*ISBN: 978-93-94570-62-7*

# 8. Phosphate Solubilizing Microbes: Their Role in Soil Health and Plant Growth Promotion

**Dr. Nelson Xess**

Assistant Professor,
Department of Microbiology,
Bhanupratap Deo Govt. P.G. College,
Kanker, Chhattisgarh, India.

**Priyanka Kujur**

Lecturer Biology,
Govt. High School Bareli,
Block Katghora, District,
Korba, Chhattisgarh, India.

***Abstract:***

*Phosphorous is the major essential macronutrient of plants. It is known to involve many functions in the plant growth and metabolism. Soil microorganisms have the ability to solubilize the insoluble phosphates and to improve the quality of soil health and its fertility. Microorganisms play an essential role to facilitate the availability of soil phosphate to the root system and enhance the mobilization of phosphate in soil Efficacy of phosphate solubilizing microorganisms has been identified on the basis of kinetics and phosphorous accumulation.*

*Phosphate solubilizing microorganisms include bacteria, fungi and actinomycetes. The strains of Pseudomonas, Bacillus, Aspergillus, Penicillium, etc. are some known phosphate solubilizers. The ability to convert the insoluble phosphate into soluble form by secreting organic acids resulting in improved phosphate availability to the plants.*

*This chapter focuses on the identification on the based morphological, biochemical and molecular level and Phosphorus dynamics in soils and its availability to plants, metabolic pathways effecting the release of organic acids by phosphate solubilizing microorganisms are covered.*

***Keywords:***

*Phosphorous, phosphate solubilizing microorganisms, Macronutrient, organic acids.*

## 8.1 Introduction:

### 8.1.1 Phosphorus:

The world population is increasing day by day. Hence there is need for plenty of food crops requirement for 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 fertilizer into the soil [1]. After the nitrogen, Phosphorus is an essential element for plant development and growth. It plays a major role in the process of energy transfer, photosynthesis, nutrient transport, cell division, early growth and root formation, DNA and RNA formation, flower blooms, seed development, improvement in plant strength and to tolerance for unfavourable environmental conditions. Phosphorus rich soils, most of this element is in insoluble form and only a small proportion (0.1%) is available to the plants [2].

Soil contains both organic and inorganic forms of phosphorus. Phosphate is found to be present in form of phosphatic compounds like: Mineral forms- (oxyapatite, hydroxyapatite, apatite [Gen. formula $Ca_{10}(PO_4,CO_3)_6(F,OH,Cl)_2$]); Organic forms (phytins, phospholipids, nucleic acids, inositol phosphate, soil phytate, etc.); Phosphatic rock - ($Ca_{10}(PO_4)_6F_2$) [3]. Natural rock mined from P rich deposits contains 14-37% $P_2O_5$ and are rich in minor elements such as B, Zn, Ni, I; Soluble phosphorus - sometimes called available inorganic phosphorus. It can include Organic phosphorus and orthophosphate, which form taken up by plants for normal growth and plant productivity [4]. Plant take phosphate in the form of soluble orthophosphate ions ($H_2PO_4^-$ and $HPO_4^{2-}$) but due to the presence of Ca, Mg, K, Na, Al, and Fe ions in soil, the soluble orthophosphate is converted to insoluble form. Due to this action plants utilized very low amount of phosphorus, even though phosphorus rich fertilizers are used. In order to increase crop yields, chemical phosphate fertilizers are regularly incorporated into the soil.

This excessive application of phosphate causes environmental problems [5]. Current trends in modern agriculture are focused on the diminution of the use of chemical pesticides and inorganic fertilizers, compelling the search for alternative ways to improve soil fertility and crop production. In recent years much attention has been paid to natural agricultural practices in expectation of moving towards environmentally sustainable development [6]. Improving soil organic matter is therefore, vital in sustenance of soil quality and agricultural productivity.

Crop residues are the organic wastes generated by agricultural activities. These organic wastes contain lots of nutrition which are necessary for the growth of plants. They improve the quality of soil and environmental conditions [7]. The rhizosphere soil surrounding roots influenced physically, chemically, and biologically by Plant root, is an extremely encouraging habitat for the reproduction of micro-organisms that have a potential impact on soil fertility and plant health. In the rhizosphere, important and intensive Interactions occur among plants, soil, micro-organisms [8].

