BIOFERTILIZERS TECHNOLOGY: AWARENESS, MARKETING AND FUTURE PERSPECTIVES FOR SUSTAINABLE DEVELOPMENT

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"Sustainable development is development that meets
the needs of the present without compromising
the ability of future generations to meet their own needs"

Brundtland Commission, 1987

AWARENESS ON BIOFERTILIZER TECHNOLOGY

Biofertilizers technology as an inalterable part of sustainable agriculture has to fit the basic requirements for its main dimensions. The biofertilizers technology has to be:

- *Appropriate*: to suit the social and infrastructural situations of the end-users;
- *Economically feasible and viable*: to be applicable by all farmers, regardless of their financial status and position, concerning the return on investment;

- *Environmentally friendly*: enriching the environment or, at least not harming the existing agro-ecological conditions;
- *Stabile*: the positive aspects of the technology must remain stable in long-term perspective;
- *Efficient*: mode of utilization of inputs to convert them into useful and eco-sound outputs;
- *Adaptable*: adaptable to existing local conditions;
- *Socially acceptable and sustainable*: acceptable by different societal segments and satisfying personal needs;
- *Administratively manageable*: practically implementable under certain bureaucratic structure;
- *Culturally desirable*: fits the various cultural patterns of society;
- *Renewable*: use and re-use without significant additional inputs;
- *Productive*: rate and amount of production per unit of land/input; yield per unit of area (or labor input, or investment) as a dimension of sustainable agriculture.

However, successful promotion of biofertilizers technology in sustainable agriculture depends on implementation of programmes for raising awareness among the biofertilizers producers and consumers. Biofertilizers are apparently an environmentally sound and farmer-friendly renewable source of low cost agro-input. However, bioinoculants, especially those regarded as broad spectrum biofertilizers (*Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria and arbuscular mycorrhizal fungi) have not received the deserved attention. The reason for this is mainly due to the inadequate awareness of the extension workers and the farmers about the benefits of biofertilizer technology. This unawareness regards the biofertilizers' utility, short shelf-life, lack of ready availability in time and in the desired quality, inconsistency in results with their application. Other problems in the adoption of the technology by the farmers are due to the different methods of inoculation applied. A complication rising unawareness is the fact that no visual difference in the crop growth immediately after biofertilizer application is observed in comparison with that of inorganic fertilizers. In addition, there are socio-psychological constraints that lead to unawareness of biofertilizer technology: lack of motivation form extension agencies; low credibility of source of biofertilizers; farmers' belief that chemical fertilizers are more effective than biofertilizers; lack of use of biofertilizers by fellow farmers or their application being not permitted in farmers' culture.

Lack of awareness of biofertilizers is a major challenge for farmers, the private sector (i.e. agro-dealers), extension services and policy makers. Insufficient understanding of the technology obstructs the diffusion of innovation that could have otherwise been facilitated by awareness creation through dissemination of information by different channels and stakeholders. The awareness of the key stakeholders in biofertilizer technology can also be improved by national and international research organizations, as well as by the biofertilizer industry through participatory demonstration trials. After that those stakeholders could, in turn, train farmers in their communities. Demonstration trials are a good approach to increase awareness and the use of novel products by farmers; they are more useful when there is participation by various stakeholders. *Inter alia*, government support may play an important role in promoting the increased use of biofertilizers among farmers and market growth for the products. In some Asian countries, for instance, biofertilizers are supported by the government through national projects on development and use of the technology. Zonal production facilities, state departments and state agricultural facilities, public sector firms and cooperatives also produce biofertilizers. Private industries obtain subsidies from the government to cover the cost of plant and equipment for production. Farmers can get awareness of the biofertilizer technology through efforts to increase the availability of the products, research and extension for education and effective marketing strategies.

Considering these obstacles, it is apparent that, to raise awareness in biofertilizer technology, proper education of the extension personnel, dealers and farmers about their significance and economic feasibility of application is needed. Thus, extensive knowledge, practical training, adoption and perception are obligatory elements of putative approaches to better understanding and application of biofertilizer technology.

MARKETING CONSTRAINTS

By 2018, the worldwide market for biofertilizers is anticipated to exceed a market worth of US$ 10.2 billion. The top consumers of biofertilizers are Europe and Latin America, mainly because in the countries from these regions, there are stringent regulations imposed on chemical fertilizers. These are followed by Asia-Pacific, which control more than 35% of the market. Market growth together with the effective regulation of biofertilizers, are crucially important for increased availability and use of biofertilizer products. To ensure market growth of biofertilizer products, several important constraints have to be overcome.

Instability of the inputs and outputs markets

The minimum availability and adoption of agricultural inputs including biofertilizers may be considered as (at least partial) explanation for the instability of the inputs and outputs markets. In general, when farmers obtain a value/cost ratio higher than three to four, the willingness to adopt a novel agricultural technology increases as a result of the market opportunities.

