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Review Article

Contribution of Biofertilizers: Towards sustainable agriculture

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ABSTRACT:
Agricultural workers are increasingly turning to organic farming practices to balance crop input and output economics, while becoming increasingly conscious of environmental changes due to climate change. Use of eco-friendly, bio-pesticides, bio-fertilizer and bio-controls is being encouraged in the field of agriculture. Bio-pesticides like neem and *Bacillus*-based pesticides such as Aureofungin, Kasugamycin, Validamycin, Streptomycin and Sulphate and Tetracycline Hydrochloride have been identified for controlling various insect pests and diseases in agriculture.

Keywords: Biofertilizers, Agricultural, Bacterial, Rhizobium

INTRODUCTION

Agricultural workers are increasingly turning to organic farming practices to balance crop input and output economics, while becoming increasingly conscious of environmental changes due to climate change.

In nature, there are a number of useful soil micro organisms which can help plants to absorb nutrients. Their utility can be enhanced with human intervention by selecting efficient organisms, culturing them and adding them to soils directly or through seeds. The cultured micro organisms packed in some carrier material for easy application in the field are called bio-fertilisers.(1)

BIOFERTILIZERS

The use of microbial inoculants is of strategic interest for their potential to replace chemical fertilizers and pesticides in agricultural systems, and improve environmental sustainability.

Plant-aiding microorganisms, often referred to as plant growth-promoting rhizobacteria (PGPR)(2) and arbuscular mycorrhizal fungi (AMF) (3), interact with plants roots (4) by enhancing growth, mineral nutrition, drought tolerance, and disease resistance (5).

Bacteria can beneficially contribute to plant growth *via* N_2-fixation and solubilization of low mobile nutrients. Biological N_2-fixation is carried out by various symbiotic and nonsymbiotic bacteria (6).

Based on type of microorganism, the bio-fertilizer can also be classified as follows:

- **Bacterial Biofertilizers**: e.g. Rhizobium, Azospirilium, Azotobacter, Phosphobacteria.
- **Fungal Biofertilizers**: e.g. Mycorhiza
- **Algal Biofertilizers**: e.g. Blue Green Algae (BGA) and Azolla.
- **Actinimycetes Biofertilizer**: e.g. Frankia.

Bio-fertilizer are mostly cultured and multiplied it the laboratory. However, blue green algae and azolla can be mass-multiplied in the field.

Characteristics Features of common Biofertilizers

- **Rhizobium** :

Rhizobium is relatively more effective and widely used biofertilizer. Rhizobium, in association wit legumes, fixes atmospheric N. The legumes and their symbiotic association with the rhizobium bacterium result in the formation of root nodules that fix atmospheric N. Successful nodulation of leguminous crop by rhizobium largely depends on the availability of a compatible stain for a particular legume. Rhizobium population in the soil is dependent on the presence of legumes crops in field. In the absence of legumes the population of rhizobium in the soil diminishes.

- **Azospirillum** :

Azospirillum is known to have a close associative symbiosis with the higher plant system. These bacteria have association with cereals like; sorghum, maize, pearl millet, finger millet, foxtail millet and other minor millets and also fodder grasses.

- **Azotobacter** :

It is a common soil bacterium. *A. chrococcum* is present widely in Indian soil. Soil organic matter is the important factor that decides the growth of this bacteria.

- **Blue Green Algae (BGA)** :

Blue green algae are referred to as rice organisms because of their abundance in the rice field. Many species belonging to the genera, Tolypothrix, Nostic, Schizothrix, Calothrix, Anoboenosois and Plectonema are abundant in tropical conditions. Most of the nitrogen fixation BGA are filamenters, consisting of chain of vegetative cell including specialized cells called heterocyst which function as a micronodule for synthesis and N fixing machinery.