## 8.2 Role of Phosphorus in Plants Growth:

Most soils are deficient in soluble forms of phosphorus (P), one of the major essential macronutrients required for growth and productivity of plants. It plays an important role in plants in many physiological activities such as cell division, photosynthesis, and development of good root system and utilization of carbohydrate [9]. Its functions cannot be performed by any other nutrient. Adequate supply of phosphorus is required by plants for optimum growth and yield. This deficiency is a result of low inherent P fertility due to weathering, in combination with intensive, nutrient-extracting agricultural practices. Plants can absorb phosphate only in soluble form of orthophosphate ion ($HPO_4^{-2}$ and $H_2PO_4$). A large fraction of soil microbes can dissolve insoluble inorganic phosphates present in the soil and make them available to the plants [10].

About 10-20% of fertilizer is acquired by the plants for promoting their functions. Once inside the plant root, phosphorus may be stored in the root or transported to the upper portions of the plant. It is also one of the primary structural components of membranes that surround plant cells.

The deficiency of phosphorus affects not only growth and development in plants, but also crop yield and the quality of fruit and formation of seeds. Deficiency of phosphorus can delay the ripening of crops which can set back the harvest, risking the quality of the produce [11].

### 8 3 Soil Phosphorus:

A greater part of soil phosphorous, approximately 95-99% is present in the form of insoluble phosphates and hence cannot be utilized by the plants. Phosphorus does not occur in pure form in nature. It is always combined with other elements to form phosphates. In these forms, P is highly insoluble and unavailable to plants. As a result, the amount available to plants is usually a small proportion of this total [12].

**Table 8.1: common minerals phosphorous found in Indian soils [Adapted from Yadav and Verma (2012)].**

| Minerals | Chemical formula |
|---|---|
| Acid soils | |
| Dicalcium phosphate | $CaHPO_4$ |
| Dicalcium phosphate dihydrate | $CaHPO_4 \cdot 2H_2O$ |
| Variscite | $AlPO_4.2H_2O$ |
| Strengite | $FePO_4.2H_2O$ |
| Hydroxyapatite | $Ca_5(PO_4)_3\ OH$ |
| B-tricalcium phosphate | $Ca_3(PO_4)_2$ |
| Fluorapatite | $Ca_5(PO_4)_3\ F$ |
| Octacalcium phosphate | $Ca_4H(PO_4)_3 \cdot 2–5\ H_2O$ |

The soil P cycle is a dynamic process involving the transformation of P by geochemical and biological processes.

Plant-available P occurs in the soil solution as orthophosphate anions, predominantly $H_2PO_4^{-1}$ and $H_2PO_4^{-2}$. The type of phosphorus bearing minerals that form in soil is highly dependent on soil pH. If we look at the global phosphorus fluxes, most of the phosphorus is insoluble or poorly soluble inorganic compounds [13]. Phosphates can be very complex and more than one form of phosphate is found in nature.

The diverse soil phosphate forms can be categorized as soil solution phosphates, insoluble inorganic and insoluble organic phosphates [14].

## 8.4 Applied Phosphate:

Majority of the Indian soils are low in available phosphorus and 98 percent of the cultivated soils require P fertilizers for optimum crop production. Phosphorus is generally provided to the plants in the form of water-soluble phosphatic fertilizers such as superphosphate and diammonium phosphate. However, more than 70-80 percent of the applied P gets fixed in soil as insoluble phosphates of calcium, iron and aluminium which are unavailable for plant uptake [15]. Overcome the phosphorus deficiency, phosphorus fertilizers are added 3-4 times more than the actual crop requirement. This is cost prohibitive to the farmers in general and poor marginal farmers in particular. The situation calls for the ways and means to increase phsophorus use efficiency by making the applied P available to plants. Under the above circumstances, efficient and eco-friendly methods to release chemically fixed phosphorus from soil pool and to supplement the nitrogen through biological nitrogen fixation have immense potential in improving crop production and quality [16]. Efficiency of P fertilizer throughout the world is around 10-25% and concentration of bioavailable P in soil is very low reaching the level of 1.0 mg kg–1 soil. The addition of rock phosphate will increase total soil P with the potential to replenish labile P and plant available P. [17].

