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Biofertilizer as Prospective Input for Sustainable Agriculture in India

Manashi Barman[1*], Srijita Paul[1], Aditi Guha Choudhury[2], Pinaki Roy[4] and Jahnavi Sen[3]

[1]Department of Agronomy, [2]Department of Fruits and Orchard Management, [3]Department of Plant Physiology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal-741252, India
[4]Division of Agricultural Extension, ICAR-IARI, New Delhi-110012, India
*Corresponding author

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A B S T R A C T

The continuous increasing population in India leads huge pressure on agricultural lands along with other natural resources to produce more foods. Increasing use of chemical fertilizers in agriculture could make the country self-dependent in food production but on the contrary it deteriorates the environment and causes harmful impacts on living beings. During green revolution remarkable food production was noticed in which concern for sustainability was overlooked. Dependence on chemical fertilizers for future agricultural growth would mean further losses in soil quality and possibilities of water contamination. The term biofertilizer refers to formulation containing live microbes which helps in enhancing the soil fertility by fixing atmospheric nitrogen, solubilization of phosphorus and other nutrients and augmenting plant growth by producing growth hormones. Since the concept is not a new, multifarious advantages of biofertilizer leads to its wide applicability in sustainable agriculture. In spite of being cost effective and eco-friendly in nature, several constraints include unreliable supplies and absence of proper quality control limit the application or implementation of the technology. Extensive research is required to identify more suitable strains, develop better production technologies and quality control measures for wide commercialization of biofertilizer. The development of biofertilizer with multi-crop growth promoting activities is most important for sustainable global agriculture.

Introduction

The population in India as well as in the World is increasing day by day and it puts considering pressure on the agricultural lands and other resources to fulfill the need for food of this huge population. According to 15th Census of India in 2011, the population is 121 million with decadal growth of 17.64% and around 68.84% of this is rural population. In case of Asia, it has been estimated that each 1% increment in crop productivity leads to 0.48% reduction in number of poor people (Thirtle *et al.,* 2003); while, in India 1% rise in agricultural value added per hectare declines 0.4% poverty in the short run and 1.9% in the long run due to indirect effects of lower food prices and higher wages (Ravallion and Datt, 1996). Therefore, at present the most challenging issue is to increase the production of food from the rapidly shrinking per capita agricultural land

(Bhattacharyya, 2009; Mazid and Khan, 2014). Generally, in conventional agriculture there are two major inputs necessary for crop production, *viz*., fertilizer and pesticide; in other words, it can be said that fertilizer is food and pesticide is medicine for plants (Muraleedharan *et al.,* 2010). Though the production in India was remarkably high during periods of Green Revolution, poverty still remains as it was concentrated mainly in favorable areas.

Consequence of that, the growth of yield became downwards in addition to high utilization of chemical fertilizers caused poor soil health due to lack of organic matter, loss of inherent fertility (Mahajan and Gupta, 2009; Khare and Arora, 2015) by affecting soil micro flora and fauna (Gupta and Singh, 2008). Even it also impaired the health of human beings and animals (Gupta and Singh, 2006; Khare and Arora, 2015).

Moreover, plants cannot uptake all the nutrients applied through chemical fertilizers (Bhardwaj *et al.,* 2014) so, some amount of nutrients are either fixed in the soil or leached out and ultimately mixed with water bodies (Mahdi *et al.,* 2010). In order to make agriculture sustainable it is necessary to implement a balanced and reasonable use of nutrients which are cost effective and ecofriendly (Venkataraman and Shanmugasundaram, 1992; Mahdi *et al.*, 2010); in that case biofertilizer could be a suitable option (Pindi and Satyanarayana, 2012; Borkar, 2015). Now, the Government of India has also taken a strideto harness the full potential of the available biofertilizers by introducing it along with chemical fertilizers to the farmers (Ghosh, 2004).

Biofertilizer

'Biofertilizer', also named as 'micro inoculants' (Arora *et al.*, 2010), was derived from the retrenchment of the term 'biological fertilizer'; with *biological*, denoting the use of living organism or it can be defined as a product containing living microorganisms that colonizes in rhizosphere accompanying interior of the plant and stimulates growth by increasing the accessibility and uptake of mineral nutrients to the host plant (Vessey, 2003; Malusá *et al.*, 2012; Malusá and Vassilev, 2014).

