

Role of biofertilizers

in organic farming system

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Biofertilizers are the basic input of essential nutrients for sustainable and organic farming systems. These are the substances containing diversity of potential microbes having the capacity to enhance plant nutrient acquisition by early colonization in the rhizosphere and make the nutrients easily accessible to plant root hairs for plant growth promotion. Biofertilizers are well known for their cost effectiveness, environmental friendly nature and composition. These are an effective alternative to the hazardous agro-chemicals in the intensive cropping systems under climate changing conditions. Various types of microbial biofertilizers pronouncing symbiotic and free living nitrogen fixers, phosphorous/zinc/potassium solubilizers as well as mobilizers and their developmental strategies have been described. This knowledge can help us understand the importance of microbial inoculants in agriculture and the ways to formulate these beneficial microbes as biofertilizers for sustainable crop production.

Keywords: Bioenhancers, Biofertilizers, Organic farming, Solubilizers

CONVENTIONAL farming plays an important role in meeting the food demands of a rising human population, also contributing towards the increasing dependence on agro-chemicals. The industrial production of inorganic fertilizers is a material composed of known quantities of nitrogen, phosphorous and potassium that causes contamination of the air and groundwater through eutrophication process. A rising demand for premium organic biological fertilizers exclusive from alternative agrochemicals is being borne by the innovativeness of farming production. The promotion of alternative forms of soil fertilization in agriculture depends on organic inputs.

The growing demand for safe and healthy food, and long-term sustainability as well as environmental pollution related to the indiscriminate use of inorganic fertilizers and pesticides has become a key global priority area. Organic farming depends mainly on the soil's

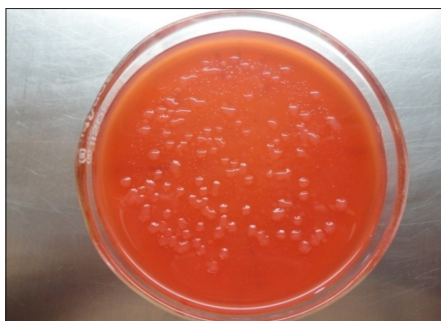
natural microflora, which comprises of all kinds of potentially beneficial indigenous bacteria and fungi, including arbuscular mycorrhiza fungi (AMF) known as plant growth promoting rhizobacteria (PGPR). Biofertilizers are important components in organic farming and are prepared using live or latent cells of successful biological nitrogen fixing strains. Solubilization of insoluble phosphates or cellulolytic micro-organisms used for seed, soil, or composting areas with the objective of enhancing population density of such micro-organisms and accelerating those microbial processes which augment the availability of nutrients that can be easily assimilated by plants. Thus, biofertilizers play an essential role, with and without plant roots in increasing soil fertility by fixing atmospheric nitrogen through biological nitrogen fixation, solubilizing insoluble soil phosphates and releasing plant growth regulatory substances, manufacturing antibiotics, and

degrading soil organic matter.

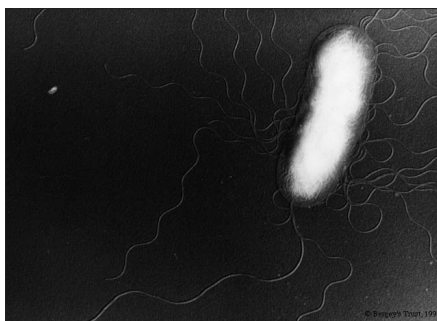
Exploring biofertilizers/bioenhancers/bioprotectants in organic farming system

Indiscriminate use of agrochemicals has led to pollution and contamination of the soil, has polluted water basins, destroyed beneficial microbial diversity and eco-friendly insects, making the crop more prone to diseases and reduced soil fertility as well as soil health.

