Research Journal of Fisheries and Hydrobiology, 6(4): 598-604, 2011
ISSN 1816-9112
This is a refereed journal and all articles are professionally screened and reviewed

ORIGINAL ARTICLES

Plant Growth Promoting Rhizobacteria (PGPR) and Sustainable Agriculture

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ABSTRACT

Sustainable agriculture is a way of practicing agriculture which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, environmental protection, and consumer safety. It is achieved through management strategies which help the producer select hybrids and varieties, soil conserving cultural practices, soil fertility programs, and pest management programs. Over application of chemical fertilizes is used to replenish soil, resulting severe environmental contamination, thus recently use of biofertilizers in combination to chemical fertilizers was suggested. Many researchers however reported that environmental protection and the need to enhance sustainable agricultural outputs caused introduction of new sustainable technologies. Studied have conclusively shown that biofertilizers as PGPR have ability to stimulate plant growth. Many of the bacteria that increase plant growth were shown to possess the ability to solubilize phosphate, increase the efficiency of biological nitrogen fixation, improve the availability of Fe and Zn, and alter the growth of roots or shoots by production of plant hormones. PGPR offer an environmentally sustainable approach to increase crop production and health. The application of molecular tools is enhancing our ability to understand and manage the rhizosphere and will lead to new products with improved effectiveness. This review will focus upon our current knowledge of the role that PGPR play on crop growth in sustainable agriculture.

Key words: PGPR, sustainable agriculture, biofertilizers, rhizosphere

Introduction

Conventional agriculture which involves high-yielding plants, mechanized tillage, inorganic fertilizers and biocides is so detrimental to the environment. For instance, fertilizer run-off from conventional agriculture is the chief culprit in creating dead zones with low oxygen areas where marine life cannot survive. The challenge of enhancing productivity while maintaining environmental soundness calls for educating farmers; emphasizing the long-term consequences of their traditional methods of agriculture; and helping them develop and implement innovative, appropriate farming practices. Studied have conclusively shown that biofertilizer as PSM solubilizes the fixed soil P and applied phosphates (Wu *et al*., 2005). The nitrogen fixing bacteria such as *Azotobacter* and *Azosperillium* produce phytohormones that are ability to stimulate plant growth and causes morphological changes, such as an increase in root surface area through the production of more root hairs, which in turn enhance mineral uptake (Cakmaci *et al*., 2005; Saharan and Nehra, 2011; Yazdani *et al*, 2012). The utilization of biofertilizers has become a feasible production practice (Zaied *et al*., 2003; Zaidi *et al*., 2006; Zahir *et al*., 2004; Anjum *et al*., 2007).

A number of different bacteria promote plant growth, including Azotobacter sp., Azospirillum sp., Pseudomonas sp., Bacillus sp. Acetobacter sp. (Turan *et al*., 2006). Economic and environmental benefits can include increased income from high yields (Swedrzynska and Sawicka., 2000; Mirza *et al*., 2000), reduced fertilizer costs and reduced emission of the greenhouse gas, N2O as well as reduced leaching of NO3 (Shaharoona *et al*., 2006). Use of biofertilizers containing beneficial microorganism instead of synthetic chemical are known to improve plant growth through supply of plant nutrients and may help to sustain environmental health and soil productivity (Orhan *et al*l., 2006). The use of plant growth promoting rhizobacteria in agriculture for promoting the circulation of plant nutrition and reducing the need of chemical fertilizers is well recognized (Regina *et al*., 2007). The utilization of biofertilizers has become a feasible production practice (Zaied *et al*., 2003; Zaidi *et al*., 2006; Zahir *et al*., 2004; Anjum *et al*., 2007). They can affect plant growth either directly or indirectly through various mechanisms of action. N2-fixing and P-solubilizing bacteria may be important for plant nutrition by increasing uptake by the plants, and playing a significant role as plant growth promoting rhizhactoria (PGPR) in the biofertilization of crops (Zahir *et al*., 2004; Yomg *et al*., 2005). Nitrogen fixation and P-solubilization, production of antibiotic (Zaidi *et al*., 2006; Cavaglieri *et al*., 2004; Idriss., 2002; Sturz and Christie., 2003; Commare *et al*., 2003) and increased rood dry

