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Efficiency of biofertilizers in increasing the production potential of cereals and pulses: A review

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Abstract
The agricultural scenario is changing rapidly. The pressure on the land is increasing day by day in order to feed a huge population. Agriculture systems are demanding new technologies that open the way towards sustainability in production and to our soil system. The use of biofertilizers is of utmost importance in agriculture because they not only increase the yield of various crops by improving their nutrient uptake, but they also helps in sustainable management of soil by having their role in nutrient transformation, increase in organic matter content, maintenance of pH due to release of various organic acids and so on. Chemical fertilizers directly increase the soil fertility by adding nutrients into the soil, whereas biofertilizers are helpful in nutrient uptake as their main function in soil is to either fix a nutrient on soil surface that is subjected to greater loss, or to solubilize a nutrient that is not available to plants because of fixation on the soil surface. They also serve as cost effective technology as they reduce the amount of inorganic fertilizers to be applied for crop production.

Keywords: Biofertilizer, increasing, production potential, cereals, pulses

Introduction
Worldwide the most limiting factor for crop production is deteriorating fertility of soils. This problem is even worse for marginal and resource poor farmers, who cannot afford to apply heavy doses of organic fertilizers for crop production. The problem of land deterioration, reduced fertility and rapidly declining agricultural production can be reduced to a greater extent by maintaining the quality of the soil. Apart from mineral and organic matter, the microorganisms are the important constituent of the soil as they affect a number of physical, chemical and biological processes that takes place in the soil (Mohammadi and Sohrabi, 2012) [27]. One such option that helps in maintaining the quality of soil is the use of biofertilizers.

What are Biofertilizers?
Biofertilizers are the products that contain cells of different microbes which are agriculturally beneficial. They can be further defined as commercial preparations, which contain living or latent cells of efficient strains of microorganisms that help the crop plants in uptake of various nutrients by their interaction in the rhizosphere. Numerous species of beneficial microorganisms are capable to stimulate the growth of plants by a plethora of mechanisms (Vessey, 2003) [44]. The biofertilizers can be applied to seeds, plant surface or to soil. Chemical fertilizers directly increase the soil fertility by adding nutrients into the soil, whereas biofertilizers are helpful in nutrient uptake as their main function in soil is to either fix a nutrient on soil surface that is subjected to greater loss, or to solubilize a nutrient that is not available to plants because of fixation on the soil surface.
Biofertilizers have a very high potential for N fixation. It has been estimated that 40-250 kg N/ha/year is fixed by different legume crops by the microbial activity of *Rhizobium*.
Apart from their role in nutrient transformation, they also secrete several growth hormones and vitamins, which enhance the seed germination and growth. Further, Biofertilizers are cost effective and environmental friendly technique and serves as a good supplement to chemical fertilizers. Thus, it can be concluded that biofertilizers are intended to improve the nutrient uptake and their use efficiency without application of extra doses of inorganic chemicals.

Types of biofertilizers
The biofertilizers includes bacteria, fungi and algae and they can be classified depending upon their nature and function as follows:

Types of biofertilizers

S. No.	Group	Examples
Nitrogen Fixing Biofertilizers		
1	Free living	*Azotobacter, Clostridium, Anabaena, Nostoc*
2	Symbiotic	*Rhizobium, Frankia*
3	Associative Symbiotic	*Azospirillum*
Phosphorus Solubilizing Biofertilizers (PSB)		
1	Bacteria	*Bacillus megaterium* var. phosphaticum, *Bacillus circulans Pseudomonas straita.*
2	Fungi	*Penicillium sp*., *Aspergillus awamori*
Phosphorus Mobilizing Biofertilizers		
1	Arbuscular Mycorrhiza	*Glomus* sp., *Gigaspora* sp.
2	Ectomycorrhiza	*Boletus* sp., *Amanita* sp.
3	Orchid Mycorrhiza	*Rhizoctonia solani*
Biofertilizers for Micronutrients		
1	Silicate and Zinc Solubilizer	*Bacillus* sp.

(**Source:** www.krishisewa.com)

Effect of biofertilizers on cereal crops

Cereal crops are grown in greater quantities and on large areas as they provide food and energy to most of the world population. They are our staple food and they are rich in energy, fibers, carbohydrate, protein, fat, vitamins and minerals. The population pressure is continuously increasing and with that the struggle to feed that population is also increasing. As the land available for growing crops is limited so it is necessary to use technologies which can enhance the production potential of crops with additional benefits like sustained soil environment and cost effectiveness.