Lack of developed marketing channels and infrastructure

Poorly developed marketing channels and infrastructure, due to limited involvement of the private sector in the distribution of inoculants and the limited farmer awareness about and access to inoculants, affects the biofertilizer market negatively. Countries that have succeeded in enhancing the biofertilizer market growth have implicated a strategy focused on reduction of distribution costs, and consequently, the costs of the products. For instance, with the increased soybean cultivation in Brazil in the 1960's, application of biofertilizers (i.e. *Rhizobium* inoculants) was immediately adopted. Use of *rhizobia* inoculants in North America is a practice that has been continuing for more than a century. The European Union encourages the use of biofertilizers by advising farmers to optimize the application of chemical fertilizers or replace them partly or completely with biofertilizers that are considered environmentally friendly.

Initiatives for promotion of biofertilizer business sector

The government purchase of large portions of biofertilizer products for distribution to farmers can ensure a continuous market for producers. Associations formed by manufacturers to coordinate the commercial sector issues in the development of government policy, are another effective instrument to encourage the biofertilizer business. In addition, non-governmental organizations and international research centers may also contribute to the increased use of biofertilizers. All these cumulative activities by the government, research institutions and industry players have put the biofertilizers branch at the forefront in the sustainable agroindustry.

On the contrary, weak linkages with private sector manufacturers, local stock holders, NGOs and small-holder farmers; the poor support of production, distribution and use may negatively affect the availability and adoption of biofertilizers. Therefore, the biofertilizer market growth will require a strong public–private partnership and enough commitment to improve. Lessons learned up to now combined with sufficient awareness creation may be useful to build the partnership to increase the awareness and understanding of the technology. As the profitability of biofertilizers is demonstrated through participatory demonstration trials and output markets, the demand is expected to increase, and consequently, the biofertilizer (i.e. input) market.

FUTURE PERSPECTIVE OF BIOFERTILIZERS

Uncontrolled over-application of chemical fertilizers by farmers during intensive agricultural practices has led to excess nutrients (particularly P) accumulation in soils, which, as a result, makes the soils dead. That is why, nowadays, the production of efficient and sustainable biofertilizers for crop plants, wherein inorganic fertilizer application can be reduced significantly to avoid further pollution problems, represents major research interest. It comprises undertaking short-term, medium and long-term research programmes combining the efforts and scientific potential of soil microbiologists, agronomists, plant breeders, plant pathologists, nutritionists and economists to work together.

The most important and specific research needs should highlight following points:

Selection of effective and competitive multi-functional biofertilizers

Microorganism(s) with multifunctional properties and biofertilizers containing more than one microorganism are currently gaining special attention. Although currently most biofertilizer products consist of a single function microorganism such as nitrogen-fixing bacteria, emphasis is given to the production of bacterial isolates that could be developed as multifunctional biofertilizer microorganisms. The multi-strain consortia confer additional characteristics to the biofertilizer they comprise in respect to improvement of crop plants growth and performance, as well as in enhancement and maintenance of soil fertility.

There is evidence that a multifunctional consortium of different strains of *Rhizobium*, phosphate-solubilizing bacteria and fungi, arbuscular mycorrhizal fungi, and free-living nitrogen-fixing *Azotobacter* strains improves the noduling ability, nitrogen content and herbage yield (up to two-fold) of subabul seedlings (*Leucaena leucocephala*) in comparison with the application of each component of the consortium alone.

On the market, there are approved products comprising multi-strain consortia that express a defined positive effect. Two such products are Bio-N® and Bio-Spark®.

Bio-Nitrogen or Bio-N® is an organic/multi-microbial inoculant fertilizer for rice and corn. It was developed by the National Institute of Molecular Biology and Biotechnology (BIOTECH, the Philippines), in the early 1980s. It contains two species of the nitrogen-fixing bacteria *Azospirillum* isolated from the roots of the grass *Saccharum spontaneum* L. It can fix and transform atmospheric nitrogen into a form usable by crops, enhance shoot growth and root development, make plants resistant to drought and pest attack, and increase the yield and milling recovery of rice. Bio-N® was originally developed for corn plants. After field tests on the preparation efficacy for rice and corn and high value crops, its application was widened. Further research helped for prolongation of its shelf-life from three to six months, and currently efforts are concentrated on finding an alternative microorganism carrier, different from the soil-dust charcoal.

