Chapter 1

Introduction

INTRODUCTION

1.1 Phosphorus

The world population is increasing day by day (Lal 2000), hence there is need for plenty of food crops to meet the requirement of growing population. Crops need several nutrients to reach their maximum potential yield. The nutrients, which are required by the plants, occur naturally in the soil, but sometimes these are added as lime or fertilizer into the soil. After nitrogen, phosphorus (P) is one of the major essential macronutrient for plant growth and development (Bagyaraj et al. 2000). About 98 % soils have inadequate supply of available Phosphorus (Hansan 1996) and likely to induce deficiency of this mineral. Phosphorus has several roles in the plants and is involved in functioning of nucleic acids, proteins, photosynthesis and in the formation of oils, sugars and starches etc. It is helpful in the rapid growth of the roots and shoots. Most of the soils contain the substantial reserves of total P; large part of it relatively remains inert and only less than 10 % of soil P enters the plant-animal cycle (Kucey et al. 1989). When P is added as fertilizer to the soil, it gets fixed. The soil microorganisms solubilize this P and make it available to the plants (Hilda and Fraga 1999).

1.2 Phosphorus in soil: Status and availability

P is present in several hundred to several thousand grams per acre in the soil, but its large amount in soils is not available to growing plants. P forms the 0.12 % of the earth crust. The amount of phosphorus which is available in the soil is 0.05 %, out of this only 0.1 % is available for the plants (Scheffer and Schachtshabel 1988). About 50 % of the districts in India need higher levels of P in soils than are currently being used (Hasan 1996). Apatite is the largest reservoir of phosphate on Earth (Stevenson 1986) and is less soluble in water. P is not found in elemental form because this form is extremely reactive. It combines with oxygen when exposed to air. In natural system like soil and water, P exists as phosphate, a chemical form in which phosphorus is surrounded by oxygen atoms (Hyland et al. 2005). Orthophosphate is the simplest phosphate with chemical formula PO_4^{-3}. In water, orthophosphate mostly exists as $H_2PO_4^{-1}$ in acidic condition or as HPO_4^{-2} in alkaline condition (Bushman et al. 2009). It is present in the form of $H_2PO_4^{-1}$ and HPO_4^{-2} for the uptake by the plants. The P fixation and precipitation is highly dependent on soil pH and type, thus, in acidic soils free oxides and hydroxides of Al and Fe fix P and in alkaline soils it is fixed by Ca, which causes its low efficiency (Goldstein 1986).

Agricultural soils have the large amount of organic and inorganic phosphorus, but this is unavailable for plants use. This is due to the high reactivity of P with some metal complexes such as Fe, Al and Ca, leading to precipitation and adsorption of P in soil (Fig. 1.1). About 30 to 50 % of the P in soil occurs in organic forms (Rodriguez and Fraga 1999). The organic phosphorus in the soil is largely in the form of inositol (soil phytate), synthesized by microorganisms and plants and is most stable (Anderson 1980; Harley 1983). The phosphorus in bound form is made available to the plants by soil microorganisms like bacteria and fungi, which solubilize the bound form of phosphorus and make it available to the plants (Jisha and Mathur 2006). The other common forms of organic phosphorus are phosphomonoesters, phosphodiesters including nucleic acids, phospholipids, glycerophosphate, sugar phosphate and coenzymes (Martinez et al. 1968). These organic forms must be converted into inorganic phosphate or low molecular weight organic acids before they can be assimilated by plants. The organic forms are utilized by plants after mineralization and subsequent release of inorganic phosphorus (Yadav and Tarafdar 2001). Plants complete their phosphorus requirement by uptake of phosphate anions from the soil solution (Richardson et al. 2000). Many of the phosphorus compounds have high molecular weight, therefore these must first be converted to either soluble phosphate (pi, HPO_4^{-2},

$H_2PO_4^{-1}$), or low molecular weight organic phosphate, to be assimilated by the plant cell (Goldstein 1994).

