Biofertilizers - Current Status of Indian Agriculture

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Article history: Received 25 October 2012, Received in revised form 28 November 2012, Accepted 3 December 2012, Published 13 December 2012.

Abstract: Present paper describes current status of biofertilizers in Indian agriculture. Biofertilizers are natural fertilizers that are microbial inoculants of bacteria, algae, fungi alone or in combination. They are defined as a product containing carrier based (solid or liquid) living microorganisms that are agriculturally useful in terms of nitrogen fixation, phosphorous solubilization or nutrient mobilization. They augment the availability of essential elements like nitrogen, potash, phosphorous, sulphur by directly supplying them or transforming them into soluble form. In addition, they also help plants to uptake several micronutrients. Types of biofertilizers viz., Rhizobium, Azospirillum, Azatobactor, blue green algae, blue green algae (BGA) inoculation, Phosphorous solubilizing biofertilizers, Mycorrhiza etc., are used predominantly in India.

Keywords: biofertilizers; Azolla; blue green algae; Mycorrhiza; acetobactor; Azospirillum.

1. Introduction

The green revolution brought impressive grains in food production but with insufficient concern of sustainability. In India availability and affordability of fossil fuel based chemical fertilizers at the farm level have been ensured only through imports and subsidies. Dependence on chemical fertilizers for future agricultural growth would mean further loss in soil quality, possibilities of water contamination and unsustainable burden on agricultural system (Rajasekaran et al., 2011). The government of India has been trying of promote an improved practice involving use of biofertilizers.
These inputs have multiple beneficial impacts on the soil and can be relatively cheap and convenient for use.

Land represents twenty nine percentage of the world’s total area, yet it provides approximately ninety eight percentage of the food to world population. Out of this only 11 percentage is of high fertility and twenty eight percentage of moderate fertility. On the other had, there is increasing world population, which demands a constant supply of food for its survival. In the developing countries like India the situation is comparatively grimmer as it is the second most populous country in the world and it has limited resources to lead its burgeoning population.

2. History

The commercial history of biofertilizers began with the launch of nitrogen by Nobbe and Hiltner, laboratory culture of rhizobia in 1895 followed by discovery of acatabacter and then blue green algae and a host of other microorganisms. In Indian, N.V. Joshi indicted first study on legume \textit{rhizobium} symbiosis and the first commercial production started as early as 1956. Biofertilizers offer a new technology for agriculture holding a promise to balance many of the shortcomings of the conventional chemical based technology. The main incentive for farmers to use biofertilizers seems to be that they hope to increase the yield or quality of their crops at a relatively low cost without a large investment of money.

2.1. What are Biofertilizers?

Biofertilizers more commonly known as microbial inoculants are artificially multiplied cultures of certain soil organisms that can improve soil fertility and crop productivity. Although the beneficial effects on legumes in improving soil fertility was known since ancient times and their role in biological nitrogen fixation was discovered more than a country ago, commercial exploitation of such biological processes is of recent interest and practice.

Biofertilizers have an ability to mobilize nutritionally important elements from non usable to usable form. These microorganisms require organic matter for their growth and activity in soil and provide valuable nutrients to the plant. Biofertilizers are ready to use live formulates of beneficial microorganisms which on application to seed, root or soil mobilize the availability of nutrients by their biological activity in particular and help in building up the micro flora and in turn the soil health in general (Rajendra et al., 1998).

Biofertilizers have the ability to fix atmospheric nitrogen and mobilize phosphorus in soil from unavailable from the plant usable form (IFA - 2003). Biofertilizers include microorganisms and their metabolites that are capable of enhancing soil fertility, crop growth and yield. These include both
indigenous microbes and microbial inoculants that are microorganisms that replace fertilizers or increase a crop's fertilizer use efficiency (Panwar et al., 2000).

Thus we can conclude that biofertilizers are ready to use live formulations of beneficial microorganisms and their metabolites which are capable of enhancing the soil fertility, crops growth and yield by mobilizing nutrients from no usable form to usable form through biological processes.

2.2. Why Biofertilizers?

An ideal fertile soil is characterized not only by optimum physical properties and chemical constituents conducive for plant growth but also by a balance micro flora in the photosphere. With the introduction of green revolution technologies, there has been an increase in use of chemical fertilizers, pesticides, hybrid seeds, assured irrigation and cautious agronomic practices that have disturbed the equilibrium of the ideal soil. Due to this there is an ongoing attempt on the part of Indian Government to promote biofertilizers in Indian agriculture.

2.3. Availability and Cost

(a). Demand is much higher than the availability. It is estimated that by 2020, to achieve the targeted production of 321 million tones of food grain, the requirement of nutrient will be 28.8 million tones, while their availability will be only 21.6 million tones being a deficit of above 7.2 million tones. (b). Increasing costs are getting unaffordable by small and marginal farmers.

2.4. Effect of Chemical Fertilizers on Soil and Environment

(a). Excessive and imbalanced use of chemical fertilizers has adversely affected the soil, causing decrease in organic carbon, reduction in microbial flora of soil, increasing acidity and alkalinity and hardening of soil. (b). Excessive use of N-fertilizer are contaminating water bodies thus affecting fish fauna and causing health hazards human beings and animals. (c). Production of chemical fertilizers adds to the pollution.