Bio-Spark® was initially developed as a composting agent. Further, it was strengthened to become a biofertilizer and bio-control agent. Bio-Spark® is a product of more than two decades of research and experimentation. In 2002, the Trichoderma series was registered as a biofertilizer with the Fertilizer and Pesticide Authority (FPA) under the brand name BioCon®. With a new investor in 2010, BioCon® was renamed BioSpark Trichoderma®. BioSpark® is a multi-microbial inoculant which consists of three different *Trichoderma* species (*T. parceramosum*, *T.*

pseudokoningii and a UV-treated strain of *T. harzianum*). The fungus is an effective biological control agent against soil-borne pathogens and biofertilizers, as it enhances the growth of plants. The further intensive R&D work resulted in significantly improved quality and marketing of BioSpark®. Its shelf-life was increased from six months to two years.

Another approach for assembling multifunctional biofertilizer preparations is to use indigenous microorganisms that have all the desired characteristics and are present in compost. Among these important characteristics are plant-growth-promoting, phosphate-solubilizing and antagonistic actions towards pathogens. Thus, multifunctional biofertilizer products based on composting are designed and produced applying the following methodological approach:

- Isolation and screening for indigenous microorganisms at each stage of the composting process, that confer at least two important characteristics, e.g. ability to solubilize phosphate and to produce indole-3-acetic acid (IAA);
- Development of these indigenous microorganisms into biofertilizer products;
- Evaluation of the effects of the products on the growth of a model plant and the contribution of N_2 to the plants in a greenhouse trial. Selection of combinations of strains that significantly enhance plant growth through promoting nitrogen-fixing effects or solubilizing insoluble inorganic phosphate compounds or hydrolyzing organic phosphate to inorganic P or stimulation of plant growth through hormonal action such as production of IAA.

Such combinations of microbial isolates that could be developed as multifunctional biofertilizers could be a good opportunity for sustainable agriculture.

Quality control systems for the production of inoculants and their field application

The interest in biofertilizers is also increasing due to their potential for use in sustainable agriculture. However, many of the products that are currently available worldwide are of poor quality. The formulation of an inoculant is a multistep process that results in one/several strains of microorganisms included in a suitable carrier, providing a safe environment to protect them from the harsh conditions during storage and ensuring survival and establishment after introduction into soils. A key issue in formulation development and production is the quality control of the products, at each stage of the production process.

The successful application and use of biofertilizers for the agricultural system is restricted by several limitations:

Non-reliable efficacy: the efficacy of most biofertilizers is doubtful, since their mechanism of action in promoting growth is not well understood, despite the extensive research in this direction.

Effect of abiotic factors on biofertilizers efficacy: it is still not clear how variations in soil type, management practices and weather affect the biofertilizer efficacy.

Field trials performance: It is still difficult to test inoculants in the field as routine experiments.

The proper quality control mechanism of biofertilizer production and application covers the whole experimental process: from microorganism isolation, through laboratory screening of the isolated strains for plant growth; greenhouse screening for plant growth promotion; field screening of the most effective microbes in cropped soil; readjustment and refining of inoculants; environmental impact test and, finally, production.

Since quality is the parameter on which the acceptance or rejection by the end-users, the farmers, depends, it is one of the most important factors influencing the progress of the biofertilizer industry.

The quality specifications of biofertilizers differ from country to country and may contain the following parameters:

- The microbial strain(s) used; the quality of biofertilizers is usually defined in terms of two important characteristics: presence of a recommended strain in the required quantity and in active form.
- Microbial density at the time of manufacture and at the time of expiry: the number of selected microorganisms in the active form per gram or milliliter of biofertilizer. The guidelines used are limited to the density of the available microorganisms and their viability and preservation.
- The permissible contamination; it is important to set control schemes that account for putative contaminating microorganisms.
- The expiry period;
- The pH, the moisture and the carrier;
- The final biofertilizer product has to manifest the major effects for quality management. These effects are used as indicators for the biofertilizer properties. The list of the major effects must include those of the guaranteed activities of the biofertilizer. Thus, there must be a system that allows distinguishing between the resident microorganisms, targeted microorganisms and the supplementary compositions on the effects of the biofertilizer. If the final results of the three experimental schemes are the same or cannot be confirmed statistically, then the product is just an organic matter. This means that the effects of microbial products have to originate from the guaranteed microorganisms and this should be presented in details as a prescription.

Quality has to be controlled at various stages of production as well: during the mother culture stage, carrier selection, broth culture stage, mixing of broth and culture, packing and storage. In China, for example the main quality parameters of biofertilizers are as follows:

- Appearance;
- Living target bacteria: fast and slow-growing *Rhizobium*, nitrogen-fixing bacteria, Si bacteria, organic/inorganic P bacteria;
- Multi-strain biofertilizer;
- Water content;
- Size;
- Organic matter;
- pH;
- non-target bacteria (contaminants);
- shelf-life.

