Research Trends in Agriculture Sciences

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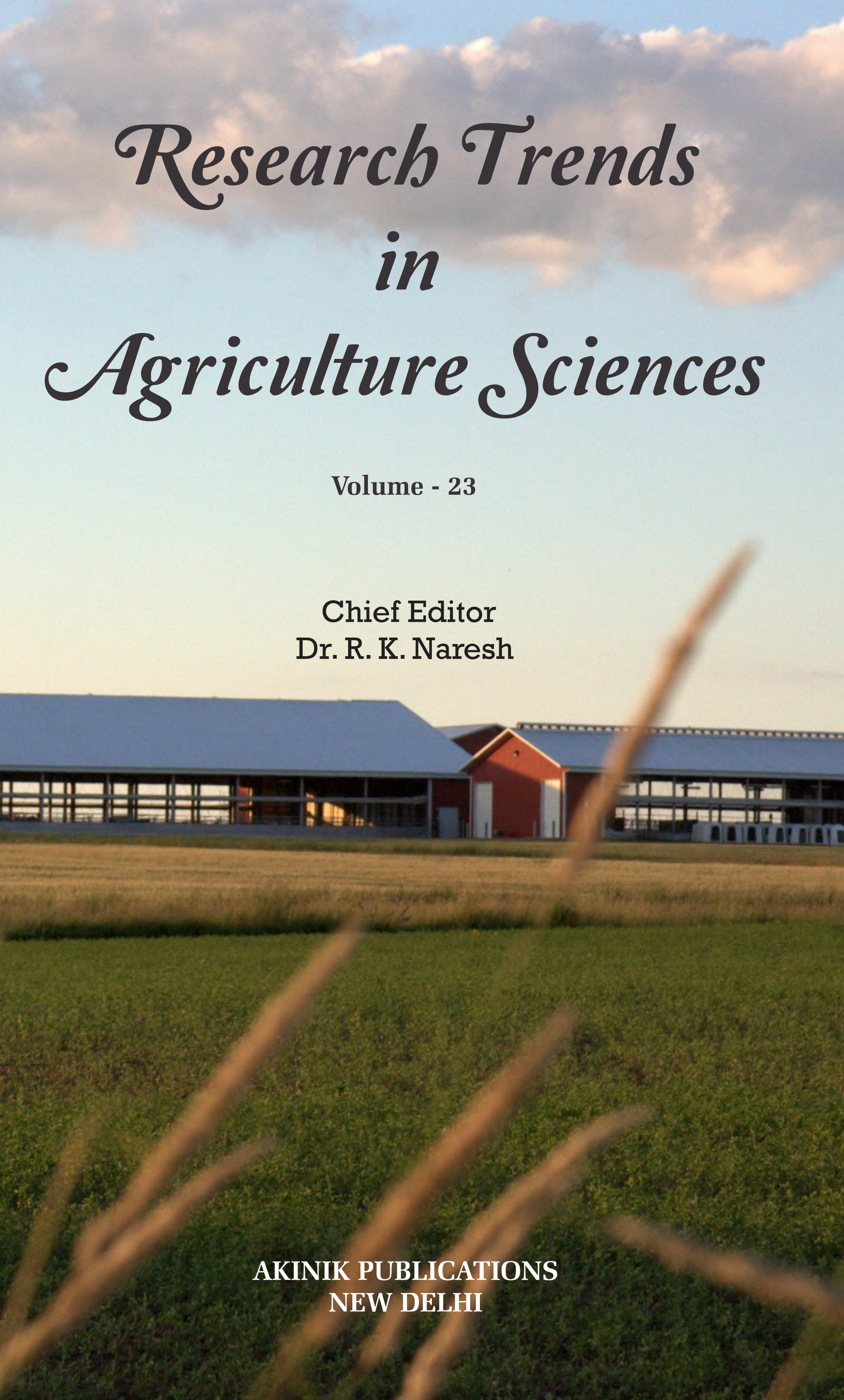
Chief Editor
Dr. R. K. Naresh



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Research Trends in Agriculture Sciences

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Chapter - 4
Phosphorus Mobilizers from Mangrove Ecosystem and Their Role in Desalination of Agricultural Lands

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Chapter - 4

Phosphorus Mobilizers from Mangrove Ecosystem and Their Role in Desalination of Agricultural Lands

