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Role of bio fertilizer in crop production (An element of sustainable agriculture): A review

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Abstract
In recent days agriculture had a played an important part in serving and full filling the food demand for the blooming population in our society which also thereby increased the application of different chemical fertilizers resulting in a slow degradation of soil physical and bio chemical characteristics which also affect the soil fertility in a greater aspect. chemical fertilizers are manufactured industrially and these substances composed of known quantities of macronutrients like Nitrogen potassium (K), phosphorous and micro-nutrients such as zinc, boron, iron etc., and their undifferentiating and imbalance use causes air, ground, and water pollution and degradation by nitrate (NO_3) leaching and different surface water bodies pollution through processes like eutrophication (Youssef *et al.*, 2014). Considering all these aspects efforts were made for maintain bio safety and for the production of nutrient rich and premium quality food without affecting the farm production and farmers economy. Organic farming came to the rescue. As it is necessary to use fertilizer and chemical substances in agriculture to deal with the growing demand for quality food in our country, there are many growing prospects in many crops and different crop growing locations and locality where the method of organic based farming and organic based production can also be encouraged in order to meet the domestic export market. Bio-fertilizers is one of the important and major part of organic based farming is the preparations containing live cells of different major strains of nitrogen fixing, p-solubilizing microorganism, which are applied to soil, seed or compost areas with a major motive of enhancing the number of such micro-organisms and catalyse the different micro-bacterial processes which enhance the major availability of nutrients that can be easily induced or utilised by plants for better growth.

Keywords: Biofertilizers, sustainable agriculture, soil fertility, bacteria, fungi

Introduction

Bio fertilizer and its classification

Biofertilizers act as a foremost contributor for the improving the of soil fertility by fixing atmospheric nitrogen, by the association with both the planting roots and excluding the plant root association, it helps in solubilising the insoluble phosphates in soil and also by producing plant growth substances. They are actually always encouraged to harvest the certainly present/available, biological method of nutrient mobilizing substance (Venkatashwar *et al.*, 2008) [23]. Effective utilization of biofertilizer can diminish the Nitrogen, Phosphorus, and potassium requirement of crops from chemical fertilizer sources. These are mostly known as the low-cost effective supplements when related to chemical /synthetic fertilizers due to its detrimental effect either on environment or soil health. The additional advantages of biofertilizers comprise of extensive storage life of microbial cells without any incompatible effects towards the natural ecology (Sahoo *et al*., 2014) [15]. Biofertilizers are usually defined as preparation processes that includes living microbes which aids in improving and nurturing the soil fertility status by fixing atmospheric-N and solubilizing phosphorus or decomposing organic waste materials or by enhancing plant qualitative and quantitative growth by producing different hormones for plant development and growth with their biological activities (Chaparro *et al.*, 2014) [7].

Table 1: Classification of Bio-fertilizer on the basis of type of micro-organism

Bio fertilizer group		Examples	Reference
Nitrogen-fixing bio fertilizer	Free living	*Azotobacter, Anabaena, Acetobacter, Beijerinckia, Clostridium, klebsiella, Nostoc*	Vessey *et al.*, 2003 [24]
	Symbiotic	*Rhizobium (legume), Frankia (non legume), Anabena azollae.*	
	Associative Symbiotic	*Azospirillum sp.*	
	Fungi	*Aspergillus awamori, Penicillium sp.*	
Phosphate solubilizing Bio-fertilizer	Bacteria	*Bacillus sp., C Phosphaticum, Burkholderia, Micrococcus, Rhizobium, Agrobacterium, Achromobacter, Aerobacter, Flavobacterium, Erwinia*	Khan *et al.*, 2009 [10]
	Fungi	*Aspergillus awamori, Penicillium*	
Phosphate mobilizing Bio-fertilizer	Arbuscular mycorrhizal fungi	*Glomus, Gigaspora, Scutellospora sp., Acaulospora sp.*	Jha *et al.*, 2012 [6]
	Ectomycorrhiza	*Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp.*	
	Ericoid mycorrhiza	*Pezizella ericae*	
Potassium solubilizing bio-fertilizer		*Bacillus sp., Aspergillus niger*	Jetiyanon *et al.*, 2011
Silicate solubilizing bio-fertilizer		*Bacillus circulans., Bacillus sp., Baciluus mucilaginous*	Jetiyanon *et al.*, 2011
Zinc solubilizing bio-fertilizer		*Bacillus sp., Bacillus sp., Flavobacterium, Serratia, Gluconacetobacter, Burkholderia, Saccharomyces sp.,*	Khan *et al.*, 2009 [10]
Sulphur oxidizing bio-fertilizer		*Thiobacillus sp.*	Bhattacharjee *et al.*, 2014 [5]
Organic matter decomposer bio-fertilizer	Cellulolytic	*Cellulomonas, Trichoderma*	Bhattacharjee *et al.*, 2014 [5]
	Lignolytic	*Arthobacter, Agaricus*	
Plant growth promoting rhizobacteria (PGPR)		*Psedumonas sp.*	Bhattacharjee *et al.*, 2014 [5]