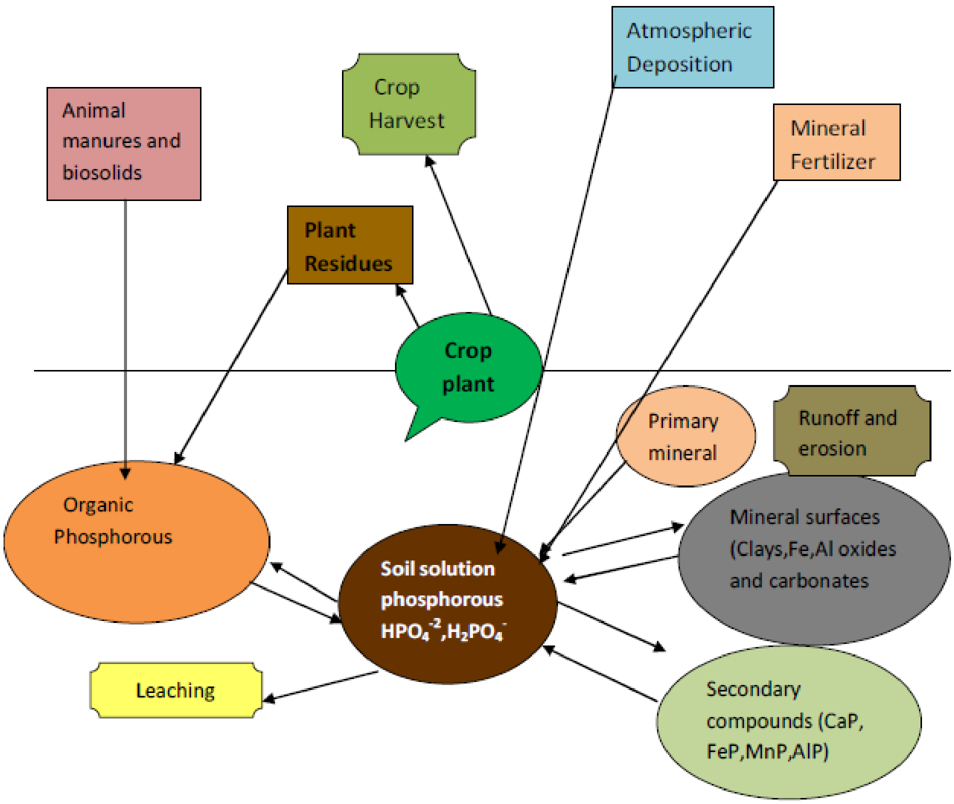

Fig. 1.1 Phosphorus cycle in nature (Anthony et al. 2009).

1.3 Phosphorus in agro ecosystem soils

In agricultural ecosystem, phosphorus constraints are much more critical, because phosphorus in the harvested crop is removed from the system, with only limited quantities being returned in crop residues and animal manures. As a result, extreme phosphorus deficiencies are quite common where no supplementary source of these elements is applied to the soils. The phosphorus cycle in soil is a system which involves soil, land and microorganisms. Major processes include the uptake of soil phosphorus by plants, recycling (the return of plant and animal residues), biological turnover (mineralization and immobilization) fixation to clay, solubilization (Stevenson 1986). Phosphorus not supplied through biochemical fixation but, must come from other sources to meet plant requirement. These sources include commercial fertilizers, animal manures, plant residues, wastes and native compounds of phosphorus, both organic and inorganic already present in the soil. The soil P cycle is a dynamic process involving the transformation of P by geochemical and biological process (Melissa and kin 2006). Fig 1.2 depicts the general cycle of phosphorus in the soils (portion of organic and inorganic form of phosphorus) into pools based on its availability in plants.

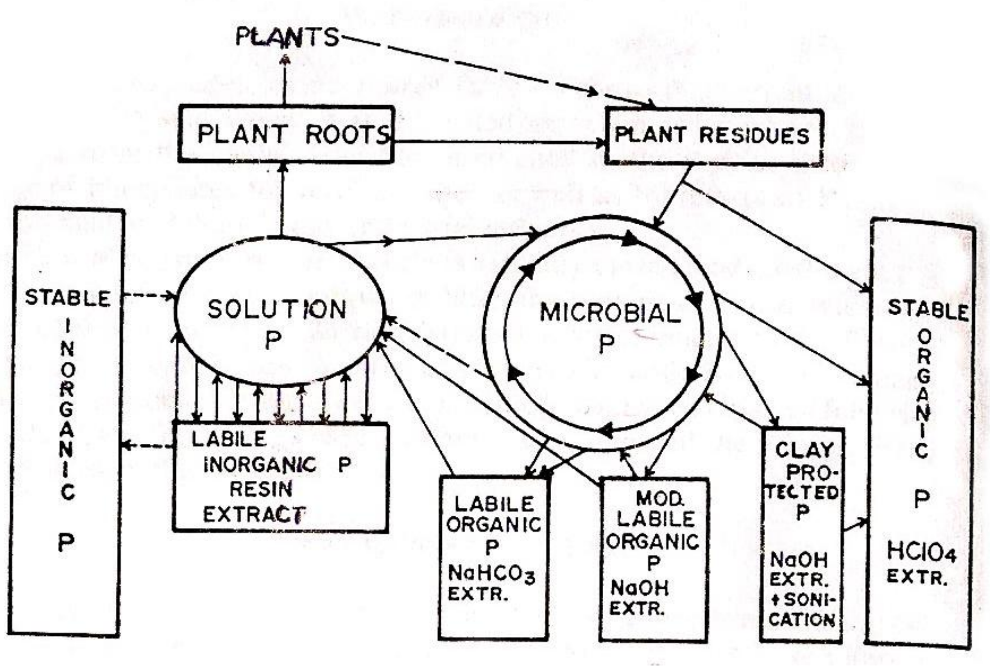

Fig. 1.2 Phosphorus cycle in soil, showing the partition of organic and inorganic forms of P into pools based on availability to plants (Stevenson 1986**).**