To overcome the deficit in nutrient supply and to overcome the adverse effects of chemical cultivation it is suggested that effects should be made to exploit all the available resources of nutrients under the theme for integrated nutrient management. Under this approach the best available option lies in the complimentary use of biofertilizers and organic manures in suitable combination with chemical fertilizers. This integrated approach of nutrient management not only ensures higher productivity but also ensures the good health of our soil and environment. Biofertilizers are essential components of this approach and are being promoted to harvest the naturally available, biological system of nutrient mobilization. Biofertilizers have important environmental and long term implications, negating the
adverse effects of chemicals. At the farm level, the gains from increased use of the technology can spill over to other farms and sector through lesser water pollution then chemical fertilizers and even to extent organic manures can cerate (Rajasekaran et al., 2009).

The gains from the new technology coming through the arrest of soil damage may not be perceived over a short span of time unlike for chemical fertilizers, which yield quick returns. At the sometime the farmer has to considerable initial cost in terms of skill acquisition, trail and failure and risk. In agrarian situations where agent’s option operates with bounded nationality, adoption may be slow and influenced greatly by neighbors experience over time.

Although biofertilizers have been promoted as supplement of chemical fertilizers, in reality they are two alternative means of accessing plant nutrients. The strength of complementarily as against substitution between two inputs is open to empirical verification. The pricing of chemical fertilizers is from marginal cost based. The external cost of using chemical fertilizers though not measurable may also be taken into account when comparing with biofertilizers if the latter is to be promoted. It is good practice to promote biofertilizers as an input conjunctive to other forms of fertilizers, but keeping in view the protection given to chemicals, there is some ground for subsidizing the former to encourage their use.

Biofertilizers have various benefits, besides accessing nutrients, for current intake as well as residual, different biofertilizers also provide growth promoting factors to plants and some have been successfully facilitating composting and effective recycling of solid wastes. By controlling soil borne diseases and improving the soil health and soil properties, these organisms help not only in saving, but also in effectively utilizing chemical fertilizers and result in higher yield rates.

3. Success of Biofertilizers Technology

Government of India and the different state governments have been promoting use of biofertilizers through grants, extension and subsidies on sales with varying degrees of emphasis. With time farmers too learn about the technology forming their perception on the basis of agronomic realities of their regions, the knowledge gained from experiences of farmers around them and including themselves and the information provided by different disseminating agents and form their own decisions of adoption. Production of biofertilizers started in India with significant government involvement with active participation of the public sector that is directed more by public policy and social objectives.

Since biofertilizers are perishable and sensitive to quality of handling, the distribution of plants would be some extent reflects the regional distribution pattern. However this is only partially valid as units with large distribution network do distribute over larger area. This region wise distribution of
biofertilizers more dispersed relative to chemical fertilizers. Biofertilizers profit the extent of commercial success would be indicated by the participation of private commercial units so long as market is free for entry.

Biofertilizers is a substance which contains living microorganisms which, when applied to seed plant surface or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply of nutrients to the to the host plant (Vessey, 2003). Biofertilizers can be expected to reduce the chemical fertilizers and pesticides. The microorganisms in biofertilizers restore the soil's natural nutrient cycle and build soil organic matter. Through the use of biofertilizers, healthy plants can be grown while enhancing the sustainability and the health of the soil.

Biofertilizers are cost effective relative to chemical fertilizers. They have lower manufacturing costs especially regarding nitrogen and phosphorous use. It is environmentally friendly in that it not only prevents damaging the natural source but also helps to some extent cleanse the plant from precipitated chemical fertilizer. Since biofertilizers technology living, it can symbiotically associate with plant root, involved microorganisms could readily and safely convert complex organic material to simple compound. So, those plants are easily taken up. Microorganisms function is in long duration causing improvement of the soil fertility. It maintains the natural habitat of the soil. It increases crop yield by 20-30% replace chemical nitrogen and phosphorous by 25% and stimulates plant growth. It can also provide protection against drought and some soil-borne disease.

One of the major concerns today's world is the pollution and contamination of soil. The use of chemical fertilizer and pesticides has caused tremendous harm to the environment. Biofertilizers are organisms that enrich the nutrient quality of soil.

3.1. Azolla

Azolla is a small-leaf floating fern, which contains an endosymbiontic community living in the dorsal lobe cavity of the leaves. The presence in this cavity of a nitrogen fixing filamentous cyanobacteria in to the only fern-cyanobacteria association that presents agricultural interest by the nitrogen input that this plant could introduce in the fields. The dwelling of fossil fuel reserves and the increasing costs of commercial nitrogen fertilizers implicate finding other alternatives, such as the use of biofertilizers, like the azolla-Anabaena symbiotic system.

The aquatic fern of the genus Azolla is a small-leaf floating plant, which contains an endosymbiotic community living in the dorsal lobe cavity of the pteridophyte leaf. This community is composed of two types of prokaryotic organisms. One species of a nitrogen-fixing filamentous cyanobacteria-Anabaena azollae and the variety of bacteria that some identified as Arthrobacter sp.,
and associate with others souring the presence of nitrogenase. In this association, it is assumed that an exchange of metabolites, namely nitrogen compounds, occurs from the cyanobiont to the host.

Azolla is an aquatic heterosporous fern, which contains an endothytic cyanobacterium, Anabaena azollae, in its leaf cavity. Anabaena is nitrogen fixing blue green algae. Azolla can grow very rapidly doubling its weight in three to four days under optimal conditions. Although Azolla Anabaena symbiosis has been used for centuries as green manure for rice in parts of China and Vietnam, intensive scientific research only began after the 1973 oil shock dramatically increased the cost of nitrogen fertilizers. It contains 2-3% nitrogen when wet and also produces organic matter in the soil. High yielding rice varieties linked to the green revolution require large amounts of expensive chemical nitrogen fertilizers. Scientists have long recognized that the aquatic nitrogen fixing Azolla-Anabaena symbiosis could replace at least part of the nitrogen requirement of rice.

