

Plant Growth Promoting Rhizobacteria: Prospects for Increasing Nutrient Acquisition and Disease Control

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This paper serves as an introduction to Plant Growth Promoting Rhizobacteria or otherwise known as PGPR. For in depth coverage of specific areas relating to PGPR the reader is directed to literature citations given at the end of this paper.

The Rhizosphere

The thin layer of soil (about 1 to 2mm thick) surrounding crop roots and the volume of soil occupied by roots is known as the rhizosphere. The sheer extent of crop roots in soil dictates that a significant portion of soil is actually within the rhizosphere (about 5 to 40% of soil in the rooting zone depending upon crop root architecture). This zone is where the majority of soil microorganism (bacteria and fungi) reside. They reside in the rhizosphere to utilize compounds and materials released from crop roots providing microorganisms with energy. The majority of microorganisms present in the rhizosphere are thought to have no direct consequence on plant growth and vigour. However there are many present that are deleterious or beneficial to plant growth. Producers have exploited to great success the use of inoculants of nitrogen fixing bacteria to limit the need for costly fertilizers in legume crops. As we strive to optimize the performance of all crops, increasingly the value of inoculating soil with other microorganisms or promoting the activity of residing beneficial microorganisms through management practices is being explored.

What are PGPR?

One group of microorganisms which are beneficial to crops is bacteria that colonize roots or rhizosphere soil of crop plants. These bacteria are referred to as plant growth promoting rhizobacteria (PGPR). Joe Kloepper presently at Auburn University in the United States coined the term in the later part of the 1980s and has been a major player in understanding the mechanisms and application of PGPR in temperate annual crop production. The science of PGPR is thus relatively young in comparison to nitrogen fixing bacteria and momentarily applications to crop production are limited. The science is developing rapidly and producers and the crop production industry wise to keep abreast of developments as they may reach the dealer level in years to come.

Highly Qualified Canadian Public PGPR Researchers

This author is not an expert in PGPR. He is however a student of soil biology and values informing producers on the intricate and fascinating events undertaken by organisms impacting upon crop production. To learn more about PGPR or to establish research support and collaboration in PGPR, the author directs the reader to world-class experts present in Canada (Table 1).

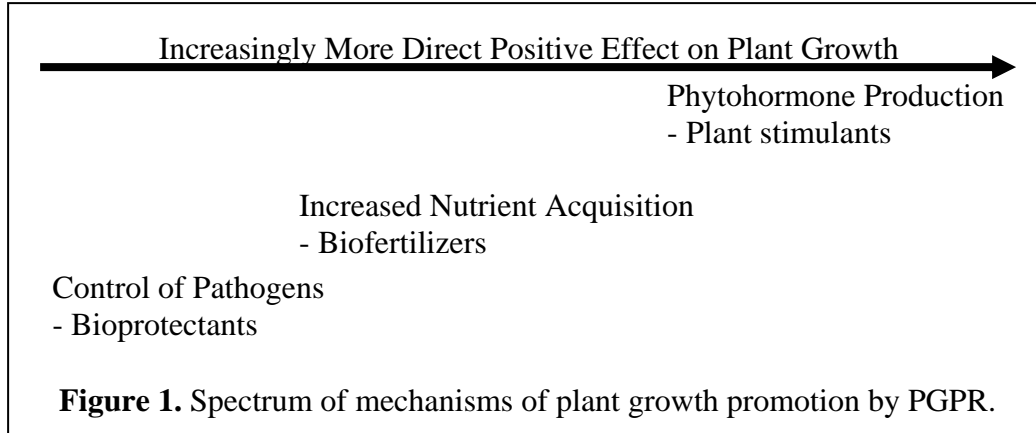
Table 1. Limited list of highly qualified Canadian public PGPR researchers.

Researcher	Location	Research Area
Chris Chanway	Faculty of Forestry, University of British Columbia	Forest biofertilizers, bioprotectants
Jim Germida	Department of Soil Science, University of Saskatchewan	Biofertilizers
Russell Hynes	Department of Soil Science, University of Saskatchewan	Biofertilizers, bioprotectants
Kevin Vessey	Department of Plant Science, University of Manitoba	Biofertilizers
Dilantha Fernando	Department of Plant Science, University of Manitoba	Bioprotectants
George Lazarovits	AAFC, London Ontario	Bioprotectants
Bernie Glick	Department of Biology, University of Waterloo	Biostimulants
Donald Smith	Macdonald College, McGill University	Biofertilizers
Hani Antoun	Sols et de génie agroalimentaire, Laval University	Rhizosphere ecology
Joe Kloeppe	Department of Entomology and Plant Pathology, Auburn University	Bioprotectants (coined PGPR; used to work in Canada)