Name	Crops suited	Benefits usually seen	Remarks
Rhizobium strains	Legumes like pulses, groundnut, soybean	10-35% yield increase, 50-200 kg N/ha.	Fodders give better results. Leaves residual N in the soil.
Azotobacter	Soil treatment for non-legume crops including dry land crops	10-15% yield increase- adds 20-25 kg N/ha	Also controls certain diseases.
Azospirillum	Non-legumes like maize, barley, oats, sorghum, millet, Sugarcane, rice etc	10-20% yield increase	Fodders give higher/enriches fodder response. Produces growth promoting substances. It can be applied to legumes as co-inoculant
Phosphate Solubilizers (there are 2 bacterial and 2 fungal species in this group)	Soil application for all crops	5-30% yield increase	Can be mixed with rock phosphate.
Blue-green algae and Azolla	Rice/wet lands	20 -30 kg N/ha, Azolla can give biomass up to 40-50 tonnes and fix 30-100 kg N/ha	Reduces soil alkalinity, can be used for fishes as feed. They have growth promoting hormonal effects.
Microhizae (VAM)	Many trees, some crops, and some ornamental plants	30-50% yield increase , enhances uptake of P. Zn, S and Water.	Usually inoculated to seedlings.

https://vikaspedia.in/agriculture/agri-inputs/bio-inputs/bioinputs-for-nutrient-management/Biofertilizers(1)

Azotobactor, a non symbiotic bio-fertilizer contributes about 20-25 kg N ha-1 in crop like wheat, maize, cotton and other crops under favorable conditions. *Phosphorus solubilising bacteria* (PSB) can solubilize 20-30 per cent of insoluble phosphate and increase yield up to 20 per cent. If these two microorganisms interact favorably they may show synergistic effect to produce even better result than expected separately. Biofertilizers being cheaper, effective and environmental friendly are gaining importance for use in crop production [7].Nitrogen-fixing bacteria such as *Azospirillum*, Vesicular arbuscular mycorrhizal (VAM) fungi improve plant growth through increased uptake of relatively immobile nutrients such as P, Zn, Cu etc. [8].

Types of Biofertilizers

- Biofertilizers are broadly classified into two main groups:
  1. **Biological nitrogen fixing biofertilizers**
  2. **Phosphate solubilising (mobilising) biofertilizers**
- Biological nitrogen fixing biofertilizers consist of micro-organisms which have the ability to fix biological molecular nitrogen (N2) either symbiotically or asymbiotically in the plants.
- Phosphate solubilising biofertilizers are capable of solubilising or mobilising the fixed insoluble phosphates of the soil
- However, Biofertilizers are divided into five main categories.
- These five types are again divided in sub-types as follows:
- **i. Nitrogen fixers:**
  - **Symbiotic:** *Rhizobium, Frankia, Anabaena azollae.*
  - **Free living**: *Azotobacter, Clostridium, Blue green algae, Azolla, Acetobacter, Nostoc, Anabaena.*
  - **Associative symbiotic:** *Azospirillum.*
- **ii. Phosphate supplier:**
  - **Phosphate solubiliser**:
    Bacteria: *Bacillus megaterium, Phosphaticum, Bacillus circulans, Pseudomonas striata, Pseudomonas* sp..
  - **Fungi:** *Penicillium sp, Aspergillus awamori.*
- **iii. Phosphate absorber biofertilisers:**
  - *Arbuscular mycorrhiza: Glomus sp., Gigaspora sp., Acaulospora sp., Scutellospora sp.* and *Sclerocystis* sp., *Ectomycorrhiza: Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp. Orchid mycorrhiza: Rhizoctonia solani.*
- **iv. Sulphur supplier:**
  - *Thiobacillus novellus, Aspergillus.*
- **v. Micronutrients supplier:**
  - Silicate and Zinc solubilisers: *Bacillus* sp. (9)

Groups	Examples
N_2 fixing biofertilizers	
Free living	*Azotobacter, Beijerinkia, Clostridium, Klebsiella, Anabaena* and *Nostoc*
Symbiotic	*Rhizobium, Frankia* and *Anabaena azollae*
Associative symbiotic	*Azospirillum*
P solubilising biofertilizers	
Bacteria	*Bacillus megaterium* var. *phosphaticum, Bacillus subtilis, Bacillus circulans* and *Pseudomonas striata*
Fungi	*Penicillium* sp. and *Aspergillus awamori*
P mobilizing biofertilizers	
Arboscular mycorhiza	*Glomus* sp., *Gigaspora* sp., *Acaulospora* sp., *Scutellospora* sp. and *Sclerocystis* sp.
Ectomycorrhiza	*Laccaria* sp., *Pisolithus* sp., *Boletus* sp. and *Amanita* sp.
Ericoidmycorrhiza	*Pezizella*
Orchid mycorrhiza	*Rhizoctonia solani*
Biofertilizers for micro nutrients	
Silicate and Zinc solubilizers	*Bacillus* sp.
Plant growth promoting rhizobacteria	
Pseudomonas	*Pseudomonas fluorescens*