Effect of biofertilizers on wheat

Wheat is grown in nearly every region of the world and represents a main source of food and income for millions of smallholder farmers. It is the most important staple food of about 36% of the world population. The role and importance of biofertilizers in wheat have been reviewed by several authors and a zest of those works is present below.

The effectiveness of *Azospirillum brasilense* strains S 63 and Sp Br 14 in increasing the yield of wheat crop by 9.14% and 14.2%, respectively was reported by Reynders and Vlassak (1982) [33]. Inoculation of wheat plants with these strains significantly affected the tillering in winter wheat. High tillering and undisturbed nutrient uptake by the plants due to *Azospirillum* inoculation was attributed to higher yield. The effect of integration of nutrients was studied by Kader *et al*, 2002 [21] in Bangladesh, and they reported that application of 168 kg N/ha as urea + cow dung + *Azotobacter* have resulted in 84% higher grain yield per plant of wheat as compared to control.

An experiment was conducted by Dileep and Ravinder, 2006 at Jammu to study the effect of biofertilizers on wheat crop. The findings highlighted that, *Azotobacter* + *Azospirillum* in 1:1 ratio was found to be effective in increasing the growth, yield attributes and yield of wheat crop to significant levels. It also resulted in higher NUE. Similarly, Bashan *et al.* (2006) [6] found that wheat plants inoculated with *Azospirillum brasilense* recorded significantly higher quantities of several photosynthetic pigments such as chlorophyll a, chlorophyll b, and the auxiliary photoprotective pigments like violaxanthin, zeaxanthin, antheroxanthin, lutein, neoxanthin and β – carotene.

A study conducted by Afzal and Asghari, 2008 [2], revealed that Single and dual inoculation of *Rhizobium* (Thal 8) and P solubilizer (54 RB) with P fertilizer has resulted in significantly higher root and shoot weight, plant height, spike length, grain yield, seed P content, leaf protein and leaf sugar content in wheat crop. They reported an increase of 30 – 40% in grain yield due to application of single or dual inoculums + P fertilizer as compared to alone application of P fertilizer. Even dual inoculation of *Rhizobium* (Thal 8) and P solubilizer (54 RB) was able to secure yield advantage of 20% as compared to application of P fertilizer alone. In the same year, Prasanna *et al*, 2008 [31] reported from IARI, New Delhi that application of vermicompost in combination with BGA biofertilizer (biofertilizer + vermicompost + N_{40} P_{30} K_{30}) has resulted in significant increase in Nitrogenase activity. They also reported that, inoculation with Azotobacter + BGA resulted in highest value of chlorophyll (1.19 µg g^{-1} soil).

Ahmed *et al*, 2011 also conducted an experiment to test the efficiency of biofertilizers and they concluded that inoculation of wheat plants with biofertilizers (*Azotobacter*, Yeast and *Azotobacter* + Yeast) resulted in significantly higher values of most of growth and yield parameters. Yeast inoculated plants showed superiority over Azotobacter inoculation. Further, they reported that mixed inoculums (*Azotobacter* + Yeast) were found to be better than single inoculums. Kumar *et al*, 2017 reported that the Rhizobacterial inoculation in wheat crop either alone or in consortium of different combinations significantly increased the growth and yield of wheat crop as compared to the mock inoculated controls. In both the field and pot trials, the combination of Rhizobacterial isolates was found to be more effective as compared to single inoculation.

Apart from traditional biofertilizers, a new microorganism was tested by Zodape *et al* (2012) [47]. They studied the effect of *Kappaphycus alvarezii* extract applied as foliar spray to wheat and they concluded that spray of 1% *Kappaphycus alvarezii* extract resulted in 80.44 per cent higher wheat grain yield as compared to control.

New techniques like use of biofilm is also popularizing in biofertilizer technology. A biofilm fertilizer prepared by using *Anabaena torulosa* as a matrix for agriculturally important microorganisms such as *Azotobacter*, *Mesorhizobium*, *Serratia* and *Pseudomonas* was tested in wheat crop. The treatments inoculated with biofilms recorded an increase of 40-50 per cent in the Nitrogen Fixing Potential or ARA (Acetylene Reduction Activity) even after 14 weeks of inoculation as compared to 4 weeks old samples. The performance of *Anabaena serratia* biofilm and dual culture inoculants in the presence of rock phosphate was most effective as they exhibited increase in N fixing potential or ARA even at harvest. (Swarnalakshmi *et al*, 2013) [42].