Ramya Abhijith, A Vennila, CS Purushothaman, Shilta MT and Lekshmi RG Kumar

Abstract

Globally the agricultural activities are having shrinkage in terms of area and salinization of agricultural lands is one of the most serious environmental problems. Nationally our land is affected by salinity and alkalinity, and thus results in decreased production. Phosphorus being one of the essential mineral nutrients limits the plant growth and is unavailable to plants due to its low solubility and high fixation in the soil. Hence, this is rectified with additional supply of as phosphatic fertilizers. However, major portion of soluble inorganic phosphate in form of chemical fertilizer applied to soil is immobilized rapidly and occurs in oxidised form as phosphates bounded to aluminium, calcium or iron and becomes unavailable to plants. Hence, the use of phosphorus-mobilizing bacteria can provide a solution to the problem of limited phosphorus availability in salt-affected soils. The application of phosphorus-mobilizing bacteria as biofertilizer can not only improves the growth and quality of produce, but also drastically reduces the usage of chemical fertilizers. Hence, phosphorus-mobilizing bacteria can be used as environment friendly bio-fertilizers help to reduce the requirement of phosphatic fertilizers

Keywords: phosphorus, rhizosphere, phosphate-solubilizing bacteria, phosphatase producing bacteria, acid and alkaline phosphatase activity,

1. Introduction

Phosphorus (P) is a major growth-limiting nutrient second to nitrogen. It is one of major constituents of nucleic acids, ATPs and phospholipids. It has both merits and demerits in terms of productivity as low quantity limits the productivity and excess leads to eutrophication. P is having sedimentary cycle and simpler compared to other nutrient cycles, and inorganic P especially orthophosphates is the main source of P for primary producers.

Mangroves such as *Avicennia* spp. in general are tolerant to high organic load. Organically rich mangrove ecosystem, by and large are nutrient-deficient. Feller *et al.* (2002) found that N and P are not uniformly distributed within the mangrove ecosystems. Romine and Metzger (1939) suggested that the total N and P content in soil is very low as strong weathering occurs. P is the essential mineral nutrient limits the plant growth and not readily available to plants due to its low solubility and high fixation in the soil (McVicker *et al.*, 1963). Hence, this nutrient is supplied as phosphatic fertilizers. However, a large portion of soluble inorganic phosphate applied to the soil as chemical fertilizer is immobilized rapidly (Goldstein, 1995), and occurs in oxidised form as phosphates bound to aluminium, calcium or iron and becomes unavailable to plants.

Being one of the major essential macronutrients for plants and is applied to soil in the form of phosphatic fertilizers. A large portion of soluble inorganic phosphate applied to the soil as chemical fertilizer is immobilized rapidly and becomes unavailable to plants (Goldstein, 1995) and the quantity available to plants is usually a small proportion (Stevenson and Cole, 1999) in two soluble forms, the monobasic ($H_2PO_4^-$) and the diabasic (HPO_4^{2-}) ions. In marine sediments, abundance of cation in the interstitial water makes phosphorus gets precipitated and largely unavailable to plants and the mobilization is a slow process. Microorganisms are good mobilizers especially bacteria and fungi. They help in releasing phosphorus from organic and inorganic matters through the process of mineralization and solubilization. This is mainly done by the phosphate-solubilizing bacteria and phosphatase-producing bacteria altogether constituting the plant growth promoting rhizobacteria in and around the rhizosphere by secretion of organic acids and production of phosphatase enzyme facilitating the conversion of insoluble forms of P to plant-available forms (Kim *et al.*, 1998).

Sediment acts as a source and sink for P. During heavy loading periods, P gets deposited in sediment and slowly releases to overlying water (Sundby *et al.*, 1992). Froelich (1988) suggested that P can be deposited and buried in sediment either from adjacent land by overlying water or as a result of organic decomposition. Adsorption on metal oxides in the sediment has been considered as one of the principle reactions involving phosphate. Fabre *et al.* (1999) suggested that the wave action seems to control the re-suspension of the sediments and subsequently exchange of phosphate between the suspended matter and the water column. The degree of water logging, stagnancy, inundation frequency, flushing by the tidal waters is the interrelated factors that can deeply influence or control the availability because it strongly influences salinity and anoxia (Boto and Wellington, 1983).