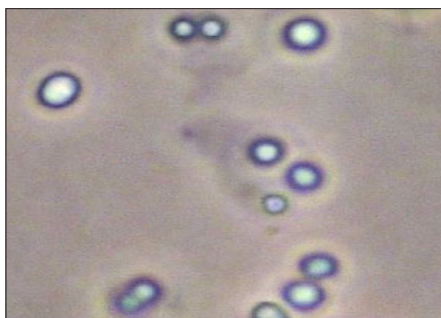
- Depleting feedstock/fossil fuels (energy crisis) leading to enhanced cost of agrochemical production is becoming unaffordable for small and marginal rural farmers.
- Depleting soil fertility and soil health due to widening gap between essential nutrient removal and supplies.
- Growing concern about environmental hazards due to indiscriminate use of agrochemicals.
- Increasing threat to sustainable agriculture due to destroyed



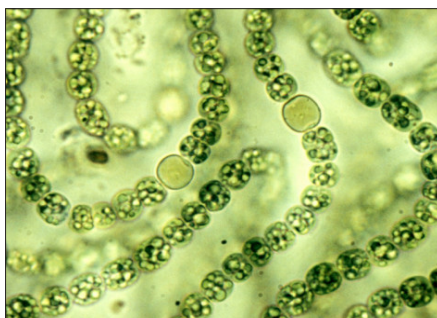
Rhizobium growing on CRYEMA medium



Microscopic view of *Azospirillum*



Microscopic view of *Azotobacter*



Microscopic view of *Cyanobacteria*

beneficial micro-flora and macro-fauna.

The long term use of biofertilizers is economical, eco-friendly, efficiently uses nutrients, productive and accessible to rural farmers over the different types of agro-chemicals. To get an insight about the biofertilizers before application in the sustainable agriculture activities as an indispensable part of organic farming, it is essential to know how biofertilizers work when they are applied.

- Biofertilizers fix atmospheric nitrogen in the soil and nodules of legume crops through symbiotic association between Rhizobia and legumes and make it available to the plants.
- They solubilize the insoluble forms of phosphate, zinc, potassium such as tricalcium phosphate, zinc phosphate and potassium sulphate into available forms.
- They scavenge/mobilize phosphate from soil layers by arbuscular mycorrhiza fungi (AMF).
- They produce phytohormones, antibiotics, siderophores and cell wall degrading enzymes like cellulase, proteases etc.

which promote plant growth as well as protect plants against phytopathogens.

- Rapidly decompose organic matter and help in the mineralization of essential nutrients in soil and makes them available to plants for growth and development.
- When applied to seeds, seedlings or soil, biofertilizers/bioenhancers improve the availability of essential nutrients and enhance the grain yield by 10–30% without adversely affecting the soil and environmental health.

Potential multifarious plant growth promoting characteristics of different biofertilizers/ bioenhancers

Nitrogen fixers

Certain bacteria and cyanobacteria, convert atmospheric nitrogen into plant usable forms like ammonical and nitrate forms. This process is called symbiotic nitrogen fixation (SNF). This mechanism is exploited by utilizing such beneficial indigenous microorganisms in the form of potent biofertilizers which act as a substitute for agrochemicals, help in maintenance of soil nitrogen reserves and improve productivity of legume crops. They can be grouped into free-living bacteria

like *Azotobacter*, associative like *Azospirillum*, cyanobacteria and symbiotic organisms like *Rhizobium*, *Frankia* and *Azolla*.

***Rhizobium*:** It is an example of symbiotic association colonizing legume root nodules and fixes the atmospheric nitrogen through biological nitrogen fixation. Symbiotic bacteria obtain products of photosynthesis as energy source from plant and fix nitrogen (50–100 kg/ha) from the air for their host plant development. The morphology and physiology of *Rhizobium* at free-living condition is different from bacteroid infection of nodules. It is useful for various legumes i.e. chickpea, red-gram, field pea, pigeon pea, lentil, black gram, soybean, groundnut and forage legumes like berseem and lucerne. Successful nodulation of leguminous crops by *Rhizobium* largely depends on the availability of specific compatible bacterial strains for a particular legume. Cross inoculation plays an important role in host specificity of *Rhizobium* and host. The expression of nod, nif and fix genes control the nodulation and nitrogen fixation by the bacterium.

***Azotobacter*:** It is a free living aerobic, gram-negative and heterotrophic, nitrogen fixing bacteria. With the capacity of independent BNF, it has been found that some *Azotobacter* species are in association with some crops like wheat, maize etc. They are generally present in natural and alkaline soil occurring more in arable soils. *Azotobacter* spp. are motile and mesophilic (25–30°C) with ability of fixing an average 20 kg N/ha/year, synthesis of phytohormones, antibiotics, biofilm and exopolysaccharide production. The genus *Azotobacter* comprises of different species: *A. chroococcum*, *A. vinelandii*, *A. beijerinckii*, *A. paspali*, *A. armeniacus*, *A. nigricans* and *A. salinestri*.