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weight (Zahir *et al*., 2004) are the principal mechanism for the PGPR. A number of different bacteria promote plant growth, including *Azotobacter* sp., *Azospirillum sp*., *Pseudomonas sp*., *Bacillus sp. Acetobacter sp.* (Turan *et al*., 2006). Economic and environmental benefits can include increased income from high yields (Swedrzynska and Sawicka., 2000; Mirza *et al*., 2000), reduced fertilizer costs and reduced emission of the greenhouse gas, N_2O as well as reduced leaching of NO_3 (Shaharoona *et al*., 2006). The aim of this paper is reviewing of different researches focused on PGPR roles and important and their application in sustainable agriculture.

The influence of PGPR on crop growth in sustainable agriculture:

PGPR and enhance plant growth:

PGPR can affect plant growth by different direct and indirect mechanisms (Vessey, 2003), but the specific mechanisms involved have not all been well-characterized. Direct mechanisms of plant growth promotion by PGPR can be demonstrated in the absence of plant pathogens or other rhizosphere microorganisms, while indirect mechanisms involve the ability of PGPR to reduce the deleterious effects of plant pathogens on crop yield. PGPR have been reported to directly enhance plant growth by a variety of mechanisms: fixation of atmospheric nitrogen that is transferred to the plant, production of siderophores that chelate iron and make it available to the plant root, solubilization of minerals such as phosphorus, and synthesis of phytohormones. Direct enhancement of mineral uptake due to increases in specific ion fluxes at the root surface in the presence of PGPR has also been reported (Requena *et al*., 1997; Kennedy *et al*, 2004). PGPR strains may use one or more of these mechanisms in the rhizosphere. Molecular approaches using microbial and plant mutants altered in their ability to synthesize or respond to specific phytohormones have increased our understanding of the role of phytohormone synthesis as a direct mechanism of plant growth enhancement by PGPR (Nelson, L. M. 2004; Wu *et al*., 2005).

PGPR that indirectly enhance plant growth via suppression of phytopathogens do so by a variety of mechanisms (Han *et al*., 2004; Cakmaci *et al*., 2005). These include the ability to produce siderophores that chelate iron, making it unavailable to pathogens; the ability to synthesize anti-fungal metabolites such as antibiotics, fungal cell wall-lysing enzymes, or hydrogen cyanide, which suppress the growth of fungal pathogens; the ability to successfully compete with pathogens for nutrients or specific niches on the root; and the ability to induce systemic resistance (Vessey, 2003; Kennedy *et al*., 2004). Plant studies have shown that the beneficial effects of Azospirillum on plants can be enhanced by co-inoculation with other microorganisms. Co-inoculation, frequently, increased growth and yield, compared to single inoculation, provided the plants with more balanced nutrition, and improved absorption of nitrogen, phosphorus, and mineral nutrients (Yazdani *et al*, 2011).

Fig. 1: Effects of plant growth promoting rhizohactoria (PGPR) on root growth of corn (Yazdani *et al*, 2012). Figure 1 show interaction of PGPR with other soil microorganisms such as phosphate, solubiling microorganisms (PSM).

Bacterial Biofertilizers:

Nitrogen is one of the most important nutrients for maize production as it affects dry matter production by influencing leaf area development and maintenance as well as photosynthetic efficiency. It can be applied through chemical or organic manure (Devi *et al*., 2007; Warman and Havard., 1998) and biological means

(Zahir *et al*., 2004; Lerner *et al*., 2006), but chemical nitrogen fertilizer is expensive. N can be easily lost by leaching, denitrification or volatilization (Yomg *et al*., 2005; Zaidi *et al*, 2009). Agricultural systems require surplus N additions in order to produce desired yields because current management practices tend to disengage energy flows and nutrient cycles in space and time (Tonitto *et al*, 2006; Violante and Portugal. 2007). Phosphorus is second only to nitrogen in mineral nutrients most commonly limiting the growth of terrestrial plants. Ironically, soils may have large reserves of total P, but the amounts available to plants is usually a tiny proportion of this total (Stevenson and Cole, 1999; Karnataka, 2007; Stajkovic *et al*, 2010). The low availability of P to plants is because the vast majority of soil P is found in insoluble forms, and plants can only absorb P in two soluble forms, the monobasic ($H2PO4^{-}$) and the dibasic ($HPO4^{2-}$) ions (Glass, 1989). Symbiotic nitrogen fixing bacteria replaced 60% of the nitrogen requirements of sugarcane amounting to 200 kg N/ha.