1.4 Interaction of phosphatic compounds in soil

Many soils throughout the world are P-deficient. Most mineral nutrients in soil solution are present in milli molar amount; phosphorus is only available in micro molar quantity or less (Goldstein 1994). Free phosphorus concentration even in fertile soil is generally not higher than 10 mM even at pH 6.5. The majority of applied phosphorus is rapidly fixed in soil into fractions that are poorly available to plant roots (Fig. 1.3) (Sanyal and De Data 1991; Yadav and Dadarwal 1997). In soils, inorganic forms of phosphorus such as fluorapatites, hydroxyapatite, chloroapaties, iron and aluminium phosphate as in combination with clay fractions do occur. Inorganic phosphates in acidic soils are associated with iron (Fe) and aluminium (Al) compounds where as calcium (Ca) phosphates are predominant forms of inorganic phosphates in neutral as calcareous soils (Gyaneshwar et al. 2002).

Beside this, large quantities of xenobioties phosphonates, which are used as pesticides, detergent additives, antibiotics and flame retardants, are released into the environment. These C-P compounds are generally resistant to chemical hydrolysis and bio-degradation, but several reports have documented microbial P release from these sources (Mc Grath et al. 1998).

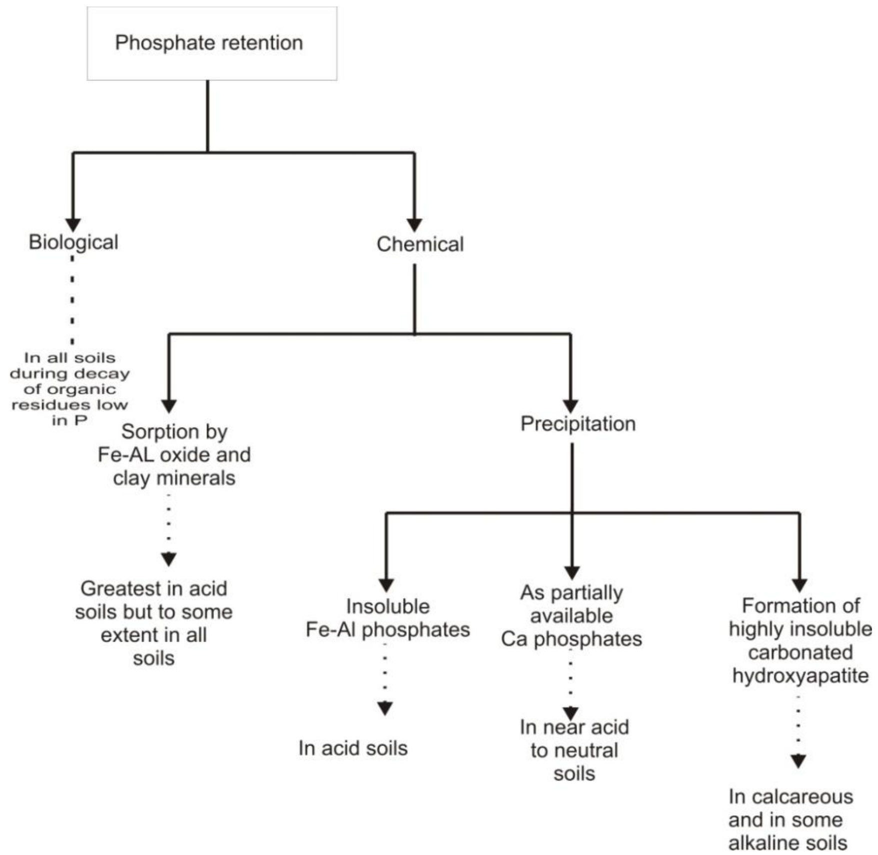

Fig. 1.3 Phosphate fixation reactions in soil (Sauchelli 1951).

1.5 Chemical phosphate fertilizers

To increase the availability of P for the plants, large amount of fertilizers are being applied to soil. But a proportion of fertilizer P after application is quickly transformed to the insoluble form (Vassilev and Vassilev 2003; Pradhan and Sukla 2005). This lead to the frequent application of phosphate fertilizers, but its use on a regular basis has become costly affair and also environmentally undesirable (Reddy et al. 2002).