***Azospirillum*:** These are gram-negative, non-nodule forming, aerobic, nitrogen-fixing bacteria belonging to the family Spirillaceae. They are associated with roots of mainly C₄ crops (sorghum) having dicarboxylic pathway (Hatch-Slack

Table 1. Different type of biofertilizers/bioenhancers for cereals and legumes

Nitrogen (N ₂) fixing biofertilizers	
Free living	<i>Azotobacter</i> , <i>Clostridium</i> , <i>Anabeana</i> , <i>Nostoc</i>
Symbiotic Association	<i>Rhizobium</i> , <i>Bradyrhizobium</i> , <i>Mesorhizobium</i> , <i>Frankia</i> and <i>Anabeana azolle</i>
Associative symbiotic	<i>Azospirillum</i> sp.
P-Solubilizing biofertilizers	
Bacteria	<i>Bacillus subtilis</i> , <i>Pseudomonas striata</i> , <i>Bacillus megaterium</i> var. <i>phosphaticum</i> , <i>Bacillus circulans</i> , <i>Pseudomonas aeruginosa</i> , <i>Pseudomonas oryzihabitans</i>
Fungi	<i>Penicillium</i> sp., <i>Aspergillus awamori</i> , <i>Aspergillus niger</i>
P-Mobilizing biofertilizers	
Arbuscular Mycorrhizae	<i>Glomus</i> sp., <i>Gigaspora</i> sp., <i>Acaulospora</i> sp., <i>Scutellospora</i> sp. & <i>Sclerocystis</i>
Ectomycorrhiza	<i>Laccarai</i> sp., <i>Pisolithus</i> sp., <i>Boletus</i> sp., <i>Amantia</i> sp.
Ericoid mycorrhiza	<i>Pezizella ericae</i>
Orchid mycorrhiza	<i>Rhizoctonia solani</i>
K- solubilizers	
Bacteria	<i>Bacillus</i> sp., <i>Frateuria aurantia</i> , <i>Pseudomonas</i> sp.
Micronutrient solubilizers (Silicate and zinc solubilizers)	
Bacteria	<i>Bacillus</i> sp., <i>Pseudomonas</i> sp., <i>Enterococcus</i> sp., <i>Enterobacter</i> sp., <i>Paenibacillus</i> sp. and <i>Klebsiella</i> sp.
Plant Growth Promoting Rhizobacteria	
Bacteria	<i>Pseudomonas fluorescens</i> , <i>P. aeruginosa</i> ., <i>P. oryzihabitans</i> and <i>Bacillus</i> sp.

pathway) of photosynthesis because they grow and fix nitrogen on the organic salts of malic and aspartic acid. *Azospirillum* greatly affects root development and exudation, and fixes 20–40 kg nitrogen under micro-aerobic conditions. Important species of *Azospirillum* are *A. lipoferum*, *A. brasilense*, *A. amazonense*, *A. halopreferans* and *A. trakenense*.

Cyanobacteria and *Azolla*: Cyanobacteria are prokaryotes responsible for water blooms in stagnant water bodies and are also found in snow and hot springs. They are photosynthetic and can fix atmospheric nitrogen. They also promote plant growth by producing phytohormones (indole acetic acid, gibberllic acid and cytokinin) and can fix around 20–30 kg N/ha in submerged rice fields. *Azolla* is a biofertilizer used in rice cultivation extensively. It is an aquatic fern sheltering cyanobacteria (*Anabaena azollae*). *Azolla* as biofertilizer may be used as a partial substitute for inorganic fertilizer N due to its sustainable supplementation of N to rice crops and the associated

improvement of soil fertility and soil health.