Effect of biofertilizers on rice

Rice crop has fed more people over a longer time than has any other crop. It is spectacularly diverse, both in the way it is grown and how it is used by humans. Rice is unique because it can grow in wet environments in which other crops cannot survive. The response of rice crop to application of biofertilizers has been reviewed by several authors and a core of that is present below.

Dubey and Rai (1995) [13] reported that different doses of N fertilizers (supplied as urea) together with biofertilizers *Aulosira fertilissima* and *Anabaena doliolum* has significantly increased the plant height, number of tillers per hill, root length, leaf length, chlorophyll content, number of panicles per hill, number of seeds per ear, seed weight, grain yield, protein and N content of the grain. N applied @ 90 kg N/ha together with 12.5 kg/ha of algal biofertilizers produced highest qualitative improvement in rice production. Further they reported that *Aulosira fertilissima* yielded better results than application of *Anabaena doliolum* which resulted in saving of about 25% of chemical N demand of the crop.

Inoculation of wet land rice with different *Rhizobium* strains such as *Rhizobium leguminosarum* bv. trifolii E11, *Rhizobium* sp. IRBG 74 and *Bradyrhizobium* sp. IRBG 271 was found to be effective in increasing rice grain and straw yield by 8-22 and 4-19%, respectively at different N application rates. There was an increase of 10-28% in the NPK uptake due to rhizobial inoculation (Biswas *et al*. 1999) [9]. Dixit and Gupta (2000) [12] reported that there was an average increase of 7.5% (0.24 t/ha) in the grain yield of rice by the application of BGA biofertilizer (Blue Green Algae). Further, when BGA was combined with FYM it has showed an increase of 19.2% (0.6 t/ha) in the rice yield. Application of BGA along with FYM also reported to have positive changes in organic carbon and N content of the soil.

Field experiment conducted by Shanmugam and Veeraputhran in Coimbatore in the year 2000 revealed that application of biofertilizer *Azospirillum* (@ 2 kg/ha) along with either green manure (*Sesbania aculeata* @ 6.25 t/ha) or FYM (@12.5 t/ha) resulted in significant increase in the growth attributes of rice. *Azospirillum* along with green manure recorded significantly shorter period for 50% flowering, highest values of yield attributing characters such as number of productive tillers/ m^2, filled grains /panicle, panicle length and grain yield (5282 and 5218 kg/ha in two years, respectively).

Mishra and Pabbi (2004) [26] also concluded that use of Cyanobacteria as biofertilizer is an economically attractive and ecologically sound alternative for chemical fertilizers to increase the production potential of rice crop. The nitrogen fixation done by free living Cyanobacteria in the wet land ecosystem of rice also supplements the soil nitrogen.

Subashini *et al*. (2007) [41] also concluded from their experiment that biofertilizers (Azospirillum + BGA) played a major role in improving the soil fertility and thereby increased the rice yield. It was helpful in improving the soil biota and minimized the sole use of inorganic fertilizers and the cost of cultivation. Integration of biofertilizers with inorganic fertilizers is also beneficial, in this context Pattanayak *et al*. (2007) [29] reported from Bhubaneswar, Orissa that integration of inorganic NPK fertilizers with biofertilizers produced maximum rice yield. Application of 40 kg N/ha (50% of N dose) + 17.5 kg P_2O_5/ha + 32 kg K_2O/ha, integrated with biofertilizers (*Azotobacter*, *Azospirillum* and Azolla) resulted in highest grain yield (3.57 t/ha) and straw yield (4.32 t/ha) of rice. Further when peanut crop was grown on this residual soil fertility, it produced the highest pod yield (2.38 t/ha). This shows that biofertilizers applied to one crop in the cropping sequence have beneficial effect on the next crop aslo.

Tripathi *et al*. (2008) [43] reported that the rice crop (Saryu 52) produced best growth response and mineral composition, when the soil was amended with fly ash @ 10 t/ha, Nitrogen fertilizer @ 90 kg/ha and biofertilizer BGA @12.5 kg/ha. In the same year Dhar *et al*. (2008) also emphasized from their investigation that, chemical fertilizers supplemented with newly developed biofertilizers such as 'multani mitti' based and 'wheat straw' based is helpful in increasing the productivity of rice crop, reduces the need of chemical fertilizers and sustains the fertility of the soil.