## 8.5 Phosphate Solubilisation Problem in Soil:

Soil contains both organic and inorganic forms of phosphorus. The soil being poor in organic matter (1.5- 4.2 mg $kg^{-1}$), most of the phosphorus is present in inorganic form as minerals of insoluble calcium, iron or aluminium phosphates. Calcium phosphate dominates in neutral to alkaline soils whereas iron and aluminium phosphates dominate in acidic soils.

The release of P from these bound forms in soils is relatively a slow process [18]. Plant take phosphate in the form of soluble orthophosphate ions $H_2PO_4^{-1}$, $HPO_4^{-2}$ and $PO_4^{-3}$ but due to the presence of Ca, Mg, K, Na, Al and Fe ions in soil, the soluble orthophosphate is converted to insoluble form. Because of is not available for plants growth, even though phosphorus containing fertilizers are added [19].

## 8.6 Phosphate Solubilizing Microorganisms and Phosphate Solubilization:

Phosphate solubilizing microorganisms have been isolated from numerous terrestrial and aquatic sources. Rhizospheric microorganisms are metabolically more active than non-rhizospheric microorganisms. Numerous strains of bacteria have been reported and investigated for their phosphate solubilizing abilities.

The important genera of phosphate solubilizing Bacteria include *Pseudomonas, Bacilli, Rhizobium* and *Enterobacter* are great phosphate solubilizers. Other microorganisms playing an important role in P acquisition by plants include mycorrhizal fungi and endosymbiotic rhizobia [20]. Different sources of insoluble inorganic phosphate are used like aluminium phosphate, iron phosphate, tricalcium phosphate and zinc phosphate.

PSMs exhibiting inorganic phosphate solubilization produce a clear zone or halo around their colonies. PSMs exhibiting inorganic phosphate solubilization produce a clear zone or halo around their colonies. The selection of inorganic and organic phosphate compound for testing phosphate solubilizing microorganisms depends upon the type of soil where the phosphate solubilizing microbes will be used.

Soil microorganisms play a significant role in mobilizing phosphorus for the use of plants from the native soil phosphorous pool as well as from added insoluble phosphates such as rock phosphates.

PSM could produce effective chelating materials in the immediate vicinity of rock phosphate or phosphatic fertilizer or in the rhizosphere. The application of PSMs as inoculums or the management of their populations in soil is alternatives to improve P availability for plants [21].

**Table 8.2: Diversity of phosphate solubilizing microorganisms [Adapted from Mendes et al (2013)].**

| Microorganism | Examples |
|---|---|
| **Bacteria** | *Bacillus* sp., *Bacillus circulans*, *B. cereus*, *B. fusiformis*, *B. megaterium*, *B. mycoides*, *B. polymyxa*, *B. chitinolyticus*, *B. subtilis*, *Bradyrhizobium* sp., *Pseudomonas* sp., *P putida*, *P. striata*, *P. fluorescens*, *Flavobacterium* sp., *Nitrosomonas* sp., *Micrococcus* sp., *Agrobacterium* sp., *Azospirillum brasilense*, *Escherichia intermedia*, *Enterobacter asburiae*, *Nitrobacter* sp., *Thiobacillus ferrooxidans*, *Rhizobium meliloti*, *Xanthomonas* sp. *Alcaligenes* sp., *Aerobactor aerogenes*, *Achromobacter* sp., *Actinomadura* |
| **Fungi** | *Aspergillus awamori*, *A. niger*, *A. flavus*, *A. nidulans*, *Fusarium oxysporum*, *Alternaria tenuis*, *Achrothcium* sp., *Penicillium digitatum*, *P. lilacinium*, *P. funiculosum*, *Cephalosporium* sp., *Cladosporium* sp., *Candida* sp., *Chaetomium globosum*, *Humicola insolens*, *Helminthosporium* sp., *Pythium* sp.,*Phoma* sp., *Populospora mytilina*, *Myrothecium roridum*, *Mortierella* sp., *Micromonospora* sp., *Oidiodendron* sp., *Rhizoctonia solani*, *Rhizopus* sp., *Mucor* sp., *Trichoderma viride*, *Torula Sclerotium rolfsii* |
| **Cyanobacteria** | *Nostoc* sp., *Scytonema* sp., *Anabaena* sp., *Calothrix braunii*, |
| **Actinomycetes** | *Actinomyces*, *Streptomyces* |
| **Vesicular arbuscular mycorrhiza** | *Glomus fasciculatum* |

## 8.7 Phosphate Fertilizers Use in Agriculture and the Environmental Impacts:

The population of the world is increasing continuously, with which the need for food also increasing. Due to which there is more pressure in the agriculture sector and excessive use of fertilizers has started, continuous use of fertilizers is generating environmental problems. Use of chemical fertilizers on regular basis has become a costly affair and also environmentally undesirable.

