Biofertilizer for Sustainable Rice Production and Reduction of Environmental Pollution

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Abstract Rice is the staple food for more than half of the world's population. Rice production needs a huge amount of chemical fertilizer application, especially urea, which is one of the causes of global warming and groundwater pollution. Nitrous oxide emission and nitrate leaching can be reduced only via the reduction of chemical nitrogen fertilizer use or by developing a mechanism whereby the plant can get atmospheric nitrogen directly without any loss in the soil system. After nitrogen the second most important nutrient is phosphorus. Phosphorus availability is very much pH dependent. It may prevail in the soil but may not be bioavailable to the plant. In this case a group of microorganisms can help to make bioavailable phosphorus and simultaneously reduce use of chemical phosphorus fertilizer. Biological nitrogen fixation by the free-living bacteria and solubilization of insoluble organic and inorganic phosphorus by microorganisms are well documented. Free-living diazotroph, phosphate solubilizing bacteria, and plant growth-promoting bacterial strains containing biofertilizer are commonly used for the production of field crops. Biofertilizer containing these microbes will supplement the need for chemical fertilizer and will ensure a healthy environment. The objective of the chapter is to discuss briefly the scope and potential of biofertilizer containing free-living diazotrophs, phosphate-solubilizing bacteria, and plant growth-promoting rhizobacteria for sustainable rice production in an ecofriendly environment.

Keywords Biological nitrogen fixation • Diazotrophs • Global warming • Fertilizer • PGPR • Phosphate-solubilizing bacteria

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1 Introduction

Because of increasing global population, the high demand for food leads agriculture to rely on inorganic fertilizer. Fertilizers play a central role between food security and environmental degradation, which can be minimized but not eliminated. Agriculture currently contributes to about 30 % of total global emissions (up to 80 % in some countries) of the greenhouse gases that are the driving force for climatic change. The world population is increasing about 2 % per year and the nitrogen fertilizer demand in agriculture is increasing approximately equivalent to the rate of increase in the population (FAO 1992). The manufacture of N fertilizers, the burning of fossil fuels, and the cultivation of leguminous crops resulted in N fixation which increasingly exceeds the natural fixation of N_2. Over the next few decades, this alteration of the N fixation cycle will become more severe (Walker and Steffen 1999). Annual production of 77×10^6 tons ammoniacal-N requires 0.1×10^9 tons of oil equivalent per year (Bockman et al. 1997). An average of 1.3 tons of oil or the equivalent of that much energy is needed to fix 1 ton of ammonia (Ladha and Reddy 1995).

2 Fertilizer Consumption

Global rice production is fully dependent on chemical fertilizers, although every year some scarcities of chemical fertilizer (Table 1) remain. In the year 2020 the global targeted food production is 321 million tons which will require 28.8 million tons of chemical fertilizer. But the availability projected only 21.6 million tons with a deficit of about 7.2 million tons of chemical fertilizer (Sheraz Mahdi et al. 2010). In this situation biofertilizer can be a complementary source to chemical fertilizer.

2.1 Nitrogenous Fertilizer

Nitrogen is the most used fertilizer in rice production (Hakeem et al. 2011, 2012a, b, c). It is proved that to produce 1 ton of rough grain, 15 kg of nitrogen is needed. Asia is the highest consumer of nitrogen fertilizer (64 %) followed by America (FAO 2008; Fig. 1).

