Role of Phosphate Solubilizing Bacteria in Crop Growth and Disease Management

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Plant growth promoting rhizobacteria (PGPR) are the living micro-organisms which colonize the rhizosphere or the interior of the plant or promotes growth by increasing the supply or availability of primary nutrients to the host plant when applied to the seed, plant surface, or soil. Bacteria having growth promoting property in plants through the control of deleterious organisms have been categorized as biopesticides and are different from biofertlizers. However, some PGPR promote growth of plants by acting both as biofertilizer and biopesticides. PGPR can be Rhizospheric or Endophytic in nature depending upon their relationship with their hosts. The solubilization of 'P' in the rhizosphere is the most common mode of action that increases nutrient availability to host plants. Insoluble inorganic 'P' associated with the solid phase can be adsorbed to the surface of soil constituents which occur as Ca, Fe or Al minerals. Mineral 'P' is further released and made available to plant mostly by the action of phosphate solubilizing micro-organisms.

Key words: Rhizobacteria, Phosphatase, PGPR, Disease management.

Phosphorus (P) is one of the major nutrients to plants as well as microorganisms second only to nitrogen in requirement. It is involved in several physiological processes; however, approximately 95–99% of phosphorus is present in the soil as insoluble phosphates and hence cannot be utilized by the plants[1]. Organic phosphorus constitutes a large proportion of the total phosphorus in several soils. Inositol phosphate (soil phytate) is the major form of organic phosphorus in soil, and other organic P compounds in soil are in the form of phosphomonoesters, phosphodiesters including phospholipids, nucleic acids and phosphotriesters. Plants can only utilize P in inorganic form. Mineralization of most organic phosphorus compound is carried out by means of phosphatase enzymes. The major source of phosphatase activity in soil is considered to be of the microbial origin. To increase the availability of phosphorus for plants, now a day's large numbers of bacteria known as 'Phosphate Solubilizing Bacteria' are used for the conversion of soil organic phosphorus in to the soluble inorganic forms[2,3]. Some phosphate solubilizing bacteria can also accumulate heavy metals and are thus beneficial in eradicating heavy metal Phytotoxicity and promoting growth in plants[4].

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One of the major elements is phosphorous, largely used in membranes, cell division, nucleic acids and high energy compounds. Its deficiency is second in importance next only to nitrogen, and is likely to effect the development of roots. Leaves tend to be undersized, erect and somewhat necrotic as well as relatively few lateral buds are formed. Foliage may be red or of purple tinge. Phosphate and potassium generally have the tendency to decrease susceptibility. Effects of P on some important disease have been summarized by Patil[5] and Huber[6]. According to them, diseases such as damping-off of pea (*Rhizoctonia solani*), downy mildews of cabbage and grapes, flag smut of wheat (*Urocystic tritici*), root rot of tobacco (*Thielaviopsis basicola*), root rot of soyabean (*R. solani*), and take-all of wheat (*Ophiobolus graminis*) decrease as a result of phosphate application.

In this review we focused on the acquisition of nutrients from soil by plants roots with the help of PSB that influence the availability and uptake of P with specific emphasis on their role in disease management.

Phosphate solubilizing microorganisms (PSMs)

Many soil and rhizospheric microorganisms have the ability to release phosphate from sparingly soluble mineral phosphates found in soils and are important in providing soil phosphates to plants[7]. Insoluble inorganic 'P' associated with the solid phase can be adsorbed to the surface of soil constituents which occur as Ca, Fe or Al minerals. Mineral P is further released and made available to plant mostly by the action of phosphate solubilizing microorganisms[8]. The addition of rock phosphate significantly increased N, P and total plant biomass by arbuscular mycorrhizal infection[9].