Plants utilize very small amounts of phosphatic fertilizers that are applied and the rest (70-80%) is rapidly converted into insoluble complexes in the soil [22]. large amount of P applied as fertilizer enters in to the immobile pools through precipitation reaction with highly reactive $Al^{3+}$ and $Fe^{3+}$ in acidic and $Ca^{2+}$ in calcareous or normal soils.

Efficiency of P fertilizer throughout the world is around 10-25% and concentration of bioavailable P in soil is very low reaching the level of 1.0 mg $kg^{-1}$ soil. The addition of RP will increase total soil P with the potential to replenish labile P and plant available P [23].

## 8.8 Rock Phosphate:

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 of rock phosphate (RP) deposits are available and this material provides a cheap source of phosphate fertilizer for crop production.

The optimal development of crops demands a high and often costly input of P fertilizers. Current concepts in sustainability involve application of alternative strategies based on the use of less expensive natural sources of plant nutrients. Natural phosphate rocks have been recognized as a valuable alternative for P fertilizers [24].

The beneficial effect of rock phosphate has made this material an attractive component for management in agriculture. Phosphate rocks are the biggest reserves of phosphorus. Direct application of RP would minimize pollution and decreases the cost of chemical fertilizer. The use of rock phosphate as phosphate fertilizer and its solubilization by microbes and become available for plants.

Therefore natural rock phosphates have been recognized as a valuable alternative source for P fertilizer, especially for acidic soils. The P released from directly applied ground RP is often too low to provide sufficient P for crop uptake. Low-technology alternatives to the energy intensive and costly methods of conventional P fertilizer production have been proposed including enhancing plant and microbiological mechanisms that promote RP solubilization [25].

## 8.9 Solubilization of Rock Phosphate:

Rock phosphate 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 Fluor apatite, hydroxyapatite, carbonate-hydroxyapatite, and francolite. In general, high carbonate-substituted forms of apatite (francolite) will solubilize more readily than pure forms of Fluor apatite, releasing more P for plant use. In addition to RP source, the major influences on RP solubility are soil properties, crop species and management practices. These factors have various influences on the equilibrium of the dissolution reaction of a given apatite mineral [26]. A simplified dissolution equation is shown in Equation 1.

$$\mathbf{Ca_{10}F_2\,(PO_4)_6 + 12H^+ \rightarrow 10Ca^{2+} + 6H_2PO_4^- + 2F^-} \qquad \mathbf{(1)}$$

The lower the soil pH, the more available the P from RP becomes. Moreover, since apatite dissolution releases $Ca^{2+}$, soils high in calcium do not support RP dissolution, in accordance with the mass action law.

The dissolution of RP will be favoured if $Ca^{2+}$ is removed from soil solution. One traditional method used to increasing P availability is the acidulation of RP with small amounts of $H_2SO_4$ or $H_3PO_4$ to produce partially acidulated RP [27]. Rock phosphate has been found to have high P contents of nearly 28-30%, it cannot be used directly as fertilizer owing to limited solubility and subsequent release of P that can be taken up by the plants. The particle size, chemical properties and mineralogical nature of phosphate rocks in accordance with the important soil properties need to be considered to assess the suitability and efficacy of the phosphate rocks in releasing the phosphates in forms which are considerably plant available [28]. Rock phosphate can be converted Phosphorus to plant available forms by utilizing them in the preparation of composts due to the prevalent low pH environment during the process of composting which in turn can also improve the nutritional value of the compost. Since farmyard manure and conventionally prepared traditional composts contain very small amount of nutrients (generally), particularly P, compost enriched with rock phosphate can be effectively used as a potential alternative for sustaining the soil quality [29].

