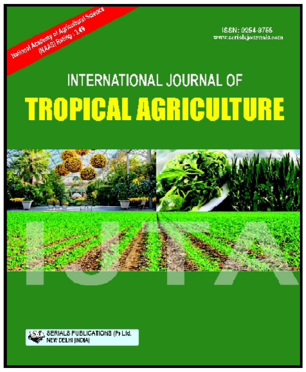

INTERNATIONAL JOURNAL OF TROPICAL AGRICULTURE

ISSN : 0254-8755

available at http: www.serialsjournals.com

Volume 36 • Number 3 • 2018

Plant growth promoting rhizobacteria (PGPR): An alternative source of biofertilizer for sustainable agriculture

Awadhesh Kumar Shukla

Department of Botany, K. S. Saket P.G. College, Ayodhya, Faizabad affiliated to Dr. Ram Manohar Lohia Avadh University, Faizabad-224001, Uttar Pradesh, India, E-mail: awadhkshukla@gmail.com

Abstract: Enormous increasing human population and its life forms depend on the sustainable agriculture, food security and also on the soil characteristics. Due to overpopulation the demands for agricultural production have been tremendously enhanced the utilization of chemical fertilizers by farmers in the field. In the recent past the agricultural productivity, soil quality and fertility are badly affected because of large scale utilization of chemical fertilizer and pesticide. Hence researchers are paying attention for the exploitation of safer and productive means of sustainable agriculture. Soil harbors bacterial populations that possess inherent potential for enhancement of growth and yield of the crop plants. PGPR are exogenous bacteria that introduced into agricultural ecosystems and actively engaged in positive development of plants. PGPR possess potential to promote the plant growth in various ways through phosphate solubilization, production of phytohormone, nutrient cycling and siderophore production. The potential applicability of PGPR is steadily increasing in agriculture because it offers a promising approach to replace the use of chemical fertilizers, pesticides and other supplements. Recent progress in our understanding enhances on the diversity of PGPR in the rhizosphere along with their colonization ability and mechanism of action that would facilitate their wider application in the management of sustainable agricultural crop production. Further, PGPR is being functioning as a connecting link between plants and microbes that could express antagonistic and synergistic interactions with microorganisms and the soil. Rhizospheric bacterial communities are directly or indirectly also affected by the plant age, environmental stresses and agricultural practices.

Key words: PGPR, diversity, nutrient cycling, biofertilizer

INTRODUCTION

Chemical fertilizers are immensely used by farmers to supplement the essential nutrients to the soil associated plant system widely. The ease of availability and the environmental concerns of chemical fertilizers in special relation to the N fertilizers are real issues of today's agriculture. However, the use of chemical fertilizers has its own merit and demerits in agriculture land application and sustainable crop yields. Hence, there is an urgent requirement to alternative strategies in order to enhance the crop production and maintain the nutrient in the soil for ecological balance in agro-ecosystem. In the present scenario the use of microbial inoculants or PGPR is promising and widely accepted practices in intensive agriculture for the sustainable agricultural production. PGPR are free-living soil bacteria that colonizes root rhizosphere/of plant and promotes the plant growth in terms of crop yields. (Kumar *et al.*, 2014).

These rhizospheric microbes derive benefit from the plant roots because it secretes metabolites that can be utilized as nutrients. It is reported that the bacterial concentration in the rhizosphere is found to be order 10 to 1000 times higher than that in bulk soil (Lugtenberg and Kamilova, 2009). To exert their beneficial effects in the root environment, bacteria have to be rhizosphere competent, i.e., able to compete well with other rhizosphere microbes for nutrients secreted by the roots. The discriminative use of food source by the microbes in root zone is not still well understood (Uren, 2007). An exception is the composition of the root exudates of tomato, in which organic acids, followed by sugars, are the major components (Lugtenberg *et al.,* 2001). Study was carried out by the earlier researcher and they have confirmed the role of organic acids in root colonization and found that the mutants affected in organic acid utilization are poor competitive in root colonization compare to the parental strain (Weert S *et al.,* 2007). It is reported that only a small part of the root surface is covered by bacteria, while, there is better chance of bacterial growth between epidermal cells and areas where side roots appear. This chapter highlights the diversity of PGPR and their potential exploitation in agricultural landscape in order to enhance the sustainable crop production.