Phosphate solubilizing bacteria (PSB)

Phosphorus is the second most important nutrient after nitrogen for the growth of plants and microorganisms. Out of added phosphorus fertilizer only 10-20% is available for the plants. The rest remains in the soil as insoluble phosphate in the form of rock phosphate and tri-calcium phosphate. Phosphate solubilizing Bacteria (PSB) significantly helps in the release of this insoluble inorganic phosphate and makes it available to the plants. PSB are a group of beneficial bacteria capable of hydrolysing organic and inorganic phosphorus from insoluble compounds. P-solubilization ability of the microorganisms is considered to be one of the most important traits associated with plant phosphate nutrition. It is generally accepted that the mechanism of mineral phosphate solubilization by PSB strains is associated with the release of low molecular weight organic acids through which their hydroxyl and carboxyl groups chelate the cations bound to phosphate, thereby converting it into soluble forms. In addition, some PSB produce phosphatase like phytase that hydrolyse organic forms of phosphate compounds efficiently. One or both types of PSB have been introduced to agricultural community as phosphate 'Biofertilizer'. Some important organic phosphate solubilizing bacterial genera which were reported as plant growth promoter are listed in Table1.

Table 1. Some important bacterial genera which are reported as phosphate solubilizer

PSB	Reference	PSB	Reference
Actinomycetes	[82]	*Enterobactor*	[90, 87]
Agrobacterium	[83]	*Klebsiella*	[91]
Arthrobacter	[84]	*Micrococcus*	[92]
Azospirillum	[85]	*Mycobacterium*	[93]
Azotobacter	[86]	*Proteus*	[94]
Bacillus	[71]	*Pseudomonas*	[95, 112]
Bradirhizobium	[87]	*Serratia*	[94]
Burkholderia	[88, 87]	*Staphylococcus*	[92]
Citrobactor	[89]	*Xanthomonas*	[96]

Earlier studies have shown that soil inoculation with phosphate solubilizing bacteria (PSB) improves solubilization of fixed soil P and applied phosphates resulting in higher crop yields. PSB are naturally found in majority of soils[10,11], however, their activity is severely influenced by the environmental factors especially under stress conditions[12].

Phosphatic fertilizers with available P_2O_5 when added to the soil, form tricalcium phosphate (TCP) in calcareous and alkaline soils, and ferrous phosphate (FP) or ferric hydroxyl phosphate or aluminium phosphate (AP) in acidic soil[13]. The role of microorganisms in solubilizing insoluble phosphates and making it available to the plants is well known[14]. Phosphate solubilizing microorganisms (PSM) includes bacteria as well as fungi. Among bacteria most efficient phosphate solubilizers belong to genera *Bacillus* and *Pseudomonas*. Cultures isolated from rhizospheric and non-rhizospheric soils solubilize phosphate with a fall in pH due to the production of organic acids but no correlation could be established between acidic pH and quantity of P_2O_5 liberated. Rise in pH observed later, may be due to organic acid produced by the organisms[15].

Phosphate solubilization activity was also found in symbiotic nitrogenous bacteria[16]. However, it was shown that 'P' solubilizing activity of microorganisms is affected by the presence of soluble phosphate in medium. Goldstein and Liu have shown that mineral phosphate solubilizing activity is generally coded in a gene cluster on plasmids of microorganisms. They also transferred this gene cluster to *E. coli* strain that had not shown 'P' solubilizing activity before and could demonstrate the transferred gene expression in the transgenic *E. coli* strain[17]. Furthermore, the gene expression and mineral phosphate solubilizing activity of bacteria was affected by the presence of soluble phosphate in medium (feedback regulator). Regulation of the 'P'-solubilizing activity by the presence of soluble phosphates in medium was also shown in other organisms. Chhonkar and Subba-Rao determined the 'P' solubilizing activity of different fungi in medium containing soluble KH_2PO_4. Although the fungi showed a high 'P' solubilizing activity in medium without soluble phosphate, it was completely inhibited in medium containing soluble phosphate[18].