These types of biofertilizers are used all over the world. It is mainly used in cooler region. But there is need to develop a strain tolerant to high temperature, salinity and strain resistant pest and diseases. The only constraints in Azolla are that it has to be kept always growing on water and water becomes limiting factor.

Production technology is very easy, and can be adopted by rice farmers. Recently Azolla anabaena symbiosis has becomes very popular in China, Indonesia, Philippines, India and Bangladesh. A total of seven species of Azolla are known so far A. caroliniana, A. filoiculoides, A. mexicana, A. microphylla, A. nilotica, A. pinanta and A. rubra. Out of these A. pinnata is commonly found in India. The global collections of several species of Azolla are maintained at CRRI (Cuttack). The 70% to 80% of the nitrogen in Azolla is derived from atmospheric fixation and there is no evidence of significant competition with limited soil nitrogen. Anabaena Azolla multiplies 100 folds, resulting in yield of 10-5 tons fresh materials/ha and thus improves the physicochemical properties of soil fixers considerable amount of nitrogen (60-80 kg/ha). In fact, the most recent experiments have shown that a cover of Azalla floating on the surface of rice flood water can even improve the efficiency of chemical nitrogen fertilizers.

Azolla fortunately limits algae growth through shading of the flood water. Following fertilizer applications, lower pH values by one to two units were observed when Azolla was present. The second effect is that Azolla takes up part of the nitrogen fertilizer from the water. If the Azolla is then incorporated into soil, this nitrogen fertilizer becomes available to the rice along with the fixed nitrogen. When Azolla was incorporated into the soil, it proved to be good as urea as a nitrogen source for rice. Not only the up take of nitrogen from Azolla was equal to that from urea but there was also the additional benefit that more of the nitrogen added as Azolla remained in the soil after harvest. In case,
may be the next crop to produce a yield increase of two to three times compared to urea, estimated savings from one crop of rice by the use of Azolla as a nitrogen fertilizer is substantial.

3.2. Blue Green Algae

Blue green algae (BGA) are photosynthetic nitrogen fixers and are free living. They are found in abundance in India. They too add growth promoting substances including vitamin B12 improve the soil aeration and water holding capacity and add to biomass when decomposed after life cycle.

BGA are considered to be an important group of fixing atmospheric nitrogen both symbiotically and asymbiotically. Their maximum utilization is in the economic development, environment management like production of fine chemicals, treatment of waste, purification of contaminated polluted water, nitrogen fixation and in production of methane fuel. Most of the biological nitrogen fixing strains of BGA belongs to the order Nostocales and stigonematales under the various genera - Anabaenopsis, Aulosira, Calothrix, Chloroglea, Cylindrodermum, Nostoc, Calothrix, Scytonema, Tolypotheix, Ereila, Haplosiphon, MasFischitigocladius, Stigonema and Westnellopsis. In pure cultures, blue-green algae fix varying amounts of nitrogen raging from 5.2 to 14.8 mg/100 mL of the medium, depending upon the incubation time (Carrapico et al., 2000).

In general, nitrogen fixation is associated with forms possessing heterocyst, although there are some unicellular and filamentous non-heterocyst strains, which fix nitrogen. The amount of nitrogen fixed is dependent on physiological and environmental factors such as intensity of light, concentration of inorganic nitrogen sources, and concentration of dissolved organic compounds, temperature and aeration of substrate. The nitrogen fixing capacity of blue green algae can be estimated by means of heterocyst. Heterocyst provide a congenial environment for the effective functioning of nitrogenous, to generate energy and reluctant required for nitrogen, fixation, to bring the nitrogen fixed into organic combination and to maintain a dual transport system for getting carbon and sending out nitrogen into the vegetative cell.

Blue green algae as biofertilizers, can play an important role in the nitrogen economy of India. The port trial suggests that the algae N-fixation rates are as much as 70 kg N/ha. In six weeks increased grain yields of 33% N-fixation and grain yield from the field tails have been judged against controls without added inorganic nitrogen in the field, an average of 30 kg N/ha fixed per rice cycle. BGA can grow in extreme conditions and show luxuriant growth in flooded paddy fields within two weeks. No need to use chemical fertilizers like urea, Di-ammonium phosphate for the crop while using algal biofertilizers.

Biofertilization of rice fields by inoculation with free-living BGA is termed algalization. Algalization technology or method of inoculation production by farmers was developed in India.
Technical methods for production of cyanobacterial biomass were first developed in Japan for *Tolypothrix terris*. In 1979, All India Co-ordinated project on Algae (AICPA) recommended that Indian farmers should prepare their own algal inocula in out door soil culture.

Usually a mixed culture of *Aulosira, Anobaena, Nostoc Plectonema* and *Tolypothrix* is grown in small (2 square meter) ponds for two months. Dry algal flake is taken from these ponds and 6.8 kg of there are inoculated per hectare one week after transplanting rice seedlings. This technology has been applied to cover 3 million hectares in India and good results are shown. Many Indian paddy soils already having large numbers of heterocystous BGA therefore, legalization might be easy to the farmers.

