Research Journal of Fisheries and Hydrobiology, 6(4): 592-597, 2011
ISSN 1816-9112
This is a refereed journal and all articles are professionally screened and reviewed

ORIGINAL ARTICLES

Phosphate Solobilaizer Microorganism (PSM) and Sustainable Agriculture

Mohammad Yazdani and Hossein Bagheri

PhD student, Department of Agronomy, Tabriz Branch, Islamic Azad University, Tabriz, Iran

ABSTRACT

Sustainable agriculture is a way of raising food that is healthy for consumers and animals, does not harm the environment, is humane for workers, respects animals, provides a fair wage to the farmer, and supports and enhances rural communities. 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 commonly proposed that microorganisms may therefore play an important role in the development of integrated and sustainable production systems to improve P-use efficiency through use of specific inoculants. Phosphorus solubilization is carried out by a large number of saprophytic bacteria and fungi acting on sparingly soluble soil phosphates, mainly by chelation-mediated mechanisms. According to high amount of phosphorous in soil, using of phosphate, solubiling microorganisms (PSM) for solobilizng of consolable forms of P is necessary. The main mechanism of PSM, is production of organic acids by sugar oxidation. This process reduces pH and increase P solubilization. This paper aim is to review role of phosphate solobilaizer microorganism (PSM) in sustainable agriculture.

Key words: Sustainable Agriculture, Phosphate, PSM, Biofertilizars

Introduction

The prevailing agricultural system, variously called "conventional farming," "modern agriculture," or "industrial farming" has delivered tremendous gains in productivity and efficiency. Food production worldwide has risen in the past 50 years; the World Bank estimates that between 70 percent and 90 percent of the recent increases in food production is the results of conventional agriculture rather than greater acreage under cultivation (Filipovic *et al*, 2006). But, large quantities of chemical fertilizes are used to replenish soil P, resulting in high costs and severe environmental contamination (Dai *et al*, 2004). As a result, poor farmers have no easy access to chemical fertilizers. Additionally, a high mineral P input supports surface runoff, and P might be lost by soil erosion or leaching (Yomg *et al*, 2005), which is a waste of the limited P resources and results in eutrophication of rivers, lakes and natural habitats. As with many industrial practices, potential health hazards are often tied to farming practices (Clive *et al*, 1989; Mall *et al*, 2006). Under research and investigation currently is the sub-therapeutic use of antibiotics in animal production, and pesticide and nitrate contamination of water and food. Farmer worker health is also a consideration in all farming practices (Wu *et al*, 2005). Environmental protection and the need to enhance agricultural output have made research in new sustainable technologies necessary.

The term "sustainable agriculture" means an integrated system of plant and animal production practices having a site-specific application that will over the long-term: a; Satisfy human food and fiber needs. b; Enhance environmental quality and the natural resource base upon which the agriculture economy depends. c; Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls. d; Sustain the economic viability of farm operations. e; Enhance the quality of life for farmers and society as a whole. Therefore, the goal of sustainable agriculture is to minimize adverse impacts to the immediate and off-farm environments while providing a sustained level of production and profit (Elizabeth *et al*, 1995; Devi *et al*, 2007). Utilization of microorganisms to increase the availability of P in soil therefore is an attractive proposition for developing a more sustainable agriculture. Numerous reasons have been suggested for this, but none of them have been conclusively investigated. Despite the variations in their performance, PSM are widely applied in agronomic practices in order to increase the productivity of crops while maintaining the health of soils (Saghir Khan *et al*, 2007).

Corresponding Author: Mohammad Yazdani, Ph.D Student, Department of Agronomy, Tabriz Branch, Islamic Azad University, Tabriz, Iran.
E-mail:Yazdanisavadkoohi@yahoo.com

Role of Phosphorous in Plants:

Phosphorus is second only to nitrogen in mineral nutrients most commonly limiting the growth of terrestrial plants. Phosphorus is classified as a major nutrient, meaning that it is frequently deficient for crop production and is required by crops in relatively large amounts. Plants absorb P as orthophosphate ions (H_2PO_4 and HPO_4^{2}-) (Han *et al*, 2004; Shaharoona *et al*, 2006; Delvasto *et al*, 2008). Phosphorus plays a vital role in virtually every plant process that involves energy transfer. High-energy phosphate, held as a part of the chemical structures of adenosine diphosphate (ADP) and ATP, is the source of energy that drives the multitude of chemical reactions within the plant (Hayat *et al*, 2010). When ADP and ATP transfer the high-energy phosphate to other molecules (phosphorylation), the stage is set for many essential processes to occur. Phosphorus deficiency is more difficult to diagnose than a deficiency of nitrogen or potassium. Crops usually display no obvious symptoms of phosphorus deficiency, other than a general stunting of the plant during early growth, and by the time a visual deficiency is recognized it may be too late to correct in annual crops.