There are several potential mechanisms reported for phosphate solubilization that include modification of pH by secretion of organic acids and protons or cation dissociation[19-21]. *A. halopraeferans*, a non glucose utilizing bacteria does not exhibit acidity in the presence of glucose[22]. Acid production is not the only reason for P release into the media[2,23,24] and this can be related to the cation dissociation processes[25]. A study on the molecular mechanisms would throw light on the ps (phosphate solubilizing) genes that could be incorporated sustainable agriculture. *A. halopraeferans* offers traits for nitrogen fixation, phosphate solubilization and salinity tolerance[26]. Living plants can utilize only soluble inorganic phosphorus. The transformation of mineral or organic phosphorus into soluble inorganic form is brought about by microbial action. Plants utilize this available phosphorus and transform it into organic form (Fig.1).

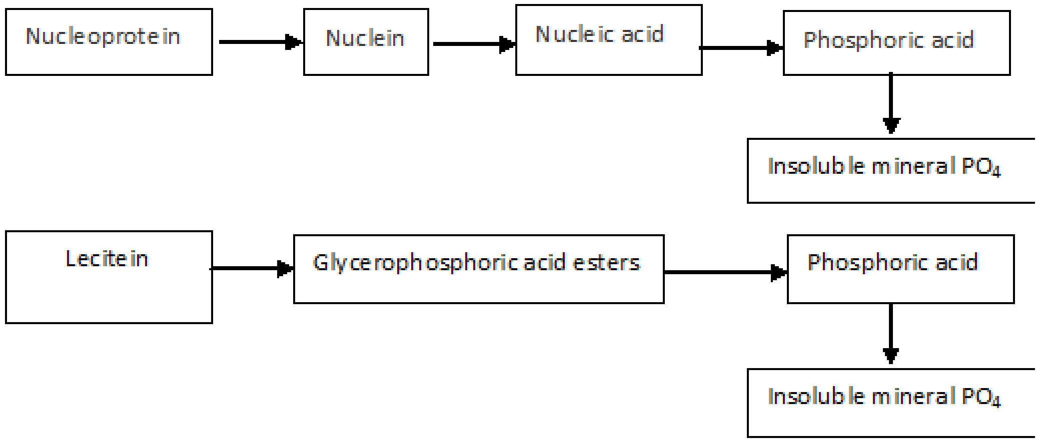
The last two decades have seen a significantly increased knowledge on phosphate solubilizing microorganisms. The metabolic activities of microorganisms (production of acids) solubilize phosphate from insoluble calcium, iron and aluminium phosphates, in addition to it microbial degradation of organic compounds like nucleic acids which releases phosphates. These biochemical changes that take place in the soil prove that microorganisms perform numerous essential functions that contribute to the productivity of soil.

Conversion of organic phosphate in to insoluble inorganic phosphate

Many soil microorganisms produce enzymes (phosphatases) that decompose different organic phosphorus compounds (nucleoproteins and leciteins) in the soil. In this decomposition organic phosphorus is converted into phosphoric acid which combines with the soil bases to produce salts of calcium, magnesium and iron. These salts are less soluble and thus less available to the plants. This mineralization takes place as under:

Conversion of insoluble inorganic phosphates into soluble inorganic phosphates

The solubility of phosphorus is mobilized by phosphoric acids. This is brought by microorganisms such as *Pseudomonas, Mycobacterium*, *Micrococcus* etc. These



microorganisms produce acids like sulphuric acid and nitric acid which ultimately help in mobilizing phosphorus. The process of conversion of insoluble phosphates into soluble once is generally known as 'solubilization'.

Isolation and evaluation of phosphate solubilising bacteria

The insoluble calcium phosphate constitutes a major portion of insoluble phosphate in the soil[27]. Tricalcium phosphate (TCP) is considered as a model compound for measuring the potential or relative rates of microbial solubilisation of insoluble inorganic phosphate compounds. Solubilization of precipitated TCP in unbuffered solid agar medium plates has been used widely as the initial criterion for the isolation of phosphate solubilising microorganisms[28]. Microorganisms on precipitated calcium phosphate agar produces clear zones around their colonies if they are capable of solubilizing calcium phosphate (Fig. 2).

