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BIO-FERTILIZERS, AN IMPORTANT COMPONENT OF MODERN AGRICULTURE

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Abstract: Bio-fertilizers are one of the important components of modern agriculture. Bio-fertilizers are applied in the agricultural fields as a substitute to our conventional fertilizers containing compost, household wastes and green manure. Conventional fertilizers being less effective than chemical fertilizers are not preferably used by farmers and they often try to use chemical fertilizers in the field for crop improvement. The chemical fertilizers on the other hand are not ecofriendly. They negatively affect the environment by diluting the quality of water, air and soil and can spread cancer causing agents. Moreover, they may destroy the fertility of soil in the long run. Bio-fertilizers contain microorganisms which promote the adequate supply of nutrients to the host plants and ensure their proper growth and development. Only those microorganisms are used which have specific functions to enhance plant growth and reproduction. Bio-fertilizer being essential components of organic farming plays a vital role in maintaining long term soil fertility and sustainability.

Introduction: Bio-fertilizers form one of the important components of modern agriculture. Bio-fertilizers are applied in the agricultural field as a substitute to our conventional fertilizers. Conventional fertilizers comprises of compost, household wastes and green manure. These are not as effective as chemical fertilizers. So, farmers often try to use chemical fertilizers in the field for crop improvement. But chemical fertilizers are not environment friendly. They are responsible for water, air and soil pollution and can spread cancer causing agents. Moreover, they may destroy the fertility of the soil in a long run. The bio-fertilizers provide nutrient supplement inputs for plant growth which are biological origin. The bio-fertilizers in agricultural production assume special significance, particularly in the present context of expensive chemical fertilizers. Moreover, it can provide the farmers with a new strategy which is helpful for achieving the goal of increasing productivity. Keeping in mind the environment safety, food security and availability of resources, it becomes obligatory to explore the full potential of the available bio-fertilizers.

Organic farming has emerged as an important priority area globally in view of the growing demand for safe and healthy food, sustainability and concerns on environmental pollution associated with indiscriminate use of agro chemicals. Though the use of chemical inputs in agriculture is inevitable to meet the growing demand for food in world, there are opportunities in selected crops and niche areas where organic production can be encouraged to tap the domestic export market. Bio-fertilizers being essential component of organic farming are the preparations containing live or latent cells of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic micro-organisms. Bio-fertilizers play a very significant role in improving soil fertility by fixing atmospheric nitrogen, both, in association with plant roots and without it. It also helps to solubilise insoluble soil phosphates and produces plant growth substances in the soil. They are in fact being promoted to harvest the naturally available, biological system of nutrient mobilization^[1]. The role and importance of bio-fertilizers in sustainable crop production has been reviewed

by several authors. But the progress in the field of Bio-fertilizers production technology remained always below satisfaction in Asia because of various constraints. Bio-fertilizer use has therefore become an essential input along with the use of other organics in intensive agriculture due to its crucial role in augmenting nutrient supply to crops, by increasing the nutrient availability through exploitation of natural processes like biological N fixation, solubilization of insoluble P, decomposition and recycling of organic wastes, etc. It has become more so at a time when excessive use of chemical fertilizers and their increasing demand in intensive farming have increased, but posing a serious threat to soil health, environment and sustainability in food grain production. In contrast to chemical fertilizers, bio-fertilizers release nutrients slowly to the soil. Thus, the management of long-term soil fertility and sustaining crop productivity through biological fertilizers is a very important component of agriculture [2,3]. Since a bio-fertilizer is technically living, it can symbiotically associate with plant roots. The microorganisms involved could readily and safely convert complex organic material in simple compounds, so that plants may easily taken up.

Microorganism functions for long duration, causing improvement of the soil fertility. It increases crop yield by 20-30%, replaces chemical nitrogen and phosphorus by 25%, and stimulates plant growth. It can also provide protection against drought and some soil-borne diseases. Bio-fertilizers are cost-effective relative to chemical fertilizers. They have lower manufacturing costs, especially regarding nitrogen and phosphorus use. The commercial history of bio-fertilizers began with the launch of 'Nitragin' by Nobbe and Hiltner, a laboratory culture of Rhizobia in 1895, followed by the discovery of Azotobacter and then the blue green algae (BGA) and a host of other micro-organisms. Azospirillum and Vesicular-Arbuscular Micorrhizae (VAM) are fairly recent discoveries. In India, the first study on legume Rhizobium symbiosis was conducted by N.V.Joshi and the first commercial production started as early as 1956. However, the Ministry of Agriculture under the Ninth Plan initiated the real effort to popularize and promote the input with the setting up of the National Project on Development and Use of bio-fertilizers (NPDB). Bio-fertilizers 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 sectors through lesser water pollution than chemical fertilizers and even to an extent organic manures can create. The producer firms have serious uncertainty about the demand or suitability of the product, which deters investment, particularly if it is irreversible. The success or failures of early entrants who take the initiative or those who indulge in research for an improved product convey important information to others and thereby to society. The market however does not always reward the initiative. The capital market is also not always ready to provide the risk capital at reasonable rates.