1.1 Phosphorus in coastal zone

Sundby *et al.* (1992) studied the distribution of P in coastal marine sediments and the influences of P cycle – adsorption and desorption near the sediment-water interface on the flux of phosphate to the overlying water and reported that half of the particulate phosphate of sedimentation flux from Gulf of St. Lawrence is mobilized within the sediment. The pore-water profile of phosphate and the flux across the sediment-water interface depend on the mineralization rate of phosphate, the buffering capacity of sediment, and the thickness of the diffusive sub-layer at the sediment-water interface. de Lacerda *et al.* (1993) found that the total P concentration varying between 100 and 1600 µg g^{-1}, as a function of sediment source (continental or marine origin). P concentration is comparatively lower in the sandy coastal zone than the clay or silty deep water zone (Lukawska- Matuszewska and Bolaek, 2008).

1.2 Phosphorus in mangroves sediments

Feller *et al.* (2002) found that essential nutrients like N and P are not uniformly distributed in mangrove ecosystems. The soil fertility can switch over from conditions of N to P limitation across narrow ecotonal gradients. It is reported that few tropical and subtropical mangrove wetlands appeared to be the P limited (Boto and Wellington, 1983). Total P concentration varies between 800 and 1600 µg g^{-1} (Hesse 1961; 1963) in mangrove sediments of Sierra Leone. Alongi *et al.* (1992) reported lower P (100-670 µg g^{-1}) in mangrove sediments of Gautami-Godavari estuary. Silva and Mozeto (1997) reported that total P varies from 170 to 270 µg g^{-1} in mangrove sediments of Sepetiba Bay, Brazil. Fabre *et al.* (1999) found a quite higher range of total P in Guianese mangrove varying between 600-800 µg g^{-1}. Kathiresan *et al.* (1996) reported seasonal variation in the total sediment P in Pichavaram mangrove, which ranges from 0.42 to 1.52 g m^{-2} and the spatial variation of total sediment P higher in the lower inter-tidal (0.84 g m^{-2}) than in upper inter tidal zone (0.65 g m^{-2}).

Silva *et al.* (2007) has reported that sediment as a major reservoir for P in mangrove ecosystem. Walsh (1967) reported that soil releases phosphates and nitrates during freshwater condition and absorbs them from overlying water when the water becomes salty again. According to Boto and Wellington (1988), in mangrove sediments the major fraction in the P pools is organic P and this is mostly unavailable to plants. Alongi *et al.* (1992)

proposed that dissolved and particulate P concentrations in mangrove sediment are generally low and the major proportion of the inorganic P is bound as salts or oxides. In contrast, Fabre *et al.* (1999) reported that inorganic P is higher than the organic P. The extractable P concentrations across a mangrove forest gradient decrease with tidal height, it can become limiting in elevated areas (Boto and Wellington, 1983; Silva and Sampaio, 1998; Feller *et al*., 2002) suggesting a tidal influence in the deposition of P (Mackey *et al*., 1992).

1.3 Phosphorus in rhizosphere

The rhizosphere concept was introduced by Hiltner L (1904) and defined the word rhizosphere as the narrow zone of soil surrounding the roots where the microbial populations are getting stimulated by the root activities of the plant. These fine roots act as binders (Hesse, 1961). The rhizosphere (true roots) and pneumatophore (respiratory root) zones may harbour unique bacterial community than that of bulk sediments. The physicochemical and biological characteristics of rhizospheric sediment are significantly differing from bulk sediment (Hinsinger, 2001). Ryan *et al*. (2001) had proposed that organic anions secreted from plant roots increase the P availability by desorbing inorganic P from a mineral surface and chelating or complexing cations such as Al, Fe and Ca which gets bound to P. Hinsinger (2001) and Trolove *et al*. (2003) suggested that biochemical changes occur in the rhizosphere during P uptake. Gahoonia and Nielsen (1992) and Hinsinger (2001) suggested that pH of the rhizosphere soil may be changed by imbalance in the uptake of cations and anions by plants, which can affect the P availability in the soil. The plant-microbial interactions in rhizosphere will lead to increase in the plant health and also will lead to the soil fertility (Khan *et al.*, 2009). The bacteria inhabiting in the rhizospheric region and which are beneficial to plants are termed plant growth promoting rhizobacteria (Khaled *et al*., 2010). The solubilization and mineralization of P in the rhizosphere is the most common mode of action implicated in plant growth promoting rhizobacteria that increase nutrient availability to host plants (Richard, 1996). Plant roots also secrete enzymes known as phosphatases which can catalyze organic P hydrolysis. It is reported that higher phosphatase activity in rhizospheric sediment compared to bulk or non rhizospheric sediment. This can lead to reduction of organic P forms in the rhizosphere (Radersma and Grierson, 2004). In contrast to this, no depletion of organic P forms occurred in the rhizosphere in spite of higher phosphatase activity in the rhizosphere (Hedley *et al.*, 1982). Additionally, organic compounds secreted by plant roots will stimulate microbial activity in the rhizosphere, which may also influence the P availability (Bowen and Rovira, 1999).