From serially diluted rhizosphere soil suspension, suitable dilutions (10^{-4}) are poured and plated on Pikovskaya's Agar Medium comprising glucose (10g), $Ca_3(PO_4)_2$ (5g), $(NH_4)_2SO_4$ (0.5g), KCl (0.2g), $MgSO_4$ (0.1g), $MnSO_4$ (traces), $FeSO_4$ (traces), Yeast Extract (0.5g), Agar (15g), Distilled water (1L), pH (7.0). The plates are then incubated at 30±5ºC for 48–96 h. Phosphate solubilisation is indicated by the formation of a clear zone around the bacterial colonies. Single bacterial colonies having a clear solubilisation zones are isolated separately on to fresh Pikovskaya's agar plates and incubated at 30±5ºC for 10 days. An analysis of the MPS trait is made by measuring the zone of solubilisation around the growing colonies. The solubilisation efficiency (E) of these isolates is calculated using the following formula:

Solubilisation efficiency (E) = Solubilisation diameter (S)/Growth diameter (G) X 100

The release of soluble P from TCP can be determined by the method described by Jackson[29].

Role of PSB in plant growth

Phosphates, widely distributed in nature in both organic and inorganic forms, are not readily available to plants in a bound state[30]. Bacteria are widely distributed in the rhizosphere of tropical and subtropical grasses and sugarcane[31]. Many soil bacteria are reported to solubilize these insoluble phosphates through various processes[21, 22]. A few reports have also indicated the P-solubilizing activity of some nitrogen fixers[32-34].

Many soil bacteria such as *Pseudomonas, Rhizobium, Enterobactor, Bacillus* etc possess the ability to solubilize insoluble inorganic phosphates and make them available to the plants[35]. Production of organic acids i.e. lactic, gluconic, fumeric, succinic & acetic acid by these organisms results in the solubilizing effect. These organisms are also known to produce amino acids, vitamins and growth promoting substances like Indole Acetic Acid (IAA) and Gibberellic Acid (GA), which results in better growth of plants.

Addition of these phosphate solubilizing organisms saves almost fifty per cent of phosphorus fertilizers applied to the fields. Besides, it also optimizes the intake of phosphorus by the plants. Consequently, the growth and yield of a wide variety of crops increases by 10-20%. Crops like paddy, maize, mustard, barley, oats, chick-pea, groundnut, soybean and vegetables are some of the important examples.

Azotobacter

Azotobacter, a free-living bacterium, fixes atmospheric nitrogen and has been used as a very effective bio-fertilizer for several non-leguminous crops including fruits, vegetables and medicinal plants. *Azotobacter* has the ability to produce growth-promoting substances such as IAA, GA, vitamins and cytokinins, which have a beneficial effect on crop growth. *Azotobacter* is also used for Wheat, Paddy, Maize, Barley, Jowar, Oat, Sugarcane, Sugarbeet, Cotton, Tobacco, Sunflower, Mustard, Potato, Brinjal, Onion, Cauliflower, Tomato, Cabbage, Fruits, Vegetables, flowering plants and medicinal plants[36].

Rhizobium

Rhizobium is an efficient plant rhizosphere colonizing bacteria which reside in the vicinity of roots and benefit the plants through their growth promoting excretions as well as bio-static properties. It produces growth-promoting substances that help plants in the optimal uptake of nutrients and thus helps them grow efficiently. The presence of *Rhizobium* in soil is also helpful in controlling many seed-borne, air-borne and soil-borne diseases caused by bacteria and fungus. *Rhizobium* is suitable for a wide range of crops including pulses, cereals, cash crops, medicinal crops, fodder crops, oil crops, fruits and vegetable crops[36].

Pseudomonas

These bacteria are widely distributed in soil and water. Some *Pseudomonas* spp. are reported as P solubilizer which solubilize the organic phosphate compounds and play an important role in plant growth promotion e.g. *Pseudomonas fluorescens*[37], *P. putida*[38] etc. *Pseudomonas spp.* is reported to suppress several major plant pathogens as well.