The quality control of microbial products in favour of the customer needs a strong quality management system operating. The control management is very essential and must be performed continually. The procedure of biofertilizer quality control includes the following steps:

- Guaranteed identification of the strains;
- Guaranteed cell density of the strains;
- Assessment of the main activities as effect indicators of biofertilizers; regular inspection for quality control by the competent authorities;
- Evaluation of the effect on target crops;
- Registration under the regulation.

The quality of biofertilizers can be ensured by taking into account the following quality control constraints: legislative, environmental, technical and lack of awareness. In addition, for capacity building of the personnel engaged with quality control initiatives, regular trainings have to be organized by national/regional centres for organic farming. Training modules for laboratory analysts for field level officers and fertilizer inspectors have to be designed and implemented as a part of the quality control systems for efficient production and application of inoculants.

Study of microbial persistence of biofertilizers in soil environments under stressful conditions

The assessment of the persistence and traceability in soil of the strains applied with biofertilizers can be a big challenge. There are several important reasons for this.

1. The huge and complex population of microorganisms present in the soil and the rhizosphere.
2. The high variability of the microbial communities which reflects ecological, environmental and structural soil characteristics.
3. The large variety of agricultural management systems.

That is why one cannot choose a single qualitative and quantitative approach to trace the persistence of bio-inoculants in the soil because of the variety of organisms forming the biofertilizers. This difficulty, consequently, raises the questions about the methods to be considered suitable for monitoring the persistence of different inoculated strains. The methodological approach is of crucial importance for evaluation of the success of inoculation, consequently, the biofertilization.

The situation is further complicated due to the significant spatial and temporal variability of crop responses to biofertilization. It is due, to some extent, to the poor understanding of where and when to apply biofertilizers. On the other hand, in soils that experience stress conditions, the effectiveness of the products may be different. A biofertilizer has to be tested in variable conditions including abiotic stresses such as drought, soil acidity or low soil fertility to develop adequate recommendations for use.

During the past two decades, phenotypic and PCR-based methods have been developed to better characterize the structure, dynamics and diversity of soil microbial communities. For detection of microorganisms released in the environment, molecular methods based on PCR techniques that use natural genome polymorphism have largely facilitated and allowed discrimination at the strain level of natural and introduced organisms, minimizing the costs and the time efforts.

The PCR-based methods are predominantly molecular DNA fingerprinting methods, mainly qualitative and not quantitative. The non-culture-based methods that are usually used for assessment of the biodiversity of soil microbial communities include traditional molecular fingerprinting, sequencing or a combination thereof. However, the traditional molecular fingerprinting method based on universal bacterial primers has been found insufficient to discriminate between non-native and native microorganisms. To overcome this problem, community level fingerprinting (e.g. T-RFLP) combined with phylogenetic strain identification applying the culture-dependent approach is used as a modern approach to highlight differences in community structure and at the same time to successfully track inoculants.

The molecular marker-assisted approach, such as T-RFLP, DGGE, TGGE, appears to be particularly useful for monitoring purposes. The combination of two non-culture-based methods can assess the persistence of microbial inoculants introduced in the soil, on the one hand, and evaluate the possible changes occurring at species level for the native strains, on the other hand.

Agronomic, soil and economic evaluation of biofertilizers for diverse agricultural production systems

The positive effect of biofertilizer application depends on many factors. Similarly, the evaluation of the biofertilizer application is also complex. The mechanisms involved in plant promotion may be both host-plant-specific and strain-specific. Plant-growth-promoting microorganisms, when released into the soil, are subjected to competitive conditions that may severely reduce their beneficial effects. That is, the beneficial effects due to the application of a specific biofertilizer may differ significantly under different agro-environmental conditions, questioning the efficacy of microbial-based products.

To overcome such awareness, it is important to consider which factors affect the efficacy of biofertilizers on crop productivity. The factors mostly affecting the efficacy of biofertilizers are related to the plant (agronomic), the soil and the economy of the products.

Factors related to the plant

Plants can exercise a significant effect on the strain(s) comprising the biofertilizer and on their efficacy in promoting the growth and yield. This is undoubtedly related to the plant physiological status and phenological phase of growth. Plants can modify the release of compounds from their roots depending on their nutritional status. This act results in changes (quantitative and qualitative) in the nutrients deposit in the rhizosphere. The changes themselves vary in time and space regarding the position of the root and the growth stage, causing selection of specific rhizosphere bacterial communities.

Plant roots excrete exudates that contain compounds with either stimulatory or inhibitory effect on rhizosphere microorganisms. Such compounds affect the microbial capacity of establishing beneficial relations with the plant. For instance, under P-deficiency conditions, plants release more chemical signals stimulating hyphal branching and colonization of AMF in comparison with P-sufficient conditions.