Need of biofertilizers over chemical fertilizers

Bio-fertilizer has been considered as a competitive option to synthetic fertilizer to enhance the soil fertility and crop production in sustainable agriculture. They mostly fix nitrogen, solubilize, mobilize phosphate, and promote rhizobacterial (Bhat *et al.*, 2010) [5]. Bio fertilizer effectiveness mainly depends upon the selected micro organism that may enhance the soil characteristic for a extensive period of time (Brar *et al.*, 2012). Synthetic fertilizer changes the metabolic activities that may be for reduction in osmotic potential. Chemical fertilizer release more salt ions to the growth media thus, increasing the osmotic pressure outside the embryo, and consequently water is osmotically bound and soil concentration increase resulting in low water availability for embryo generation (Rafiq *et al*., 2010). Bio-fertilizer act as a soil quality enhacer and thereby improving the organic matter content to the soil which enhance the soil property and improves soil structure by which the whole plant system is benefited and respond well to the nutrient supplied or applied to the soil (Sanginga *et al*., 2010) [17]. Chemical fertilizer were quite expensive and were unavailable during the time of application in right quantity and further affects the farmers economy. Bio-fertilizer on other hand is not only economical but also eco-friendly (Yadav *et al*., 2019) [26]. Human, plant, and the environment are protected from pollution as well as save wages through the application of bio-fertilizer and it also enhances soil biota and reduces the use of harmful synthetic fertilizers (Jalilian *et al.*, 2012) [9].

Characteristics of different types of bio-fertilizer

Plant growth promoting rhizobacteria (PGPR)

Plant growth promoting bacteria (PGPR) includes those bacteria which are mainly free-living, and form specific symbiotic relationship with plants, bacterial organisation that can inhabit at some parts of plant tissue, and Cyanobacteria (Farrar *et al*., 2014). Rhizosphere microorganisms closely associated with roots with beneficial properties are plant-growth-promoting-rhizobacteria (PGPR). PGPR includes a assorted group of different soil bacteria that can improve host plant growth by interacting with other soil organisms, thereby either by promoting the growth of beneficial microbes such as rhizobia or phosphate solubilizers or plants directly or by impeding the development of pathogenic bacteria (Vejan *et al*., 2016) [22]. These are mainly crop growth promoting bio fertilizer and are crop specific. They produce anti-metabolites and hormones and improve the root growth and hasten the process of organic matter decomposition. This decomposition process helps in mineralization and improves the bio availability of the nutrient (Bhattacharya *et al.*, 2012) [6]. The phosphorus in-take done by the activity of PSB, thereby the uptake of phosphorus in the plant system enhances which results in enhancing and improving plant growth and development (Yadav *et al*., 2011) [26]

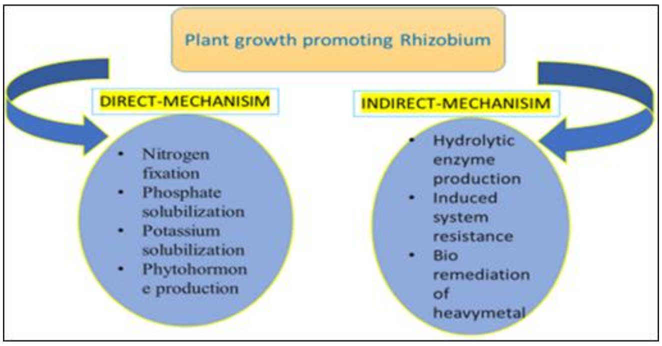

Fig 1: Mechanisim of Plant Growth Promoting Rhizobium (PGPR)

Effects of plant growth promoting rhizobium (PGPR)