Azospirillum

Azospirillum is an important micro-organism which fixes atmospheric nitrogen as an associate symbiotic nitrogen fixing bacterium. It secretes growth-promoting substances like Garlic acid and cytokinins which enhance tillering, growth and vigour of the plants. *Azospirillum* is known for its N_2 fixing ability at a higher pace than other micro-organisms. *Azospirillum* is also used for non-leguminous crops. It has been found to be extremely beneficial for wheat, paddy, maize, bajra, sugarcane, vegetables and medicinal plants[39].

Interaction of phosphate solubilizing microorganisms and plants

In general, two phenomena take place in soil that makes phosphorus the least available element to plants. One of them is immobilization which is carried out by those microorganisms that populate the mineral deficient regions and require performing their vital processes[40]. The other one is precipitation or fixation to insoluble complex minerals which is due to the union of phosphorus with elements such as iron and aluminum in acid soils, and calcium in alkaline soils. This denies the plant up to 75% of all soluble P and thus, generates a 0.002-0.5% concentration of the mineral in the soil[41]. This has forced many crop growers to apply up to four times the required amount of phosphorous to the crop. In case of sugarcane, this figure falls between 40 and 200 kg of phosphorous per hectare. This procedure not only generates an increase in the application of chemical fertilizers but also increases the production costs. Production and application of bio-preparations could therefore improve the availability of soluble phosphorus which would cause a decrease in the use of phosphate fertilizers. This will have a positive effect on the environment besides the cost economy[42].

Low organic matter coupled with low native soil phosphorus (P) concentrations is a major constraint limiting the productivity of soybean-wheat system on Vertisols in the Indian semi-arid tropics. Phosphorus promotes N_2 fixation in legume crops and is vital for photosynthesis, energy transfer and formation of sugars[13]. Legumes weed high amount of P in readily available form around their roots for rhizobia and the host plant. Only a small fraction of phosphate fertilizer is utilized by crops while remaining portion of applied P gets fixed in the soil and remains unavailable to plants[43]. Rock phosphate being available in plenty in the country is a good source of P for acid soils, but ineffective in neutral to alkaline soils[44]. Continuous efforts have been made by adding 'P' solubilising microorganisms to increase the efficiency of soil having a pH value of more than 7 [13].

Pseudomonas, Bacillus, Azospirillum, Azotobacter, Enterobacter, Klebsiella and *Serratia* are the most frequent non-symbiotic genera including strains with plant growth promotion activity[45]. PGPR have been studied in several herbaceous plants such as potato, bean, soybean, tomato, cucumber and radish[46, 47]. Reports are also available on some woody plants like apple[48], citrus[49], and alder[50]. *P. agglomerans* and *P. fluorescens* have been found effective in consistently enhancing development of *Prunus* root stocks after irrigation with relatively diluted bacterial suspension. This opened the possibility of its use in commercial nurseries. The effect of these strains on plant root stock development is particularly important because an optimal growth during the first year is essential for good establishment in the field with an additional advantage of shortening the time required for plant production[51].

Nutrients availability in the rhizopshere

There are ample evidences to show that many PGPR increase the availability of nutrients for the plants in the rhizosphere[52]. The mode of action of the PGPR involves solubilization of available forms of nutrients and/or siderophore production which helps in facilitating the transport of certain nutrients.

Solubilization of phosphates

The solubilization of P in the rhizosphere is the most common mode of action implicated in PGPR that increase nutrient availability to host plants[53]. Most effective associations are listed in table 2.