Chemical fertilizers have played a significant role in the green revolution, but unbalanced use of them, lead to reduction in soil fertility and to environment degradation (Gyaneshwar et al. 2002). Traditional P fertilizer production is based on chemical processing of insoluble mineral phosphate high-grade ore, which includes an energy intensive treatment with sulphuric acid at high temperature. This process is environmentally undesirable and also is manufactured from non-renewable resources and its usage leads to air, water and land pollution and reduction of biomass production and biological diversity (Vance 1998). By seeing the harmful effects of chemical fertilizers, an integrated concept of ‘Sustainability’ in agriculture started. As it pertain to agriculture, sustainable describes farming systems that are capable of maintaining their productivity and usefulness to society indefinitely. Such systems must be resource conserving, socially supportive, commercially competitive and environmentally sound. Thus, the term sustainable agriculture means as integrated system of plant and animal production practices with a site specific application that will, over time the long term: satisfy human food and fiber need, enhance environmental quality and sustain the economic viability of farm operations. The goal of sustainable agriculture is, hence, to minimize adverse impacts to the immediate and off-farm environments while providing a sustained level of production and profit. However, the most important constraint limiting crop yields in developing nation worldwide, and especially among resource-poor farmers, is soil fertility. Unless the soil fertility is restored in these areas, farmers can get little benefits from the use of improved varieties and more productive cultural practices. Moreover, the consistent and alarming increase in the human population has again threatened the world's food security. There is therefore, an urgent need for a second green revolution to increase the food production by around 50 % in the next year in order to sustain the population pressure (Vasil 1998; Leisinger 1999). Scientists are therefore looking vigorously for an alternative source of phosphatic fertilizers to supplement, or replace in some cases, the chemical fertilizers to ensure competitive yields of crops with sustainability. So an alternative to chemical phosphatic fertilizers is microbial inoculants (biofertilizers). The utilization of microbial products has several advantages over conventional chemicals for agricultural purposes: (i) microbial products are considered safer than many of the chemicals now in use; (ii) neither toxic substances nor microbes themselves will be accumulated in the food chain; (iii) self-replication of microbes circumvents the need for repeated application; (iv) target organism seldom develop resistance as is the case when chemical agents are used to eliminate the pests harmful to plant growth; and (v) properly developed bio-control agents are not considered harmful to ecological processes of the environment (Gould 1990; Shen 1997).

1.6 Rock phosphate (RP); economic source of phosphate fertilizers

In order to ensure food security in developing countries, there is a need for the sustainable intensification of agricultural production systems towards supporting productivity gains and income generation. In this context, novel, soil-specific technologies will have to be developed, pilot tested and transferred to farmers in a relatively short time. Phosphorus is an essential nutrient element for plants and animals. The appropriate and sound utilization of rock phosphate (RP) as P sources can contribute to sustainable agricultural intensification, particularly in developing countries endowed with RP resources. In recent years, the possibility of practical use of rock phosphate as fertilizer has received significant interest in India. It is estimated that about 260 million tons rock phosphate deposits are available and this material should provides a cheap source of phosphate fertilizer for crop production (FAI 2002). Out of the total resources, 35 % are in Jharkhand, 31 % in Rajasthan, 17 % in Madhya Pradesh, 9 % in Utter Pradesh and 8 % in Uttarakhand.

Direct application of RP would minimize pollution and decreases the costs of chemical treatment. The use of rock phosphate as phosphate fertilizer and its solubilization by microbes (Kang et al. 2002), through the production of organic acids (Maliha et al. 2004), have become a valid alternative to chemical fertilizers. Rock phosphate is widely distributed throughout the world both geographically and geologically (Zapata and Roy 2004), in conjugation with phosphate-solubilizing microorganisms, rock phosphate provides a cheap source of P fertilizer for crop production (Zaidi 1999; Gull et al. 2004). RP may originate from igneous, sedimentary, metamorphic, and biogenic sources, with sedimentary being the most widespread forms of apatite, the primary P bearing mineral in RP, include fluorapatites, hydroxyl apatite, carbonated–hydroxyapatite, and francolite (Van Straaten 2002). Ghani et al (1994) found that lower the soil pH, more available the P from RP becomes. Even with soil acidity below pH 5.5-6.6, RP becomes as effective as super phosphate only after 4 years of annual direct application.