Mechanisms of PGPR Plant Growth Promotion

The mechanisms by which PGPR increase crop performance is not well understood. There are several PGPR inoculants currently commercialized that seem to promote growth through at least one mechanism; suppression of plant disease (termed Bioprotectants), improved nutrient acquisition (termed Biofertilizers), or phytohormone production (termed Biostimulants). Inoculant development has been most successful to deliver biological control agents of plant disease, that is organisms capable of killing other organisms pathogenic or disease causing to crops. Bacteria in the genera *Bacillus*, *Streptomyces*, *Pseudomonas*, *Burkholderia* and *Agrobacterium* are the biological control agents predominantly studied and increasingly marketed. They suppress plant disease through at least one mechanism; induction of systemic resistance, and production of siderophores or antibiotics. Exposure to the PGPR triggers a defense response by the crop as if attacked by pathogenic organisms. The crop is thus armed and prepared to mount a successful defense against eventual challenge by a pathogenic organism. Siderophores produced by some PGPR scavenge heavy metal micronutrients in the rhizosphere (e.g. iron) starving pathogenic organisms of proper nutrition to mount an attack of the crop. Interestingly, plants seem capable to still acquire adequate micro-nutrient nutrition in the presence of these PGPR. Antibiotic producing PGPR release compounds that prevent the growth of pathogens. The compounds produced are not unlike antibiotics we take to rid of pathogens of human. Bioprotectants are currently being studied by the laboratories of Dr. Fernando and Daayf in the Department of Plant Science, University of Manitoba.

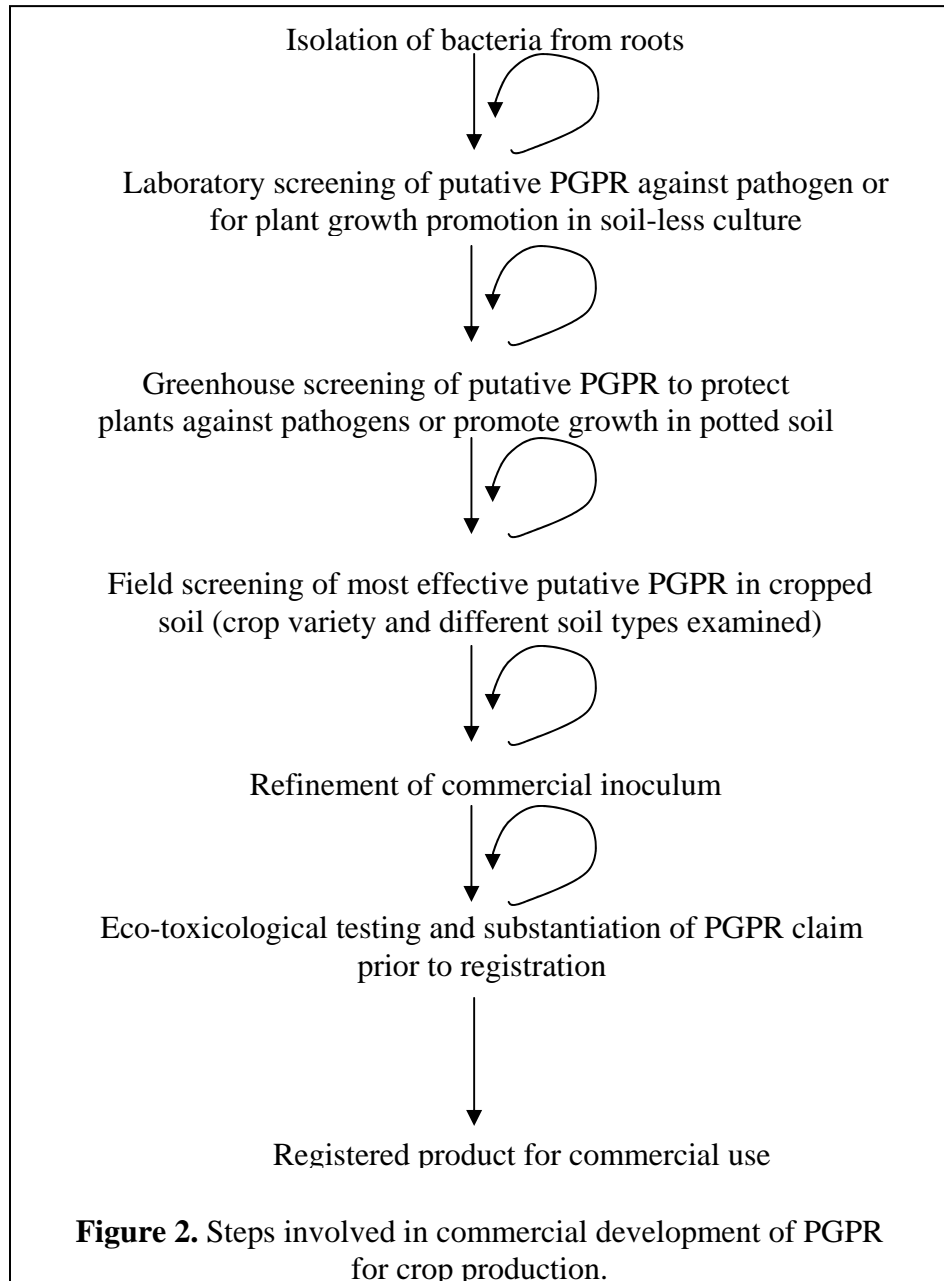
Biofertilizers are also available for increasing crop nutrient uptake of nitrogen from nitrogen fixing bacteria associated with roots (*Azospirillum*), iron uptake from siderophore producing bacteria (*Pseudomonas*), sulfur uptake from sulfur-oxidizing bacteria (*Thiobacillus*), and phosphorus uptake from phosphate-mineral solubilizing bacteria (*Bacillus*, *Pseudomonas*). Nitrogen fixing biofertilizers provide only a modest increase in crop nitrogen uptake (at best an increase of 20 lbs N per acre). Research is being conducted by Dr. Vessey in the Department of Plant Science, University of Manitoba to increase the efficiency of nitrogen fixation by biofertilizers. The popular inoculants presently commercialized for increasing phosphorus uptake through phosphorus solubilization (*Penicillium* and *Aspergillus*) and phosphorus transfer directly to roots (mycorrhizae) are not bacteria but fungi. Species of *Pseudomonas* and *Bacillus* can produce as yet not well characterized phytohormones or growth regulators that cause crops to have greater amounts of fine roots which have the effect of increasing the absorptive surface of plant roots for uptake of water and nutrients. These PGPR are referred to as Biostimulants and the phytohormones they produce include indole-acetic acid, cytokinins, gibberellins and inhibitors of ethylene production. Figure 1 depicts the relation of the PGPR mechanisms in relation to the effect on the crop.