Table 2. List of effective associations of PGPR that increase nutrient availability to host plants

PGPR	Host crop	References
Azotobacter chroococcus	Wheat	[97]
Azospirillum brasilense	Rice	[98]
Bacillus endophyticus, B. pumilus, B. subtilis, Bacillus sp.	Common bean	[99]
Enterobacter agglomerans	Tomato	[72]
Pseudomonas chlororphis ps. *putida*	Soybean	[55]
Pseudomonas aeruginosa	Green gram	[91]
Rhizobium sp.Bradyrhizobium japonicum	Radish	[100]
Rhizobium leguminosarum bv. *Phaseoli*	Maize	[101]

Phosphate solubilizing bacteria are common in rhizosphere[11,54]. However, some of them appear to be crop specific. Cattelan *et al.* found only two out of five rhizosphere isolates positive for 'P' solubilization that actually had a positive effect on soybean seedling growth[55]. This suggested that all P solubilizing PGPR do not increase plant growth by increasing P availability to the hosts. A number of P solubilizing *Bacillus* sp. isolates and a *Xanthomonas maltophilia* isolate were found from canola (*Brassica napus* L.) rhizosphere which had positive effects on plant growth, but no effects on P content for the host plants[56]. It was also found that in many plant species, inactivation of nitrate reductase (NR) is initiated with phosphorylation of a species seryl residue by Ca^{2+}/Mg^{2+} dependent protein kinase, followed by Mg^{2+} dependent association of 14-3-3 type inhibitor protein with phosphor-NR. Reactivation of NR occurs after NR protein dephosphorylation catalized by an okadaic acid sensitive serine/threonine phosphatase, most probably for the type 2-A [57]. This regulatory mechanism of direct NR protein modifications has been shown to provide a rapid regulation of NR activity and thus to allow fast adaptation to changing environmental conditions, such as light, CO_2 and O_2 availability [58]. Furthermore it was also reported that low temperature, an important environmental factor, causes a rapid activation of NR in winter wheat leaves resulting from NR protein dephosphorylation[59].

Plant Growth Promotion and Microbe-Metal Interactions

Heavy metal toxicity to plants can be reduced by the use of plant growth promoting bacteria, free living soil bacteria, these exert beneficial effects on plant development when they are applied to seed or incorporated in the soil. There has been a tremendous work on P-solubilizing, metal resistant, siderophore producing and plant growth promoting bacteria and their mutants.

Moreover, microbial gene pool has been developed which could be further exploited in heavy metal contaminated sites for biodegradation and plant growth promotion purposes reported in table 3.

Table 3. List of some important bioinoculants used for biodegradation and plant growth promotion purposes

Strains	Activities	Crop	Reference
KNP9*Pseudomonas putida*	Sid+, Cd^r, Cu^r, Pb^r, Growth Promotion	Mung bean	[38]
PRS 9*Pseudomonas sp.*	Hg^r,Growth Promotion	Soybean	[102]
CRPF5,CRPF8Pseudomonas sp.	'P' Dynamics of soil	Mung bean	[103]
NBRI 4014Pseudomonas aeruginosa	Sid+ , P+, IAA+	Soybean	[104, 105]
CRPF8Pseudomonas fluorescens	Sid+,Growth Promotion	Mung Bean	[4]
TH18	Cu^r ,'P' Solubilizer	Black Gram	[105]
CRPF1Pseudomonas fluorescens	Cold Resistant, Growth Promotion	Mung Bean	[106]
CRPF7Pseudomonas mutant	Cold Resistant, 'P' Solubilizers	Mung Bean	[103]
CD7	Metal Resistant,Osmophilic	Pulses	[107]
CG1	Cu^r ,'P' Solubilizer	Black Gram	[108]
GRS1	'P' Solubilizer & Sid+	Soybean	[109]
PRS1*Rhyzopertha dominica*	Sid^+, Biocontrol	Wheat	[110]
PB16 *Pseudomonas* sp.	'P' Solubilizer	black pepper	[111]
PIAR6-2*Azospirillum* sp.	'P' Solubilizer	black pepper	[111]