1.7 Phosphate-solubilizing microorganisms

From several years, great attention has been dedicated to study the role, that soil microorganisms play in the dynamics of phosphate, particularly those able to solubilize insoluble P forms (Rao 1992). These microorganisms are bacteria and fungi that inhabitant the rhizosphere (Barea and Azcon 1975, Bowen and Rovira 1999). Evidence of the involvement of microorganisms in solubilization of inorganic phosphates was reported as early as 1903 (Kucey et al. 1989; Khan et al. 2007). Since then, extensive studies on the solubilization of mineral phosphates by microorganisms have been reviewed (Goldstein

1986; Kucey et al. 1989; Reddy et al. 2002; Tarafdar et al. 2003; Achal et al. 2007; Aseri et al. 2009; Himani and Reddy 2012). Phosphate-solubilizing microorganisms (PSMs) are ubiquitous, and their numbers vary from soil to soil. In general, among the whole microbial population in soil, P-solubilizing bacteria constitute 1-50 % and P-solubilizing fungi 0.1 to 0.5 % of the total respective population (Chen et al. 2006). Phosphate-solubilizing bacteria generally out-number P-solubilizing fungi by 2-150 folds (Kucey et al. 1989; Alam et al. 2002). Some researchers prefer to use fungal P solubilizers arguing that bacterial strains can lost their ability to solubilize P after several cycles of *in vitro* culture (Whitelaw 2000), but this point is quite controversial. Most P-solubilizing bacteria (Venkateswarul et al. 1984) and fungi (Venkateswarul et al. 1984; Tarafdar et al. 2003; Tarafdar & Gharu 2005; Achal et al. 2007; Yadav and Tarafdar 2007; Aseri et al. 2009; Yadav and Tarafdar 2010) were isolated from the rhizosphere of various plants and are known to be metabolically more active than those isolated from sources other than rhizosphere. The rhizosphere is the region of soil that is immediately near to the root surface and that is affected by root exudates (Kennedy 1999). There are different types of substances that diffuse from the roots and that stimulate the microbial activity, such as carbohydrates (sugars and oligosaccharides), organic acids, vitamins, nucleotides, flavonoids, enzymes, hormones, and volatile compounds (Prescott et al. 1999). The result is a dense and active microbial population that interacts with the roots and within it.

1.8 Phosphate-solubilizing microorganisms as plant growth promoters

These organisms in addition to providing P to plants also facilitate plant growth by other mechanisms. PSMs include largely bacteria and fungi. Phosphate-solubilizing microorganisms can enhance the plant growth by a wide variety of mechanisms like:

1.8.1 Phosphate solubilization

Despite the fact that the amount of phosphorus in the soil is generally quite high (often between 400 and 1,200 mg kg^{-1} of soil) most of this phosphorus is insoluble and therefore not available to support plant growth. The insoluble phosphorus is present either as an inorganic mineral such as apatite or as one of several organic forms including inositol phosphate (soil phytate), phosphomonesters, and phosphotriesters (Khan et al. 2007). In addition, much of the soluble inorganic phosphorus that is used as chemical fertilizer is immobilized soon after it is applied so that it then become unavailable to plants and is therefore wasted. The limited bioavailability of phosphorus from the soil, combined with the fact that this element is essential for plant growth and inability to obtain sufficient phosphorus often limits plant growth (Feng et al. 2004). Thus, solubilization and mineralization of phosphorus by phosphate-solubilizing microorganisms is an important trait in plant growth-promoting bacteria (PGPB) as well as in plant growth-promoting fungi (PGPF) (Richardson 2001; Rodríguez and Fraga 1999).

Typically, the solubilization of inorganic phosphorus occurs as a consequence of the action of low molecular weight organic acids such as gluconic acid and citric acid, both of which are synthesized by various soil bacteria (Bnayahu 1991; Rodriguez et al. 2004). On the other hand, the mineralization of organic phosphorus occurs through the synthesis of a variety of different phosphatases, catalyzing the hydrolysis of phosphoric esters (Rodríguez and Fraga 1999). Importantly, phosphate solubilization and mineralization can coexist in the same bacterial strain (Tao et al. 2008). Plant-growth-promoting rhizobacteria (PGPR) are also known to have beneficial influence on phytoremediation process (Singh and Cameotra 2013).

1.8.2 Nitrogen fixation

About 78 % of the earth atmosphere is made up of free nitrogen (N_2) produced by biological and chemical processes within the biosphere and not combined with other elements. All plants need nitrogen for their growth. However, plants cannot get the nitrogen they need, from atmospheric supply. This limitation can be compensated by moving closer to or inside the plants, viz. in diazotrophs present in rhizosphere, rhizoplane or those growing endophytically. Some important non-symbiotic nitrogen-fixing bacteria include *Gluconacetobacter diazotrophicus*, *Herbaspirillium* sp., *Azotobacter* sp. (Barriuso and Solano 2008), *Achromobacter*, *Acetobacter*, *Alcaligenes*, *Arthrobacter*, *Azospirillum*, *Azomonas*, *Bacillus*, *Beijerinckia*, *Clostridium*, *Corynebacterium*, *Derxia*, *Enterobacter*, *Klebsiella*, *Pseudomonas*, *Rhodospirillum*, *Rhodopseudomonas* and *Xanthobacter* (Saxena and Tilak 1998).