Free-living nitrogen-fixing bacteria containing biofertilizer are able to supply 25–40 % of the nitrogen requirement by a biological process in rice plants

Table 1 World fertilizer supply and demand in the year 2012

Fertilizer (1000 tons)			
	N	P	K
Total supply	154,199	43,299	43,213
Total demand	139,140	40,426	36,453
Deficit/Surplus	15,059	2873	6760

Note: *N* nitrogenous fertilizer, *P* phosphatic fertilizer, *K* potash fertilizer
Source: Adapted from FAO (2008)

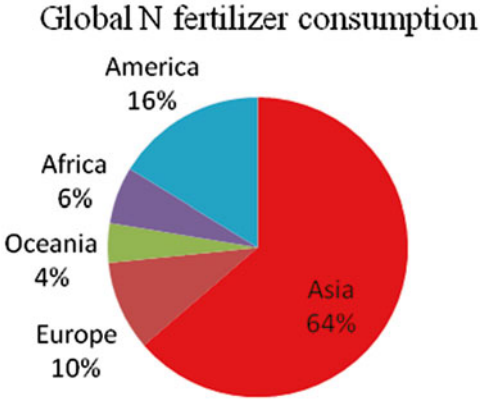

Fig. 1 Global nitrogen consumption in the year 2007/2008 to 2011/2012. *Source*: Adapted from FAO (2008)

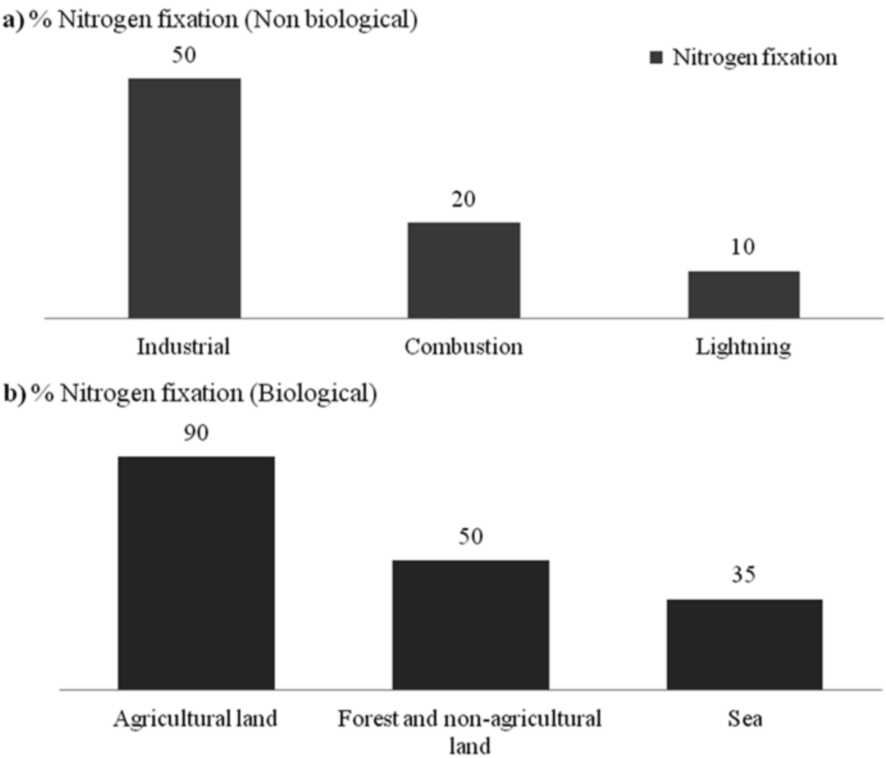

Fig. 2 Global nitrogen fixation nonbiological and biological process. (**a**) Nitrogen fixation (Non-biological), (**b**) Nitrogen fixation (Biological). *Source*: Adapted from Bezdicek and Kennedy (1998)

(Naher et al. 2011). About 90 % of soil nitrogen in agricultural land is derived from biological nitrogen fixation, whereas industrial fixation is only 50 % (Fig. 2). The contribution of nitrogen-fixing bacteria in the nitrogen cycle proves its important role in the soil nitrogen-fixation process.