1.4 Phosphorus Immobilization

The phosphate form of P is one of the least soluble mineral nutrients in soil. The P content of soils may range up to 19 g kg^{-1} but usually less than 5% of this is available to the plants and microorganisms in soluble form and the rest 95% is unavailable being in the form of insoluble inorganic phosphate and organic P complexes. These forms of P being held in the sediments for a long time remains excluded from cycling (Paul *et al*., 1988). The primary source of P for plants is inorganic P, depending on the analytical methodology also termed extractable, exchangeable, labile, and available or bioavailable P (Salcedo and Medeiros, 1995). Experimental additions of P have yielded increase in growth of mangroves. It has long been recognized that it is possible that some of the beneficial effect of applied phosphate in acid soils is due to fixation of aluminium and not just due to phosphate uptake by the plant (Pierre and Stuart, 1933). Hesse (1963) suggested that aluminium will be precipitated by phosphate and prevents its uptake. Aluminium can be relatively abundant in mangrove soils (Naidoo, 2006) and the acidic conditions of mangrove soils may result in aluminium being mobilized to toxic levels. Rout *et al*., 2001 has studied the relation and proposed that mangroves are having a large storage capacity for aluminium in their canopy.

1.5 Phosphorus Mobilization

The P immobilization occurs rapidly whereas the mobilization is a slow process and microbial activity is responsible for major nutrient transformations within a mangrove ecosystem (Alongi, 1993; Holguin, 1999). Microorganisms are involved in a range of processes that affect the transformation of soil P and are thus an integral part of the soil P cycle. Mangrove growth is very much limited primarily by phosphate availability because phosphorus will get adsorbed or co-precipitated with carbonate compounds (Koch and Snedaker, 1997).

Bio-geographical, anthropological and ecological properties including food web in the ecosystem, nutrient cycling and the presence of organic and inorganic matters strongly influences the microbial load in mangrove forest sediments. Major nutrient transformators within a mangrove ecosystem are bacteria and fungi constituting major portion of total microbial biomass (Alongi *et al*. 1993; Holguin *et al*. 1999; 2001) and are thus an integral part of the soil P cycle.

Rhizobiales, Campylobacterales, Methylococcales and Vibrionales tended to be more abundant in the rhizosphere samples than in the bulk sediment (Gomes *et al.*, 2010). Soil in the mangrove region has salinity of 6.3 g l^{-1} and it is very rich in microbial (Halophilic aerobic bacterial) load as it gives too numerous to count (TNTC) colonies even at 10^{-8} dilution (Kathiresan, 2001).

Khan *et al.(*2009) proposed that top most soil of mangrove ecosystem (0 to 5 cm) shows higher aerobic bacterial load and the load is decreasing with depth due to increasing trend of anaerobic conditions and the exchange of seawater and fresh water i.e. the circa-tidal rhythm, which shows wide fluctuation of salinity. The study reveals that a perfect stratification exists between the depths of soil in the mangrove ecosystem and salt tolerance nature of the bacteria. This stratification may be responsible for a perfect nutritive management of the mangrove forests. Thus, they provide unique ecological niche to variety of microorganisms (Khan *et al*., 2009).

In particular, soil microorganisms are effective in releasing P from inorganic and organic pools of total soil P through solubilization and mineralization (Hilda and Fraga, 1999). This is mainly done by the phosphate-solubilizing bacteria and phosphatase-producing bacteria in and around the rhizosphere by secretion of organic acids and phosphatase enzyme production facilitating the conversion of insoluble forms of P to plant-available forms (Kim *et al*., 1998). There exist two forms of phosphorus-mobilizing bacteria in the rhizosphere namely phosphate-solubilising bacteria (PSB) and phosphatase-producing bacteria (PPB).