1.8.3 Indole acetic acid production (IAA)

IAA (indole-3-acetic acid) is the member of the group of phytohormones and is generally considered the most important native auxin (Ashrafuzzaman 2009). It functions as an important signal molecule in the regulation of plant development including organogenesis, tropic responses, cellular responses such as cell expansion, division, and differentiation, and gene regulation (Ryu and Patten 2008). The phytohormones synthesized by plant growth promoting rhizobacteria (PGPRs) influenced the root hair development, respiration rate, metabolism and root proliferation which in turn resulted in better mineral uptake of the inoculated plants (Bar and Okon 1993).

Diverse bacterial species possess the ability to produce the auxin phytohormone IAA. Different biosynthesis pathways have been identified and redundancy for IAA biosynthesis is widespread among plant-associated bacteria. Interactions between IAA-producing bacteria and plants lead to diverse outcomes on the plant side, varying from pathogenesis to phytostimulation. Reviewing the role of bacterial IAA in different microorganism–plant interactions highlights the fact that bacteria use this phytohormone to interact with plants as part of their colonization strategy, including phytostimulation and circumvention of basal plant defense mechanisms. There are numerous soil microflora involved in the synthesis of auxin in pure culture and soil (Barazani and Friedman 1999). The potential for auxin biosynthesis by rhizobacteria can be used as a tool for the screening of effective strains (Khalid 2004).

1.8.4 Siderophore production

Iron, an element essential for microbial growth, is mostly unavailable because it is mainly present in soil in a hard-to-solubilize mineral form. To sequester iron from the environment, numerous soil microorganisms secrete low-molecular-weight, iron binding molecules, called siderophore, which have a high capacity for binding Fe^{3+}. The low-soluble, bound iron is transported back to the microbial cell and is available for growth. Siderophores produced by biocontrol-PGPRs have a higher affinity for iron than the siderophores produced by fungal pathogens, allowing the former microbes to scavenge most of the available iron, and thereby prevent proliferation of fungal pathogens. Depletion of iron from the rhizosphere does not affect plant growth as plants can thrive on less iron than microorganisms. Moreover, some plants can bind and release iron from bacterial iron-siderophore complexes, and use the iron for growth. Thus, the plant benefits in two ways: from the suppression of pathogens (Jagadeesh et al. 2001) and from enhanced iron nutrition, resulting in increased plant growth (Bashan and Bashan 2005) (Fig. 1.4).