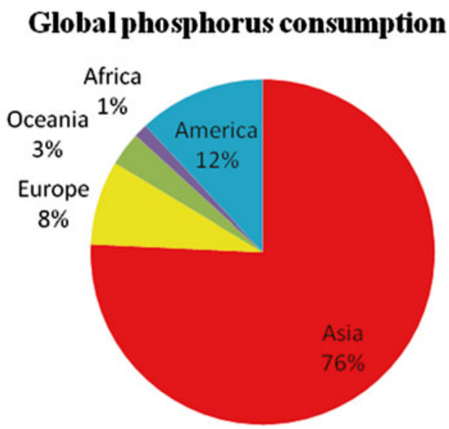

Fig. 3 Global phosphorus consumption in the year 2007/2008 to 2011/2012. *Source*: Adapted from FAO (2008)

Application of nitrogenous fertilizer increases NO_2 emission. In that consequence, biofertilizer has the potential to reduce global warming. Moreover, biofertilizer consists of organic carrier materials that improve soil carbon reserve.

2.2 Phosphate Fertilizer

Like nitrogen, Asia is the highest user of phosphatic fertilizer (Fig. 3). The higher consumption of phosphate fertilizer significantly shows the importance and huge demand of phosphate fertilizer. In soil around 95 % of P is in insoluble organic form, hence, it is very important to focus on the availability of P and its fixation problems. The plant availability and uptake of this nutrient element is largely governed by the soil pH. In low soil pH, P is fixed by Fe and Al, and at high pH, Ca. The plant-available form only remains at pH 5–7. There are some microorganisms that make organic and inorganic fixed soil P available by the production of organic acids or enzymes (Panhwar et al. 2012). Among the microbes *Pseudomonas*, *Bacillus*, and *Rhizobium* are important. There are some fungi that are also able to solubilize insoluble inorganic soil P. Mycorrhiza plays an important role to increase plant P uptake by the extended hyphal root in the upland crop.

3 Mechanism of Biofertilizer for Plant Growth Promotion

Biofertilizer contains a single or a combination of living microorganisms which is applied to the soil or plant directly to improve plant growth and yield. Free-living nitrogen-fixing microorganisms contained in the biofertilizer increase plant growth by supplying the nitrogen nutrient element and phosphate-solubilizing bacteria, increasing the availability of the phosphorus nutrient element to the plant roots.

In addition to nutrients microbes play an important role in plant growth promotion by the production of phytohormones (Panhwar et al. 2014a). The common phytohormone produced by the bacteria is indoleacetic acid, which promotes plant root growth. The vast root architecture help plants to absorb nutrients and water from the surroundings. The common bacteria genera used in biofertilizer preparation are *Rhizobium*, *Burkholderia*, *Bacillus*, *Aspergillus*, *Pseudomonas*, and *Azotobacter*, among others. These are also known as plant growth-promoting rhizobacteria (PGPR). Mycorrhiza biofertilizer is popular for management of the phosphorus nutrient in many vegetables, fruits, upland rice, and plantation crops (Naher et al. 2013a).

Plant growth promotion by microorganisms is achieved in several ways, such as associative N_2 fixation and its transfer to plants (Urquiaga et al. 1992), alteration of plant hormonal balance (Glick 1995), and solubilization of minerals, thus facilitating uptake. Secretion of succinic and lactic acid by certain PGPRs stimulate root growth and relieve environmental stress (Yoshikawa et al. 1993). The colonizing by *Azospirilla* that changes root morphology is suggested to be the production of auxin, which leads to an increase of root hairs and lateral roots (Hadas and Okon 1987). Rethati et al. (2000) reported that N_2-fixing associations of various Hungarian rice cultivars with diazotrophic bacteria, *Azospirillum brasilense*, and endophytic diazotroph, *Herbaspirillum seropedicae*, among them the growth-promoting effect of *A. brasilense* was explicit whereas *H. seropediceae* was elicit in consequential plant reactions. Rediers et al. (2003) found rice plant colonization by *Pseudomonas stutzeri* A15, to be able to express the *miaA* gene. The gene involved in the production of cytokinin was *trans*-zeatin. Expression of an auxin-responsive promoter in *Arabidopsis* indicated that the plants were able to detect bacterially synthesized IAA (O'Callaghan et al. 2001). In addition to growth improvement, PGPR can solubilize phosphorus through production of organic acids (Nautiyal et al. 2000). Several species of *Burkholderia* such as *B. vietnamiensis*, *B. unamae*, *Azoarcus*, *Azorhizobium caulinodans*, *Azosprillum* sp., and *Herbaspirillum* sp. show Aminocyclopropane-1-carboxylate (ACC) deaminase activity in the rhizosphere. ACC could be degraded by plant-associated bacteria and result in a growth-promoting effect (Dobbelaere et al. 2003).