3.3. *Rhizobium*

*Rhizobium* is a Gram negative soil bacteria, in symbiotic association with leguminous plants fix atmospheric nitrogen in nodules formed on the roots of the plants. These nodules are considered as miniatures nitrogen factoids in the field. Nitrogen fixation by contributes substantially to total biological nitrogen fixation. *Rhizobium* inoculation is a well-known agronomic practice that can supply 50-100 kg N/hect to legume and increase yield up to fifteen to twenty five percentages.

Inculcation with *Rhizobium* helps to save nitrogen fertilizer and increase grain yield by about 10-20 per cent depending upon the crop and soil conditions. The root secretions from the leguminous plants and biological material released from the decomposed nodule enrich the fertility status of soil. These inoculants are known for their ability to fix atmospheric nitrogen in symbiotic association with plants forming nodules in roots (Rajasekaran et al., 2011). The nodule forming bacteria into the following groups: Genus I: *Rhizobium* - It consists of the fast growing and flagellated strains. Genus II: *Bradyrhizibium* - It contains the slow growing or sub polar flagellated strain. *Rhizobium* is divided into several species chiefly on the basis of the legume species which are able to nodulate, for example *Rhizobium leguminosorum*.

Soil contains native species of *Rhizobium* but all are not capable of forming nodules. Some of the strains are highly specific to certain species called as cross inoculation groups. The principles of cross inoculation grouping are based on the ability of an isolate of *Rhizobium* to form nodules in limited genera of species of legumes related to one another. All *rhizobia* that could form nodules on roots of certain legume types have been collectively taken as a species. This system classification has provided a workable base for the agricultural practices of legume inoculation. The system of cross inoculation grouping of *Rhizobia* is not perfect since bacteria have often been found to cross infect.

All *Diazotrophs* possess an enzyme nitrogenous, which helps in conversion of N₂ to NH₃. Biding of nitrogen by nitrogen is the crucial step in the nitrogen fixation. *Nitrogenase* is an equilibrium
mixture of Mo-Fe-Protein (component I) and Fe-protein (component II) in the ration of 1:2. Component I is called nitrogen's and both components are essential for nitrogen's activity.

Strains of *Rhizobium* species are grown in yeast extract mannitol (YEM) broth. Sterilization of the growth medium is followed by inoculation with broth of mother culture prepared in advanced and is incubated at 3-32 °C for three to four days. The purity of the culture is tested and is transferred to a large fermented and incubated for 4-9 days. This broth is further blended with sterile carrier i.e. ligniter, farmyard manure and charcoal powder. Culture is packed in polythene bags and stored at 4 °C. Good quality of carrier culture is which contains sufficient amount of rhizobia cells i.e. $1000 \times 10^6$ to $4000 \times 10^6$ rhizobia per gram carrier.

Biofertilizers have to be applied carefully to produce desired benefits. Biofertilizers are applied to seed, seeding or soil. However seed treatment is preferable. For seed treatment inoculums slurry is prepared by dissolved 10% sugar or gaur in water, boiling and then cooling this solution and add 10% gum Arabic solution. This whole solution serves as sticker solution for rhizobial cells to seeds. Mix carrier based *Rhizobium* culture with sticker solution to form the inoculation slurry. Pour this slurry over the seeds to be treated. Mix seeds with inoculums slurry by hand. Dry the seeds in shade and show them immediately. Under adverse soil condition, adopting special method of inoculums protects the *Rhizobial* cells. One of these methods is preparation of pelleted seeds, high amount of gum Arabic (40%) or carboxyl methyl cellulose (20%) is added to the inoculums slurry. After that, pelleting agent (calium carbonate, rock phosphate, charcoal powder, and gypsum) is mixed when inoculated seeds are moist to get the seeds evenly coated.

In India, about 30 hect are of area is under pulses, including gram and forage legumes in our country. Our requirement for *Rhizobial* inoculants to cover this entire area will be around 15000 tonnes and the present production is only around 800 tons. The efficacy of *Rhizobium* inoculant on has been established in India by the result of coordinated trails conducted by the IARI in farmer’s field. Several experiments conducted in India have shown that nearly 50% nitrogen fertilizers can be saved through out inoculation with efficient strains of *Rhizobia*.

3.4. *Azotobactor*

*Azotobactor* is free-living aerobic nitrogen fixing bacteria. They grow in rhizosphere and fix atmospheric nitrogen non-symbiotically. They are mostly found in associating with cereals, vegetable crops cotton, millets, and sugarcane. *Azotobactor* was first isolated by Beijerinick. Four popular species of *Azotobactor* are *A. chroococcum*, *A. Vinclandi*, *A. beijernik*, and *A. paspali*. In addition, these bacteria produce growth promoting substances, which enhance the plant growth and yield and
suppress many root pathogens. Most efficient strains of *Azotobactor* fix 30 kg nitrogen from 1000 kg of organic matter. When applied to fields, the positive responses by field crops were observed leading to saving of 10-25 kg/ha of nitrogen. A highly efficient strain of *Azotobactor* is grown in to laboratory either as shake culture or using fermenter. *A. chroococcum* is a dominant species in arable soils; where as other species of *Azotobacter* are known to form cysts to withstand adverse conditions. Each cyst has a living cell with two coasts. The cysts accumulate polyhydroxlyic acid. With the onset of favorable conditions, the cysts give rise to important cells. Pigment production is one of the important characteristics of *Azotobacter* species. *Azotobactor* inoculation saves addition of nitrogenous fertilizers by 10-20%. Field experiments have been done in India extensively on *Azotobactor* inoculation of seed or seeding of onion, brinjal, tomato, and cabbage under different agro-climatic conditions. *Azotobactor* is effective only in soil with a native *Azotobactor* population. Many experiments have been performed in several countries to investigate the effects of the inoculation of various strains of *A. Chroococcum* on cereals and grasses.