Potential Role of Bio-fertilizers in Agriculture: The incorporation of bio-fertilizers (N-fixers) plays major role in improving soil fertility, yield attributing characters and thereby final yield has been reported by many workers. In addition, their application in soil improves soil biota and minimizes the sole use of chemical fertilizers. Under temperate conditions, inoculation of *Rhizobium* improved number of pods plant number of seed pod and seed weight (g) and thereby yield over the control. The number of pods plant number of seed/ pod and 1000-seed weight. In rice under low land conditions, the application of BGA+ *Azospirillum* improved significantly beneficial in improving LAI and all yield attributing aspects. It is an established fact that the efficiency of phosphate fertilizers is very low (15-20%) due to its fixation in acidic and alkaline soils and unfortunately both soil types are predominating in India accounting more than 34% acidity affected and more than seven million hectares of productive land salinity/alkaline affected. Therefore, the inoculations with PSB and other useful microbial inoculants in these soils become mandatory to restore and maintain the effective microbial populations for solubilization of chemically fixed phosphorus and availability of other macro and micronutrients to harvest good sustainable yield of various crops Symbiotically with the roots of leguminous plants or non-symbiotically (free living) or transfer native soil nutrients such as P, Zn, Cu, Fe, S etc. from the non-usable (fixed) form to usable form through biological processes used for application to seed, soil or composting areas with the objective of increasing number of such micro-organisms and accelerate those microbial processes which augment the availability of nutrients that can be easily assimilated by plants.

Necessity of Bio-fertilizer in India:

Indiscriminate use of synthetic fertilizers has led to the pollution and contamination of the soil, has polluted water basins, destroyed micro-organisms and friendly insects, making the crop more prone to diseases and reduced soil fertility. 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 about 7.2 million tones¹. Depleting feedstock/fossil fuels (energy crisis) and increasing cost of fertilizers. This is becoming unaffordable by small and marginal farmers, depleting soil fertility due to widening gap between nutrient removal and supplies, growing concern about environmental hazards, increasing threat to sustainable agriculture. Besides above facts, the long term use of bio-fertilizers is economical, eco-friendly, more efficient, productive and accessible to marginal and small farmers over chemical fertilizers India is one of the most important countries in bio-fertilizer production and consumption in the world. The present production capacity of different bio-fertilizer production units in the country is more than 10,000 t year⁻¹. At present there are 151 bio-fertilizer production units representing both government and non-government agencies in the country that are producing and supplying different bio-fertilizers, out of which, the Government of India has supported 71 units. Based on cultivated areas of the country and treatment of the seed sown at the rate of 200 g bio-fertilizer per 10 kg seed, the National Bio-fertilizer Development Centre (NBDC), Ghaziabad, has worked out the requirement of total bio-fertilizers as given in Table-1

Table-1: Bio-fertilizers and their estimated requirement in India

Bio-fertilizers	Estimated requirement (tonnes)
Rhizobium	34,999
Azotobacter	145,953
Azospirillum	74,342
Blue-green algae	251,378
P solubilizer	25,534

The systematic study on bio-fertilizers in India was first started by N. V. Joshi in 1920, followed by many more scientists with the changing times. The first bio-fertilizer unit was started by the Gujarat State Fertilizer Company (GSFC), Vadodara, in 1985, and many more followed thereafter. Among the different states, the

maximum production capacity is in Tamil Nadu followed by Madhya Pradesh, Uttar Pradesh, Gujarat and Maharashtra. At present, about a dozen fertilizer companies are engaged in bio-fertilizer production, marketing and promotion.

Potential Characteristic Features of Some Bio-fertilizers

Nitrogen Fixers Rhizobium: Belongs to family Rhizobiaceae, symbiotic in nature, fix nitrogen 50-100 kg/ ha in association with legumes only. It is useful for pulse legumes like chickpea, red-gram, pea, lentil, black gram, etc., oil-seed legumes like soybean and groundnut and forage legumes like berseem and lucerne. Successful nodulation of leguminous crops by Rhizobium largely depends on the availability of compatible strain for a particular legume. It colonizes the roots of specific legumes to form tumor like growths called root nodules, which acts as factories of ammonia production. Rhizobium has ability to fix atmospheric nitrogen in symbiotic association with legumes and certain non-legumes like Parasponia. Rhizobium population in the soil depends on the presence of legume crops in the field. In absence of legumes, the population decreases. Artificial seed inoculation is often needed to restore the population of effective strains of the Rhizobium near the rhizosphere to hasten N-fixation. Each legume requires a specific species of Rhizobium to form effective nodules