Nitrogen fixers

Nitrogen is a vital plant nutrient (Dudeja *et al*., 2011), as it is widely used by the majority of plants, most of the Indian soils are deficit in nitrogen. Moreover, soil N is also lost due to leaching and volatilization (Brahmaprakash *et al*., 2012). Nitrogen is one of the important restraining nutrient that decrees crops growth or production. Though it is available in large quantities in the ecosystem, plants cannot avail the N as it is in an inert form (Brahmaprakash *et al*., 2012). N is converted to available form of fertilizers which are chemical fixation of atmospheric N through the industrial process of Haber-Bosch (Motsara *et al*., 1995). The N-fixing bacteria otherwise known to be diazotrophs are type of special microorganisms which easily convert atmospheric N into ammonia in the existence of nitrogenase enzyme. Microorganisms and plants integrate N in their body system to ammoniacal form for development and growth. On the basis of their mode of N-fixation, these bacteria are classified into three physiological groups, i.e., symbiotic, associative symbiotic and free living

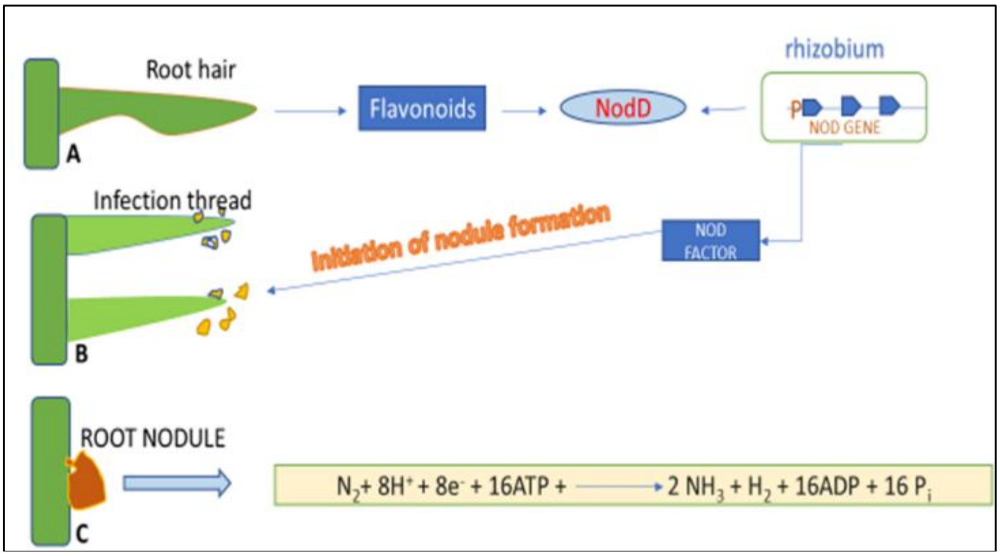

Fig 2: Bacterial Nirogen Fixation

1. *Azospirillum*
It belongs to Rhizobiaceae family, it is naturally symbiotic, there by fixing about nitrogen 50-100 kg/ ha in combination with legumes crops only. It is very useful for different pulse legumes like, pea, lentil, chickpea, red gram, black gram, etc., and different oil-seed legumes like soybean and groundnut and forage legumes consisting of berseem and lucerne. The process of leguminous nodulation of different crops by Rhizobium mostly depends on the available strain of a particular legume**.**

2. *Azotobacter*
These were mainly available in neutral or alkaline soils and *Azotobacter chroococcum* is the most generally occurring species in arable soils are *A. insignis*, *A. vinelandii*, and *A. macrocytogenes* are the different reported species.

3. *Blue Green Algae (Cyanobacteria) and Azolla*
It is phototrophic in nature and also produce Indole acetic acid, auxin and Gibberellic acid, fix about 20-30 kg N/ha in submerged paddy fields as they are plentiful in paddy for which it is termed as “paddy organisms”. Nitrogen is the crucial input that is required in excessive or large quantities for paddy production in low land. Soil Nitrogen and BNF by associative organisms are important sources of Nitrogen for low land paddy. Mostly 50-60% N requirement is acquired through the grouping process of mineralization of soil organic N and BNF by free living and paddy plant associated bacteria **(**Mishra *et al*., 2013) [14]