Biofertilizers can fix atmospheric nitrogen through the process of biological nitrogen fixation (BNF) and solubilize plant nutrients like phosphates, potash; in addition, it also stimulates plant growth through synthesis of different growth promoting substances and has C: N ratio 20:1 indicating its stability (Wani *et al.,* 2013; Borkar, 2015). Biofertilizers can be categorized into five groups based on their nature and activity as follows (Table 1):

Recently, the potash mobilizers like *Frateuri aaurentia*, zinc and sulphur solubilizers like *Thiobacillus sp*. and manganese solubilizer fungal culture like *Pencillium citrinum* have also been identified for commercial operations (Borkar, 2015).

History of biofertilizer use in India

In India, systematic study on biofertilizers was started by N. V. Joshi in 1920. *Rhizobium* was the first isolated from various cultivated legumes and this was followed by extensive research by Gangulee, Sarkaria and Madhok on the physiology of the nodule bacteria along with its inoculation for better crop production (Panda, 2011). The milestones in research, production and promotion of biofertilizer in India are given in table 2.

Now, *Rhizobium* and Blue Green Algae (BGA) can be considered as established biofertilizers whereas Azolla, *Azospirillum* and *Azotobacter* are at an intermediate stage (Panda, 2011).

Practical significance of biofertilizer

Biofertilizers make nutrients available that are naturally abundant in soil and atmosphere to plants. Various field studies have demonstrated these to be effective and cheap inputs, free from any environmental hazards (Ghosh, 2004; Sahoo *et al.,* 2014; Borkar, 2015). In a nutshell, it provides "ecofriendly" organic agro-input which has the ability to convert nutritionally important elements from unavailable to available form through biological processes (Vessey, 2003). So, it can be expected to reduce the use of chemical fertilizers and pesticides by introducing biofertilizers (Subashini *et al.,* 2007). The microorganisms in biofertilizers reestablish natural nutrient cycle, maintain optimum nutrient level in soil and also increase soil organic matter content as a result healthy plants can be grown, while upholding sustainability and fertility of the soil (Singh *et al.,* 2011; Sinha *et al.,* 2014; Shelat *et al.,* 2017). Therefore, they are extremely advantageous in enriching soil fertility and fulfilling plant nutrient requirements by supplying organic nutrients. Besides accessing nutrients for current intake as well as residual, different biofertilizers provide growth-promoting factors to plants through secretion of different vitamins, phytohormones (Revillas *et al.*, 2000; Abd El-Fattah *et al.,* 2013) and by successfully facilitating composting and controlling attack of pest and soil borne diseases (Board, 2004; Sinha *et al.,* 2014). It not only saves chemical fertilizers but also help in its effective utilization and results in higher yield rates (Ghosh, 2004).

Dryland agriculture constitutes a very large part of agricultural area in India including majority of the poor people and more than 90% of coarse cereals, 80% of groundnut and 85% of pulses come from these regions (Ghosh, 2004). Dryland agriculture is characterized by low productivity, unpredictable climatic swings and low dosage of chemical fertilizers and in this situation biofertilizers, particularly *Rhizobium*, could be a bridge between removals and additions to soil nutrients where farmers can scarcely afford costly inputs (Das *et al.,* 2015).

It is an established fact that due to fixation in acidic and alkaline soils, the efficiency of phosphatic fertilizers is very low (15-20%) and unfortunately both soil types are prevailing in India (Board, 2004).

On that account, the inoculation of phosphate solubilizing bacteria in soils is needed to restore and maintain the effective microbial populations for solubilization of chemically fixed phosphorus as well as availability of other macro and micronutrients to harvest good sustainable yield of various crops (Mahdi *et al.*, 2010).

Marketed biofertilizers in India

The following types of microorganisms as biofertilizers are available to the farmers in India:

Nitrogen fixer, e.g. *Rhizobium*, *Bradyrhizobium*, *Azospirillum*, *Azotobacter*, Acetobacter, Azolla and BGA.

Phosphorus solubilizer, e.g. *Bacillus*, *Pseudomonas* and *Aspergillus*.

Phosphate mobilizer, e.g. VA-mycorrhiza (VAM) like *Glomus.*

K-solubilizer, e.g. *Frateuria aurantia*.

Silicate solubilzer, e.g. *Thiobacillus thiooxidans*.

Plant growth promoting biofertilizers, e.g. *Pseudomonas sp*. (Muraleedharan, 2010; Mishra and Arora, 2016).