PGPR can play a significant role in crop nutrition, increasing total uptake and in some cases nutrient use efficiency (Yazdani *et al*, 2011). This may be associated with increased growth and yield. In many cases PGPR cause a change in the absorption of several nutrients by the host simultaneously, though the effect on different nutrients is rarely the same. Bacterial inoculants -A formulation containing one or more beneficial bacterial strains (or species) in an easy-to-use and economical carrier material, either organic, inorganic, or synthesized from defined molecules. The inoculants are the means of bacterial transport from the factory to the living plant. The desired effects of the inoculants on plant growth can include nitrogen fixation in legumes, biocontrol of (mainly) soil-borne diseases, the enhancement of mineral uptake, weathering of soil minerals, and nutritional or hormonal effects. Bacterial inoculants may require lengthy and expensive registration procedures in some countries. 'Biofertilizer" - A misleading but widely used term meaning "bacterial inoculants. Usually it refers to preparations of microorganisms that may be a partial or complete substitute for chemical fertilization (like rhizobial inoculants). However, other bacterial effects on plant growth are largely ignored. The reason for using the word "fertilizer" is that in some countries it allows easier registration for commercial use. This term, although is appropriate for rhizobia, should be abandoned.

Mode of action of PGPR as biofertilizers:

As our understanding of the complex environment of the rhizosphere, of the mechanisms of action of PGPR, and of the practical aspects of inoculants formulation and delivery increases, we can expect to see new PGPR products becoming available. The success of these products will depend on our ability to manage the rhizosphere to enhance survival and competitiveness of these beneficial microorganisms (Violante and Portugal, 2007). Rhizosphere management will require consideration of soil and crop cultural practices as well as inoculants formulation and delivery (Date, 2001). The use of multi-strain inoculate of PGPR with known functions is of interest as these formulations may increase consistency in the field (Nikolay *et al*, 2006; Figueiredo *et al*, 2007; Kramany *et al*, 2007). They offer the potential to address multiple modes of action, multiple pathogens, and temporal or spatial variability (Nelson, 2004; Saharan and Nehra, 2011).

The means by which PGPR enhance the nutrient status of host plants can be categorized into five areas: (1) biologicalN2 fixation, (2) increasing the availability of nutrients in the rhizosphere, (3) inducing increases in root surface area (Figure 1), (4) enhancing other beneficial symbioses of the host, and (5) combination of modes of action. Each of these areas will be examined in this section of the review (Vessey, 2003). The nitrogen fixing bacteria such as *Azotobacter* and *Azosperillium* reduce the nitrogen gas to ammonia using intensive energy to break the nitrogen bonds so that it can combine with hydrogen to form ammonia. Many actual and putative are biofertilizer PGPR produce phytohormones that are believed to be related to their ability to stimulate plant growth. Inoculation of plants with this bacterium causes morphological changes, such as an increase in root surface area through the production of more root hairs, which in turn enhance mineral uptake (Vessey., 2003; Requena *et al*., 1997; Kennedy *et al*, 2004). Economic and environmental benefits can include increased income from high yields, reduced fertilizer costs and reduced emission of the greenhouse gas, N_2O as well as reduced leaching of NO_3. Phosphate solubilizing bacteria are common in the rhizosphere and secretion of organic acids and phosphates are common method of facilitating the conversion of insoluble forms of P to plant-available forms (Kim *et al*., 1998).

Induced Resistance:

Induced disease resistance occurs when a plant exhibits an increased level of resistance to infection by a pathogen after prior treatment with an inducing agent. Some selected strains of plant growth-promoting rhizobacteria (PGPR) have been found to activate plant defense via induced systemic resistance (ISR) (Zkoc and Hanifi, 2001). Treatment of plants with selected strains of plant growth-promoting rhizobacteria (PGPR) can induce systemic resistance in carnation, cucumber, radish, tobacco, and Arabidopsis as evidenced by an enhanced defensive capacity upon challenge inoculation with a pathogen (Kloepper *et al*, 1992).