Rhizobium (RHZ): These inoculants are known for their ability to fix atmospheric nitrogen in symbiotic association with plants forming nodules in roots (stem nodules in sesabania mrostrata). RHZ are however limited by their specificity and only certain legumes are benefited from this symbiosis. Rhizobium is a soil habitat bacterium, which can able to colonize the legume roots and fixes the atmospheric nitrogen symbiotically. The morphology and physiology of Rhizobium will vary from free-living condition to the bacteroid of nodules. They are the most efficient biofertilizer as per the quantity of nitrogen fixed concerned. They have seven genera and highly specific to form nodule in legumes, referred as cross inoculation group. *Rhizobium* inoculant was first made in USA and commercialized by private enterprise in 1930s and the strange situation at that time has been chronicled. Initially, due to absence of efficient bradyrhizobial strains in soil, soybean inoculation at that time resulted in bumper crops but incessant inoculation during the last four decades by US farmers has resulted in the build

up of a plethora of inefficient strains in soil whose replacement by efficient strains of bradyrhizobia has become an insurmountable problem

Azospirillum: It belongs to family Spirillaceae, heterotrophic and associative in nature. In addition to their nitrogen fixing ability of about 20-40 kg/ha, they also produce growth regulating substances. Although there are many species under this genus like, *A.amazonense*, *A.halopraeferens*, *A.brasilense*, but, worldwide distribution and benefits of inoculation have been proved mainly with the *A.lipoferum* and *A.brasilense*. The *Azospirillum* form associative symbiosis with many plants particularly with those having the C4-dicarboxylic path way of photosynthesis (Hatch and Slack pathway), because they grow and fix nitrogen on salts of organic acids such as malic, aspartic acid. Thus it is mainly recommended for maize, sugarcane, sorghum, pearl millet etc. The *Azotobacter* colonizing the roots not only remains on the root surface but also a sizable proportion of them penetrates into the root tissues and lives in harmony with the plants. They do not, however, produce any visible nodules or out growth on root tissue.

Azospirillum (AZS): This is also a nitrogen-fixing micro organism beneficial for non-leguminous plants. The AZT, benefits transcend nitrogen enrichment through production of growth promoting substances. *Azospirillum lipoferum* and *A. brasilense* (*Spirillum lipoferum* in earlier literature) are primary inhabitants of soil, the rhizosphere and intercellular spaces of root cortex of graminaceous plants. They perform the associative symbiotic relation with the graminaceous plants. The bacteria of genus *Azospirillum* are N₂ fixing organisms isolated from the root and above ground parts of a variety of crop plants. They are gram negative (-v), *Vibrio* or *Spirillum* having abundant accumulation of polybetahydroxybutyrate (70 %) in cytoplasm.

A.brasilense, *A.lipoferum*, *A.amazonense*, *A.halopraeferens* and *A.irakense*. The organism proliferates under both anaerobic and aerobic conditions but it is preferentially micro-aerophilic in the presence or absence of combined nitrogen in the medium. Apart from nitrogen fixation, growth promoting substance production (IAA), disease resistance and drought tolerance are some of the additional benefits due to *Azospirillum* inoculation.

Azotobacter: *Azotobacter* belongs to family *Azotobacteriaceae*, aerobic, free living, and heterotrophic in nature. *Azotobacters* are present in neutral or alkaline soils and *A. chroococcum* is the most commonly occurring species in arable soils. *A. vinelandii*, *A. beijerinckii*, *A. insignis* and *A. macrocytogenes* are other reported species. The number of *Azotobacter* rarely exceeds of 10⁴ to 10⁵ g⁻¹ of soil due to lack of organic matter and presence of antagonistic microorganisms in soil. The bacterium produces anti-fungal antibiotics which inhibits the growth of several pathogenic fungi in the root region thereby preventing seedling mortality to a certain extent. The population of *Azotobacter* is generally low in the rhizosphere of the crop plants and in uncultivated soils. The occurrence of this organism has been reported from the rhizosphere of a number of crop plants such as rice, maize, sugarcane, bajra, vegetables and plantation crops

Azotobacter (AZT): This has been found beneficial to a wide array of crops covering cereals, millets, vegetables, cotton and sugarcane. It is free living and non-symbiotic nitrogen fixing organism that also produces certain substances good for the growth of plants and antibodies that suppress many root pathogens. *Azotobacter*, of the several species of *Azotobacter*, *A. chroococcum* happens to be the dominant inhabitant in arable soils capable of fixing N₂ (2-15 mg N₂ fixed /g of carbon source) in culture media. The bacterium produces abundant slime which helps in soil aggregation. The numbers of *A. chroococcum* in Indian soils rarely exceeds 10⁵/g soil due to lack of organic matter and the presence of antagonistic microorganisms in soil