2. Phosphatase-producing bacteria

The word ‘Phosphatase’ was coined by Plimmer (1913). Suzuki *et al.* (1907) suggested that a group of enzymes were responsible for microbial mineralization of organic phosphate compounds and the role of bacteria in mineralization of organic P compounds was first suggested by Waksman (1934). These bacteria were named as phosphatase- producing bacteria (PPB) produce extracellular enzymes such as phosphatase and are able to mineralize organic phosphates into inorganic form, that eventually become available to the plants (George *et al.,* 2002).

In bacteria, alkaline phosphatase is usually located in the periplasmic space to generate free phosphate groups for uptake and use. This is in accordance with the fact that alkaline phosphatase is usually secreted by bacteria during the phosphate starvation only (Garen and Levinthal, 1960). Alkaline phosphatase catalyzes the phosphate-derived molecules to produce inorganic phosphate and a hydrolyzed molecule. Aaronson and Patni (1976) proposed that decomposition and mineralization of organic P compounds by many enzymatic complexes are especially by heterotrophic bacteria. The release of extracellular phosphatase from actively growing marine bacteria, *Pseudomonas* sp. isolated from the North Pacific Ocean was first reported by Kobori and Taga (1980). Ammerman and Azam (1985) suggested that phosphatase enzyme catalyse the hydrolysis of phosphate esters and promotes the degradation of complex organic P compounds into an organic moiety and ortho-phosphates which is the bioavailable form for primary producers.

Phosphatases have been typically classified into alkaline and acid phosphatases according to their maximum hydrolysing capacity at different pH values (Jansson, 1988). Mangrove ecosystem constituted more populations of PPB than backwaters, estuaries and marine biotopes and phosphatase activity was higher in clayey sediments irrespective of other environment factors (Venkateswaran, 1981).

Pseudomonas sp., *Vibrio* sp., *Bacillus* sp., *Corynebacterium* sp., *Micrococcus* sp., and *Flavobacterium cytophaga* are found to be alkaline phosphatase-producers in the sea and brackish water areas of Porto Novo (Venkateswaran and Natarajan 1983). Tarafdar and Junk (1988) reported that almost half of the microorganisms in soil and on plant roots were able to mineralize the organic P through the production of phosphatase.

In a marine environment, organic P will be available in macromolecular form and will not be readily available to the organisms. Soil phosphatases play a major role in the mineralization processes (dephosphorylation) of organic P substrates. The organic P compounds are to be preconditioned by extra-cellular bacterial enzymes called “phosphatases” for making them available to the nutrient cycles. Three groups of bacteria *viz*., *Pseudomonas, Vibrio* and *Bacillus* were identified from mangrove sediments (Ravikumar *et al*., 2007).The enzymes in soils originate from animal, plant and microbial sources and the resulting soil biological activity includes the metabolic processes of all organisms (Cookson, 2002).

2.1 Distribution of phosphatase-producing bacteria

de Freitas *et al*. (1997) reported that several bacterial strains exhibit both P solubilizing and mineralizing activity. Guang-cam *et al*. (2008) studied the P- solubilizing activity and P- mineralizing activity of the bacterial strains isolated from the soil. Kim *et al*. (1997; 1998) reported that *Enterobacter agglomerans* isolated from wheat rhizosphere solubilised hydroxyapatite and also the Organic P.

2.2 Phosphatase activity of phosphatase-producing bacteria

Bacillus cereus was the dominant species and the phosphatase activity was also higher (Ravikumar *et al.*, 2007). Ramkumar and kannapiran (2011) reported phosphatase activity of the PSB isolates, and showed that the strain KPB6 had higher activity (28.78±1.18 µmoles g^{-1} hr^{-1}) followed by the strain KPB5 (26.13±1.10 µmoles g^{-1} hr^{-1}). Phosphatase activity was low in KPB11 (10.61±0.18 µmoles g^{-1} hr^{-1}), KPB2 (10.82±0.23 µmoles g^{-1} hr^{-1}) and KPB12 (10.84±0.23 µmoles g^{-1} hr^{-1}).