PGPR

The plant growth promoting (PGP) effect of the PGPR is generally explained by the release of metabolites which directly promotes the plant growth. There are several ways to explain the activities of PGPR benefit to the host plant. PGPR have potential to produce plant growth regulators such as indole acetic acid (IAA), cytokinins, and gibberellins (Glick, 1995; Marques *et al.,* 2010), enhancing nitrogen fixation process (Sahin *et al.,* 2004; Khan, 2005), promote solubilization and mineralization of inorganic and organic phosphate, respectively. (Bashan and de-Bashan, 2010). PGPR strains and their potential application in agricultural fields are summarized in Table1.1.

On the basis of association of PGPR with the plant root cells, it is classified into two groups namely extracellular (ePGPR) and intracellular (iPGPR) (Martinez-Viveros *et al.,* 2010). The ePGPRs mostly found in the rhizosphere, rhizoplane or spaces present between the cells of root cortex, conversely, iPGPRs presents generally inside the specialized nodular structures of root cells. Various bacterial genera such as *Agrobacterium*, *Arthrobacter*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Erwinia*, *Flavobacterium*, *Micrococcous*, *Pseudomonas* and *Serratia* belongs to the ePGPR category (Gray and Smith, 2005; Bhattacharyya and Jha, 2012). The iPGPR shows activity with endophytes and Frankia species which possess potential to fix atmospheric N_2 symbiotically with the higher plants (Jeon *et al.,* 2003). PGPR also express to protect the plants against phytopathogenic microorganisms by production of siderophores, synthesis of new antibiotics, enzymes, and/also competes with detrimental microorganisms in the soil (Dey *et al.,* 2004; Lucy *et al.,* 2004).The beneficial rhizobacteria associated with cereals has increased attention to clearly demonstrated the positive and beneficial effects of PGPR on growth and yield of different crops especially wheat at variable environmental and ecological conditions (Ozturk *et al.,* 2003; Marques *et al.,* 2010; Zhang *et al.,* 2012). The inoculation with PGPR strain such as *Azotobacter* sp. possesses potential to minimize the utilization of nitrogen based chemical fertilizer (Narula *et al.,* 2005). More recently, Kumar *et al.* (2014) conducted experiments on wheat under pot and field condition to examine the effect of PGPRs on the growth and yield of wheat and found that triple combination of strains *B. megaterium*, *A. chlorophenolicus,* and *Enterobacter* significantly increased in plant height and yields of grain and straw. Majeed *et al.* (2015) reported effects of plant growth-promoting rhizobacteria isolated from wheat rhizosphere. They observed that growth of wheat was promoted in the presence of PGPR.

PHOSPHATE SOLUBILIZATION

Phosphorus is second most essential nutrient which is required by plant in adequate amount for the growth promotion. However, almost 95–99% of phosphorus is present in insoluble, immobilized, or precipitated forms, hence, phosphorus is easily not available to the plants and unable to support plants. PGPR and fungi such as *mychorriza,* possess potential to solubilize and mineralize phosphorus and made ease of availability to the plants (Richardson, 2001). It is reported that the low molecular weight organic acids are generally synthesized by various soil bacteria and help in solubilization of inorganic phosphorus (Zaidi *et al.,* 2009). On the contrary, the synthesis of a variety of different phosphorus made possible with the hydrolysis of phosphoric acid esters and leads to the mineralization process of organic phosphorus. Tao *et al.* (2008) investigated the bacteria that possess both phosphate solubilization and mineralization potential which could be useful for plant growth promotion. It is well established that most of the soils are poor in phosphorus content and farmers are also unable to use phosphate fertilizer in the field due its high cost. Hence, it is important to exploit the soil microorganisms as inoculum for phosphate mobilization in the field condition. Phosphate solubilizing bacteria such as *Bacillus, Rhizobium* and *Pseudomonas* are the potent bacterial genera which are efficient to hydrolyze the inorganic phosphorus into soluble form and easily made available to the plant for growth promotion. Plants absorb phosphate in the form $H_2PO_4^{-}$ and HPO_4^{-2} ions. Gouda *et al.* (2018) reviewed that solubilization and mineralization of phosphorus by phosphate-solubilizing bacteria is an important trait which could be achieved by the exploitation of PGPR strain. There is great variety of bacterial genera have been investigated as a phosphate solubilizing PGPR. These genera includes *Arthrobacter*, *Beijerinckia, Pseudomonas*, *Erwinia*, *Rhizobium*, *Mesorhizobium* etc., have been used as soil inoculants by agriculture scientist enhance the plant growth and yield (Oteino *et al.,* 2015). Among them, *Mesorhizobium ciceri* and *Mesorhizobium mediterraneum*, which are isolated from chickpea nodules, are good phosphate solubilizers (Parmar and Sindhu, 2013). Although these microbes solubilize phosphorus resulting in increased soil fertility, studies regarding their use as a bio-fertilizer are limited.