Blue Green Algae (Cyanobacteria) and Azolla: These belong to eight different families, phototrophic in nature and produce Auxin, Indole acetic acid and Gibberlic acid, fix 20-30 kg N/ha in submerged rice fields as they are abundant in paddy, so also referred as "paddy organisms". N is the key input required in large quantities for low land rice production. Soil N and BNF by associated organisms are major sources of N for low land rice. The 50-60% N requirement is met through the combination of mineralization of soil organic N and BNF by free living and rice plant associated bacteria. To achieve food security through sustainable agriculture, the requirement for fixed nitrogen must be increasingly met by BNF rather than by industrial nitrogen fixation. BGA forms symbiotic association capable of fixing nitrogen with fungi, ferns and flowering

plants, but the most common symbiotic association has been found between a free floating aquatic fern, the *Azolla* and *Anabaena azollae* (BGA). *Azolla* contains 4-5% N on dry basis and 0.2-0.4% on wet basis and can be the potential source of organic manure and nitrogen in rice production. The important factor in using *Azolla* as biofertilizer for rice crop is its quick decomposition in the soil and efficient availability of its nitrogen to rice plants. Besides N-fixation, these bio-fertilizers or biomanures also contribute significant amounts of P, K, S, Zn, Fe, Mb and other micronutrient. The fern forms a green mat over water with a branched stem, deeply bilobed leaves and roots. The dorsal fleshy lobe of the leaf contains the algal symbiont within the central cavity. *Azolla* can be applied as green manure by incorporating in the fields prior to rice planting. The most common species occurring in India is *A. pinnata* and same can be propagated on commercial scale by vegetative means. It may yield on average about 1.5 kg per square meter in a week. India has recently introduced some species of *Azolla* for their large biomass production, which are *A. caroliniana*, *A. microphylla*, *A. filiculoides* and *A. Mexicana*

Blue Green Algae (BGA) and Azolla: 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 bio mass when decomposed after lifecycle. *Azolla* is an aquatic fern found in small and shallow water bodies and in rice fields. It has symbiotic relation with BGA and can help rice or other crops through dual cropping or green manuring of soil.

Azolla-Anabena Symbiosis: *Azolla* is a small, eukaryotic, aquatic fern having global distribution. Prokaryotic blue green algae *Anabena azolla* resides in its leaves as a symbiont. *Azolla* is an alternative nitrogen source. This association has gained wide interest because of its potential use as an alternative to chemical fertilizers.

Cyanobacteria: Both free-living as well as symbiotic cyanobacteria (blue green algae) have been harnessed in rice cultivation in India. A composite culture of BGA having heterocystous *Nostoc*, *Anabaena*, *Aulosira* etc. is given as primary inoculum in trays, polythene lined pots and later mass multiplied in the field for application as soil based flakes to the rice growing field at the rate of 10 kg/ha. The final

product is not free from extraneous contaminants and not very often monitored for checking the presence of desired algal flora.

Once so much publicized as a bio-fertilizer for the rice crop, it has not presently attracted the attention of rice growers all over India except pockets in the Southern States, notably Tamil Nadu. The benefits due to algalization could be to the extent of 20-30 kg N/ha under ideal conditions but the labour oriented methodology for the preparation of BGA biofertilizer is in itself a limitation. Quality control measures are not usually followed except perhaps for random checking for the presence of desired species qualitatively.

Phosphate Solubilizers (Phosphorus Solubilizing Bio-fertilizers): Several reports have examined the ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. Among the bacterial genera with this capacity is *Pseudomonas*, *Bacillus*, *Rhizobium*, *Burkholderia*, *Achromobacter*, *Agrobacterium*, *Micrococcus*, *Aerobacter*, *Flavobacterium* and *Erwinia*. There are considerable populations of phosphatesolubilizing bacteria in soil and in plant rhizospheres. These include both aerobic and anaerobic strains, with a prevalence of aerobic strains in submerged soils. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non rhizosphere soil. The soil bacteria belonging to the genera *Pseudomonas* and *Bacillus* and *Fungi* are more common.