Ponmurugan and Gopi (2006) stated that there is a positive correlation between the phosphate solubilization with phosphatase activity of bacteria. Sakurai *et al.* (2008) also found similar correlation between phosphatase activities with phosphate solubilization. Fitriatin *et al.* (2011) used the cluster analysis to obtain the most excellent bacterial isolates for producing phosphatase and solubilizing phosphate, and also capabilities of pre-eminent isolates to hydrolyze synthetic and natural organic phosphate. The results of the cluster analysis of 57 isolates based on phosphatase activity and dissolved P showed ten isolates of PPB with highest phosphatase activity and dissolved P. The phosphatase activity and dissolved P ranged from 44.71 to 74.76 µg *p*-NP ml^{-1} hr^{-1} and 16.69 to 32.94 mg l^{-1}. Phosphatase activity of ten selected isolates ranged from 0.35 to 4.96 µg *p*-NP ml^{-1} hr^{-1} on MS medium with phytic acid as organic P substrate. Meanwhile, in medium containing extract of cow-dung manure, phosphatase activity ranged from 0.20 to 4.26 µg *p*-NP ml^{-1} hr^{-1}. It can be seen that the higher phosphatase activity on MS medium containing phytic acid than extract of cow-dung manure. The results of this experiment showed that organic P substrate is affecting phosphatase activity and were consistent with the research of Moura *et al*. (2001) who explained that the different organic P substrates affect bacterial phosphatase activity.

3. Phosphate-solubilising Bacteria

Phosphate- solubilizing bacteria (PSB), as potential suppliers of soluble forms of phosphorus, would provide a great advantage to mangrove plants. PSB act on insoluble inorganic form of phosphorus and are being used as bio-fertilizer in agriculture sector since 1950's. They are capable of secreting different types of organic acids e.g. carboxylic acid (Deubel and merbach, 2005). Many rhizobacteria are able to solubilise sparingly soluble phosphates, usually by releasing chelating organic acids (Vessey *et al*., 2004).

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 (Goldstein, 1995; Kim *et al*., 1997), which through their hydroxyl and carboxyl groups chelate the cations bound to phosphate, thereby converting it into soluble forms (Kpomblekou and Tabatabai, 1994). The acid production will lower the pH in rhizosphere and the acids are acting as metal chelators displacing metals from phosphate complexes and hence there occurs the dissociation of phosphate. The low pH cause release of phosphate from $Ca_3 (PO_4)_2$ in calcareous soils (He and Zhu, 1998). However, phosphate-solubilization is a complex phenomenon, which depends on many factors such as nutritional, physiological and growth conditions of the culture (Reyes *et al*., 1999).

Phosphate-solubilizing microorganisms including bacteria and fungi can grow in media where $Ca_3 (PO_4)_2$, $Fe_3 (PO_4)_2$, $Al_3 (PO_4)_2$, apatite, bone meal, rock phosphate or similar insoluble phosphate compounds are the sole source of phosphate. These organisms assimilate P and also release a large portion of excess soluble phosphates. The solubilization of P by phosphate-solubilizing microorganisms is attributed to the excretion of organic acids like citric, glutamic, succinic, lactic, oxalic, malic, fumaric and tartaric acid (Rao, 1982; Gaur, 1990). The other mechanism is the alteration of solubility of product by acids, producing chelates with Ca^{2+} (Vazquez *et al.*, 2000).

In the aquatic environment, due to the action of organic and mineral acid, the precipitated inorganic phosphates are brought into media (Fleischer *et al*., 1988). In mangrove sediments, phosphates usually precipitate because of the abundance of cations in the interstitial water, making P largely unavailable to organisms. PSB as potential suppliers of soluble forms of P would provide a great advantage to mangrove plants.

The mechanisms involved in phosphate-solubilisation by phosphate-solubilizing microorganisms have been attributed to protonation (Illmer and Schinner, 1995) or their potential to produce various organic acids (Rodriguez and Fraga, 1999). The PSB are also found to produce extracellular acid and alkaline phosphatases (Rodriguez and Fraga, 1999). Dissolution of phosphates can result from anion exchange or chelation of Ca, Fe or Al cations associated with insoluble phosphates by organic acids (Gyaneshwar *et al*., 2002) and PSB have been shown to enhance the solubilization of insoluble P compounds through the release of low molecular weight organic acids (Sahu and Jana, 2000).

3.1 Distribution of Phosphate-solubilizing Bacteria

Vazquez *et al.* (2000) isolated and characterized phosphate-solubilizing microorganisms from the rhizosphere of mangroves and reported that organic acids produced in rhizosphere lead to complete solubilization of insoluble calcium phosphate in the media. Main acids found are seen to be lactic acid, acetic acid, isovaleric and isobutyric acid. Of the 13 isolates, 12 are bacteria belonging to *Bacillus, Paenibacillus, Enterobacter, Pseudomonas, Vibrio and Xanthobacter* and one is fungus i.e. *Aspergillus niger*. Most of the bacterial isolates produce more than one acid. The *Aspergillus niger* produces only succinic acid.