FUTURE PERSPECTIVE

Currently it is established that PGPR have potential to enhance the agriculture productivity via various routes and processes. However, there is a great deal of variation in the performance of PGPR that might be due to the environmental factors which may affect their growth and exert their effects on plant. The environmental factors include climate change, soil characteristics and the composite activity of the indigenous microbial flora of the soil (Gupta *et al.,* 2015). Now then there are various modern tools and techniques such as biosensors, nano-fertilizers and development in the fields of biotechnology and nanotechnology has been applied in the agriculture and allied sector for enhancing the crop productivity and yields. It is important to develop better insight of complex environment of the rhizosphere and associated bacteria, their mechanisms of action and exploitation of these bacterial inoculant formulations, there is possibility to develop a new PGPR strain for the enhancement of growth and yields of the crop plants. The success of getting new strain could enhance our ability to manage the rhizosphere and promote the survival and competitiveness of these beneficial microorganisms. Potential strain could be managed via high throughput genetic engineering of PGPR strains to improve the colonization efficacy and their effectiveness may involve addition of one or more traits associated with plant growth promotion. The use of multi-strain inocula of PGPR with known functions is of interest as these formulations may increase consistency in the field. They offer the potential to address multiple modes of action, multiple pathogens, and temporal or spatial variability. PGPR offer an environmentally sustainable approach to increase crop production

PGPR based biotechnologies can be exploited for sustainable and eco-friendly technology for the management of plant stresses and biocontrol. It is reported that nanobased products and processes are being utilized by various developed countries like USA, Germany, France etc. for enhancing the agricultural growth and sustainable development. However, In India, there is urgent need to develop such useful technologies to increase the agricultural food products which fulfilled the meet the requirements of large population.

CONCLUSIONS

The use of bacterial fertilizers has made significant improvement in terms of growth, health and yield of plants. The mechanism by which PGPR stimulates can be direct or indirect. PGPR also support growth by reducing the phytopathogens which reduce the yield and growth. The outcome of PGPR inoculation is greatly influenced by plant age and by the chemical, physical and biological properties of the soil. There are several challenges for using PGPR such as natural variation but by the virtue of advance techniques and applying biotechnology can overcome the challenges faced by PGPR. Hence future prospects can be replacement of chemical fertilizers and supporting the ecosystem in terms of safety. Further understanding of the complete mechanism and factor affecting diversity of PGPR could help in obtaining more specific strain that will be able to work under more adverse and varying environmental conditions.

Table 1
PGPR strain and its application in agriculture

Bacterial species	*Host plant*	*Utilization*	*References*
Azospirillum sp.	*Zea mays*	N_2 fixation (rhizosphere)	Garcia de Salamone *et al.* (1996)
Bacillus polymyxa	*Triticum aestivum*	N_2 fixation (rhizosphere)	Omar *et al.* (1996)
Agrobacterium sp.	*Lactuca sativa*	IAA production	Barazani and Friedman (1999)
Pseudomonas fluorescens	*Glycine max*	Cytokinin production	Garcia de Salamone *et al.* (2001)
Bacillus sp.	*Alnus*	Gibberelin production	Gutierrez-Manero *et al.* (2001)
Herbaspirillum sp.	*Oryza sativa*	N_2 fixation (endophytic)	James *et al.* (2002)
Azospirillium lipoferum	*Triticum aestivum*	Promoting root development	Belimov *et al.* (2004)
Herbaspirillum seropedicae	*Oryza sativa*	Increase the production of gibberellins	Araujo *et al.* (2009)

Application of modern tools and techniques would be promising for the enhancement of PGPR strain that could play pivotal roles in sustainable agriculture by improving soil fertility, crop productivity, and management of nutrient cycle. Further there is need to carry out more studies for selecting suitable rhizospheric microbial communities along with combination with interdisciplinary approaches in order to formulate their potential under field conditions.

REFERENCES

Araujo, A.S.F., Leite, L.F.C., Santos, V.B. and Carneiro, R.F.V. (2009), Soil microbial activity in conventional and organic agricultural system, Sustainability, 1, 268–276.