The role of PGPR in promotion of plant growth has widely been accepted[60]. A number of possible mechanisms have been proposed regarding activity of PGPR. These include suppression of diseases caused by plant pathogens[61], competition with pathogenic microorganisms by colonizing roots[62], production of plant-growth-regulating substances such as indole-3-acetic acid (IAA)[63] and lowering of ethylene levels in root cells[64]. PGPR, especially phosphate-solubilizing and diazotrophic bacteria, increase the availability of limited plant nutrients such as nitrogen, phosphorus, B-vitamins and amino acids in the rhizosphere showing their plant-stimulatory effects[11]. A number of PGPR are efficient in phytostimulation and biofertilization and also in biological control, however, there are difficulties in obtaining successful formulations in most cases due to lack of sufficient knowledge on the basic principles of their action[65]. Therefore, extensive studies are required on the mechanism of their action using molecular approaches for their production and use at commercial level.

Gram-positive bacteria are able to form heat and desiccation-resistant spores which can be formulated readily into stable products and hence offer a biological solution to the formulation problem[66]. Root colonizing *Bacillus* and *Paenibacillus* strains are well known for enhancing the growth of plants[67, 68].

Enzymes that affect the plant growth regulation

The use of phosphate solubilizing bacteria as inoculants simultaneously increases P uptake by the plant and crop yield. Strains from the genera *Pseudomonas, Bacillus* and *Rhizobium* are among the most powerful phosphate solubilizers. The principal mechanism for mineral phosphate solubilization is the production of organic acids, and acid phosphatases play a major role in the mineralization of organic phosphorous in soil. Several phosphatase-encoding genes have been cloned and characterized and a few genes involved in mineral phosphate solubilization have been isolated. Therefore, genetic manipulation of phosphate-solubilizing bacteria to improve their ability to improve plant growth may include cloning genes involved in both mineral and organic phosphate solubilization, followed by their expression in selected rhizobacterial strains. Chromosomal insertion of these genes under appropriate promoters is an interesting approach. Phosphatases are generally unable to hydrolyse phytate[69], however, a special group of phosphomonoesterases has evolved in prokaryotic and eukaryotic organisms that is capable of hydrolysing phytate to a series of lower phosphate

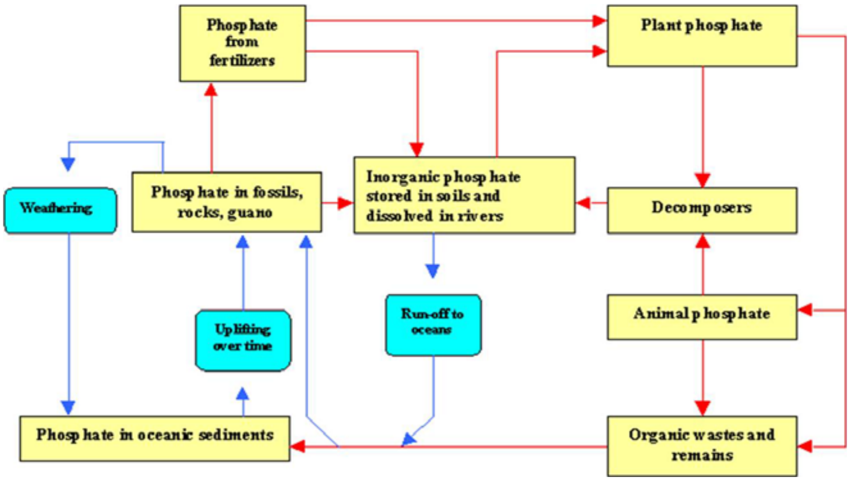


Fig. 1. Phosphorus Cycle. [*Source: Lenntech BV, Netherland*]