Keneni *et al*. (2010) obtained fifteen isolates of PSB from faba bean rhizosphere and studied their effect on releases of soluble P from insoluble P sources with different sources of P in the media. *Pseudomonas* was found to be the main strain. Highest solubilization was observed with tricalcium phosphate followed by Egyptian rock phosphate.

Ravikumar *et al*. (2007) studied the effect of heavy metals on growth and phosphate solubilization ability of halophilic phosphobacteria from Manakudi mangrove habitat and reported that as the concentrations of heavy metal increases, the contents of sugars (carbohydrate) and the proteins also increase in the cell supernatant. They proposed that the halophilic phosphobacteria survive better in the heavy metal stressed condition. Eight species of saline tolerant inorganic PSB such as *Bacillus subtilis, B. cereus, B. megaterium, Arthrobacter illicis, Escherichia coli, Pseudomonas aeruginosa, Enterobacter aerogenes* and *Micrococcus luteus* were identified. Of them, *Bacillus subtilis* was predominantly found in mangrove sediments **(**Ravikumar, 2008).

Endophytic bacteria from the surface sterilized pneumatophores of *A. marina* are found to be *Bacillus* sp., *Enterobacter* sp. and *Sporosarcina aquimarina*. The colonization of pneumatophores by endophytic bacteria enhances growth of the entire plant, increasing productivity and the yield of reproductive organs (Janarthine *et al.*, 2011).

3.2 Phosphate-solubilizing activity of bacteria

Bacillus strains isolated from wheat rhizosphere solubilized 112-157 mg l^{-1} of phosphate after 14 days (Sundara-Rao and Sinha, 1963). *Vibrio* sp. and *Pseudomonas* sp. solubilized 0.5-0.55 mg l^{-1} (Promod and Dhevendaran, 1987), where maximum growth coincided with the maximum quantity of solubilised phosphate. The highest reported phosphate solubilization was by an unidentified marine bacterium, 300 mg l^{-1}, isolated from the rhizosphere of the sea grass *Zostera marina* (Craven and Hayasaka, 1982). de Freitas *et al*. (1997) reported the phosphate solubilizing rhizobacteria majority belong to the genus *Bacillus* from field crops and their solubilization activity ranged from 7.5 to 22 µg P ml^{-1} from rock phosphate in liquid culture.

Phosphate-solubilizing activity of one strain, *Bacillus amyloliquefaciens,* had an average solubilization capacity of 400 mg of phosphate per litre of bacterial suspension (10^8cfu ml^{-1}). This quantity could theoretically sufficient to a small terrestrial plant with its daily requirement of phosphate. The mechanism involved in phosphate solubilization was probably the production of organic acids (Vazquez *et al.*, 2000).

4. Conclusion

At present salinization of agricultural lands is one of the most serious environmental problems influencing crop growth around the world. In India, 7 million hectare land area is affected by salinity and alkalinity, and decrease in productivity is expected from these lands (Ravikumar, 2008). Hence, the use of phosphorus-mobilizing bacteria can provide a solution to the problem of limited P availability in salt-affected soils. Aquaculture in salt-affected inland and coastal areas is also gaining importance. Large quantity of organic material is settled in the aquaculture ponds. The phosphatase-producing bacteria (PPB) can be used to mobilize P from un-utilized feed and other organic wastes. The application of phosphorus-mobilizing bacteria as biofertilizer can not only improves the growth and quality of produce, but also drastically reduces the usage of chemical fertilizers. The importance of mangroves in protecting coastal communities in India is clearly evident after the Tsunami in 2004 (WWF, 2005). It has been reported that mangrove growth is very much limited primarily by phosphate availability because phosphorus will get adsorbed or co-precipitated with carbonate compounds (Koch and Snedaker, 1997). Hence, phosphorus-mobilizing bacteria can be used as environment friendly bio-fertilizers help to reduce the requirement of phosphatic fertilizers in mangrove afforestation programmes too, and also to aid in easy establishment of planted saplings. These organisms can also be used as biosensors, molecular biology and bioremediators.

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