Arshad, M. and Frankenberger, W.T.J. (1998), Plant growth regulating substances in the rhizosphere: microbial production and functions, Adv in Agron, 27-42.

Barazani, O. and Friedman, J. (1999), Is IAA the major root growth factor secreted from plant-growth-mediating bacteria?, J Chem Ecol, 25(10),2397–2406. doi:10.1023/A:1020890311499.

Bashan, Y.and de-Bashan, L.E. (2010), Chapter two—How the plant growth-promoting bacterium *Azospirillum* promotes plant growth–a critical assessment, Adv Agron, 108,77–136

Belimov, A.A., Kunakova, A.M., Safronova, V.I., Stepanok, V.V., Yu, L., Yu, Y., Alekseev, Y. and Kozhemyakov, A.P. (2004), Employment of rhizobacteria for the inoculation of barley plants cultivated in soil contaminated with lead and cadmium, Microbiol, 73, 99–106.

Beneduzi, A., Ambrosini, A. and Passaglia, L.M.P. (2012), Plant growth-promoting rhizobacteria: their potential as antagonists and biocontrol agents, Genet Mol Biol, 35, (4), 1044–1051.

Bertrand, H., Plassard, C., Pinochet, X., Toraine, B. and Normand P. (2000), Stimulation of the ionic transport system in *Brassica napus* by a plant growth-promoting rhizobacterium. Can J Microbiol, 46, 229-236.

Bhattacharyya, P., Goswami, M. and Bhattacharyya, L. (2016), Perspective of beneficial microbes in agriculture under changing climatic scenario: A review, J Phytol, 8, 26-41.

Bhattacharyya, P.N. and Jha, D.K. (2012), Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbial Biotechnol, 28, 1327–1350.

Castro-Sowinski, S., Herschkovitz, Y., Okon, Y. and Jurkevitch, E. (2007), E¡ects of inoculationwith plant growth-promoting rhizobacteria on resident rhizosphere microorganisms, FEMS Microbiol Lett, 276, 1–11.

Costacurta, A. and Vanderleyden, J. (1995), Synthesis of phytohormones by plant associated bacteria, Crit Rev Microbiol, 21, 1-18.

De, Weert, S., Kuiper, I., Kamilova, F., Mulders, I.H.M. Bloemberg, G.V, et al. (2007) , The role of competitive root tip colonization in the biological control of tomato foot and root rot, In *Biological Control of Plant Diseases*, ed. SB Chincolkar, KGMukerji, New York/London/Oxford, Haworth, 103–22.

DeAngelis, K.M., Lindow, S.E.and Firestone, M.K. (2008), Bacterial quorum sensing and nitrogen cycling in rhizosphere soil, FEMS Microbiol Ecol, 66, 197–207.

deSalamone, G.G., Dobereiner, I.E., Urquiaga, J.S.and Boddey, R.M. (1996), Biological nitrogen fixation in *Azospirillum* strain maize genotype associations as evaluated by the ^{15}N isotope dilution technique, Biol Fertile Soils, 23, 249-256.

Dey, R., Pal, K. K., Bhatt, D. M. and Chauhan, S. M. (2004), Growth promotion and yield enhancement of peanut (*Arachis hypogaea* L.) by application of plant growth promoting rhizobacteria, Microbiol Res, 159, 371–394. doi: 10.1016/j.micres.2004.08.004.

Fray, R.G. (2002), Altering plant-microbe interaction through artificially manipulating bacterial quorum sensing, Ann Bot, 89, 245–253.

Garcia de Salamone, I.E., Hynes, R.K. and Nelson, L.M. (2001), Cytokinin production by plant growth promoting rhizobacteria and selected mutants, Can J Microbiol, 47,404–411.

Glick, B. R. (1995), The enhancement of plant growth by freeliving bacteria, CanJ Microbiol, 4, 1109–1114.

Gouda, S., Kerry, R.G., Das, G., Paramithiotis, X., Shin, H.S. and Patra, J.K. (2018), Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture, Microbiol Res, 206,131–140.

Gray, E.J. and Smith, D.L. (2005), Intracellular and extracellular PGPR: commonalities and distinctions in the plant-bacterium signaling processes, Soil Biol Biochem, 37,395–412.