Plants can also influence the functions of soil microorganisms, such as nitrification. It is shown that increased release of genistein, a phenylpropanoid compound, significantly stimulates total AMF hyphal length, probably due to its participation in the chemical signaling leading to AMF root colonization. Phenolic acids, also exuded by roots, are responsible for the shift in soil microbial communities.

It has been suggested that rhizosphere microbial communities respond to other rhizosphere carbon pools (e.g. microbial exudates) as well. Thus the coexistence of native strains and the strains inoculated with the biofertilizer with the plant host makes the role of rhizodeposits in shaping the rhizosphere microbial community very complicated.

Despite of this complex picture, root exudates are likely to be of great importance in initiating the rhizosphere effect in very young seedlings and on emerging lateral roots. In this respect, the application of biofertilizers on seeds and seedlings would increase the efficacy of the treatment.

Factors related to soil conditions

Biofertilizers, known as microbial products, act as nutrient suppliers and soil conditioners that lower the agricultural burden and conserve the environment. Good soil conditions are imperative to increased crop production, as well as human and/or animal health welfare.

Several biotic and abiotic factors pose challenges in the successful application of commercial biofertilizers and are responsible for the efficacy of the biofertilizers as a field practice. On the other hand, there are several tools and actions which can be utilized and implemented to improve the field efficacy of biofertilizers. To guarantee the efficacy of a biofertilizer in a particular soil with a specific variety of crop is, thus, a complex task, which shall be considered by researchers, manufacturers, agricultural advisors and farmers when designing and applying a specific biofertilizer: a challenge to transform the fertilization with these products into a common practice for twenty-first century agriculture.

Abiotic factors

The shaping of bacterial and fungal soil communities is strongly dependent on soil chemical (pH, nutrient content) and physical (texture) characteristics. Soil pH has been found to be the most important factor influencing the bacterial community structure at the ecosystem level. In general, higher diversity is associated with neutral soils and lower diversity, with acidic soils. This is reasonable due to the relatively narrow pH growth tolerance of bacterial taxa. The field surveys of AMF communities in a wide range of soil pH suggest that it is also the major driving force for structuring fungal communities, thus affecting the colonization potential and efficacy of all kinds of plant-growth-promoting microorganisms included in biofertilizers.

Other abiotic factors that influence the AMF adaptation are soil temperature and nutrient availability and they can strongly influence the effect of the AMF symbiosis on plant growth.

Interaction with native soil microorganisms

Mathematical simulations showed that the most significant factors affecting the survival of plant-growth-promoting microorganisms, and thus the ability of providing beneficial effect to plants, are the competition with autochthonous bacteria, the compatibility with the exuded compounds by the plant host (rhizodeposition) and their ability to utilize them.

When introduced into the soil, the biofertilizer strain(s) begin to compete with the autochthonous microorganisms. The understanding of the ecological interactions among soil microorganisms and the impact of those microorganisms included into biofertilizers with the soil microbial populations are still limited. Lack of knowledge about these complex interactions does not allow to effectively predict the effect of inoculants introduced with the biofertilizers.

Despite these shortcomings, the research community puts great efforts in evaluating these interrelationships and their impact on biofertilizer efficacy, both in the short- and long-term, using a variety of methodological approaches. Some of the exploited methods are analysis of soil microbial biomass, soil microbial activity, soil microbial community structure and diversity. Using these techniques, it has been demonstrated that inoculation with biofertilizers containing different plant-growth-promoting microorganisms (e.g. fluorescent pseudomonad, symbiotic and free-living nitrogen-fixing bacteria, AM fungi, etc.) affects various taxonomical or functional groups of autochthonous soil microorganisms in different ways. The application of inoculums based on nitrogen-fixing bacteria can either increase or strongly reduce the local bacterial community structure and diversity, even when the inoculation is carried out with a multi-strain consortium. A symbiotic nitrogen-fixing strain has been shown to particularly affect a specific group of Proteobacteria. Many studies have confirmed a high degree of specificity of the bacterial species associated with AMF. Inoculation with AMF also significantly affects the general development of rhizospheric bacterial and fungal biomass. Once established successfully, introduced AMF have been shown to decrease the species richness of indigenous AM fungal communities in most roots.

A key factor accounting for biofertilizer efficacy is the selection of strains that express features supporting the colonization process of the root environment. In this respect, quorum sensing confers an enormous competitive advantage on bacteria, improving their chances to survive (e.g. through biofilm formation) and the ability to explore more complex niches by moving in the soil through motility. In other words, at least a minimum population level of the initial PGPR inoculum needs to be available to promote plant growth.

The efficacy of biofertilizers is also mediated by protozoa, particularly by naked amoeba, which is the most important bacterial grazer in soil. An increase in the bacterial and fungal feeding nematodes population has been observed after application of a biofertilizer composed of both AMF and PGPR. The wheat rhizosphere colonization by two *Pseudomonas* species and *Bacillus subtilis* was substantially reduced by three species of nematodes (*Caenorhabditis elegans*, *Acrobeloides thornei* and *Cruznema* sp.).