Gluconacetobacter diazotrophicus: It is a nitrogen fixing bacterium originally found in sugarcane (monocot) plants in which the bacterium actively fixes atmospheric nitrogen and provides significant amounts of nitrogen to plants. This bacterium mainly colonizes intercellular spaces within the roots and stems of plants and does not require information of the complex root organ like nodule. It is less plant/crop specific and has been found in a number of unrelated plant species. Importantly, as the bacterium is of monocot plant origin, there exists a possibility that the nitrogen fixation feature of the bacterium may be used in many other monocot crops.

P-solubilization

Most of the phosphorus is fixed and remains unavailable to promote plant growth. It only exists in two soluble forms: monobasic and dibasic. Fixed form of P is present in the form of organic matter (phosphodiester, inositol phosphate and apatite). Immobilization of soluble inorganic P fertilizers

makes it unavailable for the plants. Phosphorus solubilizing bacteria (PSB) in rhizosphere such as *Bacillus subtilis*, *B. cereus*, *P. putida* and *B. megaterium* and fungi like *Aspergillus* and *Penicillium* solubilize bound phosphate and fixed phosphorus to make it available for plant growth and development. Different studies demonstrate the ability of different bacterial species to solubilize inorganic phosphates such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite and rock phosphate. Amongst the bacterial genera with this capacity are *Pseudomonas*, *Bacillus*, *Rhizobium*, *Burkholderia*, *Enterococcus*, *Enterobacter*, *Leclercia*, *Achromobacter*, *Agrobacterium*, *Bradyrhizobium*, *Mesorhizobium*, *Ensifer meliloti*, *Micrococcus*, *Aerobacter*, *Flavobacterium* and *Erwinia* etc. There is considerable microbial diversity of phosphate solubilizing bacteria in the rhizosphere. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with phyllosphere, endosphere and non-rhizosphere soil. The soil bacteria belonging to the genera *Pseudomonas*, *Bacillus* and *Fungi* are more common.

P-mobilizers/absorbers

Different microorganisms (especially Mycorrhiza) enhance the uptake of P through mobilizing it from a P rich environment to plants instead of solubilizing P. Such microorganisms are called P-mobilizers/absorbers. The term Mycorrhiza is a symbiotic association between higher plants and certain group of fungi at the root system, in 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, iron, manganese calcium, copper, zinc etc. which are otherwise inaccessible to it, with the help of the fine absorbing hyphae/mycelium of the fungus. These fungi are associated with majority of agricultural crops, except with crops/plants belonging to families of Chenopodiaceae, Amaranthaceae,

Caryophyllaceae, Polygonaceae, Brassicaceae, Commelinaceae, Juncaceae and Cyperaceae.

Zinc solubilizers

The nitrogen fixers like *Rhizobium*, *Bradyrhizobium*, *Azospirillum*, *Azotobacter*, BGA, Mycorrhiza, phosphate solubilizing bacteria (*B. magisterium*, *Pseudomonas striata*) and phosphate mobilizing bacteria have been widely accepted as bioenhancers. However, these supply only macronutrients but a host of microorganism that can transform micronutrients are there in soil that can be used as biofertilizers to supply micronutrients like zinc, iron, copper etc. The zinc can be solubilized by microorganisms, viz. *B. subtilis*, *Thiobacillus thiooxidans*, *P. aeruginosa*, *P. oryzae*, *Bradyrhizobium* sp., *Flavobacterium* sp., *Enterococcus* sp., *Enterobacter* sp., *Leclercia* sp. and *Saccharomyces* sp. These beneficial potent microorganisms can be used as biofertilizers for solubilization of fixed micronutrients like zinc. The results have shown that a *Bacillus* sp. (Zn solubilizing bacteria) can be used as biofertilizer 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.

Plant Growth Promoting Rhizobacteria (PGPR)

The group of bacteria that colonize different tissues of plant i.e. roots stem, leaves, nodules or rhizospheric soil and beneficial to crops are referred to as plant growth promoting rhizobacteria (PGPR). They are also called as bioprotectants e.g. *Bacillus* spp. and *Pseudomonas* fluorescence. PGPR inoculants currently commercialized are ones that seem to promote growth through at least one mechanism; suppression of plant disease through antibiotic action production of siderophore and cell wall degrading enzymes (termed bioprotectants), improved nutrient acquisition via solubilization (termed biofertilizers), or phytohormone production like indole acetic acids