Development of PGPR Inoculants

Development of PGPR inoculants is not refined and very laborious. This definitely has contributed to the lack of reliable inoculants available to market. The steps involved in bringing a PGPR to market is outlined in Figure 2.

Current means of delivery of inoculants include peat, granular, liquid and wetttable powder formulations and are not unlike present delivery mechanisms for legume inoculants. However, growth promotion is often inconsistent in the field compared to greenhouse or growth-chamber studies and is the dominant barrier to widespread use of PGPR. A major determinant of growth promotion is degree of colonization of the surface or interior of roots. The ability of a PGPR to establish in the rhizosphere is referred to as rhizocompetence. A big part of the laboratory and greenhouse screening is to obtain types of PGPR with the most rhizocompetence. However in field soil, environmental conditions and competition or displacement by the myriad of organisms present in the rhizosphere limit colonization. Improving delivery as well as selection of PGPR to thrive on specific crop varieties and specific soil types promises more consistent crop performance response.



Limitations in the Use of PGPR

There are several limitations to the use of PGPR for commercial use. Primarily, efficacy is not reliable for most PGPR. This is because the mechanism of action of the PGPR in promoting growth is not well understood. Research needs also to be conducted determining if and how variations in soil type, management practices (e.g. agrochemical use, rotations), and weather effect PGPR efficacy. Research into PGPR is increasing, attempting to deal with these issues. From about 1988 when the term PGPR first became coined, research activity as gauged by scientific publications has steadily increased (Figure 3). A hurdle in PGPR development is the lack of field testing. This because conducting field trials is laborious, costly and progression is slow as usually only one crop can be grown in a year. In light of this, researchers resort to laboratory and greenhouse testing. Though valuable, as evident in Figure 2, field testing must be

conducted repeatedly for selection of vigorous PGPR organisms as well as to demonstrate efficacy using different crop varieties, soil types and weather conditions. Of special note, bogus and unfounded efficacy claims that abound in the PGPR inoculant industry in the United States, hampers product development. Companies amounting to being basically snake-oil salespeople tarnish the industry and prevent legitimate companies from raising capital required to bring effective products to market. Regulatory bodies in the United States (Environmental Protection Agency) and Canada (Canadian Food Inspection Agency and the Pest Management Regulatory Agency) have established procedures for the registration of PGPR. Demonstration primarily of efficacy and safety are required prior to PGPR registration. Producers should not use PGPR unless the product is registered and approved to be a Biofertilizer or Bioprotectant in Canada. Currently there are no such products registered in Canada and only a handful in the United States.

Recent advances in molecular techniques also are encouraging in that tools are becoming available to determine the mechanism by which crop performance is improved using PGPR and track survival and activity of PGPR organisms in soil and roots. The science of PGPR is at the stage where genetically modified PGPR can be produced. PGPR with antibiotic, phytohormone and siderophore production can be made. However until GMO-PGPR is accepted by regulators in response to public will, such products will not be available commercially.