The observed relationships between indigenous and introduced microorganisms depend largely on the techniques used to assess the dynamics of soil microbial communities. The modern metagenomic approaches combined with culture-based methods for microbial quantification could clearly identify the number of microbial taxa. However, there are several important issues that still need to be resolved:

- to recognize which functions are attributable to a specific microorganism or group; the study of genes coding for important enzymatic activities or key genes in the interaction process between the inoculant and native microbial population may contribute to gain knowledge about them;

- to identify the metabolic potential of soil microbial communities in response to inoculation;
- to find the link between the effects on the soil microbial communities structure and the functional capabilities of soil microbial population;
- to identify possible functions for the application of biofertilizers specifically designed for particular soil/crops.

Economic conditions

The growth in the organic food market is a major driving force for the increasing trends in the global biofertilizers and biopesticides market. The reason for this advancement is due to the fact that future organic industry is strongly dependent upon the crop promotion and protection products free of chemicals.

The global market for biofertilizers in terms of revenue was estimated to amount to about 5 billion USD in 2011. The Asia-Pacific region was responsible for approximately 34% of the total demand in 2011. According to a detailed analysis of the current market and of the scenarios for its development in different continents, it is forecasted to double by 2017, actively in Latin America, India and China. The global market for biofertilizers is expected to exceed a market worth of USD 10.2 billion by 2018. Latin America is currently among the top consumers of biofertilizers: in Mexico, a programme to support the introduction of nitrogen-fixing biofertilizers based on *Azospirillum* was carried on 1.5 million hectares. According to estimates of the Indian National Biofertilizer Development Center (NBDC) and the Bio-Tech Consortium of India Ltd (BCIL), about 350.000–500.000 tons of biofertilizers are potentially required for Indian agriculture. European and Latin American countries are the leading consumers of biofertilizers, owing to the stringent regulations imposed to chemical fertilizers, which tend to be replaced by biofertilizers. The global bio-pesticide market was valued at $1.3 billion in 2011 and is expected to reach $3.2 billion by 2017. North America dominated the global bio-pesticide market, contributing for about 40% of the worldwide demand in 2011. Europe is expected to be the fastest growing market in the near future owing to the stringent regulations for pesticides and the increasing demand for organic products.

Global biofertilizer market revenue share, by product segment (2012)

Product segment	Global biofertilizer market revenue share (%)
Nitrogen-fixing	78.7
Phosphate-solubilizing	14.6
Others	6.7

However, slow effects of biofertilizers over chemical fertilizers and low adoption of biofertilizers by end-users is anticipated to hinder the growth of the market.

Nitrogen-fixing biofertilizers were the ones mostly consumed in the industry in 2012, accounting for over 78% of the global demand. These biofertilizers are undoubtedly agriculturally useful being applied to improve crop yield and they involve several potential benefits in environmental application. Furthermore, the demand for bio-based soil treatments due to the increasing environmental concern is also expected to stimulate the demand for biofertilizers over the next few years. In addition, increasing consumption for leguminous and non-leguminous plant products is also expected to augment the demand for nitrogen-fixing biofertilizers in the near future.

Phosphate-solubilizing bacteria are expected to show the fastest growth over the next few years because of their potential use in agriculture, namely in developing cost-effective and eco-friendly multifunctional biocontrol agents and biofertilizers. The market for other types of biofertilizers such as potash-mobilizing and zinc-mobilizing ones is saturated due to the low demand from the farmers.

The demand for biofertilizers is segmented at the market in accordance with their mode of application. The highest demand is that for seed treatment, accounting for approximately 72% of the global demand. Biofertilizers are extensively used in seed treatment due to technological advancement and rising environmental concern about the application of chemical fertilizers.

The biofertilizer demand was significantly high in North America in 2012, accounting for 32% of the global demand, owing to the presence of a large industry of genetically modified (GM) crops in the region, especially in the USA, where biofertilizers are widely used in the treatment of crops. The rest of the world ranked as the second largest region in the industry. The reason for this is the rising demand for natural food products, the environmental hazards associated with chemical fertilizers and the promotion of biofertilizers to create awareness among the society.

Asia-Pacific is expected to boost the demand for biofertilizers because of the growing demand for organic food coupled with intensive organic farming in the region. Furthermore, national governments of emerging economies such as China and India are promoting the use of biofertilizers through tax incentives and exemptions, and grants for the production and distribution of biofertilizers.