3.5. *Azospirillum*

*Azospirillum*, a member of Spirillaceae, is associative nitrogen fixing microorganism beneficial for non-leguminous plants. Associative diazotrophs are those in which is some in independence between the partners but they can grow satisfactory apart. They are found in association with cereals, grasses, vegetables, and oil seeds either freely in soil or indeed the root system. They not only fix nitrogen but also benefit plants by supplying growth hormones and vitamins. *Azospirillum* with farmyard manure (FYM), led to saving of 15.25 kg equivalent of nitrogen also the above ground portion of plant through associative symbiosis. They fix nitrogen from 10 to 40 kg/ha. The *Azospirillum* inoculation helps the plants in better vegetative growth saving nitrogenous fertilizers by 25-30%. *Azospirillum* are micro-arophilic in nature. Three species of *Azospirillum* have been identified, and they are *A. lipoferum*, *A. brasilense*, and *A. amazonenes*. *Azospirillum brasilese* is abundant in Indian soil. *Azospirillum* is often used with Mycorrhizal fungi for optimum growth and yield. One of the characteristics of *Azospirillum* is its ability to reduce and denitrify, therefore it is these characters. Inoculations with *Azospirillum* have registered increased in different vegetable crops. Its application is common practice in vegetables in Tamil Nadu. Increased yield in pear miller obtained by inoculation of *Azospirillum* was due to production of indole acetic acid (IAA), gibberellins, any cytokine like substances by the bacterium and their subsequent effect on the plant (Kumar *et al.*, 2010).

*Azospirillum*, a bacterial biofertilizer is highly beneficial for cereals, millets, sugarcane, cotton sunflower and other crops. *Azospirillum* assimilates atmospheric nitrogen. It also secretes *phyto-hormones* in the plant root regions, which intern enhances the root growth. The results of the various
experiments conducted throughout India have clearly shown that **Azospirillum** can be used as a potential biofertilizer in both expensive and intensive agriculture. In developing countries like India, the use of **Azospirillum** as a biofertilizer would not only to the nitrogen supplementation to crops but also help in improving the fertility of soil in the long run.

### 4. Phosphorous Biofertilizers

Phosphorous is very often present in the soil in unavailable form. Several soil bacteria particularly those belonging to the genera Bacillus and Pseudomonas posses the ability to bring insoluble phosphates in the soluble forms by secreting organic acids. These acids lower the pH and bring about the dissolution of bound forms of phosphorous. These bacteria are commonly known as **phosphobacteria**. They can be applied either through seed or soil application. Phosphorus, both native in soil and applied to inorganic fertilizers becomes mostly unavailable to crops because of its low level of mobility and solubility and its tendency to become fixed in soil. The phosphate solubulizing bacteria are life forms that can soil. The phosphate solubulizing bacteria are life forms that can help in improving phosphate uptake of plantain on different ways.

Phosphorous is one of the important elements for plant growth. It is the second major chemical fertilizer, being applied for crop production. For optimum crop production such as wheat, soil level should be maintained above 30 ppm available P in the top 15 cm. It is anticipated that only 10-15% recovery is obtained for applied P fertilizers by plants. The remainder of the fertilizers-P is accumulating in the soil. This is as two major forms: inorganic soil 'P' which comprises adsorbed phosphate and precipitated Fe, Al, Mn (e.g. FePO₄, AlPO₃, Ca₃(PO₄)₂⁻ acidic soil and Ca salts (e.g. Ca₃(PO₄)₂⁻ alkaline soils. Another general form of unavailable soil phosphorus is organic soil P, which comprises in phosphates, phospholipids, nucleic acids etc. It occurs in inorganic as well as organic form, inorganic forms are compounds of calcium, iron, and aluminium in rock phosphates and organic forms are phytin, phospholipids, nucleic acids, mositol phosphates which are added to the soil by decaying vegetation. Rock phosphate is the raw material for the production of phosphate fertilizers. Phosphate biofertilizers were first prepared by USSR using *Bacillus magaterium* var. *Phosphaticum* as phosphate solubulizing bacteria and product was termed as phosphobacter. Phosphorous both native in soil and inorganic fertilizer becomes mostly unavailable to crops due to chemical fixation. It is due to low level of mobility and solubility of phosphorus and its tendency to become fixed in soil. Phosphate solubulizing biofertilizers are life forms that can help in improving phosphate. Soil contains body indigenous heterotrophic microorganisms, which solubilize mineral bound phosphates by the excretion of chelating organic acids. Microorganisms viz. *Bacillus megaturium*, *Bicillus polymyxa*, *Pseudomonas striata*, *Aspergillus arvamori*, *Penicillium*, can produce several organic acids (butyric citric acid,
fumaric acid, succinic acid, and propionic acid) and convert unavailable phosphorous to available phosphorous which is called as phosphorous solubilization. These acids lower the pH and bring about dissolution of phosphate by crops. In grassland soil phosphate solubilizing microorganisms made 1% of bacterial population and 10% fungal population. Many countries are studying the direct utilization of rock phosphate. Australia has developed "Biosuper" i.e. pellets composed of rock phosphate, sulphur and sulphur oxidizing bacteria. Heterotrophic phosphate solubilizing microorganisms need a large amount of organic matter before they can excrete organic acids. Even if phosphate is solubilized, and phosphate ions are incorporated into the microbial biomass, so roots cannot absorb enough of them. The following strategy will be effective in this condition. The addition of large amount of organic matter makes phosphate-solubilizing microorganisms proliferate and these solubilise bound phosphate. Solubilized phosphates are incorporated into microbial biomass during other microbial multiplication, using organic matter.