P is mobile in the plant, so P absorbed during early growth is later redirected for use in seed formation (Richardson *et al*, 2009). A good supply of P has been associated with increased root growth, which means the plant can explore more soil for nutrients and moisture (Han *et al*, 2004; Delvasto *et al*, 2008). Cereals, for example, rely heavily on the P taken up in the first 4 weeks of growth for crop establishment, tillering and final yield.

Phosphorous in Soil:

Although phosphorus is abundant in soils in both organic and inorganic forms, it is frequently a major or even the prime limiting factor for plant growth (Rodr guez and Fraga, 1999; Khan *et al*, 2009). The bioavailability of soil inorganic phosphorus in the rhizosphere varies considerably with plant species, nutritional status of soil and ambient soil conditions. Phosphorous is relatively immobile (moves very little) in the soil. Thus, it will not leach like nitrogen and sulphur or be carried to plant roots by soil water. Furthermore, P from phosphate fertilizer will readily react with soil minerals making it less plant available (Saghir *et al*, 2007; Karnataka, 2007). When granular phosphate fertilizer is added to moist soil, it quickly dissolves releasing orthophosphate ions to the soil solution. Most liquid P fertilizer is ammonium polyphosphate, which when added to soil reacts with water to form orthophosphate. Over time these ions react with calcium and other ions forming less plant available P compounds (Khan *et al*, 2009).

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). However phosphorus after application, a considerable amount of P is rapidly transformed into less available forms (up to 80 %) by forming a complex with Al or Fe in acid soils or Ca in calcareous soils before plant roots have had a chance to absorb it (Mkhabela and Warman, 2005; Zaidi *et al*, 2009).

P availability is dependent on several factors. 1; Soil texture: soils high in clay content fix more P than those with less clay. 2; Calcium carbonate content: more P is converted to the 'less available P compounds' in soils containing more calcium carbonate. 3; Soil temperature: low soil temperature will reduce P availability by slowing the movement of P from the soil to the root and by reducing the mineralization of organic matter to plant available P. 4; Soil moisture: P is more plant available with 'good' soil moisture. 5; Soil pH: P is most plant available between pH 6.5 and 7.0 6; Plant root type: plants with fibrous roots explore more soil volume in the 0 to 6 inch depth than tap roots and thus are better able to recover P. 7; Microorganisms: Soil micro-organisms can immobilize P while breaking down organic matter, making it temporarily unavailable. To circumvent phosphorus deficiency, phosphate-solubilizing microorganisms (PSM) could play an important role in supplying phosphate to plants in a more environmentally-friendly and sustainable manner.

The influence of PSM on crop growth in sustainable agriculture:

PSM as a biofertilizars:

Several studies have conclusively shown that PSM solubilizes the fixed soil P and applied phosphates, resulting in higher crop yields (Zaidi *et al*, 1999; Gull *et al*, 2004; Roesti *et al*, 2006; Steenhoudt and Vanderleyden, 2000; Violante and Portugal, 2007; Esitken *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 (Han *et al*, 2004; Orhan *et al*l, 2006; Wilhelm *et al*, 2007). Studied have conclusively shown that biofertilizer as PSM solubilizes the fixed soil P and applied phosphates (Wu *et al*, 2005). In addition, Significant amounts of P can be released from the microbial biomass in response to seasonal conditions when either C becomes limiting, soils undergo cycles of wetting and drying, or during processes of higher tropic-level predation (Zaied *et al*, 2003; Zahir *et al*, 2004; Zaidi *et al*, 2006; Anjum *et al*, 2007). Yazdani *et al* (2011) reported that application of PSM and PGPR together and reduce P application by 50% (N_{50}PK+PGPR$_{+}$PSM), increased nitrogen and potassium of grain and nitrogen, phosphorus and potassium uptake of corn leaf. In these experimental, grain yield, biological yield and harvest index increased compared to check significantly (Figure 1).