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An economically significant share of the fertilizer market is already allocated to nitrogen-fixing biofertilizers, phosphate-solubilizing biofertilizers, potash-mobilizing biofertilizers and other biofertilizers like zinc and sulphur-solubilizing biofertilizers. A bottleneck step in the progress of the biofertilizer industry and market growth is the lack of awareness about the concept of biofertilizers, the low rate of adoption by the farmers and the presence of low-quality products in the market that hinder its development. It would thus be important to define a legal framework on biofertilizers to protect both the reliable manufacturers of biofertilizers and the farmers utilizing an effective product from a market which allows low-quality products.

The marketing of biofertilizers should be regulated assuring a minimum quality standard of the final product. Improvement of quality standards for production and establishing a clear legal framework that guarantees both manufacturers and farmers are needed to sustain such potential economic development.

Considering the fact that 60–90% of the total applied fertilizer is lost and only 30–50% of applied N fertilizers and 10–45% of P fertilizers are taken up by crops, the application of biofertilizers can play a key role to develop an integrated nutrient management system, sustaining agricultural productivity with low environmental impact. The general goal is to reach the same crop productivity obtained without biofertilizers, but with a significant reduction of mineral fertilizers use, rather than to expect the application of biofertilizers to result in an increased yield over respective uninoculated controls. Biofertilizers have the potential to help reduce the buildup, leaching or runoff of nutrients from fields when used in the framework of an integrated nutrient management system, participating in nutrient cycling and benefiting crop productivity.

More stimuli for a wider and effective use of biofertilizers can be derived from recent knowledge on microorganisms and technological development. Use of strains cooperating with autochthonous microorganisms, or exploiting the synergies with microbial communities, as well as the inclusion of protozoa in the formulation of biofertilizers could also play a key role in the development of new kinds of biofertilizers.

Biofertilizers are profitable to farmers; they offer higher nutrient use efficiency, benefit–cost ratio, reduced requirements for chemical fertilizers and environmental benefits. As long as the cost of inorganic fertilizers is quite high and less profitable, biofertilizers will play a significant role when well-understood and correctly applied. Good practices of profitability of biofertilizers in various countries where they have been successfully applied may be useful to support policy and farmers' decisions related to incorporation of biofertilizers into their agricultural systems.

In Brazil, great savings estimated to US$ 3 billion per cropping season are realized with the reduced need for N fertilizers. Inoculation with *Rhizobium* has resulted in cost savings of US$ 1.3 billion in production cost. Soybean and other legumes are inoculated with rhizosphere bacteria instead of applying chemical nitrogen fertilization. Such microbial inoculants increase the nutrient use efficiency.

BIOFERTILIZERS TECHNOLOGY: AWARENESS, MARKETING AND FUTURE PERSPECTIVES FOR SUSTAINABLE DEVELOPMENT

The nutrient use efficiency can be enhanced by use of plant-growth-promoting rhizobacteria (PGPR) or co-inoculants of PGPR and arbuscular mycorrhiza fungi (AMF). The fertilizer efficiency of all biofertilizers is ≥ 90%, as there are very minimal losses due to leaching and fixation. Reducing the application rate of inorganic fertilizers when used together with biofertilizers may result in fewer nutrient losses and, consequently, in both economic savings and environmental protection without negatively impacting the yields.

Farmers generally apply excessive amounts of chemical fertilizers as a result of the low nutrient use efficiency. The cost of excessive inorganic fertilizer inputs in North America is estimated at US$ 2.5 billion per year. Farmers in Europe and North America have applied generous amounts of chemical phosphorus and nitrogen fertilizers for a long period of time. Besides the high price, this practice has negatively affected human health and the environment; hence the need to make agriculture environmentally and economically sound. Biofertilizers therefore offer a good opportunity to minimize such negative impacts on the environment and human health. For example, under the intensive farming system in Egypt, prevention of potential loss of N through leaching and significant increase in maize yield was achieved with the application of half the recommended N rate and biofertilizer, i.e. *Azospirillum*. Reducing the application rate of chemical fertilizers following the integration of biofertilizers for similar crop yields is expected to result in better economic return given that biofertilizers are considered cost effective.

Biofertilizers are many times cheaper than chemical fertilizers with a cost–benefit ratio of more than 1:10. It is reported that the application rate of chemical fertilizers could generally be reduced by 25–50% for nitrogen and 25% for phosphorus when appropriate biofertilizers are used without negatively affecting the yield performance. Mono cultures continue to dominate the market but mixed cultures are picking up fast and may surpass the single-strain inoculants in the next 5 to 7 years.

Transferring technological know-how on biofertilizer production to the industrial level

Improvement in crop production due to application of biofertilizers has been reported extensively. At present various biofertilizers are produced in large scale industrially and are available for field application. For instance, inoculants using *Rhizobium* and *Azotobacter* are produced industrially following a production technology comprising three important steps:

1) Development of strains;

2) Upscale of biomass;

3) Preparation of inoculants.