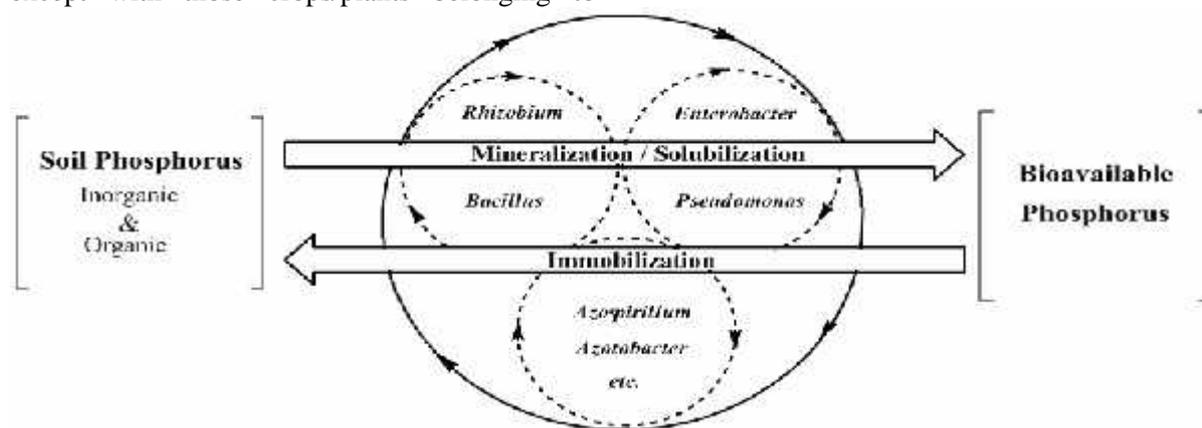
Phosphate-solubilizing bacteria, such as *Pantoea agglomerans* strain P₅ or *Pseudomonas putida* strain P₁₃ are able to solubilize the insoluble phosphate from organic and inorganic phosphate sources. In fact, due to immobilization of phosphate by mineral ions such as Fe, Al and Ca or organic acids, the rate of available phosphate (P_i) in soil is well below plant needs. In addition, chemical P_i fertilizers are also immobilized in the soil, immediately, so that less than 20 percent of added fertilizer is absorbed by plants. Therefore, reduction in P_i resources, on one hand, and environmental pollutions resulting from both production and applications of chemical P_i fertilizer, on the other hand, have already demanded the use of new generation of phosphate fertilizers globally

known as phosphate-solubilizing bacteria or phosphate bio-fertilizers

Phosphate Absorbers (Mycorrhiza): The term Mycorrhiza denotes “fungus roots”. It is a symbiotic association between host plants and certain group of fungi at the root system, which the fungal partner is benefited by obtaining its carbon requirements from the photosynthates of the host and the host in turn is benefited by obtaining the much needed nutrients especially phosphorus, calcium, copper, zinc etc., which are otherwise inaccessible to it, with the help of the fine absorbing hyphae of the fungus. These fungi are associated with majority of agricultural crops, except with those crops/plants belonging to

families of *Chenopodiaceae*, *Amaranthaceae*, *Caryophyllaceae*, *Polygonaceae*, *Brassicaceae*, *Commelinaceae*, *Juncaceae* and *Cyperaceae*.

Phosphate Solubilizing (PSB)/Mobilizing: Bio-fertilizer Phosphorus, both native in soil and applied in inorganic fertilizers becomes mostly unavailable to crops because of its low levels of mobility and solubility and its tendency to become fixed in soil. The PSB are life forms that can help in improving phosphate uptake of plants in different ways. The PSB also has the potential to make utilization of India’s abundant deposits of rock phosphates possible, much of which is not enriched.



AM Fungi: The transfer of nutrients mainly phosphorus and also zinc and sulphur from the soil to the cells of the root cortex is mediated by intracellular obligate fungal endosymbionts of the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocystis* and *Endogone* which possess vesicles for storage of nutrients and arbuscles for funneling these nutrients into the root system. By far, the commonest genus appears to be *Glomus*, which has several species distributed in soil. Availability for pure cultures of AM (Arbuscular Mycorrhiza) fungi is an impediment in large scale production despite the fact that beneficial effects of AM fungal inoculation to plants have been repeatedly shown under experimental conditions in the laboratory especially in conjunction with other nitrogen fixers.

Vesicular-Arbuscular Mycorrhizae (VAM): This fungi is often used as Biofertilizer. It is widely found in both aquatic and desert soil environments. VAM provides significant amount of nutrients to the plants such as copper, zinc, phosphorus and sulphur by making their widely extended hyphal network on the upper or lower side of the soil layer. VAM is commercially used in the fields of India

Zinc solubilizers: The nitrogen fixers like *Rhizobium*, *Azospirillum*, *Azotobacter*, BGA and Phosphate solubilizing bacteria like *B. magisterium*, *Pseudomonas striata*, and phosphate mobilizing Mycorrhiza have been widely accepted as bio-fertilizers. However these supply only major nutrients but a host of microorganism that can transform micronutrients are there in soil that can be used as bio-fertilizers to supply micronutrients like zinc, iron, copper etc., The zinc can be solubilized by microorganisms viz., *B. subtilis*, *Thiobacillusthioxidans* and *Saccharomyces sp.* These microorganisms can be used as bio-fertilizers for solubilization of fixed micronutrients like zinc. The results have shown that a *Bacillus sp.* (Zn solubilizing bacteria) can be used as bio-fertilizer for zinc or in soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate (ZnCO₃) and zinc sulphide (ZnS) instead of costly zinc sulphate.

