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THE ROLE OF PHOSPHORUS SOLUBLIZING BACTERIA (PSB) IN SOIL MANAGEMENT-AN OVERVIEW

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ABSTRACT

Phosphorus is an essential element for plant growth and development. Because of its sparingly soluble nature it is present in very less proportion in the soil for plant uptake. Major proportions of soil-P remains interlocked in various insoluble forms and not available for plant use. To circumvent the P-deficiency, large amount of chemical P fertilizers are applied to attain reasonable crop yields. Indiscriminate use of P-fertilizers deteriorates the soil quality as well as cause negative impact in respect to both environment and economy. Consequently, it is important to search for sustainable strategies to alleviate the detrimental effects of chemical fertilizer on soil. Some bacterial species have a natural potential to solublize the phosphorus. The use of phosphorus solubilizing bacteria (PSBs) as an inoculant simultaneously enhances P availability to plants and crop yield. Present review emphasizes availability and dynamics of soil-phosphorus and the occurrence, mechanism and role of Phosphate solubilizing bacteria in sustainable management of soil by solubilization of fixed-phosphorus in relation to crop responses. This review exhaustively explores the potential of PSB to solublize phosphate by highlighting the current practices and future prospects of their utility in soil management.

INTRODUCTION

Phosphorus (P) is second only to nitrogen as most essential macro-nutrient required by plants (Srinivasan *et al*., 2012). It is a key nutrient for higher and sustained agriculture productivity (Scervino *et al*., 2011) which limiting plant growth in many soils. However, Phosphorus deficiency is the most common nutritional stress in many regions of the world, affecting 42% of the cultivated land over the world (Liu *et al*., 1994). Phosphorus, the master key element is known to be involved in a plethora of functions in the plant growth and metabolism (Mahdi *et al*., 2011). It's deficiency results in the leaves turning brown accompanied by small leaves, weak stem and slow development (Mahantesh and Patil, 2011), which result in low yielding of crops (Khan *et al*., 2013). Therefore the scarcity of Phosphorus as fertilizer and the consequences of climate change can dramatically influence the food security of future generations (Mäder *et al*., 2011). Hence with increasing demand of agricultural production, phosphorus (P) is receiving more attention as a non-renewable resource. Because it is the least mobile element in plants and soil contrary to other macronutrients (Sharma *et al*., 2011). Plants take P in soluble form but soil P is present as insoluble phosphate form thereby not utilized by plants. So that the maintenance of high levels of soil phosphorus has been a major challenge to agricultural scientists, ecologists and farm managers. Even in phosphorus rich soils, due to insolubility, only a small proportion (~0. 1%) is available to plants (Madhi *et al*., 2011). Consequently, Since the sixties large amount of chemical P-fertilizers are used to overcome such limitation and sustain high yielding agro-ecosystems. But almost 75 to 90% of added P fertilizer is precipitated by iron, aluminum and calcium complexes present in the soils (Turan *et al*., 2006) and is virtually unavailable to most plant species when applied to P deficient soil. Mined phosphate rocks that are used for phosphate fertilizer manufacturing are also a finite resource (Dawson and Hilton, 2011). Moreover, imbalanced nutrient management has caused soil P to become an environmental rather than an agronomic problem in developed countries (Delgadol and Scalenghe, 2008). As the production and manufacture cost of the chemical fertilizer are very high and its availability and uses are also becoming imperative. Hence, new options are needed to better exploit soil P resources

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through either the selection of efficient cultivars or using alternative strategies of management of soil and agro-ecosystems to optimize P bioavailability. In this context, the reduced use of chemical fertilizers with the increased application of bio-fertilizers is considered a compulsory route to alleviate the pressure on the soil and environment derived from agricultural practices (Malus, 2012). Microorganisms are integral to the soil phosphorus (P) cycle and play an important role in mediating the availability of P to plants (Kannapiran *et al*., 2011). Particularly, phosphate-solubilizing micro-organisms are able to solubilize unavailable soil P and enhance the yield of crops (Adesemoye and Kloepper, 2009).

Microorganisms, especially the use of such phosphate solublizing bacteria (PSB) as inoculants simultaneously increases P uptake by the plant and therefore can be used as bio fertilizer (Nico *et al*., 2011). PSBs have a high potential to be used for the management of phosphorus in P deficient soils as well as disease suppression (Panhwar *et al*., 2012). Therefore, their use as inoculant or control agents for agricultural improvement has been a focus of numerous researchers for a number of years (Rodriguez *et al*., 2006). A large number of literatures are available regarding the Phosphorus, microbial interaction and beneficial uses in agriculture. 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 soil management . Moreover, the soil quality is being threatened by indiscriminate and uncontrolled use of P fertilizers. Hence, the use of PSB emerged as an economically sound innovative alternative option to traditional chemical P fertilizers. Keeping this in view, attention is paid to understanding the fundamental of some important information regarding the phosphorus related issues, Phosphorus solubilizing bacteria and their application for the development of sustainable technology for soil management has been reviewed here.