Table1: Group of Bio-fertiliser based on their nature and function (10)

Table 2: Changing composition of biofertilizers in India

	Year						
Biofertilizers	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
Rhizobium	57.27	40.50	29.41	21.15	20.84	19.85	18.62
Azotobacter	13.00	22.20	18.47	18.46	15.51	17.30	17.74
Azospirillum	12.54	11.11	14.08	17.99	11.34	10.17	11.77
Nitrogen fixers	82.81	73.80	61.96	57.61	47.69	47.32	48.12
Blue green algae	0.00	0.00	0.06	0.04	0.01	0.02	0.04
Phosphate solubilizer	17.19	26.20	35.77	40.46	49.88	48.75	48.98
Acetobacter	0.00	0.00	2.21	1.90	1.13	1.06	1.00
Total (tones) % share	1600.01	2914.37	4988.90	6688.32	6681.44	6295.63	6700.30

Table 3: Use intensity of biofertilizers and chemical fertilizers (in India agriculture)

	Year		
Location	2008-2009	2009-2010	2010-2011
South	125.21	18.46	0.05
North	130.43	22.32	0.01
West	60.82	4.91	0.06
East	70.63	18.32	0.01
Total	477.13	100.01	0.13

Source: Fertilizers association of India(11)

DISCUSSION

Effect of Biofertilizers on Crop

Agrawal *et al.* [12] reported that at 80 DAS, about 72.03% increase in nitrogen uptake over the control was recorded due to *Azotobacter* inoculation and it was at par with the addition of 20 kg N ha-1 alone. *Azotobacter* alone and 20 kg N ha-1 were statistically at par in affecting the nitrogen content in straw as well as in grain.

Inoculation alone increased about 37.97, 39.17 and 37.37% phosphorus uptake over the control in the yields of straw, grain and total yield, respectively, whereas, potassium uptake was 95.25, 43.23 and 44.81%, respectively. Kachroo and Razdan [13] reported that nitrogen use efficiency values were higher with combined inoculation of *Azotobacter* + *Azospirillum* in 1:1 in wheat. Grain N content of wheat increased in response to increasing rates of nitrogen application. Similarly, Kader *et al.* [14] reported that the highest N uptake (23.2 mg plant-1) was recorded with the treatment having 168 kg N ha-1 + cowdung + *Azotobacter* and the lowest with the control (11.03 mg plant-1) in wheat.

Azotobacter plays an important role in the nitrogen cycle in nature as it possesses a variety of metabolic functions [15]. Besides playing role in nitrogen fixation, *Azotobacter* has the capacity to produce vitamins such as thiamine and riboflavin [16], and plant hormones *viz.,* indole acetic acid (IAA), gibberellins (GA) and cytokinins (CK) [17]. *A. chroococcum* improves the plant growth by enhancing seed germination and advancing the root architecture [18] by inhibiting pathogenic microorganisms around the root systems of crop plants [19]. This genus includes diverse species, namely, *A. chroococcum, A.vinelandii, A. beijerinckii, A. nigricans, A. armeniacus* and *A. paspali*. It is used as a biofertilizer for different crops *viz.,* wheat, oat, barley mustard, seasum, rice, linseeds, sunflower, castor, maize, sorghum, cotton, jute, sugar beets, tobacco, tea, coffee, rubber and coconuts [20]. *Azospirillum* is another free-living, motile, gram variable and aerobic bacterium that can thrive in flooded conditions [21] and promotes various aspects of plant growth and development [22]. *Azospirillum* was shown to exert beneficial effects on plant growth and crop yields both in greenhouse and in field trials [23]. Diverse species of the genus *Azospirillum* including *A. lipoferum*, *A. brasilense*, *A. amazonense*, *A. halopraeferens* and *A. irakense* have been reported to improve productivity of various crops [21]. Interestingly, it was observed that *Azospirillum* inoculation can change the root morphology via producing plant growth regulating substances [24] via siderophore production [21]. It also increases the number of lateral roots and enhances root hairs formation to provide more root surface area to absorb sufficient nutrients [25]. This improves the water status of plant and aids the nutrient profile in the advancement of plant growth and development [26,27]. Co-inoculation of *Azospirillium brasilense* and *Rhizobium meliloti* plus 2,4D posed positive effect on grain yield and N,P,K content of *Triticum aestivum*[28]. *Rhizobium* has been used as an efficient nitrogen fixer for many years. It plays an important role in increasing yield by converting atmospheric nitrogen into usable forms [29]. Being resistant to different temperature ranges *Rhizobium* normally enters the root hairs, multiplies there and forms nodules [30]. *Rhizobium* inoculants in different locations and soil types were reported to significantly increase the grain yields of bengal gram [31], lentil [32], pea, alfalfa and sugar beet rhizosphere [33], berseem [34], ground nut [29] and soybean [35]. These *Rhizobium* isolates obtained from wild rice have been reported to supply nitrogen to the rice plant to promote growth and development [36].