Effect of biofertilizers on maize

Maize or corn (*Zea mays* L.) is an important cereal crop of the world. It is a rich source of nutrition to humans as well as livestocks. The response of maize towards biofertilizers is prominent and few of those works are present below.

Monem *et al.* (2001) [1] reported that use of biofertilizer *Azospirillum brasilense* or commercial biofertilizer 'cerealin' with half amount of N (144 kg N/ha) resulted in significant increase in maize yield. Cerealin along with half the amount of normal N application recorded higher net benefit, B:C and marginal rate of returns as compared to other N fertilizers, that clearly gave the evidence of saving of 50% of N fertilizers in maize, if biofertilizers are used. Wu *et al*., 2005 from China reported that application of biofertilizers (containing *Glomus mosseae* or *Glomus intraradices* + *Azotobacter chroococcum*, *Bacillus megaterium* and *Bacillus mucilaginous*) resulted in significantly higher growth of maize. Their study also indicated that application of half the amount of biofertilizer had similar effects as compared to organic or chemical fertilizers. Microbial inoculums were also found to be effective in improving the soil properties such as organic matter content and total N in the soil. Experiment conducted by Jilani *et al.* (2007) [20] showed that application of half dose of NP fertilizer along with Biopower + Bacterial Potassium Fertilizer (BPF) / EM (effective microorganisms) was able to produce similar maize yield as compared to full rate of application of N and P fertilizers. It also resulted in higher net returns as the production cost was reduced.

Yosefi *et al.* 2011 [46] also concluded that combined application of both biological and chemical phosphate fertilizer was a practical and useful method to increase the yield levels of maize and also to reduce environmental pollution. Beyranvand *et al*. 2013 [7] also recorded significantly higher maize yield and yield components due to application of biofertilizers in maize.

Biofertilizers were also found effective to save the crop from dangerous effects of heavy metals. The use of bacterium containing biofertilizers was found effective in moderating the toxic effects of cadmium present in the soil under maize and sunflower cultivation (Gajdos *et al*. 2012) [12].

Effect of biofertilizers on pulse crops

Pulses are very important crops in agriculture. They are not only a quality source of protein for human beings, but also called as 'fertility restorer crops'. They are able to fix atmospheric nitrogen with the help of symbiotic nitrogen fixers. This helps in improving the nitrogen economy of the soil. Use of biofertilizers in pulses has been studied by various researchers and a brief summary of that is listed below.

Srivastava and Ahlawat (1993) reported that seed inoculation of pea (*Pisum sativum* L.) with *Rhizobium* or PSB or a combined application of both resulted in conspicuous increase in nodulation, Nitrogenase activity, growth, yield and nutrient uptake by the crop as compared to uninoculated control crop.

Jati (2004) [19] reported from New Delhi that chickpea seed inoculation with *Rhizobium* and PSB has markedly enhanced the growth and yield attributes, seed yield (2.4 t/ha) and straw yield as compared to uninoculated control. Similarly, Singh *et al*., 2004 [38] also reported that dual inoculation with *Rhizobium* and VAM resulted in 48.6, 1.6 and 38.7% increase in grain yield as compared to uninoculated control.

Balachandran *et al*. (2005) [5] concluded from their experiment that, application of ½ RDF + 5 tones press mud + *Rhizobium* + PSB has significantly increased the plant height, number of branches, leaf area, leaf dry matter production and number and dry weight of root nodules in green gram. The yield contributing characters and yield was also greater with the above treatment. El Habbasha *et al*., 2007 inferred from their experiment that, combined application of 30 or 45 kg P_2O_5 along with *Rhizobium* + nitrobein inoculums was proved to be best treatment to get high quality and quantity of faba bean.

Khatkar *et al*. (2007) [22] reported from Allahabad that black gram (*Vigna mungo* L.) responded efficiently to application of biofertilizers. The dual inoculation of *Rhizobium* and PSB along with sulfur, resulted in significantly higher growth characters and yield. Singh and Yadav (2008) reported from Varanasi that pigeon pea inoculated with *Rhizobium* + PSB produced significantly taller plants, maximum number of branches per plant, dry matter per plant, grain yield, stalk yield and uptake of N and P as compared to other inoculated and control treatments.