phosphorus availability and dynamics in soil

The ability to predict long-term plant-availability of soil Phosphorus provides an additional management tool for sustainable agriculture and soil management .Phosphorus availability in soils can be one of the major factors limiting growth for both natural ecosystems and agricultural systems. It is present at levels of 400–1200 $mg \cdot kg^{-1}$of soil. However, 95-99 % soil Phosphorus is present in insoluble Phosphate form and hence cannot be utilized by the plants (Sridevi *et al*., 2013). Even though some soils may have high levels of total P, they can still be P-deficient due to low levels of soluble phosphate available to plants (Gyaneshwar *et al*., 2002). Therefore in both natural and agricultural ecosystems, the quantity of P available for plant uptake is generally low due to the low solubility of P compounds present in soils. Because much of the total soil phosphorus is unavailable for immediate plant consumption, many investigations have been conducted to quantify the relationship between unavailable and available soil Phosphorus. Soil phosphorus is mainly in two form inorganic and organic phosphorus (Richardson and Simpson, 2011). The proportion of different phosphorus fractions differs significantly because of soil type, soil use and management strategies (Li *et al*., 2007). These phosphorus forms differ in their behaviour and fate in soils. Inorganic phosphorus (Pi) usually accounts for 35% to 70% and Organic P 15-80% of the total phosphorus in soils. Organic P in soil is mainly exists in stabilizing forms as inositol phosphates (soil phytate), phosphonates, and active forms as orthophosphate diesters, labile orthophosphate monoesters, and organic polyphosphates (Condron *et al*., 2005). One unique characteristic of phosphorus is its low availability due to slow diffusion and high fixation in soils. The phenomenon of fixation and precipitation is generally highly dependent on pH and soil type (Mahatesh and Patil, 2011). Thus, in acid soils, P can be dominantly adsorbed by Fe/Al oxides by forming various complexes (Mohammadi , 2012). While in alkaline soils it is fixed by calcium (Oliveira *et al*., 2009). Therefore, efficiency of P solubilization rarely exceeding10–20% (Kuhad *et al*., 2011). Hence, a holistic understanding of P dynamics from soil to plant is necessary for optimizing P management and improving P-use efficiency, aiming at reducing consumption of chemical P fertilizer, maximizing exploitation of the biological potential of root/rhizosphere processes for efficient mobilization, and acquisition of soil P by plants .Therefore, the availability of soil P is extremely complex and needs to be systemically evaluated because it is highly associated with P dynamics and transformation among various P pools.

Strategies for Improving Phosphorus Efficiency in the Soil

Use of Phosphate fertilizer in Soil

Due to the poor mobility and concentration of plant-available P in soils, soil phosphate deficiency occurs, which has been traditionally overcome by adding P-fertilizers. But a small part of which is utilized by the plant and the remainder converted into fixed and insoluble forms of phosphorus. In most of the soil up to 85% of applied phosphate fertilizer may become unavailable to the plant because of mineral phase precipitation (Rodríguez and Fraga, 1999). Hence the efficiency of P-fertilizer is only 25-30% (Madhi *et al*., 2011). Despite being the fact that the P fertilizer application increases P only from 2.65% to 5.78% (Yang *et al*., 2012), Phosphorus is world's second largest agricultural Chemical (Hameeda *et al*., 2008). Increasing environmental concerns, especially in many industrialized countries where soils have developed high P levels resulting from many years of over-fertilization with phosphorus (FAO, 2003), showed the substantial losses of applied P through leaching via macro-pore water flow.

As a result, excessively applied fertilizer P easily enters the surface water and leads to water eutrophication (Vadas *et al*., 2009). The excessive and injudicious applications of the P-fertilizers leads to a severe threat to microbial diversity, soil microbial community structure, soil fertility and consequently deteriorates soil quality. Therefore, the balancing of fertilization is essential for the reduction of product cost and the protection of the environment. The further increasing of use of P fertilizer to augment the crop production in a context of increasing world food demand is no longer an option. Further in order to ensure the sustainability of agro-ecosystem, new options are needed to better exploit soil P resources through either the selection of efficient micro-organisms as an alternative strategy of management of soil to optimize P bioavailability and to ameliorate the adverse effect of P fertilizers. Moreover, the best management practices (BMPs) are required to optimize P fertilization to meet the demands of crop production with minimal environmental impacts.