PSM have high potential as bio-fertilizers especially in P-deficient soils to enhance the growth and yield performance of crops (Miller *et al*, 2010; Awasth *et al*, 2011). Among the heterogeneous and naturally abundant microbes inhabiting the rhizosphere, the phosphate solubilising microorganisms including bacteria have provided an alternative biotechnological solution in sustainable agriculture to meet the P demands of plants. Other microorganisms form associations with plant roots which increase the surface area of roots and their access to P. These organisms in addition to providing P to plants also facilitate plant growth by other mechanisms. Inoculation of plants with this bacterium causes morphological changes (Kapulnik *et al*, 2007), such as an increase in root surface area through the production of more root hairs, which in turn enhance mineral uptake (Zaidi and Mohammad, 2006; Yazdani *et al*, 2012).

PSM and enhance plant growth:

Microorganisms play an integral and often unique role in the functioning of ecosystems and in maintaining a sustainable biosphere. There is evidence that certain bacteria are able to colonize the root-soil environments where they carry out a variety of interactive activities known to benefit plant growth and health, and also soil quality (Barea *et al*, 2005; Luz, 2003).The use of phosphate solubilizing microorganism as inoculants in soil increases the phosphorous uptake by the plants and also the crop yield (Richardson *et al*, 2009; Hayat *et al*, 2010). They can affect plant growth either directly or indirectly through various mechanisms of action. The ability of phosphate solubilizing bacteria to convert insoluble form of phosphorous into soluble one is an important trait in sustainable farming for increasing crops yield (Awasthi *et al*, 2011). PSM play an important role in enhancing phosphorous availability to plants by lowering soil pH and by microbial production of organic acids and mineralization of organic P by acid phosphatases. These organisms besides providing P also facilitate the growth of plants by improving the uptake of nutrients and stimulating the production of some phytohormones. There are various mechanisms by which microorganisms solubilize inorganic phosphate. It can be by secretion of organic acids or by production of siderophores (Vassilev *et al*, 2006). The secretion of phenolic compounds and humic substances is also reported (Patel *et al*, 2008). PSM solubilize phosphate by production of organic acids.

There are various heterotrophic microorganisms, which help in excretion of organic acids, they dissolve phosphatic minerals or chelate cationic partners of the phosphate ions i.e. $PO4^{-3}$ and directly release phosphorous into the soil (Khan *et al*, 2009). In soil, these organic acids reduce the pH of their surroundings (Goldstein, 1994). These acids can either dissolve the phosphorous directly by lowering the pH of soil, which can help in ion exchange of $PO4^{2-}$ by acid ions or they can chelate heavy metal ions such as Ca, Al and Fe and release associated phosphorous with them (Bardiya and Gaur, 1972; Moghimi *et al*, 1978). 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*, 2006). PSM culture contains millions of soil phosphate solubilising micro-organism per gram. These soil phosphate solubilising microorganisms stay near the roots and make the phosphorus available to plants from soil as well as fertilizers and increase the production significantly. Some rhizospheric bacteria also produce siderophores and there is evidence that a number of plant species can absorb bacterial Fe^{3+}siderophore complexes (Wang *et al*., 1990; Zaidi *et al*., 2006; Zahir *et al*., 2004). However, there is a controversy as the significance of bacterial Fe^{3+}siderophore uptake to the iron nutrition of plants (Vessey, 2003). P-solubilizing bacteria can supply plants with phosphorus from sources that are otherwise poorly available (Han *et al*, 2004; Wu *et al*, 2005).

Application of biological fertilizers such as biological phosphate fertilizers improves soil fertility. Several studies have conclusively shown that PSM solubilizes the fixed soil P and applied phosphates, resulting in higher crop growths (Roesti *et al*, 2006; Violante and Portugal, 2007; Esitken *et al*, 2006). Studied have conclusively shown that biofertilizer as PSM solubilizes the fixed soil P and applied phosphates (Wu *et al*, 2005; Turan *et al*, 2006; Saharan *et al*, 2011).

Direct application of phosphate rock is often ineffective in the short time period of most annual crops (Goenadi *et al*, 2000). Acid producing microorganisms are able to enhance the solubilization of phosphatic rock (Gyaneshwar *et al*, 2002). To circumvent phosphorus deficiency, phosphate-solubilizing micro organisms could play an important role in supplying phosphate to plants in a more environmentally-friendly and sustainable manner. The solubilization of phosphatic compounds by naturally abundant PSM is very common under in vitro conditions; the performance of PSM in situ has been contradictory.