Production scenario in India

Estimated annual requirement of *Rhizobium* inoculum varies from 1,250 to 15,000t (Panda, 2011). The highest requirements of biofertilizers can be quantified through an over-simplified approach multiplying the total legume area by dosage per hectare; therefore if 25% of area is annually treated, 3750t inoculum is needed for 30 mha and the present production is about one-fourth of this. Year wise (2008-09 to 2014-15) production in India has been listed in table 3. Based on crop area in India, the present requirement of biofertilizers is around 5,50,000 metric tonnes and there is an ample potential to increase it to 50,000-60,000 tons by 2020 (Pindi and Satyanarayana, 2012); however, the total production in our country is much less than requirement which points out the inevitability of increase in biofertilizer production.

Now, the government of India is boosting the biofertilizer industries by providing subsidies to a maximum of 20 lakh rupees and awarding a national productivity award to the efficient biofertilizer production unit (Borkar, 2015). Agro Industries Corporation has the maximum production capacity which is followed by State Agriculture Departments, National Biofertilizers Development Centers, State Agricultural universities and private sectors (Pindi and Satyanarayana, 2012).

Reasons behind little popularization of biofertilizer in India

Despite the multiple advantages of biofertilizer in agricultural production, several constraints at different levels i.e. from production unit to farmers' field are there for making it less popular in India.

Production and distribution level

Generally, activity of microorganisms are location and crop specific so, strains selected for particular areas as well as crops should have good adaptability for this specific location and some qualities like competitive ability over other strains for nodulation of host, N-fixing ability, potentiality to colonize and survive in adverse physical conditions (Panda, 2013).

Some biofertilizer production units do not have sufficient technically well-qualified microbiologist or skilled persons who can make available high quality biofertilizers rather depend on more of non-skilled labours working on contract basis that leads to sub-standard biofertilizers (Mahdi *et al.,* 2010; Mathur *et al.,* 2010; Motghare and Gauraha, 2012). In addition, non-availability of good quality peat in India has also headed to the development of alternative carriers like, lignite, charcoal, etc. which are mostly used unsterilized (Borkar, 2015; Panda, 2013).Most studies suggest that biofertilizers, sold in markets are contaminated and have a low count of microorganisms. Generally, producers do not pay attention to the host specific strains and as a result biofertilizers cannot express their potentiality (Mazid and Khan, 2014; Motghare and Gauraha, 2012). Indian Standard Institute (ISI) specifications are recently available only for *Rhizobium* and *Azotobacter*; specification for *Azospirillum* and phosphobacteria have been formulated. Till now, there is no regulatory act for production of biofertilizers (Mazid and Khan, 2014).

Storage and distribution level

Successful introduction of biofertilizers in farmers' field is still limited to certain crops and locations, either because of environmental or biological factors i.e. soil-*Rhizobium*-plant relationship (Panda, 2013). As biofertilizers are live microorganisms, usually dies or loss their activity in case of temperature fluctuation.

Table.1 Different groups of biofertilizers

Sl. No.	Groups	Examples
1. Nitrogen (N_2) fixing Biofertilizers		
I	Free-living	*Azotobacter*, *Clostridium*, *Anabaena*, Nostoc
Ii	Symbiotic	*Rhizobium*, *Frankia*, *Anabaena azollae*
Iii	Associative Symbiotic	*Azospirillum*
2. P-Solubilizing Biofertilizers		
I	Bacteria	*Bacillus megaterium* var. *phosphaticum*, *Bacillus circulans*, *Pseudomonas striata*
Ii	Fungi	*Penicillium sp*., *Aspergillus awamori*
3. P-Mobilizing Biofertilizers		
I	Arbuscular mycorrhiza	*Glomus sp*., *Gigaspora sp*., *Acaulospora sp*., *Scutellospora sp*., *Sclerocystis sp*.
Ii	Ectomycorrhiza	*Laccaria sp*., *Pisolithus sp*., *Boletus sp*., *Amanita sp*.
Iii	Orchid mycorrhiza	*Rhizoctonia solani*
4. Biofertilizers for Micro nutrients		
I	Silicate and zinc solubilizers	*Bacillus sp*.
5. Plant Growth Promoting Rhizobacteria		
I	Pseudomonas	*Pseudomonas fluorescens*