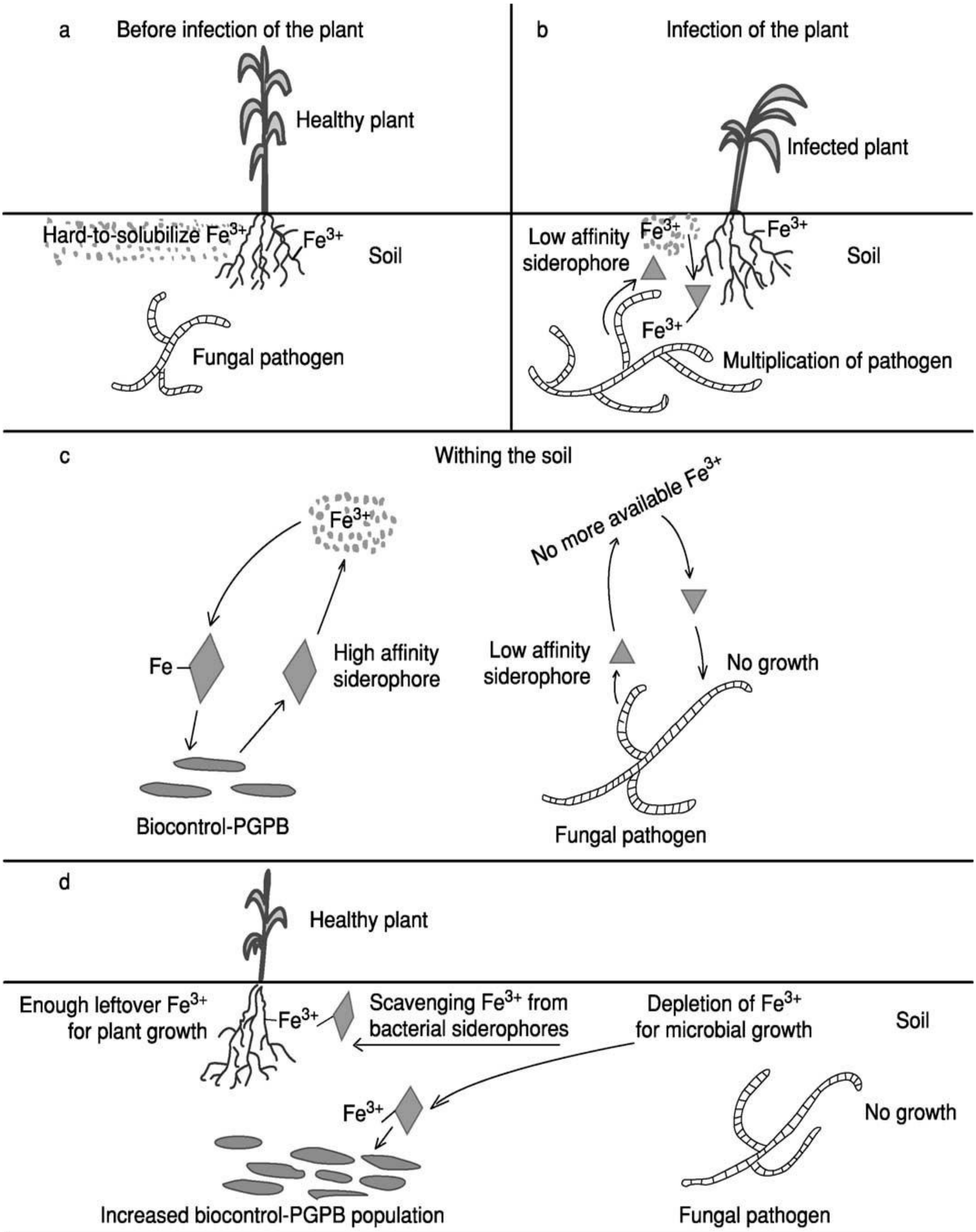

Fig. 1.4 Biological control of fungal pathogens by PGPR using siderophores (Bashan and Bashan 2005).

1.8.5 HCN production

One group of microorganisms, which acts as bio-control agents of weeds include the deleterious rhizobacteria (DRB), that can colonize plant root surfaces and able to suppress the plant growth (Suslow and Schroth 1982). Many DRB are plant specific (Schippers et al. 1987). Cyanide is a dreaded chemical, produced by them as it has toxic properties. Although cyanide acts as a general metabolic inhibitor, it is synthesized, excreted and metabolized by hundreds of organisms, including bacteria, algae, fungi, plants, and insects, as a mean to avoid predation or competition. The host plants are generally not negatively affected by inoculation with cyanide-producing bacterial strains and host-specific rhizobacteria can act as biological weed-control agents (Zeller et al. 2007). A secondary metabolite produced commonly by rhizosphere *Pseudomonads* is hydrogen cyanide (HCN), a gas known to negatively affect root metabolism and root growth (Schippers et al. 1990) and is a potential and environmentally compatible mechanism for biological control of weeds (Heydari 2008).

1.9 Phosphate-solubilizing microorganisms as bio-fertilizers

Although several phosphate-solubilizing microorganisms occur in soil, usually their numbers are not high enough to compete with other microorganisms commonly established in the rhizosphere. Thus the amount of P liberated by them is generally not sufficient for a substantial increase in, *in situ* plant growth. Therefore, inoculation of plants by a target microorganism at a much higher concentration than that normally found in soil is necessary to take advantage of the property of phosphate solubilization for plant yield enhancement.

There have been a number of reports on plant growth promotion by microorganisms that have the ability to solubilize inorganic and/or organic P from soil after their inoculation in soil or plant seeds (Klopper et al. 1989; Gaur and Ostwal 1972; Subba Rao 1982; Kucey 1989). Among the heterogeneous and naturally abundant microbes inhabiting the rhizosphere, phosphate-solubilizing microorganisms (PSM) including bacteria and fungi have provided an alternative biotechnological solution in sustainable agriculture to meet the P demands of plants. An increase in P availability to plants through the inoculation of PSMs has been reported in pot experiments and under field conditions (Richa et al. 2007; Himani and Reddy 2012). Swarnalakshmi et al (2013) also reported that addition of inoculants along with RP significantly increased P uptake in comparison with chemical fertilizers or single inoculation of bio-inoculants in wheat. Sundra et al (2002) found that application of PSBs combine with RP is more effective than chemical phosphate fertilizers.