Strategy for sustainable development

Using of Phosphorus solubilizing bacteria (PSB) in soil

Improving phosphorus nutrition is an urgent priority to meet the increasing global demand for food. So the focus is placed on the use of soil microorganisms endowed with the phosphorus solublizing ability, which could be used as inoculants to mobilize P from poorly available sources in soil. The literature reveals that a large number of autotrophic and heterotrophic soil micro-organisms demonstrate the in-vitro ability to solubilize mineral phosphorus and play a key role in the mobilization of soil P in plant-available forms. Phosphorus-solubilizing fungi (PSF) and bacteria are known as effective organisms for phosphorus solubilization. In soil, phosphorus -subilizing bacteria (PSB) constitute 1–50% and fungi 0.5–0.1% of the total respective population (Chen *et al*., 2006). The use of such PSB(s) opens up a new horizon for better plant productivity besides reducing the reliance on chemical P and protecting the agro-ecosystems from the hazards of agro chemicals. Therefore the protection of the soil environment by applying PSB(s) could become a major breakthrough for plants grown in derelict soils.

Moreover, the molecular engineering of these microbes has also provided a new insight into the promotion of crops in P-deficient soils (Kumar *et al*., 2010). PSBs are present in almost all the soils, although their number varies depending upon the soil and climatic conditions. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non-rhizosphere soil (Kundu *et al*., 2009). P-solubilizing ability of PSBs is affected by many physiological factors. Hence different bacterial species solubilize phosphorus at different extent. The prominent genera involved in mineral phosphate solubilization are shown in Table 1. These bacteria can play an important role in plant nutrition through an increase in phosphorus uptake by plants (Rodriguez *et al*., 2006). These bacteria are vital for sustainable agriculture in order to promote the growth and yield of plants and circulation of plant nutrients thereby, reducing the need for chemical fertilizers. Hence these bacteria could be a promising source for plant growth promoting agent in agriculture and can be used to ameliorate the soil health.

Table 1. List of Phosphorus solubilizing Bacterial in soil

Genera	Species	% contribution
Bacillus	*Bacillus amyloliquefaciens, B. licheniformis B. polymyxa, B. megaterium B. pulvifaciens, B. circulans B. subtilis, B. atrophaeus*	21.95 %
Enterobacter	*Enterobacter intermedium, E. aerogenes E. tayloraer, E. asburiae*	*8.6 %*
Pseudomonas	*Pseudomonas fluorescens, P. Putida, P. mendocina P. striata, P. Rathonis, P. aeruginosa*	24.39 %
Rhizobium	*Rhizobium meliloti, R . leguminosarum, R. loti*	-----

Mechnasims of phosphorus solubilization

Microorganisms and their interactions in soil play a critical role in mediating the distribution of P between the available pool in soil solution and the total soil P through solubilization, mineralization and immobilization reactions of sparingly available forms of inorganic and organic soil P. As a general sketch of P solubilization in soil is shown in (Figure 1). Principal mechanism for phosphate solublizing includes following:

- Production of organic acids (Hu *et al*., 2009)
- Production of acid phosphatase. (Turner and Haygarth, 2005)

Production of organic acids

A key mechanism for mineralization of Phosphates in soil is through microbial secretion of low molecular weight organic acids. The phosphate solublizing bacteria (PSB) have ability to reduce the pH of the surroundings by the production of organic acids (Chen *et al*., 2006). These organic acids can either dissolve phosphates as a result of anion exchange or can chelate Ca, Fe or Al ions associated with the phosphates (Gyaneshwar *et al*., 2002). However, soil microorganisms vary considerably in their ability to secrete organic acids and, thereby, solubilize mineral phosphates at different extent.

Production of acid Phosphatase

The mineralization of phosphorus compound is carried out by the action of several phosphates (also called phosphor hydrolase), which is present in a wide variety of soil microorganism and play a significant role in assimilation of phosphate from organic compounds by plants and microorganisms (Sharma *et al*., 2011). It involve the hydrolysis of phosphoester or phosphor anhydride bonds.

Effect of PSB on Crop Production

The microorganisms have enormous potential in providing soil P for plant growth. Use of PSMs can increase crop yields up to 70 percent (Mohammadi, 2012**)**. The phosphate-solubilizing bacteria as inoculants simultaneously increases P uptake by the plant and crop yield. The PSB exhibiting multiple plant growth promoting traits on soil- plant system is needed to uncover their efficacy as effective bio inoculants. The inoculation of PSB and plant growth-promoting rhizobacteria (PGPR) together could reduce 50% of P fertilizer application without any significant decrease of crop yield (Sharma *et al*., 2011). Combined inoculation of *arbuscular mycorrhiza* and PSBs give better uptake of both native P from the soil and P coming from the phosphatic rock and enhance plant growth by solublizing P from different fractions of soil (Ahmed *et al.,* 2008). The PSBs are able to synthesize phyto hormones like Indole acetic acid (IAA), Gibberellic acid (GA3) (Ramkumar and Kannapiran, 2011) and siderophore (Babna *et al*., 2013). PSBs are also enhances plant growth by increasing the efficiency of biological nitrogen fixation or enhancing the availability of other trace elements such as iron, zinc, etc. (Ponmurugan and Gopi, 2006).