Source: Biofertilizers- types and their application, KrishiSewa

Table.2 Some milestones in research, production and promotion of biofertilizer in India

Year	Events
1920	First study on Legume-*Rhizobium* symbiosis by N. V. Joshi.
1934	Earliest documented production of *Rhizobium* inoculant by M. R. Madhok.
1939	Discovery of nitrogen fixation by Blue Green Algea (BGA) in rice field by P. K. Dey.
1939	Report on performance of *Azotobacter* in rice soil by B. N. Uppal.
1956	First commercial production of biofertilizer.
1957	Study on solubilization of phosphate by microorganisms by Sen and Pal.
1958	First attempt to standardize quality of legume inoculant by A. Sankaran.
1960	First isolation of new non-symbiotic N-fixing organism *Derxiagummosa* in the world by P. K. Dey and R. Bhattacharyya.
1964	Spurt in demand of biofertilizer for soybean particularly in Madhya Pradesh.
1968	All India Pulse Improvement Project and Soybean Project set up by ICAR where *Rhizobium* study got priority.
1969	Use of Indian peat as carrier reported by V. Iswaran.
1975	Coal as alternate carrier to peat reported by J. N. Dube.
1976	Indian Standard Specification for *Rhizobium*.
1977	Use of ISI mark for *Rhizobium*.
1979	Initiation of All India Coordinated Project on BNF.
1979	ISI standard for *Azotobacter* inoculant.
1983	Setting up of National Project on Development and use of Biofertilizer by Ministry of Agriculture, Govt. of India.
1985	First National Productivity award on Biofertilizer.
1988	Setting up of National Facility Centre for BGA at IARI.

Source: Panda, 2011

Table.3 Year wise biofertilizer production (in tonnes) in India

Name of the State	Year						
	2008-09	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**
South Zone							
Andhra Pradesh	168.136	1345.28	999.60	1126.35	1335.74	2714.22	2668.80
Karnataka	11921.057	3695.50	6930.00	5760.32	7683.72	9907.34	16462.62
Kerala	1187.001	1936.45	3257.00	904.17	1045.64	3520.66	4916.97
Pondicherry	561.7924	452.79	783.00	509.45	621.00	516.98	560.95
Tamil Nadu	4687.818	3732.59	8691.00	3373.81	11575.70	14104.8	15373.29
Total	**18525.804**	**11162.61**	**20660.60**	**11674.10**	**22261.80**	**30764.03**	**39982.63**
West Zone							
Chhattisgarh	0.00	0.00	0.00	276.34	501.63	712.07	1024.68
Gujarat	1149.695	1309.19	6318.00	2037.35	978.48	6411.434	3667.929
Goa	0.00	0.00	443.40	0.00	370.00	66.26	802.52
Madhya Pradesh	848.448	1587.68	2455.57	2309.06	1408.08	4824.194	2637.99
Maharashtra	1249.87	1861.33	2924.00	8743.69	5897.91	6218.607	14847.397
Rajasthan	353.67	805.57	819.75	199.78	982.00	1315.00	599.898
Total	**3601.683**	**5563.77**	**12960.72**	**13566.22**	**10138.10**	**19547.565**	**23580.414**
North Zone							
Delhi	1165.1	1021.85	1205.00	1617.00	0.00	396.00	104.50
Chandigarh	0.00	0.00	0.00	0.00	0.00	1146.483	872.955
Haryana	14.25	6.20	6.53	914.41	5832.61	26.147	0.768
Himachal Pradesh	0.00	8.50	9.00	1.29	0.00	45.26	0.00
Punjab	1.14	301.23	2.50	692.22	2311.33	2124.85	6305.453
Uttar Pradesh	885.5174	962.64	1217.45	8695.08	1310.02	2682.27	4099.068
Uttarakhand	48.23	32.00	45.00	263.01	2758.21	5493.85	2129.952
Total	**2114.2374**	**2332.42**	**2485.48**	**12183.01**	**12212.17**	**11914.86**	**13512.696**
East Zone							
Bihar	0.00	0.00	136.26	75.00	52.40	52.40	64.90
Jharkhand	15.00	15.00	0.00	8.38	35.30	14.20	9.08
Odisha	405.03	289.87	357.66	590.12	407.10	1097.61	1074.46
West Bengal	241.24	256.50	393.39	603.20	1110.00	1682.71	2061.83
Total	**661.27**	**561.37**	**887.31**	**1276.70**	**1604.80**	**2846.92**	**3210.27**
North East Zone							
Arunachal Pradesh	0.00	0.00	0.00	0.00	0.00	59.00	59.0
Assam	129.3552	121.04	130.00	68.33	89.00	149.00	88.0
Mizoram	1.996	2.50	2.00	0.00	0.00	4.00	3.60
Nagaland	16.0092	18.25	21.50	13.00	7.45	7.45	7.45
Sikkim	0.00	0.00	0.00	0.00	9.50	10.10	12.40
Tripura	14.68	278.40	850.00	1542.85	514.00	225.00	240.0
Total	**162.0404**	**420.19**	**1003.50**	**1624.18**	**619.95**	**454.55**	**410.45**
Grand Total	**25065.035**	**20040.36**	**37997.61**	**40324.21**	**46836.82**	**65527.87**	**80696.46**