1.10 PSMs as bio-inoculants in organic farming

Organic farming is a method of farming system which primarily aimed at cultivating the land and raising crops in such a way, as to keep the soil alive and in good health by use of organic wastes (crop, animal and farm wastes, aquatic wastes) and other biological materials along with beneficial microorganisms (biofertilizers) to release nutrients to crops for increased sustainable production in an eco-friendly pollution free environment. To the maximum extent, feasible relies upon crop rotations, crop residues, animal manures, off-farm organic waste, and mineral grade rock additives (Lampkin 1990). The nutrient reservoirs in the soil shrink when crops are removed from the field at harvest. This nutrient export creates a P deficit, necessitating regular P addition to replace the harvested P. Several studies investigating whole form P budgets have found nutrient P deficits in many organic forms and illustrate the need for nutrient additions (Nelson and Mikkelson 2008). This leads to the need of frequent application of phosphate fertilizers, but organic farming avoids the inputs of synthetic chemicals and their consequences (Hajra 2001). An active soil microflora and a considerable pool of accessible nutrients are, therefore, important priorities in organic farming (Fliebbach and Mader 2000). Natural rock phosphate along with phosphate-solubilizing microorganisms may be a valuable alternative for P fertilizers in an organic farming.

1.11 Inoculum formulations

For sustainable agriculture, substitution of high priced chemical fertilizers with eco-friendly biofertilizers is the most desired practice. The microbial inoculation in the form of seed bacterization has been proved beneficial for the maintenance of soil health, but the use of a suitable carrier, capable of supporting high viable microbial population for a prolonged duration is of utmost importance. Though, a number of carriers including charcoal soil mixture, wheat bran (Gaind and Gaur 1990), peat, press mud (Jauhri and Philip 1984), calcium alginate (Viveganandan and Jauhri 2000), fly ash (Gaind and Gaur 2002; Grewal et al. 2001; Kalra et al. 2000) have been found successful in maintaining high shelf life of phosphobacteria, but still there is wide scope for exploring some cheap and easily available waste material as a carrier for biological inoculants.

1.12 Aim of present study

Phosphorus is an essential macronutrient required by the plants for their growth and development. Added P fertilizers undergo fixation due to the complex exchanges within the soil (Altomare et al. 1999). This leads to the need of frequent application of phosphate fertilizers, but its use on a regular basis has become a costly affair and also environmentally undesirable (Reddy et al. 2002). Chemical fertilizers are also adversely affecting the soil microbial population (Vassilev and Vassileva 2003). Natural rock phosphates have been recognized as a valuable alternative for P fertilizers. In India, it is estimated that there are almost 260 million tons of rock phosphate deposits and this material should provide a cheap source of phosphate fertilizer for crop production (FAI 2002). Unfortunately, rock phosphate (RP) is not readily available to the plants in soils with a pH > 5.5-6.0. Because of this, extension services are reluctant to be recommended and farmers are hesitant to utilize RP directly. Several P-solubilizing microorganisms have the ability to convert insoluble low grade rock phosphates into soluble forms available for plant growth (Vyas and Gulati 2009). Organic applications increased nutrient status, microbial activity and productive potential of soil while the use of only chemical fertilizers in the cropping system resulted in a poor microbial activity and productive potential of soil (Kang et al. 2005).

There is no doubt that bacterial inocula can increase the yield of various crops significantly, but the performance has generally been inconsistent. A key factor involved in the lack of success has been the rapid decline of the size of populations of active cells, to levels ineffective to achieve the objective, following introduction into soil. Potential of bacterial inoculums may be determined in a single experiment, but the consistent performance can only be determined in multiple trails (Kloepper et al. 1989).

Keeping in view the effect of conventional (chemical fertilization) methods and organic farming practices on diversity and productivity of microorganisms, in the present investigation, we have isolated phosphate-solubilizing microorganisms from the rhizospheric soil of an organic farm and studied their plant growth promotion activities. To check the consistent performance, selected isolates were used as bio-inoculants alone or along with RP fertilization at three different sites come under different agroclimatic regions. In the present study, we have also evaluated the comparative effect of phosphate chemical fertilizer, biological phosphate fertilizers (phosphate-solubilizing bacteria and fungi) and biological phosphate fertilizers in association with rock phosphate fertilizer on the growth, yield and nutrients uptake of maize and wheat crop. The effect of theses fertilizers on physiochemical properties of rhizospheric soil of all experimental fields were also studied. We have developed the inoculum formulations of these selected isolates on the basis of their shelf life and productive potential by using different carrier materials.

OBJECTIVES

- Isolation and identification of phosphate solubilizing microorganisms for alkaline soils
- To study the physiological characteristics and elucidation of mechanism of phosphate solubilization
- To develop the inoculum formulations for field applications with respect to phosphate solubilization efficiency and shelf life