These Bacteria enhance the growth and grain yield of different plants as reported in *Zea mays* (Yasmin *et al*., 2012) and wheat (Afzal *et al*., 2005*)*. Moreover, PSB and NPK had a positive effect on germination and seed quality of some plants like radish that directly improved vigour index (Lamo *et al*., 2012). The effect of phosphate-solubilizing microorganisms is also known on growth of medicinal plants and their biosynthesis of

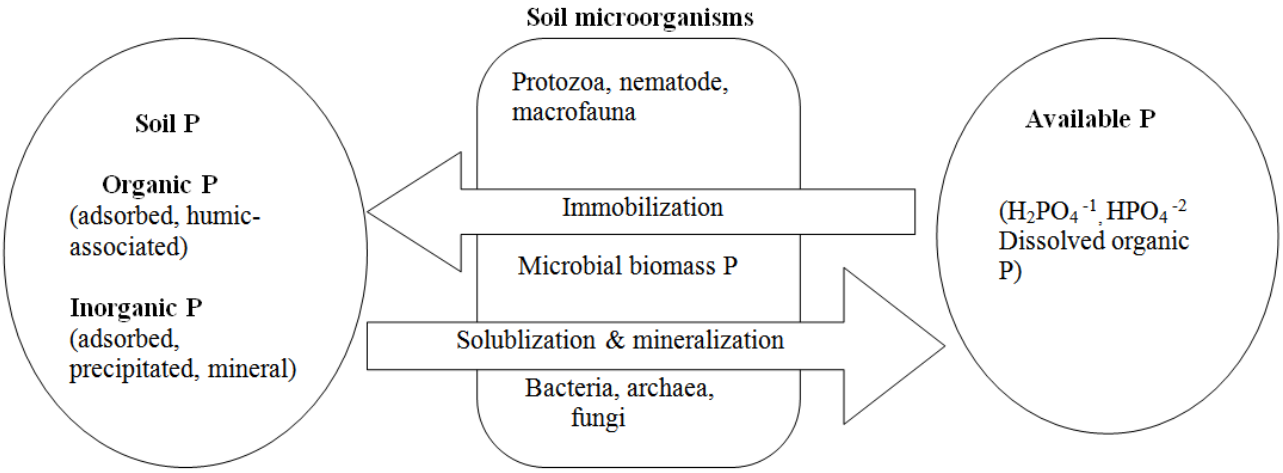

Figure 1. Schematic representation of the importance of microorganisms to Phosphorus Availability in soil

specific drugs (Gupta *et al*., 2012). Field experiments revealed that P-solubilizing bacteria (PSB) not only improved the growth, yield and quality of crops but also drastically reduced (1/3-1/2) the usage of chemical or organic fertilizers (Yasmin and Bano, 2011). The application of these inoculants by different methods can be positive to enhance the efficiency of naturally and synthetically produced P resources and thus, optimize the crop production.

Future prospectus

PSBs are an integral component of soil microbial community and play an important role in P cycle in soil rendering the unavailable P to plants. These have enormous potential for making use of fixed P in the soil particularly in soils with low P availability. However, despite considerable promise microbial products for P mobilization have not had major application to broad-acre farming systems. Because phosphate solubilization by bacteria is a complex phenomenon affected by many factors, such as PSB used, nutritional status of soil and environmental factors. The success of bacterization program ultimately depends on aspects such as cost effective ratio, widespread applicability of specific strain, development of practical delivery systems and sustained positive results. Although potential clearly exists for developing such inoculants, but their widespread application remains limited by a poor understanding of microbial ecology and population dynamics in soil, and by inconsistent performance over a range of environments. Hence the formulation of PSB inoculation with a reliable and consistent effect, under field conditions is still a bottleneck for their wider use.

Therefore, more research is needed to explore the impact of PSB in affecting the various physiological, biochemical and molecular events governing the stimulation of growth by these microbes in the plants. Hence, it needs further studies to understand the characteristics and mechanisms of phosphate solubilization by PSB. To conclude, the efforts should be made to identify, screen and characterize more PSB for their ultimate application under field conditions. So that, the successful implementation of PSB to better exploit soil P resources can be an alternative sustainable strategy for management of soil to optimize P bioavailability. The use of PSB has considerable promise for the future as a best management practice (BMP) for soil to optimize P fertilization to meet the demands of crop production with minimal soil impacts. The use of PSB as an inoculants becomes important to the sustainable management of soil and likewise contributes to environmental and economic stability.

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