4 Role of Biofertilizer for Sustainable Rice Production

In addition to chemical fertilizer, alternative crop and resource management strategies to sustain crop productivity and profitability are needed. Sustainable agriculture and food security imply a high output from agricultural systems. These systems must be economically viable, environmentally sound, socially acceptable, and politically supportable (Reeves 1999). In this case biofertilizer can be a new approach for sustainable rice production (Panhwar et al. 2014b). Biofertilizers containing free-living nitrogen-fixing bacteria and phosphate-solubilizing bacteria have the potential to supply the nitrogen element and to make insoluble organic and

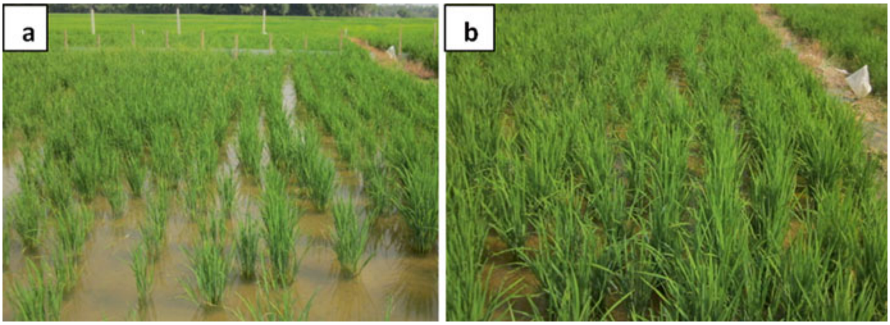

Fig. 4 Comparison of (**a**) farmer's plot versus (**b**) biofertilizer with ground magnesium limestone (GML) applied acid sulfate soil

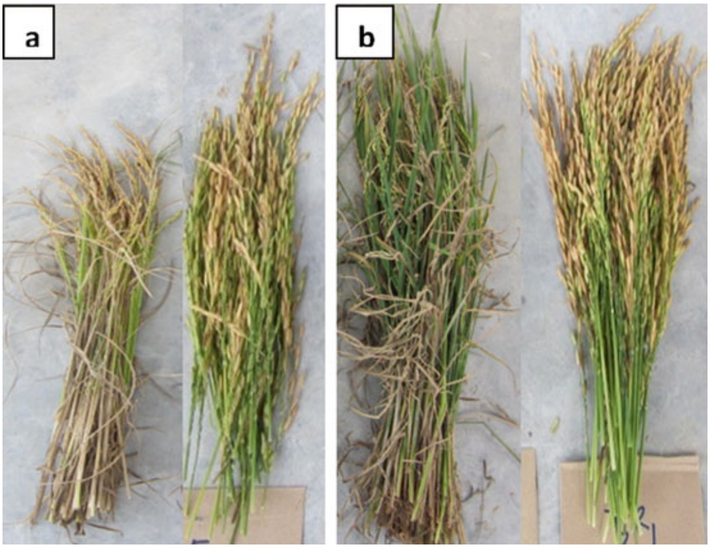

Fig. 5 Effect of biofertilizer on grain yield of rice (**a**) farmer's plot versus (**b**) biofertilizer with ground magnesium limestone (GML) applied plot

inorganic P nutrient available for rice production. A large number of biofertilizers are being used in many countries such as China, India, Pakistan, Egypt, Vietnam, and Indonesia (Kennedy and Cocking 1997). Recently, Malaysia has also been using several products. Valid field data showed a significant increase in grain yield in the farmer's field (Figs. 4 and 5). Application of biofertilizer with 30 % reduced chemical nitrogen fertilizer increased the rice grain yield by 69 % and straw yield 35 %, compared to the farmer's usual practice (Table 2). To prove the efficacy of biofertilizer, Nguyen et al. (2001) trialed 60 farmers with reduced nitrogen fertilizer and found a significant increase in grain yield. This result proves substantial benefits to farmers with reduced input costs, and more income from enhanced grain yield.