Gutierrez-Manero, F.J., Ramos-Solano, B., Probanza, A., Mehouachi, J., Tadeo, F.R. and Talon, M. (2001), The plant-growth promoting rhizobacteria *Bacillus pumilus* and *Bacillus licheniformis* produce high amounts of physiologically active gibberellins, Physiol Plantarum, 111, 206–211.

Higa, T.and Wididana, G. (1991), The concept and theories of effective microorganisms. In: Proceedings of the first international conference on Kyusei nature farming, US Department of Agriculture, Washington, DC, USA, 1991. 118-124.

Jeon, J. S., Lee, S. S., Kim, H. Y., Ahn, T. S. and Song, H. G. (2003), Plant growth promotion in soil by some inoculated microorganisms, J Microbiol, 41, 271–276.

Kaiser, C., Kilburn, M.R.and Clode, P.L. Fuchslueger, L., Koranda, M., Cliff, J. B., Solaiman, Z. M. and Murphy, D. V. (2015), Exploring the transfer of recent plant photosynthates to soil microbes: mycorrhizal pathway vs direct root exudation, New Phytol, 205, 1537–1551.

Khan, A. G. (2005), Role of soil microbes in the rhizospheres of plants growing on trace metal contaminated soils in phytoremediation, J Trace Elem Med Biol,18, 355–364. doi: 10.1016/j.jtemb.2005.02.006.

Kumar, A., Maurya, B. R. and Raghuwanshi, R. (2014), Isolation and characterization of PGPR and their effect on growth, yield and nutrient content in wheat (*Triticum aestivum* L.), Biocatal Agric Biotechnol, 3, 121–128.

Lucy, M., Reed, E. and Glick, B. R. (2004), Application of free living plant-promoting rhizobacteria, Antonie van Leeuwenhoek, 86, 1–25. doi: 10.1023/B:ANTO.0000024903.10757.6e.

Lugtenberg, B.J.J., Dekkers, L.C. and Bloemberg, G.V. (2001), Molecular determinants of rhizosphere colonization by *Pseudomonas*, Annu Rev Phytopathol, 39,461–90.

Lugtenberg. B, and Kamilova, F. (2009), Plant growth promoting rhizobacteria, Annu Rev Microbiol, 63,541–56.

Li Z, Xu J, Tang C, Wu J, Muhammad A &Wang H (2006) Application of 16S rDNA-PCR amplification and DGGE fingerprinting for detection of shift in microbial community diversity in Cu-, Zn-, and Cd-contaminated paddy soils. Chemosphere 8: 1374–1380.

Lupwayi NZ, Rice WA & Clayton GW (1998) Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. Soil Biol Biochem 30: 1733–1741.

Majeed, A., Abbasi, M.K., Hameed, S., Imran, A. and Rahim, N. (2015), Isolation and characterization of plant growth-promoting rhizobacteria from wheat rhizosphere and their effect on plant growth promotion, Front Microbiol, 6,198. doi: 10.3389/fmicb.2015.00198.

Marques, A. P. G. C., Pires, C., Moreira, H., Rangel, A. O. S. S. and Castro, P.M. L. (2010), Assessment of the plant growth promotion abilities of six bacterial isolates using *Zea mays* as indicator plant. Soil Biol Biochem 42, 1229–1235. doi: 10.1016/j.soilbio.2010.04.014.

Martinez-Viveros, O, Jorquera, M.A., Crowley, D.E., Gajardo, G.and Mora, M.L. (2010), Mechanisms and practical considerations involved in plant growth promotion by rhizobacteria, J Soil Sci Plant Nutr, 10,293–319.

Narula, N., Kumar, V., Singh, B., Bhatia, R. and Laxminarayana, K. (2005), Impact of biofertilizers on grain yield in spring wheat under varying fertility conditions and wheat-cotton rotation, Arch Agron Soil Sc. 51, 79–89. doi: 10.1080/03650340400029382.

Ngumbi, E. and Kloepper, J. (2016), Bacterial-mediated drought tolerance: current and future prospects, Appl Soil Ecol 105, 109–125.

Omar, M.N.A., Mahrous, N.M. and Hamouda, A.M. (1996), Evaluating the efficiency of inoculating some diazatrophs on yield and protein content of 3 wheat cultivars under graded levels of nitrogen fertilization, Ann Agric Sci, 41,579–590.

Orlandini, V., Emiliani, G., Fondi, M., Maida, E., Perrin, E. and Fani, R. (2014), Network Analysis of Plasmidomes: The *Azospirillum Brasilense* Sp245 Case. Hindawi Publishing Corporation, . 1–14.