Res. J. Fish & Hydrobiol., 6(4): 592-597, 2011

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

Although, high buffering capacity of soil reduces the effectiveness of PSM in releasing P from bound phosphates; however, enhancing microbial activity through P solubilizing inoculants may contribute considerably in plant P uptake. Research found that the main reason for the soil losing its fertility with slash and burn farming was that the rain was washing out phosphorus. A key requirement for successful deployment of inoculants is the development of appropriate formulation and delivery systems to ensure survival and effective establishment of target microorganisms within the rhizosphere. Poor competitive ability and lack of persistence of inoculants in soils is commonly considered to be an important factor that may restrict their effectiveness. High proportion of PSM is concentrated in the rhizosphere, and they are metabolically more active than from other sources.

Conclusion:

PSM have the various beneficial effects on the plants. These bacteria exert the direct or indirect effects on the plants. Direct effects include the increased solubilisation and uptake of nutrients or production of plant growth regulators while the indirect effects include suppression of pathogens and producing metal binding molecules, known as siderophores. We offer phosphate solubilizing microorganisms that are used and widely recommended for all crops. There are many types of micro-organisms present in soil out of which some microbes and fungi can solubilise the complex insoluble form of phosphorus into simple soluble forms that can be taken up by plants. Generally these micro-organisms are very few in soil. Current developments in our understanding of the functional diversity, rhizosphere colonizing ability, mode of actions and judicious application are likely to facilitate their use as reliable components in the management of sustainable agricultural systems. There is a need to explore PSM with greater efficiency and synergy with other microbes interacting with plants.

References

Awasthi, R., R. Tewari and H. Nayyar, 2011. Synergy between Plants and P-Solubilizing Microbes in soils: Effects on Growth and Physiology of Crops. International Research Journal of Microbiology, 2: 484-503.

Blanco, J.M. and P.M. Bakker, 2007. Interactions between plants and beneficial *Pseudomonas* spp: exploiting bacterial traits for crop protection. JournalAntonie van Leeuwenhoek, 4: 367-389.

Biswas, J.C., J.K. Ladha and F.B. Dazzo, 2000. Rhizobia inoculation improves nutrient uptake and growth of lowland rice. Soil Science Society of America Journal, 64: 1644-1650.

Clive, A., Edwards, Rattan Lal, Patrick Madden, Robert H. Miller and Gar House, 1989. editors, Sustainable Agricultural Systems (Soil and Water Conservation Society, 1989). Chapters 1-6 and Chapter 38.

Cherr, C.M., J.M.S. Scholberg and R. McSorley, 2006. Green manure approaches to crop production. Agronomy Journal, 98: 302-319.

Delvasto, P., A. Valverde, A. Ballester, J.A. Munoz, F. Gonzalez, M.L. Blazquez, J.M. Igual and C.G. Balboa, 2008. Diversity and activity of phosphate bioleaching bacteria from a high-phosphorus iron ore. Hydrometallurgy, 92: 124-129.

Devi, R., A. Kumar and B. Deboch, 2007. Organic farming and sustainable development in Ethiopia. Scientific Research, 2: 199-203.

Elizabeth Ann, R. Bird, Gordon L. Bultena and John C. Gardner, 1995. Planting the Future: Developing an Agriculture that Sustains Land and Community. Chapter 1, Part 1 and Chapter 2, Introduction.

Han, H.S.K. Supanjani and D. Lee, 2004. Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. Agronomy Journal, 24: 169-176.

Han, H.S., K. Supanjani and D. Lee, 2004. Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. Agronomy Journal, 24: 169-176.

Hayat, R.A.S., U. Amara, R. Khalid, I. Ahmed, 2010. Soil beneficial bacteria and their role in plant growth promotion: a review. Ann. Microbiol., 1-20.

Khan, A.A., G. Jilani, M.S. Akhtar, S.M.S. Naqvi, M. Rasheed, 2009. Phosphate solubilizing bacteria: occurrence, mechanism and their role in crop production. J. Agric. Biol. Sci., 1: 48-58.

Karnataka, J., 2007. Effect of integrated nutrient management on economics of Maize cultivation. Agriculture Science, 20: 831-832.

Kumar, V.K., 2001. Enriching vermicompost by nitrogen fixing and phosphate solubilizing bacteria. Bioresource Technology, 76: 173-175.

Mall, R.K., R. Singh, A. Gupta, G. Srinivasan and L.S. Rathore, 2006. Impact of climate change on Indian agriculture. Climatic Change, 78: 445-478.