Table 2 Effect of biofertilizer on rice production in farmer's field Melor, Kelantan

Treatment	Grain yield (tons ha^{-1})	Grain yield (%) increase	Straw yield (tons ha^{-1})	Straw yield (%) increase
Farmer's practice	4.2	–	7.9	–
Full chemical fertilizer	5.1	21	9.2	16
Biofertilizer[a]	7.1	69	10.7	35

[a]Biofertilizer with 30 % reduced chemical fertilizer

5 Efficacy of Biofertilizer

The efficacy of biofertilizer depends on many factors, one of which is the plant–microorganism association. Beneficial microbes get carbon from root exudates or soil organic matter. The preferences of sugar uptake are mediated in plant growth-promoting bacteria according to their structure, availability of carbon substrates, and mode of living. Rhizosphere carbon sources determine the plant–microbe association. Three groups of diazotrophic bacteria were categorized based on physiological and biochemical characteristics: In group 1, the ability to use glucose as the carbon source and no requirement of biotin; group 2, glucose and biotin required; and group 3, similar to group 1, but able to reduce NO_2^- to N_2. Several diazotrophs were reported to have depended on different carbon sources and chemotaxis characteristics found among them. However, the nitrogen fixation by free-living diazotroph or plant association is fully dependent on carbohydrate substrates (Naher et al. 2013b).

Earlier, biofertilizers were mostly prepared with single strains. A new concept, multistrain biofertilizer, has recently been created. A multistrain biofertilizer with different functions has more efficacy than single-strain biofertilizer. For example, a biofertilizer containing nitrogen-fixing and phosphate-solubilizing microorganisms poses a dual function. It can fix atmospheric nitrogen and simultaneously make phosphorus bioavailable. Moreover, biofertilizer containing many strains can supply more growth phytohormone, another potential increment for plant growth promotion. However, to get the benefit from any biofertilizer the following points need to be considered:

1. The carrier material in biofertilizer should be rich in nutrient and carbon sources otherwise the strain will not survive in the biofertilizer.
2. The strains should be suitable for that particular environment. Strain survival and desired number are essential for colonization with the host plant.
3. The biofertilizer should be suitable for that particular crop to which it is applied. Plant–microbe association is very important. If the microorganism does not form an association with that particular crop, the plant will not benefit.
4. The fast-growing strain should be used in nonsterile carrier material.
5. Before application of biofertilizer, the desired population should be confirmed.

6 Summary and Future Prospective

Biofertilizer can mitigate partial requirement of chemical fertilizer. Use of biofertilizer improves crop productivity, and reduces the use of chemical N and P fertilizer with promotion of a natural source of P instead of chemical phosphatic fertilizer. It promotes more plant growth (15–50 %) than chemical fertilizer. Application of biofertilizer improves the beneficial microbial community throughout the crop growing season. In an environmental context, biological nitrogen-fixing bacteria that fixes atmospheric nitrogen reduces use of chemical N fertilizer by one fourth. Reduction of chemical nitrogen fertilizer reduces nitrous oxide emission and nitrate leaching. The natural source of phosphate rock can be used instead of chemical phosphate fertilizer as phosphate-solubilizing bacteria can solubilize rock phosphate and make it available to the plant. In addition to reducing the cost of chemical fertilizer, biofertilizer ensures a higher yield benefit to the farmers and a safe environment.

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