The biofertilizer production comprises blending aseptically pure bacterial broth with high cell density and sterilized carrier (e.g. peat, charcoal and/or lignite) to obtain a moist powdered formulation having high population of desired microbes. It is generally recommended for products free from contaminants to have a microbial load of approximately 10^7 cells per gram carrier. It is thought that this formulation can give optimum results of plant growth promotion in the designated crop following the recommended method of application.

The main bottleneck in the biofertilizer production at industrial level is that bacterial strains are usually developed and maintained by research laboratories and not by the production units. Further, in order to use efficient strains, research efforts must be concentrated on obtaining region-, soil- and crop-specific strains and make them easily available to the entrepreneurs in the industrial production units for scaling up of biomass yield.

As biofertilizers are live microbial preparations of very high cell density, the desired microorganisms have to be carefully monitored during the production process. It is logical, since the quality of inoculants in a biofertilizer is one of the most important factors resulting in their success or failure, acceptance or rejection by the farmers. The quality means the presence of the right type of microorganism in an active form and in desired numbers. The production stages that require quality control are:

- Preparation of mother culture;
- Carrier selection;
- Broth culture stage;
- Mixing of broth with carrier;
- Packing;
- Storage.

Testing of the culture is usually done by taking a sample from the finished product for comparison with a standard specification at the time of mixing of the broth with the carrier.

Biopesticides and biofertilizers are two important cornerstones that need intensive research to improve the quality mainly to achieve food security for the growing population and restore soil fertility. Nature has provided wide possibilities for research in these fields which need to be explored. The development of new biopesticides with multiple modes of action against pests and of biofertilizers with multi-crop growth-promoting activities is most important for sustainable global agriculture. These two study trends need to be prioritized in agricultural research by universities, research organizations, R & D wings of manufacturers for technology development to the farming community. The technologies so developed need to be transferred worldwide to achieve maximum benefits to the society.

Establishment of "Biofertilizer Act" and strict regulation for quality control in markets and application.

Common Agricultural Policy (CAP)

The Common Agricultural Policy (CAP) and its system of European Union agricultural subsidies and programmes require farmland to be maintained in 'Good Agricultural Condition' and encourage application of particular land management activities to benefit the environment. Furthermore, some countries have included the principles of "humus/organic matter management" in these requirements and check it in the frame of the cross-compliance obligations.

CAP in EU is built on the following pillars:

- Subsidizing production of basic foodstuffs in the interests of self-sufficiency.
- Emphasis on direct payments to farmers as the best way of guaranteeing farms' income, food safety and quality, and environmentally sustainable production.
- EU (considering its 27 member-states and a number of farmers increased by nearly 70 percent) has made funding available to modernize farms, food processing and marketing structures, and to encourage environmentally sound farming. A special three-year post-enlargement funding package tailored specifically to the needs of these farmers is now providing € 5800 million to help early retirement, less favoured areas, environmental protection, afforestation, semi-subsistence farms, producer groups and for compliance with EU food, hygiene and animal welfare standards.

Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91

1) **Organic production** is an overall system of *farm management and food production* that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes. The organic production method thus plays a dual societal role, where it on the one hand provides for a specific market responding to a consumer demand for organic products, and on the other hand delivers public goods contributing to the protection of the environment and animal welfare, as well as to rural development.

2) The **share of the organic agricultural sector** is on the increase in most Member States. Growth in consumer demand in recent years is particularly remarkable. Recent reforms of the common agricultural policy, with its emphasis on market-orientation and the supply of quality products to meet consumer demands, are likely to further stimulate the market in organic produce. Against this background, the legislation on organic production plays an increasingly important role

in the agricultural policy framework and is closely related to developments in the agricultural markets.

3) The development of organic production should be facilitated further, in particular, by **fostering the use of new techniques and substances** better suited to organic production. There is a need for development of an organic-based biofertilizer for organic farming. Organic farmers are no more allowed to use manure from conventional farming.

What should be done for better sustainable future?

The applicable regulatory bodies, the policy makers, the scientific community, the product proponents, and the farmer associations/organizations should concentrate their efforts to:

- Develop and/or review existing fertilizer and pesticide policies to include biofertilizers and biopesticides;
- Enact and/or review laws on fertilizers and pesticides to include biofertilizers and biopesticides;
- Review of existing regulations on fertilizers and pesticides to include biofertilizers and biopesticides;
- Develop standards for biofertilizers and biopesticides. These should include Standards Operating Procedures (SOPs) and norms on quality, safety, efficacy, testing, labeling and registration;
- Establish institutions, facilities and human resources to facilitate the production and testing;
- Encourage regional integration efforts for harmonization of policies, laws, regulations and standards;
- Disseminate information to stakeholder groups and ensure access to approved biofertilizers and biopesticide products.

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