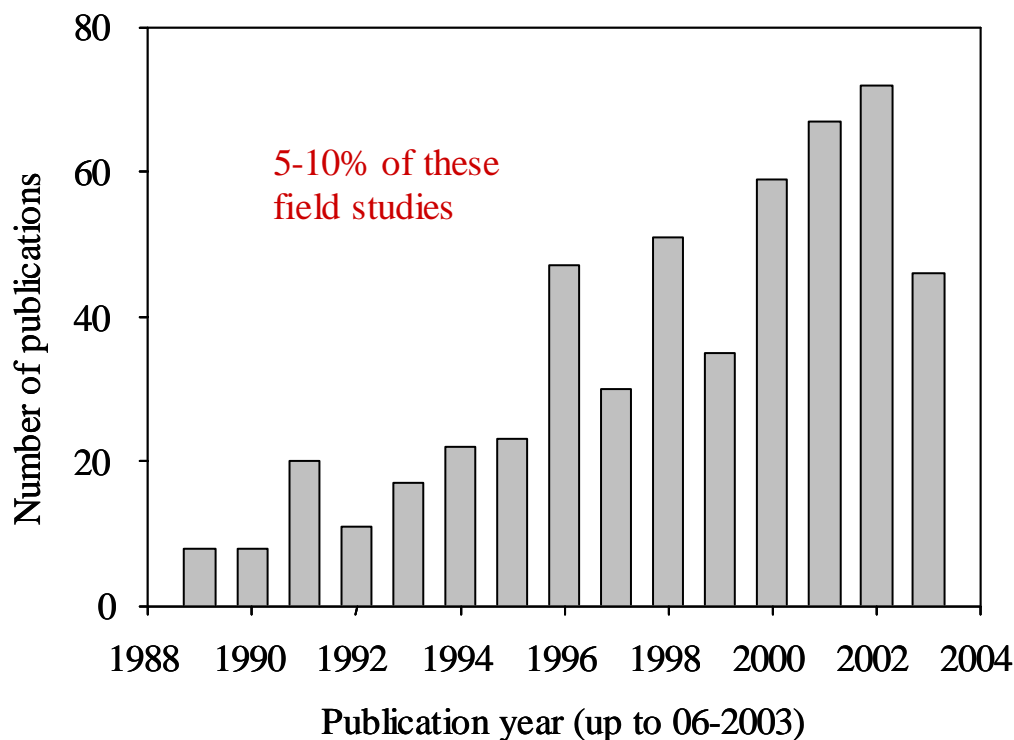


Figure 3. The steady growth in PGPR research activity evident as scientific publications (peer-reviewed articles). Results obtained by searching Biological Abstracts Database using the keyword “Plant Growth Promoting Bacteria”.

Final Comments

The agronomics of crop production is ever changing. Recent developments has invigorated research into commercialization of PGPR. These developments include the need for alternatives to soil fumigants to control soilborne plant pathogens. Current fumigants are being banned or restricted in use or are too

costly for annual crop producers. Biofertilizers are being explored as a means to reduce fertilizer costs, improve timing of nutrient availability and crop uptake to prevent contamination of water and air with nutrients. The organic crop production industry requires new means to protect crops and supply nutrients. As PGPR development is costly, commercialization will likely occur of products first in the United States and then product registration in Canada. High value crops such as fruits and vegetables are to be targeted for PGPR application as these producers may replace costly soil fumigants with as likely costly PGPR.

Further Readings:

Arshad, M. and Frankenberger, W.T. 1993. Microbial production of plant growth regulators. Pages 307-348. In: *In: Soil Microbial Ecology: Applications in Agricultural and Environmental Management* (ed. Metting, R.B.). Marcel Dekker, New York.

Canadian Food Inspection Agency regulations

Plant growth regulators

<http://www.inspection.gc.ca/english/plaveg/fereng/fereng-gene.shtml>

Microbial supplements

<http://www.inspection.gc.ca/english/plaveg/fereng/tmemo/t-4-94e.shtml> (last accessed Jan 24, 2004).

EPA Biopesticide Registration and Regulations (link to registered biopesticides)

http://www.epa.gov/pesticides/biopesticides/reg_of_biotech/eparegofbiotech.htm (last accessed Jan 24, 2004).

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Woeng, T., Lugtenberg, B. and Bloemberg, G. 2003. Mechanisms of biological control of phytopathogenic fungi by *Pseudomonas* spp. Pages 173-225. In: *Plant-Microbe Interactions Volume 6* (eds. Stacey, G. and Keen, N.T.). American Phytopathological Society, St. Paul, MN.

Zehnder, G.W., Murphy, J.F., Sikora, E.J. and Kloepper, J.W. 2001. Application of rhizobacteria for induced resistance. *European Journal of Plant Pathology* 107:39-50.