Silicate Solubilizing Bacteria (SSB): Microorganisms are capable of degrading silicates and aluminum silicates. During the metabolism of microbes several organic acids are produced and these have a dual role in silicate

weathering. They supply H⁺ ions to the medium and promote hydrolysis and the organic acids like citric, oxalic acid, Keto acids and hydroxy carboxylic acids which form complexes with cations, promote their removal and retention in the medium in a dissolved state. The studies conducted with a *Bacillus* sp. isolated from the soil of granite crusher yard showed that the bacterium is capable of dissolving several silicate minerals under *in.vitro* condition. The examination of anthropogenic materials like cement, agro inputs like super phosphate and rock phosphate exhibited silicate solubilizing bacteria to a varying degree. The bacterial

isolates made from different locations had varying degree of silicate solubilizing potential. Soil inoculation studies with selected isolate with red soil, clay soil, sand and hilly soil showed that the organisms multiplied in all types of soil and released more of silica and the available silica increased in soil and water. Rice responded well to application of organic sliceous residue like rice straw, rice husk and black ash @ 5 t/ha. Combining SSB with these residues further resulted in increased plant growth and grain yield. This enhancement is due to increased dissolution of silica and nutrients from the soil.

Some important groups of Bio-fertilizers

S. No.	Groups	Examples
N₂ fixing Biofertilizers		
1.	Free-living	<i>Azotobacter, Beijerinckia, Clostridium, Klebsiella, Anabaena, Nostoc,</i>
2.	Symbiotic	<i>Rhizobium, Frankia, Anabaena azollae</i>
3.	Associative Symbiotic	<i>Azospirillum</i>
P Solubilizing Biofertilizers		
1.	Bacteria	<i>Bacillus megaterium var. phosphaticum, Bacillus subtilis, Bacillus circulans, Pseudomonas striata</i>
2.	Fungi	<i>Penicilliumsp, Aspergillusawamori</i>
P Mobilizing Biofertilizers		
1.	Arbuscularmycorrhiza	<i>Glomussp., Gigasporasp., Acaulospora sp., Scutellospora sp. & Sclerocystis sp.</i>
2.	Ectomycorrhiza	<i>Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp.</i>
3.	Ericoid mycorrhizae	<i>Pezizellaericae</i>
4.	Orchid mycorrhiza	<i>Rhizoctoniasolani</i>
Biofertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	<i>Bacillus</i> sp.
Plant Growth Promoting Rhizobacteria		
1.	<i>Pseudomonas</i>	<i>Pseudomonas fluorescens</i>

Table 2: Relative Cost of Access to Plant Nutrient (N)

Crop	Type Fertilizer	Treatment	Inoculants unit Price	Rs/Kg weight Kg	For1Kg Nitrogen	Bulk Cost
Rice	AZS	seedling	2.5	29.12	0.13	3.64
Wheat	AZT	seed	1.5	34.37	0.75	2.58
Oilseeds	AZT	seed	0.2	34.37	0.01	0.34
Groundnut/Soybean	RHZ	seed	1.5	30.89	0.07	2.26
Maize/Sorghum	AZS/AZT	seed	0.5	29.12-34.37	0.25	0.73-0.86
Potato	AZT	Soil/ tuber	4.5	34.37	0.225	7.73
Vegetables	AZS/AZT	seed	0.5	29.12-34.37	0.25	0.73-0.86
Sugarcane	AZS	soil	4.5	34.37	0.225	7.73
Cotton	AZT	seed	0.8	34.37	0.04	1.37
Flowers	AZS/AZT	seedling	1.75	29.12-34.37	0.09	2.55-3.01
Chemical	Urea	soil	1000	4.8	2.17	7.96
Organic	FYM	soil	1000	0.14	555.56	79.37
					Weight Kg	Rs/Kg.....

Application of Bio-fertilizers

1. Seed treatment or seed inoculation
2. Seedling root dip
3. Main field application

Seed Treatment: One packet of the inoculant is mixed with 200 ml of rice kanji to make a slurry. The seeds required for an acre are mixed in the slurry so as to have a uniform coating of the inoculant over the seeds and then shade dried for

30 minutes. The shade dried seeds should be sown within 24 hours. One packet of the inoculant (200 g) is sufficient to treat 10 kg of seeds.

Seedling Root Dip: This method is used for transplanted crops. Two packets of the inoculant is mixed in 40 litres of water. The root portion of the seedlings required for an acre is dipped in the

mixture for 5 to 10 minutes and then transplanted.