Once the organic matter becomes exhausted, the microbial biomass decreases and releases phosphate into soil. The death of microbial biomass can be accelerated by various soil treatments, including tillage, drying and sterilization. Plants can absorb phosphate after microbial proliferation has ceased. The absorption of phosphate by plants can be accelerated by inoculation with AMF.

Through biological nitrogen fixation, solubilization of insoluble phosphates and mobilization of plant nutrients more quantities of nutrients are made available for crop plants by the root associated organisms. Increased nitrogen, phosphorus and potassium content of inoculated plants at different stages of crop growth have been recorded (Rajasekaran and sundaramoorthy, 2010).

5. Production of Plant Growth Promoting Rhizobacteria

Root colonizing bacteria like, *Azospirillum*, and *Pseudomonas* species are known to produce growth hormones which often leads to increase root and shoot growth. Plants differ in the leaves and ration of the hormones required to maintain normal growth and development. Industrial production of inorganic fertilizers a costly process dependent on energy derived from fossil fuel, which is getting depleted at a faster rate. On the contrary use of microbial inoculants is not only a low cost technology but also takes adequate care of soil health and environmental safety. Intensive search a number of microorganisms have been recognized as nitrogen fixers. This is no doubt a low cost technology capable of bringing rich-dividends to the farmers. However, transferring a technology to the farmers field is of paramount importance. Generally the effect of biofertilizers on crop growth and yield is not as sticking as that of chemical fertilizers. Since it is a living system and the influence is subject to environmental, biological and nutritional stresses.
6. Mycorrhizae

More than 400 million years ago, plants evolved a symbiotic relationship with mycorrhizal fungi that is still very critical for plant health today. Mycorrhizal symbioses are attractive systems in agriculture, floriculture, horticulture, arboriculture and forest management to enhance crop and wood production in the sense of sustainable agriculture and restoring soil fertility. It can be defined as a symbiotic association of non-pathogenic fungi with roots of higher plants. So, the nutrients absorbed from the soil by the fungus are released to the host cells and in turn the fungus fulfils its food requirements from the host. Generally while the fungus provides the plant with minerals, especially, phosphorus and the plant supply the fungus with the photosynthetic sugars. Mycorrhizae are able to absorb, accumulate and transfer all of the major and minor mineral elements and water to plants more rapidly than roots with no mycorrhizae.

Mycorrhizal fungi can increase the yield of a plant by 30-40%. Plants that suffer from nutrient scarcity, especially, phosphorus develops mycorrhizae. Association of mycorrhizae is wide spread in bryophytes a large number of pteridophytes, most or all species of Gymnosperms and some 90% or more of angiosperms. In recent years use of artificially produced inoculums of mycorrhizal fungi has increased due to its significance and multifarious role: (1) Benefits more then 99% of earths plants; (2) Increase absorptive surfaces or root systems up to 700%; and (3) Can occupy 100 times more soil volume than a non-mycorrhial plants entire root system. Extend through the soil up to 30 feet away from a plant host. Depress many root diseases caused by pathogenic fungi and nematodes. Develop tolerance to climatic and edaphically stresses including high soil temperature and heavy metal toxicity.

6.1. Ectomycorrhiza

It is also called as Ectotrophic mycorrhizae and found in approximately 10% of the world flora. It colonizes outside of plants cells and a root such as the fungus completely encloses each feeder rootlet in a sheath of mantle of hyphae, which penetrate only between the cells of root hairs. But due to the presence of layer of hyphae it almost looks like a host tissue and this layer is known as pseudoparendchymatous sheath. From this sheath hyphae enter the cortex and remain only in the outer cortical cells to form a network called as Hartig net. All the nutrients are absorbed by the fungal mantle and transported to the root through the Hartig net. The fungi involved in ectomycorrhizae come under Basidiomycetes and they grow best at pH 5-6. The excess of inorganic fertilizers suppress ectomycorrhizal development and this results in the stunted growth and chlorosis. When the defense reaction of the higher symbiont diminishes, as it is likely to happen in senescent or diseased trees, the
lower symbiont may become endotropic. Such instances have been designated as *ectoendomychorrhizae*.

### 6.2. *Endomycorrhizae*

For *Endomycorrhizae*, the fungus does not form and external sheath but colonizes inside the plant root cells and establishes direct connections between the cells of the roots and surrounding soils. The fungi involved in endotropic association belong to either to the *Basidiomycetes* (possessing aseptate hyphae) or to the *Basidiomycetes* or fungi Imperfecti (possessing septate hyphae). Root colonization involves the formation of intracellular and highly branched hyphae scattered throughout the root system. The establishment of an intracellular symbiosis between the fungus and the host roots requires the penetration of the cell by fungal cell well hydrolyzing enzyme. Fungal hyphae enters the cells of the host plant and thus penetrates the cell wall at the site of contact with the aid of various hydrolytic enzymes like xylanases, pectinases and celluloses, the fungi can break down lignin and cellulose and thus contribute to the decaying of organic matter. In this respect they differ from *ectomycorrhizal* fungi on the host for their carbon nutrition.