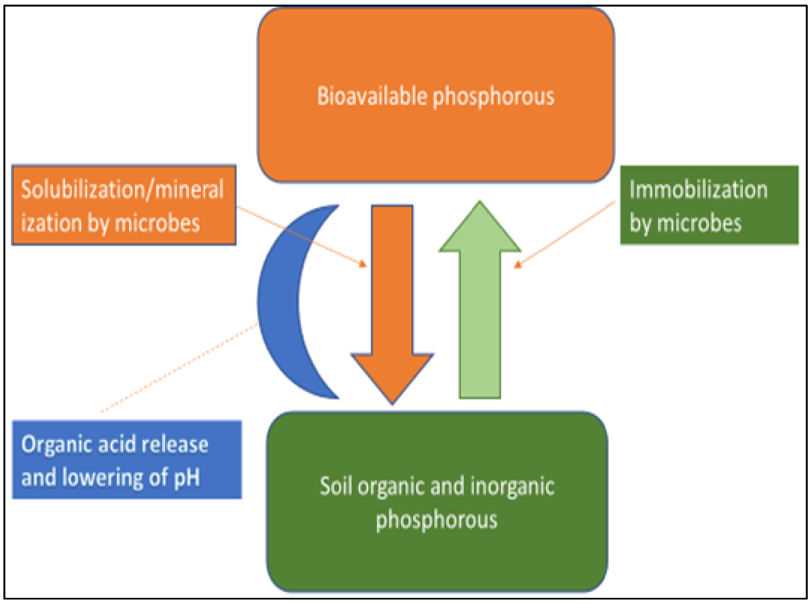

Fig 3: Phosphate solubilizer’s mechanism

Phosphate solubilizers

Numerous examination shows that the capability of different micro-bacterial species which generally have the capacity to solubilize the inorganic phosphate compounds insoluble in nature, like rock phosphate, dicalcium phosphate, hydroxyapatite, and the bacterial genera possessing this ability were *Bacillus, psedumonas, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Aereobacter, Flavobacterium* etc. In the ongoing process of phosphorus solubilization, many organic acids were produced with the ability to lower the pH and acid phosphatases changes the organic phosphorus into inorganic form (Khan *et al*., 2009) [10]. There are substantial populations of phosphate solubilizing bacteria in soil and in plant rhizospheres. This process includes strains of both aerobic and anaerobic with a incidence of aerobic strains in submerged soil. A significantly higher concentration of phosphate solubilizing bacteria is generally found in the soil rhizosphere in accordance with non rhizosphere soil. **(**Mishra *et al.,* 2013) [14]. A large part of the available Phosphorus in the super phosphate and other synthetic fertilizers immediate after application to soil converted to insoluble forms. For which, the availability of P to different crop plants has always been a limiting factor. The application phosphobacteria along with *Rhizobium* is considered as significant practice for Nitrogen and Phosphorous nutrients for pulse crops (Balamurugan *et al.,* 1996) [2].

Phosphate absorbers (Mycorrhiza)

Mycorrhiza is a symbiotic association of a special group of fungi with the roots of plants and that benefits the translocation and uptake of phosphorous in plants. Arbuscular mycorrhizal fungi (AMF) popularly known as VAM is the fungi that colonize roots of several crop plants, important in agriculture, horticulture, and tropical forestry. These were usually formed by different group of fungi that were mostly present in all soils from the phylum *Glomeromycotan* which consists of ten genera: *Glomus*, *Gigaspora*, *Geosiphon*, *Scutellospora*, *Diversispora*, *Sclerocystis*, *Acaulospora*, *Paraglomus*, *Entrophospora*, and *Archaeospora* (Schuessler *et al*., 2001) [19].

Zinc solubilizers

The zinc-solubilizing bio-fertilizer acts by secreting organic acids. These organic acids replace the zinc on insoluble chelated compound and it became accessible for plant uptake (Mahdi *et al.*, 2010). Three EPS producing strains of wheat and two of sugarcane were selected on the basis of zinc solubilization. The strains were identified as *Pseudomonas fragi* (EPS 1), two as *Pantoea dispersa* (EPS 6) and *Pantoea agglomerans* (EPS13), one sugarcane strain as *Enterobacter cloacae* (PBS 2), and one as *Rhizobium* sp. (LHRW1). These bacterial gene were commonly known to colonize rhizosphere of sugarcane and wheat thereby enhancing the plant growth (Baig *et al*., 2012) [3]. The zinc content of roots and shoots as compared to un-inoculated plants is supported by the previous research where by inoculating the plants with PGPR has resulted in increased yield, excessive plant growth and quality nutrition and different effective strains have been formulated as biofertilizers in this prospect. The identified PGPR strains mainly belong to genera *Serratia Pseudomonas, Ochrobacterum, Bacillus, Azospirillum, Azotobacter*, *Rhizobium*, *Stenotrophomonas*, and *Enterobacteria* (Maleki *et al*., 2011) [13]. Zinc solubilizing bacteria also significantly increased zinc content of roots and shoots in accordance to the un-inoculated plants which is a well processed phenomenon and has been clarified in many different research studies. Earlier research have clarified that integration of PGPR or PGPE has increased the zinc translocation toward wheat and rice grains and this ability of rhizobacteria or plant growth promoting endophytes (PGPE) is related with their ability of executing positive plant-microbe interactions such as initiation of processes such as mineralization, solubilization and physiological processes (Lucas *et al*., 2014) [12]