(termed bioenhancers). Species of *Pseudomonas* and *Bacillus* can produce (as yet not well characterized) phytohormones or growth regulators, antibiotics, siderophores, ACC deaminase that cause crops to have greater biomass of roots which have the effect of improving the absorptive capability of plant roots for uptake of water and essential nutrients. These PGPR are referred to as biostimulants and the phytohormones they produce include indole acetic acid, cytokinins, gibberellins and ACC deaminase. Rhizobacteria induce resistance through the salicylic acid-dependent SAR (systemic acquired resistance) pathway, or require jasmonic acid and ethylene perception from the plant for induced systemic resistance (ISR). Rhizobacteria belonging to the genera *Pseudomonas*, *Klebsiella*, *Enterobacter*, *Enterococcus*, *Flavobacterium*, *Burkholderia*, *Paenibacillus* and *Bacillus* etc. are well known for their antagonistic effects and ability to trigger ISR. Resistance-inducing and antagonistic rhizobacteria might be useful in formulating new inoculants with combinations of different mechanisms of action, leading to a more efficient use for biocontrol strategies to improve cropping systems.

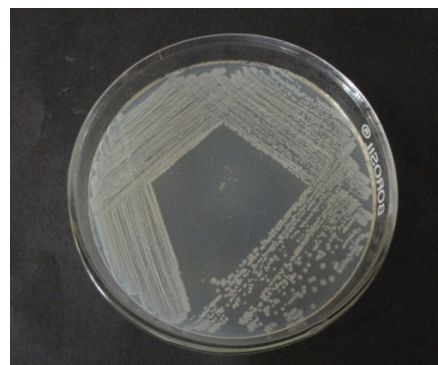
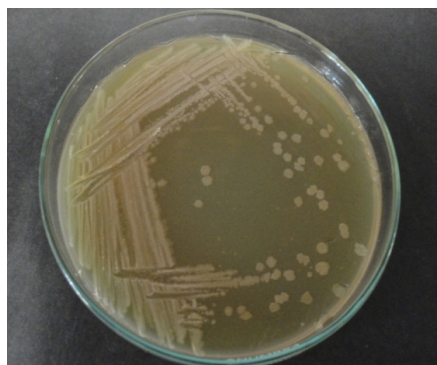
Strategies of biofertilizers development for sustainable agriculture

The strategies that can be used for rejuvenating sustainable agriculture economic development are given here:

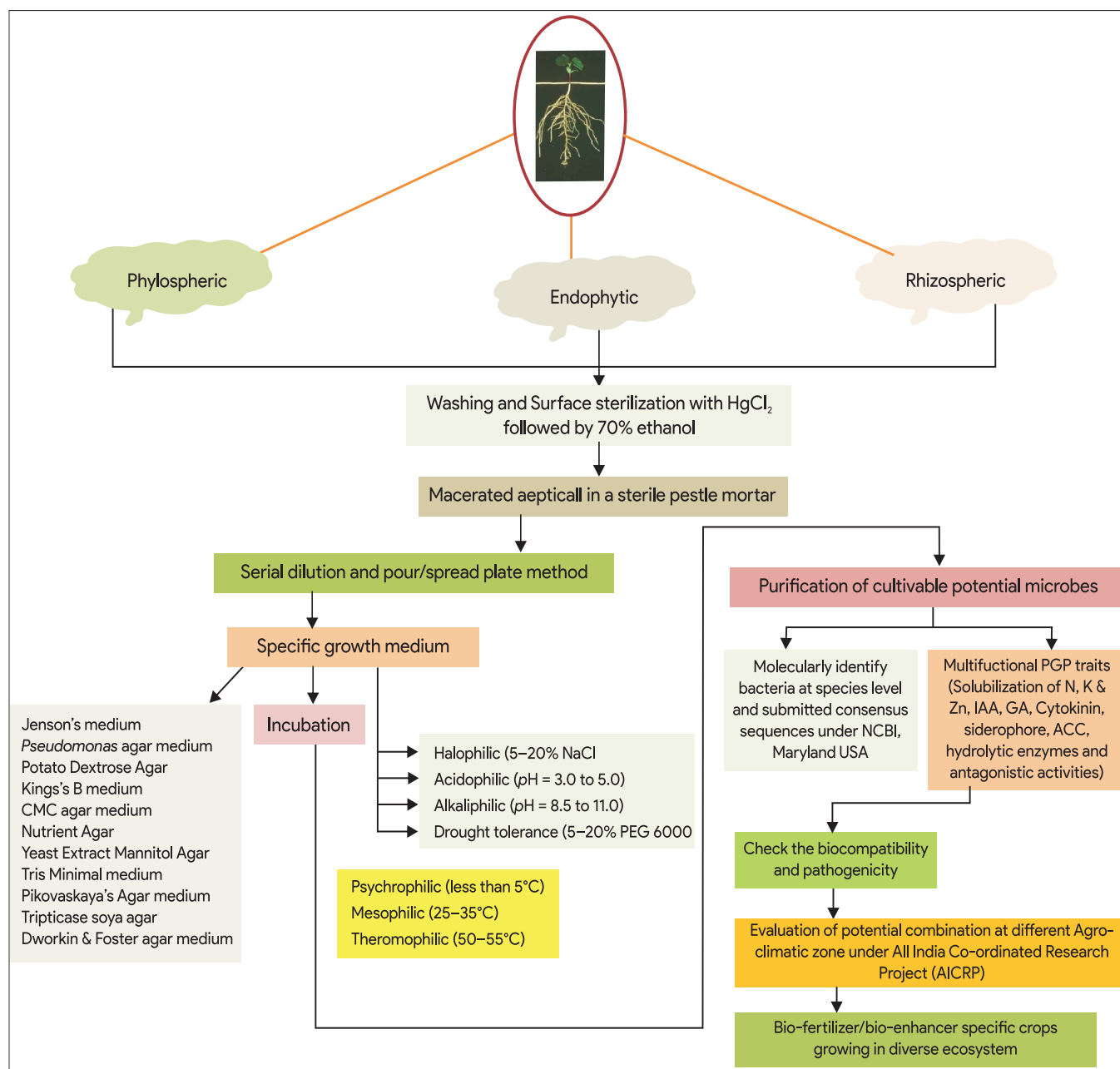
- Identifying and selecting specific crop, soil, efficient location and specific strains for higher N-fixing, P, Zn solubilizing, absorbing

(mycorrhizal) capability and antibiotic production to suit different agro-climatic conditions under abiotic and biotic stress conditions.

- Strain improvement through biotechnological approaches such genetic engineering, gene cloning etc.
- Exchanging potential beneficial bacterial strains between different countries of similar environmental conditions and evaluating their efficacy for plant growth promoting traits, nutrient accumulation, soil enzyme activities and grain yield for particular crop as well as checking the activity of bacterial strains during storage to avoid natural mutants.
- Developing suitable alternative formulations, viz. liquid inoculants/granular formulations supplemented with additives/protectants for longer shelf-life, to carrier based inoculants, standardizing the media and optimization of incubation condition etc. for the new formulations.
- Employing microbiologists in production units to monitor the quality of production.
- Developing cold storage facilities in production centers to reduce contamination.
- Technical training on the mass production and quality control to the producers and rendering technical advice and projects to manufacturers.
- Organizational training to the extension workers and rural farmers to popularize the environment friendly technology.
- Disseminating information



Phosphate solubilizing bacteria A) *Pseudomonas* sp. B) *Bacillus* sp.



Flowchart for preparation of Biofertilizer/Bioenhancer

through extension activities, research and demonstration trials, mass media communications, publications and bulletins.

SUMMARY

As a boon to farmers, the basic component of sustainable agriculture includes biofertilizers in the maintenance of long-term soil fertility, soil health and sustainability. For farmers to increase production per unit area in organic agriculture, biofertilization

will be a viable choice for a period of prosperity and the clean climate. Excessive reliance on inorganic fertilizer is not a feasible strategy in the long term, both in the sense of cost and environmental effects of chemical fertilizer, because of the costs involved in the construction of fertilizer plant and the continuation of production in both domestic and foreign exchanges. Biofertilizers are products which, as soon as adequate information is given by producers and rural farmers, will

be commercially promising in the long term. Biofertilizer utilization in country will not only have an effect on the economic development of sustainable agriculture but contribute to a sustainable environment and the overall well-being of India.

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