For *ectomycorrhizal* fungi the basidiospores, pure mycelial culture, chopped sporocarp, sclerotia and fragmented *mycorrhizal* roots or soil from *mycorrhizosphere* region can be used as inoculum. The inoculum is mixed with nursery soils and seeds are sown. Now a day's commercially available mycelial inoculum are also available in the market.

### 6.3. *VAM (Vesicular-Arbuscular Mycorrhizae) Fungi*

*Vesicular Arbuscular Mycorrhizal* (VAM) fungi form symbiotic association with a number of economically important crop plants. These fungi can improve the plant growth through increased uptake of phosphorous, sulphur, calcium and zinc. Further these fungi are known to enhance resistance to diseases and help the host plant to absorb more water under moisture stress conditions.

VAM fungi are the ubiquitous soil microbes found associated with most of the angiosperms, pteridophytes, and bryophytes but absent in plants which from only *ectomycorrhizae* (pinaceae, betulaceae) or the two other specific types of *endomycorrhiza* of Ericales and Orchidales. VAM develop special structures called as arbuscles and vesicles that help in the transfer of the nutrients especially phosphates from the soil into the root system. VAM has been reported from 1000 genera of plants representing from 200 families. Fungus associated with VAM is generally non septate *Zygomycetes* belonging to the genera Clomus, Gigaspora, Acaulospora, Seerocystis and Endogone. The fungi being obligate biotrophs don't grow on synthetic media and hence are classified according to the morphological characteristics of the spore formed in the soil.
The efficient VAM fungal strains are the potential candidates as biofertilizers for their use in crop production. VAM increases the plant growth mainly by increasing the soil volume from which plant absorbs relatively less mobile nutrients such as Zn, P, and Cu etc., which are very important for optimum plant growth (Harley and Smith, 1983). However response to VAM fungi may very depending upon crop species, soil P levels and the presence of other microorganism in the root regions.

A combination of the Rhizobium, legumes and mycorrhizal fungus brings a significant improvement in plant growth not only through increased availability of phosphorus but also with higher nitrogen fixation in the soil. The interaction of VAM fungi with nitrogen fixing microbes has synergistic effects and may prove the cheapest why to enrich the soil with nitrogen.

The potential of Arbuscular mycorrhizal fungi as biofertilizers and bioprotectors to enhance the micro propagated plantlets. One of the major implements to the success of micro propagation is the very high mortality rate of tissue culture plantlets either during acclimatization phase or during transfer to field conditions attributed mainly to desiccation and microbial infection. It appears that the advantages of VAM association, such as improved uptake and transport of water and other nutrients, tolerance to root pathogens resulted in reduction of the mortality rate of tissue culture (TC) plantlets.

Besides VAM can be used as a disease control agent as the fungus is said to be releasing such chemical compounds which have an inhibitory effect on the pathogens. Studies have shown that VAM formed by Gigaspora exhibits the inhibitory effect on the development of pigeon pea blight caused by Phytophthora drechsleri.

### 7. Green Manure

The practice of green manuring was an ancient practice in India and China. But with time availability of chemical fertilizers decreased the significance of green manuring, which is reemphasized. Green manuring is a farming practice where a plant generally a leguminous one which has derived enough benefits from its association with appropriate species of Rhizobium is ploughed into the soil and then a non legume is grown and allowed to take the benefits of the already fixed nitrogen. In addition to nitrogen, green manures also provide organic matter, phosphorus, potassium and minimize the number of pathogenic microorganisms in soil. In India, for small and marginal farmers, green manuring is very important because of high cost of chemical fertilizers.

### 8. Mixed Biofertilizers

Mixed biofertilizers containing a consortium of N fixers, P solubilisers and plant growth promoting Rhizobacteria (PGPR) were found to promote the growth of cereals, legumes and oil seeds better and save nitrogen and phosphate fertilizers in crops. Response was better and there was 50%
nutrient substitution in crops like rice and legumes depending upon soil type and yield level. The response of biofertilizers was better when used along with 75% chemical fertilizers.

9. Recent Advances in Biofertilizers and Indian Perspectives

It is quite evident that no single source of plant nutrient whether it is chemical fertilizer, organic fertilizer, and green manure or biofertilizers is in a position to meet the growing crop nutrient need. Furthermore the right kind a nutrients required by the crops may not be achieved from a single source. So, Integrated Plant Nutrient Management (IPNM) practices are being followed which aim at maintaining the soil fertility and nutrient supply for sustainable crop productivity by adjusting chemical fertilizers, organic manure, biofertilizers and crop residues. Different proportions of these components are to be used based upon crop requirements and availability of materials India, being agriculturally diverse in terms of soil fertility, harvesting pattern, irrigation habits and other agronomic practices, it is not possible to study every individual field or crop with respect of the IPNM. On the other hand the cropping system and the farming system can be the focus of the strategies to develop IPNM systems for major agro-ecological zones and various categories of farms throughout the country.