Oteino, N., Lally, R.D., Kiwanuka, S., Lloyd, A., Ryan, D., Germaine, K.J. and Dowling, D.N. (2015), Plant growth promotion induced by phosphate solubilizing endophytic *Pseudomonas* isolates, Front Microbiol, 6, 745.

Ozturk, A., Caglar, O. and Sahin, F. (2003), Yield response of wheat and barley to inoculation of plant growth promoting rhizobacteria at various levels of nitrogen fertilization, J Plant Nutr Soil Sci, 166, 262–266. doi: 10.1002/jpln.200390038.

Parmar, P. and Sindhu, S.S. (2013), Potassium solubilisation by rhizosphere Bacteria: influence of nutritional and environmental conditions, J Microbial Res, 3, 25–31.

Prathap, M. and Ranjitha, K.B.D. (2015), A critical review on plant growth promoting rhizobacteria, J Plant Pathol Microbiol, 6 (4), 1–4.

Rathore, P.(2015), A review on approaches to develop plant growth promoting rhizobacteria Int J Recent Sci Res, 5 (2), 403–407.

Richardson, A.E. (2001), Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants, Funct Plant Biol, 28, 897-906.

Rivas, R., Peix, A., Mateos, P.F., Trujillo, M.E. and Martinez-Molina, E. and Velázquez, E. (2006), Biodiversity of populations of phosphate solubilizing rhizobia that nodulates chickpea in different spanish soils, Plant and Soil, 287, 23-33.

Russo, A., Carrozza, G.P., Vettori, L., Felici, C., Cinelli, F. and Toffanin, A. (2012), Plant beneficial microbes and their application in plant biotechnology, In: Agbo EC (eds) Innovations in biotechnology, InTech, doi: 10.5772/31466.

Saha, M., Sarkar, S., Sarkar, B., Sharma, B.K., Bhattacharjee, S. and Tribedi, P. (2016), Microbial siderophores and their potential applications: a review, Environ Sci Pollut Res, 23 (5), 3984–3999.

Sahin, F., Cakmakci, R. and Kanta, F. (2004), Sugar beet and barley yields in relation to inoculation with N_2-fixing and phosphate solubilizing bacteria, Plant Soil, 265, 123–129. doi: 10.1007/s11104-005-0334-8.

Singh, L.P. Gill, S.S.and Tuteja, N. (2011), Unraveling the role of fungal symbionts in plant abiotic stress tolerance, Plant Signal Beh, 6,175-191.

Tao, G.C., Tian, S.J., Cai, M.Y. and Xie, G.H. (2008). Phosphate solubilizing and mineralizing abilities of bacteria isolated from soil, Pedosphere, 18, 515-523.

Uren, N.C. (2007). Types, amounts, and possible functions of compounds released into the rhizosphere by soil-grown plants. In *The Rhizosphere. Biochemistry and Organic Substances at the Soil-Plant Interface*, ed. R Pinton, Z Varanini, P Nannipieri, Boca Raton, FL, CRC Press/Taylor & Francis Group. 2nd ed, 1–21.

van der Heijden, M.G.A. Bruin, S. de. and Luckerhoff, L., van Logtestijn, R.S, and Schlaeppi, K. (2016), A widespread plant-fungalbacterial symbiosis promotes plant biodiversity, plant nutrition and seedling recruitment, ISME J, 10, 389–399.

Wolfe, B.E. and Klironomos, J.N. (2005), Breaking new ground: soil communities and exotic plant invasion, Bioscience, 55, 477.

Yao, H.Y,, Liu, Y.Y. and Huang, C.Y. (2006), Effect of copper on phospholipids fatty acid composition of microbial communities in two red soils, J Environ Sci, 18, 503–509.

Zaidi, A., Khan, M.S., Ahemad, M. and Oves, M. (2009), Plant growth promotion by phosphate solubilizing bacteria, Acta Microbiol Immunol Hung, 56, 263-284.

Zhang, J., Liu, J., Meng, L., Ma, Z., Tang, X. and Cao, Y. and Sun, L. (2012), Isolation and characterization of plant growth-promoting rhizobacteria from wheat roots by wheat germ agglutinin labeled with fluorescein isothiocyanate, J Microbiol, 50, 191–198. doi: 10.1007/s12275-012-1472-3.