Table 2: Role of bio-fertilizer in plant growth promotion and bio control

Types of bio-fertilizer	Role in plant growth	Role in bio control	Reference
Pseudomonas Fluorescens	By producing siderophore.	By producing antifungal antibiotics that can inhibit the growth of phytopathogenic fungi	Kloepper *et al*., 1980;
R. leguminosarum	Solubilization of minerals such as phosphorus and cytokinin	By secretion of antibiotics and degrading cell wall enzymes that can hinder the phytopathogens	Zahir *et al*., 2010; Bardin *et al*., 2004;
B. japonicum	Phosphate solubilization, IAA, siderophores	By secretion of antibiotics and degrading cell wall enzymes that can hinder the phytopathogens	Bardin *et al*., 2004 ; Shaharoona *et al*., 2006;
Bacillus	Auxin synthesis	By forming endospores and different biologically active compounds	Chakraborty *et al*., 2006
Frankia	Nitrogen fixation	NA	Simonet *et al*., 1990
Actinomycete	NA	Chitinases,proteases and cellulases	Schmidt *et al*., 2001
Microbacterium pseudomonas	Phosphate solubilization	NA	Bhattacharyya and Jha 2012 [6]
Mycobacterium	IAA	Induction of plant stress resistance	Egamberdiyeva *et al.*, 2007

Biofertilizers importance in Conservation Agriculture

The introduction of biofertilizers in agriculture plays vital role in enhancing soil fertility, nutrient supply, crop residue degradation, and soil microbial diversity and population and it also enhance the soil health and crop yield. In addition, it helps in reducing the requirement of chemical fertilizers during a particular crop production. On the other hand the AMF produced a heat-stable protein called glomalin, which is a glycoprotein that enhances soil aggregation and helps in soil carbon sequestration. The glomalin and mycorrhizal hyphae together lead to a stable soil structure. According to the reports of different research work, the high potential value of the biofertilizers is summarized in the following points

1. Application of *Rhizobium* biofertilizers significantly enhanced the agronomic yield attributes in pulse crops under temperate climatic conditions
2. The *Azospirillium* application in agricultural crops improves the leaf area index, harvest index, and yield attributes
3. By application of seed inoculant green gram by rhizobium under 20 kg N +45 kg P2O5ha^{-1} there is

increase in the fertility level and improved the grain and straw yield

4. The positive effect of *Azotobacter chroococcum* was observed in maize crop. The significant yield improved in biofertilizer-treated plots compared to control. Such type of effect also observed in wheat crop when it was inoculated with *A. Chroococcum*
5. The biofertilizers increases the soil enzyme activities in soil, alkaline phosphatase activity was more in *Azotobacter chroococcum* + P fertilizer compared to control in peach roots

Biofertilizer Strategies to be followed for conservation agriculture

1. The study of particular strain effectiveness regarding a particular crop and soil and climatic factors. For this it is needed to strengthen the research and technologies in combination with extension wing.
2. By integration and application of biotechnological tools and techniques for the better improvement of N fixation, P solubilizer, and other biofertilizers.
3. Biofertilizer dose in a particular crop and soil should be standardized.
4. Identification of better carrier material for enhancing the shelf life of strains.
5. Frequent monitoring of the biofertilizer production units to assure the proper viable count, method of production, storage, etc.
6. Biofertilizers technology for the agricultural crop production should be socialized through scientific training, farmer fairs, exhibitions, or media.

Conclusion

Bio-fertilizers being one of the important components of organic farming which plays role in sustaining long term soil fertility and sustainability by fixing atmospheric di-nitrogen (N=N), mobilizing fixed both micro and macro nutrients or conversion of insoluble P into plant available form, there by increases their efficiency and availability. The integration of bio-fertilizers (N-fixers) plays vital role in enhancing soil fertility, yield attributing characters and thereby maximum and higher yield has been reported by many workers. Also the application of biofertilizer in soil enhance soil biota and lower the sole use of chemical fertilizers and also it help in maintaining the quality of produce as well as the environment. The use of various biofertilizers as an integral component of agricultural practice is the new emerging field now a days. These bacteria are already being successfully used in few countries in the developing world and are expected to grow with time (Weekley *et al.*, 2012) [25].

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