In some countries like Japan there has been an increasing use of briefly composted organic fertilizer obscuring the direct effectiveness. The brief composting makes it less susceptible to pests. Its use is very important when there is limitation of water. Plant under stress increases the osmotic pressure in their fluid by increasing the concentrations of mono- and oligosaccharides instead of starch. This results in a higher level of sugars and vitamins in the vegetables as well as a longer post harvest storage life. When vegetables are being cultivated in a state of water stress, the application of ordinary chemical fertilizers is very difficult, because a rapid increase in the concentration of mineral nutrients in a small amount of soil water frequently damages plant growth. It can be a good perspective in Indian agriculture because only 60% of its arable land is rain fed. Especially the arid and semiarid regions of Gujarat, Rajasthan, Madiya Pradesh and Haryana etc., where there is scarcity of water, can be benefited. It only will increase the crop yield but also save the expenditure on chemical fertilizers. These possibilities can be probed with proper planning plant research programme.

Nowadays the microbes used as agricultural inoculants are improved by genetic manipulations which includes introduction of novels genes to non leguminous and leguminous crops, genetic modifications to minimize the escape of the introduced genes to other microbes and to the environment and also to optimize the expression of the desired gene.

The current gross cropped area in India is 190.6 m hectare and the current population of the country is 100 Crores. With the current rate of population increase India will have a population of 150
Corers by 2025. We need to produce 310 m tons of food grain. Green revolution technologies like heavy use of chemical fertilizer, pesticides, hybrid seeds and improved agronomic practices etc. has resulted in significant increase in agricultural productivity in India, fertilizers consumption increased from less than 50,000 tons in 1950 to 20 million tons in 2,000 indicating a direct relationship between the fertilizer use and yield increase. Consumption of chemical fertilizers has increased from 0.23 m tons in 1960-61 to 16.6 million tones in 1998-99 in which N.P.K. constitute 11.34 and 1.3 m tons respectively. Urea is the most widely used nitrogenous fertilizer and make for 83% of N₂-diammonium phosphate is dominant phosphate fertilizer accounting for 58% of total phosphorus consumption. It has been projected that in 2011, the fertilizer production and requirement will be 15.8 and 20.2 in tons respectively. Considering the level of crop production during 1996-97 in India, the annual nutrient removal from soil was about 26 m tons whereas supply from chemical fertilizers was 14 m tons thus leaving a gap of 12 tons. Biofertilizers offer a new technology to Indian agriculture holding a promise to fill this gap and balance many of the shortcomings of the conventional chemical based technology. The first commercial production of biofertilizers started in 1956 but initially there were some constraints in spreading of biofertilizers as an industry. It's only in the ninth plan that Govt. of India (GOI) has initiated some real efforts with the establishment of National Project on Development and use of Biofertilizers (NPDB).

Based on the data for 1995, 1997, and 1999 it appears that the industry witnessed a steady increase in the number of units producing the input. Over the period of 4 years the number of units went up by 53% from 62 to 95 and further to 122 in 2002 (Ministry of Agriculture, GOI). The total capacity expanded by 102% going by the information on units reporting their capacities and a considerable change has been reported in the composition of biofertilizers production (Tables 1 & 2).

The fertilizer consumption varies from 130, 125, 60 and 70 kg Hect (NPK) for north, south, west and east respectively making for a national average of approx. 90 kg/Hect. Some states like Punjab are using more than 167 kg nutrients per hectare as against some using less than 10 kg nutrients per hectare. Even the full potential of available technologies is not fully utilized due to the fact that nutrient input doesn't match the needs of crop and soil.

In case of biofertilizers the production and supply of microbial cultures, the quality of the cultures and the lack of publicity are affecting their popularity as nutrient sources. The government has no control over manufactures of biofertilizers for any of the state of India. Only a few entrepreneurs posses ISI mark for their products and most of the products are of substandard quality. Due to these laxities on the part of Govt. the farmers are confused about their rates, availability and expiry dates. The necessary action by government and its policies will certainly go to a long way in the further development of the biofertilizers.
10. Conclusions

Plants survive on essential nutrients like NPK and 13 other minerals, which they receive from soil and carbon source they derive through photosynthesis. Their requirements have gone up considerably per plant because of the leaching away of nutrients from soil and reduced uptake by the plants grown on intensively cropped soil, thus resulting in use of chemical fertilizers. In agriculture driven economy such as Indian, long-term sustainability is possible only through the use of low cost farm grown inputs which work in harmony with the nature. Biofertilizers perfectly fits in the picture with their wide spread applications as discussed above. But it should be remembered that biofertilizers are the supplements and not the substitutes to chemical fertilizers. Also the biofertilizers are crop specific, soil specific and location specific. Thus a strategy for judicious combination of chemical fertilizers and biofertilizers will be economically viable and ecologically useful. For successful launching of a biofertilizers programmed it is necessary to equip the extension machinery at the grass root level with the full technical back up of production as well as application technology. Once the farmers are convinced that the biofertilizers are an inexpensive but effective way of keeping their soil
fertility, they will accept them and this will lead to higher crop production and higher economic returns. All out efforts should be made to educate farmers to practice balanced use of biofertilizers, and the time has come for the researchers, farmers and other related communities to come forward and act in this respect.

The technology is new and it will take sometime to mature and may not give quick returns. So, the Government should play an important role in, should fund the farmers with proper polices, and should fund the research on biofertilizers open mindedly. There can be some focus on development of suitable carriers, better packaging and longer shelf life. The genetically engineered version of microbes should be released only after proper bio-safety risk assessment and the government's policy should be clear in this regard. With the proper care the biofertilizers have got a bright future ahead and certainly it will go in long way to serve Indian agriculture. Cities have argued that green revolution simply borrowed production from future generations as it improver shed soils and destroyed ecological balances. The government of India has been promoting the use of biofertilizers in agriculture through the governments also added to the process that subsidization and extension.

References