Field Application: Four packets of the inoculant is mixed with 20 kg of dried and powdered farm yard manure and then broadcasted in one acre of main field just before transplanting

Responses and Limitations: Crude calculations of bulk and cost in terms of N presented in Table 2 on the basis of reported nitrogen equivalence indicates that bio-fertilizers are cheap and convenient relative to chemical and farm organic fertilizers (FYM) and therefore have considerable promise for crops like cereals, oilseeds, vegetables and cotton. However, it is safer to note that the nitrogen equivalences reported for bio-fertilizers are only indirectly approximated through controlled experiments since the way of accessing nutrients itself in indirect unlike nutrient containing chemical fertilizers and manures, and the comparative values of bulk and cost may not be realistic. Nevertheless, a crude estimation is attempted for indication of the potential without attaching significance to the magnitudes as such.

Bio-fertilizers have various benefits. Besides accessing nutrients, for current intake as well as residual, different bio-fertilizers 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. However while positive responses have been observed in a wide range of field trials, there is remarkable inconsistency in responses across crops, regions and other conditions. Even for a given crop the range of response is quite high. For example in a sample of 411 field trials carried out across districts, plant responses to inoculation with *Azotobacter* in irrigated wheat was observed to be significant in 342 cases and ranged from 34 to 247 Kg./ha. Legume inoculation by *Rhizobium* is the most long established practice but the responses indicated by the All India Coordinated Agronomic Research Project in the cases of mungbean, uradbean, soyabean, cowpea and groundnut all under irrigated condition were significant only in a small proportion of locations tried and failed in others. Residual effect on soil pool was not noted in most cases. The variance

of responses is similar for AZT and AZS. Dryland agriculture constitutes a very large part of agricultural area in India and also houses the majority of the poor. More than 90% of coarse cereals, 80% of groundnut and 85% of pulses come from these regions. Low productivity, unpredictable climatic swings and low dosage of chemical fertilizers also characterise agriculture in drylands. Bio-fertilizers, particularly *Rhizobium*, could be a bridge between removals and additions to soil nutrients where farmers can scarcely afford costly inputs and that too in a risky environment. But consistency in gains again includes the trials conducted by All India Coordinated Pulse Improvement Project. The responses usually depend on several environmental factors. (a) The type of soil as measured by its water holding capacity, its levels of other nitrates, phosphate and even calcium and molybdenum (that help in protein synthesis in *Rhizobia*) and the alkalinity, salinity and acidity of soil all affect the response. Higher dose of mineral nitrogen as starter suppresses nodulation, reducing response of *Rhizobium* but phosphate deficiency can be an inhibitor also. (b) The inadequacy of organic matter especially common in dry land agriculture is a deterrent more for the non-symbiotic strains, which essentially depend on soil organic matter for energy. Phosphobactrin response was found to be positive only in soils with high organic content and low available phosphorous. (c) Soil water deficit and high temperature (hyper-thermia) are prominent abiotic factors that affect nitrogen fixation in dryland agriculture. (c) Native microbial population opposes the inoculants. In general predatory organisms, often already present in the soil are more adapted to the environment and out compete the inoculated population. Apart from environmental factors, deficiencies in handling procedure are a major cause of underperformance in real life application. The high sensitivity to temperature and other external conditions of these 'living' inputs, calls for enormous caution at the stage of manufacture/culture transportation/distribution and application. This involves investment and time in research (for more tolerant strains), packaging, storage and use of suitable carrier materials.

Bio-fertilizers are known to play a number of vital roles in soil fertility, crop productivity and production in agriculture as they are eco friendly and can't at any cost replace chemical fertilizers that are indispensable for

getting maximum crop yields. Some of the important functions or roles of Biofertilizers in agriculture are:

1. They supplement chemical fertilizers for meeting the integrated nutrient demand of the crops.
2. They can add 20-200 kg N/ha year (eg. *Rhizobium* sp 50-100 kg N/ha year ;*Azospirillum* , *Azotobacter* : 20-40 kg N/ha /yr; *Azolla* : 40-80 kg N/ha; BGA :20-30 kg N/ha) under optimum soil conditions and thereby increases 15-25 percent of total crop yield.
3. They can at best minimize the use of chemical fertilizers not exceeding 40-50 kg N/ha under ideal agronomic and pest-free conditions.
4. Application of Bio-fertilizers results in increased mineral and water uptake, root development, vegetative growth and nitrogen fixation.
5. Some Biofertilizers (eg, *Rhizobium* BGA, *Azotobacter* sp) stimulate production of growth promoting substance like vitamin-B complex, Indole acetic acid (IAA) and Gibberellic acids etc.
6. Phosphate mobilizing or phosphorus solubilizing Biofertilizers / microorganisms (bacteria, fungi, mycorrhiza etc.) converts insoluble soil phosphate into soluble forms by secreting several organic acids and under optimum conditions they can solubilize / mobilize about 30-50 kg P₂O₅/ha due to which crop yield may increase by 10 to 20%.
7. Mycorrhiza or VA-mycorrhiza (VAM fungi) when used as Biofertilizers enhance uptake of P, Zn, S and water, leading to uniform crop growth and increased yield and also enhance resistance to root diseases and improve hardiness of transplant stock.
8. They liberate growth promoting substances and vitamins and help to maintain soil fertility.
9. They act as antagonists and suppress the incidence of soil borne plant pathogens and thus, help in the bio-control of diseases.
10. Nitrogen fixing, phosphate mobilizing and cellulolytic microorganisms in bio-fertilizer enhance the availability of plant nutrients in the soil and thus, sustain the agricultural production and farming system.
11. They are cheaper, pollution free and renewable energy sources
12. They improve physical properties of soil, soil tilth and soil health in general.