Reductions in the severity of disease occur rather than total inhibition, but this can still result in a significant increase in yield over plants not inoculated with PGPR inoculation, and occurs despite the fact that pathogen infection generally reduces with PGPR inoculation (Tuzun, 2001; Raj *et al*, 2003; Saikia *et al*, 2004). Microbial inoculants can be used as an alternative means for controlling pests and disease in agricultural cropping systems, permitting the reduced use of pesticides that could otherwise pose threats to human health and non-targeted organisms (Saikia *et al*, 2004). When plants are invaded by micro-organisms or damaged by mechanical injuries, major physiological changes are induced and plant defense enzymes are generally activated. Induced disease resistance is an active plant defense process that depends on physical or chemical barriers in the host and is activated by biotic or abiotic inducing agents. Furthermore, perhaps the most important of these is exclusion, which seems to be a simple case of competition for space.

As a result, the most effective control is achieved when PGPR inoculated takes place before attack by the pathogen. Other factors involved may be related to changes in root exudates, which can cause changes in the rhizosphere microbial community, changes to the crop root architecture or changes to root biochemistry connected with plant defense mechanisms. Changes to plant defense mechanisms or so-called **induced resistance** result from a priming effect of the PGPR inoculated, which does not in itself cause a significant defensive response by the plant but induces the plant to respond faster to infection by pathogenic fungi Dashti *et al* (1998) reported that, Co-inoculation of soybean with *B. japonicum* and PGPR increased soybean nodulation and hastened the onset of nitrogen fixation, when the soils were still cool. Total fixed N, fixed N as a percentage of total plant N, and protein and N yield were also increased by PGPR inoculation. Ryu *et al* (2003) reported that some PGPR strains release a blend of volatile organic compounds (VOCs) that promote growth in *Arabidopsis* seedlings and induce resistance against *Erwinia carotovora* subsp. carotovora. In particular, the volatile components 2,3-butanediol and acetoin were released exclusively from two PGPR strains that trigger the greatest level of growth promotion and induced disease resistance.

Interaction with other soil microorganisms:

rhizosphere microorganisms including free living N fixing bacteria and general plant growth promoting rhizobacteria (PGPR) interact with beneficial within the mycorrhizosphere AMF (Requena *et al*., 1997; Tsimilli-Michael *et al*., 2000). Large increases in yield over un-inoculated controls have been observed with some PGPR though the interaction with PGPR can be antagonistic as well as synergistic and there seems to be a high degree of specificity between the plant, AMF and PGPR species involved in these interactions (Requena *et al*., 1997).

Conclusions:

Over the years this led to serious environmental problems such as depletion of soil quality and health, ocean and ground water pollution, and emergence of resistant pathogens. It is a big challenge to feed the increasing world population on decreasing farmland areas without damaging environment. One of new topics in sustainable agriculture for soil resource management is about soil microorganisms and beneficial symbiotic relations among ecosystem components in food chains. Today, soil biotechnology could produce biofertilizars in addition to beneficial soil microorganism for removing of toxin and other soil pollutants, plant residual decomposition, improvement of physical soil structure, enhancement of plant protection and etc. It is well known that rhizosphere and soil microorganisms (PGPR) play an important role in maintaining crop and soil health through versatile mechanisms: nutrient cycling and uptake, suppression of plant pathogens, induction of resistance in plant host, direct stimulation of plant growth. This review has shown that there is huge potential for the use of PGPR in sustainable agriculture. The use of growth promoting rhizobacteria (PGPR) is a promising solution for sustainable, environmentally friendly agriculture. Although significant control of plant pathogens or direct enhancement of plant development has been demonstrated by PGPR in the laboratory and in the greenhouse, results in the field have been less consistent. Because of these and other challenges in screening, formulation, and application, PGPR have yet to fulfill their promise and potential as commercial inoculants. Recent progress in our understanding of their diversity, colonization ability, mechanisms of action, formulation, and application should facilitate their development as reliable components in the management of sustainable agricultural systems.

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