### 8.10 Mechanisms of Phosphorus Solubilization:

The global cycling of insoluble inorganic and organic soil phosphates is attributed to microorganisms. Phosphate solubilizing microorganisms can improve the concentration of phosphorus by solubilization of organic and inorganic phosphates.

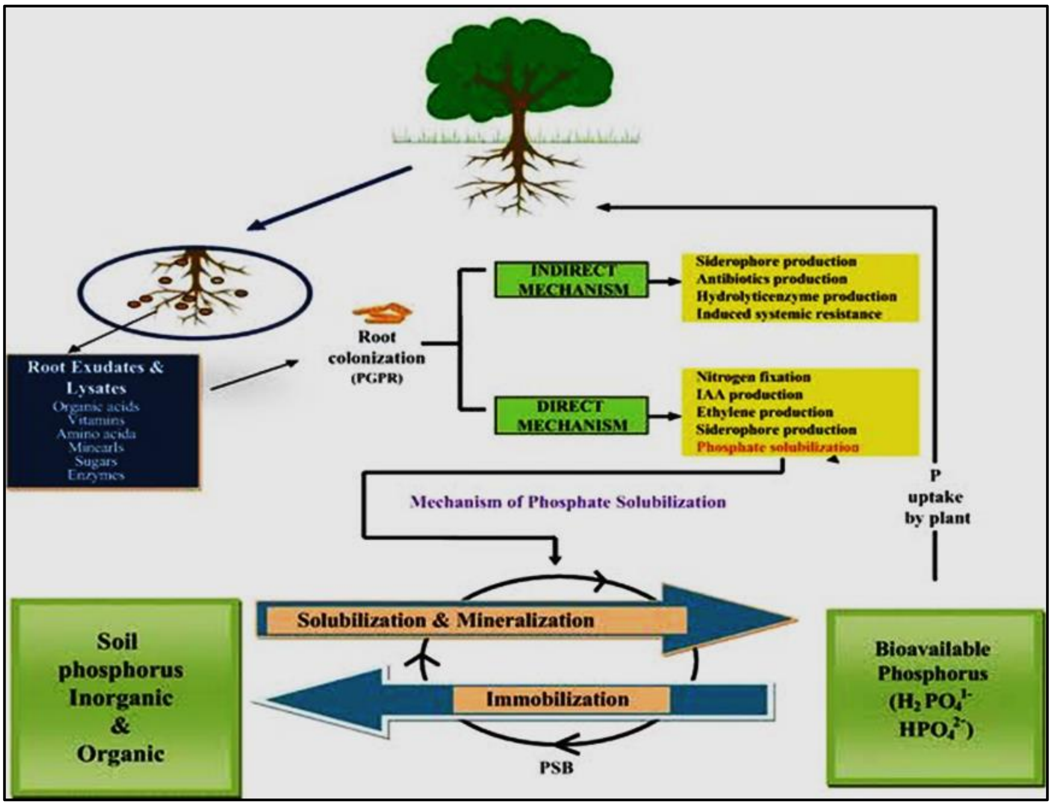


**Figure 8.1: Functional Diversity of Phosphate Solubilizing Microorganisms [Adapted from Khan et al. (2013)]**

Organic acids play a key role and responsible for solubilization of organic and inorganic phosphate. Apart from this, inorganic acids such as sulphuric, nitric and carbonic acids produced by microorganisms have been reported to solubilize inorganic phosphate.

### 8.10.1 $H^+$ Excretion:

Proton extrusion and organic acid production are the two important mechanisms for phosphate solubilization as it decreases the pH of the media which renders solubilization of inorganic phosphate.

Microbial excretion of $H^+$ occurs in response to the assimilation of cations, primarily related to N source. It is a well-known bacterial phenomenon that $H^+$ is excreted in exchange for $NH_4^+$. RP is solubilized when using an $NH_4^+$ rather than a $NO_3^-$ source of N. In the same study, it was found that pH was generally lower and titratable acidity higher, when $NH_4^+$ was used. Verity of N sources and found that ammonium sulphate promoted the most RP solubilization for bacterial and fungal species [30].