Benefits of biofertilizer

Abiotic and biotic stresses are the major constraints that are affecting the productivity of the crops.

In wheat crop, combined inoculation of *Azotobacter* + *Azospirillum* in 1:1 ratio increased the growth, yield attributes and yield significantly [38,39]. Khan and Zaidi [40] reported that the triple inoculation of *Azotobacter chroococcum* with *Bacillus* and *Glomus fasciculatum* significantly increased the dry matter by 2.6-fold above the control, grain yield of plants 2-fold higher, increased N and P concentrations, and quality of wheat grains than that of non-inoculated plants.

Verma et al. [41] reported that plots receiving recommended dose of fertilizer (RDF) + vermicompost 5 t ha-1 + *Azotobacter* and PSB as seed treatment of wheat and spraying at first and second irrigation recorded maximum grain yield (5.67 and 5.73 t ha-1), straw yield (7.29 and 8.87 tha-1), gross income (Rs. 87443 and 97127 ha-1) and net income (Rs. 37001 and 45462 ha-1) during 2011-12 and 2012-13, respectively.

Kumar et al. [42] reported that application of half of the recommended dose of N and P2O5 i.e., 60

kg N along with 30 kg P2O5 ha-1 supplemented with seed treatment of wheat by *Azotobactor* and phosphate culture, produces a mean wheat yield of 39.10 q ha-1 which is much more economical (2.69 kg grain rupee invested-1) in terms of grain produced per rupee invested in fertilizers with bio-fertilizers as compared to the plot where recommended dose of fertilizers (1.65 kg grains rupee invested-1) were applied in the form of chemical fertilizers only in both the years.

A group of rhizosphere bacteria that exert a beneficial effect on plant growth is referred as PGPR. They belong to several genera, e.g., *Actinoplanes*, *Agrobacterium*, *Alcaligenes*, *Amorphosporangium*, *Arthrobacter*, *Azotobacter*, *Bacillus*, *Cellulomonas*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *Pseudomonas*, *Rhizobium* and *Bradyrhizobium*, *Streptomyces* and *Xanthomonas*. The plant growth promoting microorganisms improved potato growth and yield in short-but not long-rotation soils, primarily by suppressing cyanide-producing deleterious rhizosphere microorganisms. Large populations of bacteria established on planting material and roots become a partial sink for nutrients in the rhizosphere, thus, reducing the amount of C and N available to stimulate spores of fungal pathogens or for subsequent colonization of the root. In field trials with wheat, potato, sugar beet and zinnia conducted showed significant yield increases varying from 7-136% with an average increase of 7-35% in different crops over the control. Seed treatment with *B. subtilis* increased yield of carrot by 48%, oats by 33% and groundnut upto 37%.(10)