Source: National Centre of Organic Farming, Department of Agriculture & Cooperation (DAC) (2013, 2014 and 2015)

Such situations occur frequently while biofertilizer containing packets are delivered from production units to sowing fields (Mathur *et al.,* 2010). There is also lack of knowledge about the storage condition among the farmers for which actual potential of biofertilizers are not explored and sometimes farmers' are unwilling to use (Panda, 2013). Besides this, in most of the cases, proper storage conditions for the inoculants are not available at each point in the distribution chain (Motghare and Gauraha, 2012).

Field level

Most of the farmers in India do not have enough perception on the use of biofertilizer. Similarly, low level of acceptance of it at farmers' level is due to slow response as compared to chemical fertilizers. Some biofertilizers are crop as well as location specific; therefore its efficacy does not remain same at different locations due to difference in agro-climatic conditions and soil edaphic factors (Panda, 2013). In addition, there is no facility of foretasting and also no extension and propaganda of biofertilizers is being undertaken on large scale (Borkar, 2015).

Moreover, the activities of microorganisms vary with the chemical properties of soil so, highly acidic as well as saline soils adversely affect the population of introduce-ed biofertilizer (Fierer and Jackson, 2006). Sometimes in soils where P availability is less, the nitrogen-fixing biofertilizer does not function effectively (Khare and Arora, 2015). Therefore, soil amendments and chemical fertilizations are essential in these situations.

Market level

Marketing of biofertilizers is troublesome as the product contains living organisms with restricted shelf life (Motghare and Gauraha, 2012), only six months in powder form as a result, it is difficult under Indian conditions to transport, store and distribute the material in time. Besides this, there is no standardization in packing, labeling and prices of biofertilizers (Das *et al.*, 2015).

Sometimes, when packets arrive in villages, they are either spoiled or over dated; therefore, they become useless because organisms contained in biofertilizers die very quickly (Borkar, 2015).

Furthermore, different state governments sometimes provide subsidies up to 50% of the sales but the manner of subsidization is rather unsystematic even in many cases discrimination and manipulation in subsidizing lead to a lot of intra industry variation in prices (Ghosh, 2004).

Liquid biofertilizers - A step forward to biofertilizer technology

Liquid biofertilizers are suspension containing desired microorganisms and special cell protectants or chemicals that encourage formation of latent spores or cysts for longer shelf life and tolerance to adverse environments (Hegde, 2008). The advantages of liquid biofertilizers over powder based are that microorganisms have longer shelf life upto 2 years, generally they circumvent the effect of high temperature, maintain high *cfu* more than $10^9 ml^{-1}$ upto 12 months and better survive on seeds and soil, in addition, liquid biofertilizers are easy to use, handling and storage by farmers, the dosage is ten times less than that of powder form, it can be packed in different volumes and save carrier materials (Verma *et al.*, 2011; Borkar, 2015).

Biofertilizers have potential role in sustainable agriculture; these can be used along with chemical fertilizers to enhance the soil fertility and crop yield. In India, farmers' specially marginal farmers can get more profit from the same size of land by using biofertilizers instead of application of chemical fertilizers alone. However, most farmers are not aware of it; therefore, to popularize this technology training should be provided to the farmers and this can be done through demonstration trials on the cultivator's fields. In this case, extension workers would play an important role. Moreover, more researches are needed to identify crop and location specific microbial strains with higher efficacy. The government should introduce strict law and policy against the quality of biofertilizers so that farmers can get benefits of this technology.

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