sustainable agriculture and environmental solutions.

Another important approach is the use of local strains because no PGPB strain exhibits the best performance in all agricultural conditions. It is difficult to obtain strains that can be effective and work equally in all environments. Therefore, if organisms with different characteristics can be integrated with each other and with plants, higher benefits can be obtained. Since the efficiency of inoculation varies depending on various parameters including target plant species and soil and weather conditions, it has been proposed to differentiate and appropriately match inoculants[20].An important step towards the use of potential plant beneficial strains is the development of strain-specific formulations and the use of modern tools to monitor cell viability[3]. Another possible approach to be developed may be the use of microbial biomass of the siderophore-producing species as an inoculum to colonize the root system of Fe-deficient plants [56].

The combination of three important sources of chemicals, organics and microbes in one formula or the enrichment of chemicals with organic and microbes will be a very high hope in the future for more economic and environmentally friendly agriculture. However, the development of new technological multigroup bio-organo-chemical fertilizers, which are developed by using the most active components of chemical, organic and biological sources to produce fertilizers, is seen as an important solution. Developing a suitable nutrient management system that integrates the use of these three kinds of fertilizers may be a challenge to achieve the goal of sustainable agriculture; however, much research is still required. Research on microbial adaptability on chemical fertilizer are strongly needed in the future for more economic and environmentally friendly agriculture and this is a new and innovative approach.

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