Miller, S.H., P. Browne, C. Prigent-Combaret, E. Combes-Meynet, J.P. Morrissey, F. Ogara, 2010. Biochemical and genomic comparison of inorganic phosphate solubilization in *Pseudomonas* species. Environ Microbiology Reports, 2: 403-411.

Mkhabela, M.S. and P.R. Warman, 2005. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. Agriculture, Ecosystems and Environment, 106: 57-67.

Oliveira, C.A., M.C. Alves, I.E. Marriel, E.A. Gomes, M.R. Scotti, N.P. Carneiro, C.T. Guimaraes, R.E. Schaffert and N.M. Sa, 2008. Phosphate solubilizing microorganisms isolated from rhizosphere of maize cultivated in an oxisol of the brazilian Cerrado Biome. Soil Biology and Biochemistry, 3: 1-6.

Patel, D.K., G. Archana, G.N. Kumar, 2008. Variation in the nature of organic acid secretion and mineral phosphate solubilization by Citrobacter sp. DHRSS in the presence of diverent sugars. Curr. Microbiol., 56: 168-174.

Filipovic, D., S. Husnjak, S. Kosutic, Z. Gospodaric, 2006. Effects of tillage systems on compaction and crop yield of Albic Luvisol in Croatia. Journal of Terramechanics, 43: 177-189.

Rodr Guez, H. and R. Fraga, 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. Biotecnology Advances, 17: 319-339.

Richardson, A.E., P.J. Hocking, R.J. Simpson, T.S. George, 2009. Plant mechanisms to optimize access to soil phosphorus. Crop Pasture Science, 60: 124-143.

Saghir Khan, M., A. Zaidi and P.A. Wani, 2007. Role of phosphate-solubilizing microorganisms in sustainable agriculture - A review. Agronomy for Sustainable Development, 27: 29-43.

Shaharoona, B., M. Arshad, A. Zahir and K. Azeem, 2006. Performance of *Pseudomonas spp*. containing ACC-deaminase for improving growth and yield of maize (Zea mays L.) in the presence of nitrogenous fertilizer. Soil Biology and Biochemistry, 38: 2971-2975.

Sturz, A.V. and B.R. Christie, 2003. The management of soil quality and plant disease with rhizobacteria. Soil and Tillage Research, 72: 107-123.

Swedrzynska, D. and A. Sawicka, 2000. Effects of Inoculation with Azospirillum brasilense on develop- ment and yielding of maize under different cultivation conditions. Environmental Studies, 6: 506-509.

Turan, M., N. Ataoglu and F. Sahin, 2006. Evaluation of the capacity of phosphate solubilizing bacteria and fungi on different forms of phosphorus in liquid culture. Sustainable Agricultural., 28: 99-108.

Varvara, P., B. Grichko, R. Glick, 2001. Amelioration of flooding stress by ACC deaminase-containing plant growth-promoting bacteria. Plant Physiology Biochemical., 39: 11-17.

Wilhelm, J.M., F. Johnson, L. Karlen and T. David, 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. Agronomy Journal, 99: 1665-1667.

Wu, B., S.C. Cao, Z.H. Lib, Z.G. Cheung and K.C. Wong, 2005. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth. Geoderma, 125: 155-162.

Vassilev, A.M., M. Vassileva, 2006. Microbial solubilization of rock phosphate on media containing agro-industrial wastes and effect of the resulting products on plant growth and P uptake. Plant Soil, 287: 77-84.

Yazdani, M., H. Pirdashti, 2012. Co-inoculation effects of P- solubilizer (PSM) and plant growth promoting rhizobacteria (PGPR) on root and shoot growth in corn (*Zea mays* L.). 8^{th} International Soil Science Congress.

Yazdani, M., P. Rahdari, S. Motevalli, 2011. Effects of Organic Manure and Biological Fertilizers on Macronutrient Uptake of Corn (*Zea Mays* L.). Advances in Environmental Biology, 5: 3761-3767.

Yomg, K., B. Bae and Y. Choung, 2005. Optimization of biological phosphorus removal from contaminated sediments with phosphate- solubilizing microorganisms. Journal of Bioscience and Bioengineering, 99: 23-29.

Zaidi, A. and S. Mohammad, 2006. Co-inoculation effects of phosphate solubilizing micro-organismsand glomus fasciculatum on green gram-bradyrhizobium symbiosis. Agricultural Science, 30: 223-230.