The recent estimated potential demand of different kinds of biofertilizers by Government of Tamil Nadu are *Rhizobium* 35 thousand tonnes; *Azospirillum* 482 thousand tonnes; *Azotobacter* 162.61 thousand tonnes; Blue-Green Algae 267.72 thousand tonnes, *Azolla* 20.38 thousand tonnes and phosphate solubiliser 275.51 thousand tonnes. The total of all these amounts to be 12.44 lakh tonnes which is significantly higher than the estimates of NBDC and BCIL, mainly because they did not indicate phosphate solubiliser and their estimates for *Azospirillum* were also low. Production technology of biofertilizer is relatively simple and its installation cost is very low compared to chemical fertilizer plants. Most of the biofertilizer units lack in this respect. Those who have very good organised marketing network have done excellently well. For example, fertilizer company like GSFC has more than 200 farm information centres-cum-depots situated in remote areas. In order to provide BF upto village level, GSFC has established its own distributor’s network. MLF and SPIC have also well organised themselves in this respect. It is found that biofertilizer like *Rhizobium* can supply 20-25 kg N ha^{-1}. Considering the prospects of biofertilizers in the country, the biofertilizer development centres are being established both in government and private sector. It is possible to establish joint venture in biofertilizer agro based industry.(10)

In general, 60% to 90% of the total applied fertilizer is lost and the remaining 10% to 40% is taken up by plants. In this regard, microbial inoculants have paramount significance in integrated nutrient management systems to sustain agricultural productivity and healthy environment [43]. The PGPR or co-inoculants of PGPR and AMF can advance the nutrient use efficiency of fertilizers. A synergistic interaction of PGPR and AMF was better suited to 70% fertilizer plus AMF and PGPR for P uptake. Similar trend were also reflected in N uptake on a whole-tissue basis which shows that 75%, 80%, or 90% fertilizer plus inoculants were significantly comparable to 100% fertilizer [44].

Pseudomonas aeruginosa has been shown to withstand biotic and abiotic stresses [45]. Paul and Nair [46] found that *P. fluorescens* MSP-393 produces osmolytes and salt-stress induced proteins that overcome the negative effects of salt. *P. putida* Rs-198 enhanced germination rate and several growth parameters *viz.*, plant height, fresh weight and dry weight of cotton under condition of alkaline and high salt via increasing the rate of uptake of K^+, Mg^{2+} and Ca^{2+}, and by decreasing the absorption of Na^+[47]. Few strains of *Pseudomonas* conferred plant tolerance via 2,4-diacetylphloroglucinol (DAPG) [48]. Interestingly, systemic response was found to be induced against *P. syringae* in *Arabidopsis thaliana* by *P. fluorescens* DAPG [49]. Calcisol produced by PGPRs *viz.*, *P. alcaligenes* PsA15, *Bacillus polymyxa* BcP26 and *Mycobacterium phlei* MbP18 provides tolerance to high temperatures and salinity stress [50].

Limitation of Bio-Fertilizer

Mahimairaja et al. [51] stated that the addition of phosphorus to wastes makes the bio-fertilizer more balanced and reduces nitrogen losses. Again storage of bio-fertilizer goes a long way in affecting its efficacy. Even though bio-fertilizer has many positive aspects, its use can sometimes not lead to the expected positive results and this could be because of exposure to high temperature or hostile conditions before usage. Bio-fertilizer should be stored at room temperature or in cold storage conditions away from heat or direct sunlight and polythene bags used in packaging bio-fertilizer should be of low density grade with a thickness of about 50 –75 microns [52]. Other constraints limiting the use of biofertilizer technology may be environmental, human resource, unawareness, unavailability of suitable strains, and unavailability of suitable carrier and so on [53]. Short shelf life, lack of suitable carrier material, susceptibility to high temperature, problem in transportation, and storage are biofertilizers bottlenecks that still need to be solved in order to obtain effective inoculation [54].

Conclusion

It is important to realize the useful aspects of bio-fertilizers so as to apply it in modern agricultural practice. The application of bio-fertilizers containing beneficial microbes promote to a large extent, crop productivity. These potential biological fertilizers would play a key role in productivity and sustainability of soil and protect the environment as eco-friendly and cost effective inputs for the farmers as righted stated by Khosro and Yousef [55]. Using the biological and organic fertilizers, a low input system can help to achieve sustainability of farming.** improved protocols of bio-fertilizers application to the field is one of the few limiting factors to bio-fertilizers usage.

The changing agriculture ecosystem with its increased emphasis on sustainability plus holistic soil and crop health management has opened immense opportunities for bio-based fertilizers. Continued R&D efforts to ensure product efficiency and field trials are critical to ensure successful adoption in agricultural practices.

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