13. They improve soil fertility and soil productivity.
14. Blue green algae like *Nostoc*, *Anabaena*, and *Scytonema* are often employed in the reclamation of alkaline soils.
15. Bio-inoculants containing cellulolytic and lignolytic microorganisms enhance the degradation/ decomposition of organic matter in soil, as well as enhance the rate of decomposition in compost pit.
16. BGA plays a vital role in the nitrogen economy of rice fields in tropical regions.
17. *Azotobacter* inoculants when applied to many non-leguminous crop plants, promote seed germination and initial vigor of plants by producing growth promoting substances.
18. *Azolla-Anabaena* grows profusely as a floating plant in the flooded rice fields and can fix 100-150 kg N/ha /year in approximately 40-60 tones of biomass produced,
19. Plays important role in the recycling of plant nutrients.

Important Points to Remember

- The term 'bio-fertilizer' denotes nutrient inputs for plant growth which are biological in origin and have no ill effects on soil health and environment.
- India is one of the major countries in bio-fertilizer production and consumption in the world. At present there are more than 120 bio-fertilizer production units representing both government and non-governmental agencies in the country that are producing and supplying different bio-fertilizers.
- The systematic study on bio-fertilizers in India was first started by N. V. Joshi in 1920 and followed by many more scientists as the time progressed.
- The first bio-fertilizer unit in India was started by the Gujarat State Fertilizer Company (GSFC), Vadodara, in 1985, and at present, about a dozen fertilizer companies are engaged in bio-fertilizer production, marketing and promotion.
- *Rhizobium* inoculants help in establishing efficient symbiotic association with leguminous pulse and fodder crops that can fix 50–100 kg N ha⁻¹ and also leave sufficient amount of N in the soil to meet a part of the requirement of the succeeding crop in rotation.
- The first commercial bio-fertilizer was developed as a *Rhizobium* culture in 1895 with the product 'Nitragin' in the United States.

- The number of *A. chroococcum* in Indian soils rarely exceeds $104\text{--}105\text{ g}^{-1}$ of soil and can save N to the tune of $25\text{--}50\text{ kg ha}^{-1}$ in cereals and millets. Apart from N fixation, this organism is also capable of producing antibacterial and antifungal compounds and growth hormones.
- There are six species of *Azotobacter*, namely *A. chroococcum*, *A. nigricans*, *A. paspali*, *A. vinelandii*, *A. beijerinckii* and *A. armeniacus*, of which *A. chroococcum* is the most commonly found in arable soils. *A. agilis* and *A. macrocytogenes* are the other species of *Azotobacter* found in soils.
- Use of *Azotobacter* culture has been found to be effective for a variety of nonleguminous crops such as directly seed-sown paddy and wheat. Its use has shown an increase in yield of rice, ranging from 1% to 20% and that of wheat from 10% to 30%.
- Use of *Azotobacter* reduces the inorganic fertilizer requirements to the tune of 25–50%.
- *Azospirillum* application increases grain productivity of cereals by 5–20%, millets by 30% and forage crops by over 50%.
- *Azospirillum* are tolerant to a high temperature range from 30°C to 40°C and also supply growth regulators and secrete antibiotics which act as pesticides.

Conclusion: Bio-fertilizers being essential components of organic farming play vital role in

maintaining long term soil fertility and sustainability by fixing atmospheric di-nitrogen ($\text{N}=\text{N}$), mobilizing fixed macro and micro nutrients or convert insoluble P in the soil into forms available to plants, thereby increases their efficiency and availability. Currently there is a gap of ten million tones of plant nutrients between removal of crops and supply through chemical fertilizers. In context of both the cost and environmental impact of chemical fertilizers, excessive reliance on the chemical fertilizers is not viable strategy in long run because of the cost, both in domestic resources and foreign exchange, involved in setting up of fertilizer plants and sustaining the production. In this context, organic manures (Bio-fertilizers) would be the viable option for farmers to increase productivity per unit area

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