esters of *myo*-inositol and phosphate[70]. Plants producing 3- and 6(4)-phytases display a low activity in roots and other plant organs, and occurrence of plant-secreted phytase within the rhizosphere has not been documented. This suggests that plant roots may not possess an innate ability to acquire phosphorus directly from soil phytate. Several PGPR are known to produce microbial phytases which has been isolated and characterized from a few Gram-positive and Gram-negative soil bacteria, e.g. *B. subtilis*[71], *Bacillus amyloliquefaciens DS*11 [72], *Klebsiella terrigena* (Greiner *et al*., 1997), *Pseudomonas* spp. [35] and *Enterobacter* sp.4 [73]. However, possible role of phytases in supporting plant growth under phosphate limitation has not been reported so far. Besides other factors, the ability of some root-colonizing bacteria to make the phytate phosphorus available in soil for plant nutrition under phosphate-starvation conditions might contribute to their plant-growth-promoting activity. Elimination of chelate-forming phytate, known to bind nutritionally important minerals, is another beneficial effect due to bacterial phytase activity in the rhizosphere[69]. An artificial sterile system consisting of maize seedlings and culture filtrates of PGPR was used to investigate the contribution of secreted phytases to the plant growth promotion by *B. amyloliquefaciens*[74].

Role of PSMs in plant disease management

Amendment of soil with decomposable organic matter or plant growth promoting microorganisms is one of the cheapest, hazard-free and eco-friendly effective methods of modifying soil environment. Sun and Huang had rightly observed that continuous extensive agricultural practices that depend heavily on use of chemical fertilizers have resulted in loss of

Fig. 2: Zone of phosphate solubilisation around the colony growth of PSB on Pikovskaya's agar plate

organic matter, an increase in acidity, and accumulation of toxic elements in cultivated soils creating an environment favorable for development of certain soil-born pathogens[75]. The reduction in common scab of potato (*S. scabies)* by green manuring through prevention of the buildup of inoculums was the first report of organic amendments as a means of disease suppression. Since this observation of[76], numerous reports have appeared regarding the beneficial effects of organic and inorganic amendments of soil.

Biocontrol of phytopathogenic microorganisms

Disease causing plant microorganisms adversely affect the crop yields by significantly reducing plant performance and crop quality. The usual method for the control of such phytopathogens is to apply chemical pesticides, but this strategy has led to increased concerns over environmental contamination and has also resulted in the development of resistance against the individual chemical over the time. This needs a constant development of new pesticides[77]. In this context, rhizobacteria that can provide biocontrol of disease or insect pests (biopesticides) are considered an effective alternative to chemical pesticides[78]. A large number of mechanisms are involved in biocontrol and can involve direct antagonism via production of antibiotics, siderophores, HCN, hydrolytic enzymes (chitinases, proteases, lipases, etc.), or indirect mechanisms in which the biocontrol organisms act as a probiotic by competing with the pathogen for a niche (infection and nutrient sites). Biocontrol can also be mediated by activation of the acquired systemic resistance (SAR), induced systemic resistance (ISR) responses in plants, and by modification of hormonal levels in the plant tissues[79-81].

Effect of Phosphorus deficiencies

Fruit trees and crop plants suffer nutritional disorder due to insufficient or excess supply of certain minerals. Antagonistic or synergistic interactions among mineral elements have also been observed in soil or in plant system by several investigators.

The macronutrients are indispensable for optimal growth and development and which plants absorb primarily through roots. Phosphorus is an important macronutrient required in larger quantity for normal plant growth and reproduction. Due to phosphorus deficiency plant grows poorly and the leaves are bluish-green with purple tints. Lower leaves sometimes turn light bronze with purple or brown spots; shoots are short, thin upright and spindly. These deficiencies cause a reduction in plant growth through slower leaf production. Older leaves exhibit marginal chlorosis along with purplish brown flecks, which gradually increase. Chlorosis spread inward from midrib, sometimes leaving areas of healthy green tissues. Necrosis of tissue leads to withering of leaves and breaking petioles at the pseudostem. The distance between leaves on the pseudostem is shortened giving a 'rosette' appearance. Younger leaves do not exhibit symptoms.

Thus it could be suggested that there as a tremendous potential associated with microbes having high 'P' solubilization activity. Moreover, along with wild types metal resistant mutants could be developed for the high yield of disease free and healthy crops.

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