Selvakumar *et al*. (2009) [35] revealed from their experiment that combined inoculation of *Rhizobium* + Phosphobacteria significantly enhanced the growth and yield of black gram as compared to control. In the same year, Dutta and Bandyopadhyay also reported from their experiment that seed inoculation of chickpea with *Rhizobium* or *Phosphobacterin* was significantly superior to non inoculated seeds and *Phosphobacterin* inoculation alone.

Ramana *et al*. (2010) [32] reported that Arka Suvidha variety of French bean recorded significantly higher plant height, number of branches per plant, leaf area and dry weight of plant, pod length, 100 seed weight, number of pods per plant, pod yield per plant and pod yield /ha due to combined effect of application of 75% RDF + VAM @ 2 kg/ha + PSB @ 2.5 kg/ha. Giri and Joshi (2010) [17] reported from Dehradun, India that *Rhizobium* inoculation is a promising biofertilizer in chickpea as the bacterized seeds showed 14.06 per cent increase in total length, 10.83 per cent increase in total weight and 9.0 per cent increase in germination as compared to control. The inoculated plants gave significantly higher nodule number, nodule weight, and root weight, shoot weight and seed yield as compared to non inoculated plants. An increase of 9.0 per cent was recorded in the biological yield of inoculated plants as compared to non inoculated ones.

Osman *et al*. 2010 tested two cyanobacterial species (*Nostoc entophytum* and *Oscillatoria angustissima*) as biofertilizers, substituting the normally used chemical fertilizers and the results revealed that, biofertilizers combined with half the recommended dose of fertilizer was more effective as compared to full rate of fertilizer application. Thus, it resulted in savings of 50% fertilizer. They also revealed that soil inoculation with suspension of each biofertilizer or combination of both has increased the germination percentage and also stimulated other growth parameters and photosynthetic pigment fractions of pea. Mishra *et al*., 2010 [25] concluded that the maximum grain yield and net profit can be obtained from dwarf field pea, when the seed were inoculated with *Rhizobium* + PSB + PGR + 100% RDF of fertilizers. This combination has improved all the growth characters, yield attributes and yield of field pea. The fresh and dry weight /plant, nodule number, number of grains /pod, number of pods /plant and pod weight /plant were also significantly higher. The above experiment resulted in grain yield of 31.0 q/ha and net returns of Rs. 26187/ha.

Combined application of biofertilizers along with 100% NPK and FYM recorded maximum green pod yield in pea (169.0 q/ha). The integrated application of chemical fertilizers in conjugation with manures and biofertilizers was found to be the best nutrient management approach in pea (Sharma and Chauhan, 2011) [8, 37].

Rokhzadi and Toashish, 2011 [34] found from their experiment that in chickpea, the grain yield, biomass dry weight and N and P uptake of grains were statistically improved due to inoculation with each PGPR such as *Azospirillum*, *Azotobacter chroococcum* 5 + *Mesorhizobium ciceri* SWR17 + *Pseudomonas fluorescens* P21. However group comparison between the treatments showed that, when *Azospirillum* or *Azotobacter* was found in the treatment composition there was an expressive improvement in grain yield and plant biomass.

Bhattacharjee and Sharma, 2012 [8] inferred from their experiment that, dual inoculation of pigeon pea with Arbuscular mycorrhiza (*Glomus fasciculatum*) led to overall increase in chlorophyll content, nitrogen and phosphorus content as compared to uninoculated control. Pramanik and Bera, 2012 [30] revealed from their study that inoculation of biofertilizers showed positive effect on chick pea. The inoculation with *Rhizobium* + PSB + VAM significantly improved the plant height, number of pods /plant, weight of pods /plant, number of grains /plant, test weight, grain yield, stalk yield and harvest index. Kumawat *et al*., 2013 [24] reported that seed inoculation of black gram with PSB, has markedly enhanced the yield attributes, seed yield, biological yield, net returns, B:C ratio as compared to seed inoculation with alone *Rhizobium* and control. Bahadur and Tiwari, 2014 [4] also confirmed that that the mung bean inoculated with *Rhizobium* and PSB showed significant –significant response to all growth and yield parameters.

Conclusion

The potential biofertilizers plays an important role in maintaining the productivity and sustainability of soil systems and in turn helps in increasing the production potential of crops. It serves as a Farmer friendly, eco friendly and cost effective input that can be easily used in the farms in a wide range of crops. Thus, it can be concluded from the above reviews that biofertilizers serves as a multitude of benefits.

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