### 8.10.2 Chelation:

In addition to pH reduction, organic acid anions can solubilize RP through chelation reactions. Chelation involves the formation of two or more coordinate bonds between an anionic or polar molecule and a cation, resulting in a ring structure complex. That organic acid anions, with oxygen containing hydroxyl and carboxyl groups, have the ability to form stable complexes with cations such as $Ca^{2+}$, $Fe^{2+}$, $Fe^{3+}$, and $Al^{3+}$, that are often bound with phosphate in poorly forms [31]. The formation of complexes between chelator and cations such as $Al^{3+}$ and $Ca^{2+}$ depends on the number and kind of functional groups involved as well as the specification. Acids with an increased number of carboxyl groups are more effective at solubilizing RP.

### 8.10.3 Organic Acid Production:

Phosphate solubilizing microorganisms has a potential to convert insoluble form of phosphorus into soluble forms for healthy plant growth. Consequently, PSMs application has increased tremendously in agriculture. PSMs are known to produce organic acids in varying concentrations and types. Commonly reported organic acids produced by microorganisms include gluconic acid, citric acid and oxalic acids. The production of organic acid was the major mechanism involved in the solubilization of rock phosphate by the PSMs but other mechanisms might be involved. In vitro conditions, the growth medium has decreased as a result of the release of organic acids by PSMs [32].

The export of organic acid anions by microbes can occur by an $H^+$ transport system, causing acidification of the extra cellular solution. Organic acid production, consequently the pH change and reduction potential are thought to be responsible for the dissolution of tricalcium phosphate in the culture medium. Plants most commonly produce citric acid, oxalic acid and malic acid. Organic acids either directly dissolve mineral phosphates as a result of anion exchange reactions or chelate iron, aluminium and calcium (Ca) ions associated with phosphate generating soluble monobasic ($H_2PO_4^-$) and dibasic ($HPO_4^{2-}$) ions [33].

$$\textbf{(Di- Calcium phosphate)} \quad CaHPO_4 + H^+ \leftrightarrow H_2PO_4^{-1} + Ca^{+2}$$

$$\textbf{(Hydroxyapatite)} \quad Ca_5(PO_4)_3(OH) + 4H^+ \leftrightarrow 3HPO_4^{-2} + 5Ca^{+2} + H_2O$$

In acidic soils, the presence of organic acids propitiates the formation of complexes with Al and Fe ions, which in turn facilitates the dissolution of these minerals.

If $Fe^{3+}$ and $Al^{3+}$ are sequestered via chelation with organic anions the following reactions proceed to the right.

$$\textbf{(Strengite)} \quad FePO_4.2H_2O \leftrightarrow HPO_4^{-2} + \text{chelate-}(Fe^{3+})\ OH^- + H_2O$$

$$\textbf{(Variscite)} \quad AlPO_4.2H_2O \leftrightarrow HPO_4^{-2} + \text{chelate-}(Al^{3+})\ OH^- + H_2O$$

The ability of PSMs to solubilize P complexes has been attributed to the process of acidification, chelation, exchange reactions and production of organic acids.

### 8.10.4 Ligand Exchange Reactions:

Through ligand exchange reactions organic acid anions can mobilize P from the phosphate anions that are adsorbed to crystalline Fe $(OH)_3$ and Al $(OH)_3$ surfaces by chelating metal ions associated with bound P. These ligand exchange reactions where hydroxide ions replace phosphate, causes decrease in the pH and P binding capacity of Fe and Al and consequently release P. In a study using four soils of varying pH, $CaCO_3$ and organic C contents, all soils more P was mobilized when citrate was added than when the soil, was subjected to a wide range of pH changes.

This study showed that the phosphorus was fixed due to ligand exchange between the citrate and the P absorbed to iron and aluminium ion sites rather than dissolution from Ca-P precipitates.

## 8.11 Mineralization of Organic P:

Soil enzymes like phosphatase (acid and alkaline) have an important role to play in the transformation of organic form of P into different inorganic forms for increasing the plant uptake, particularly when the availability of P tends to limit plant growth and its productivity. The activities of important soil enzymes like dehydrogenase and phosphatases (both acid, alkaline or neutral) are considered as important factors for regulation of the rate of mineralization of organic P in soil, and also is a conclusive determinant for P deficiency. The mixed cultures of PSMs are most effective in mineralizing organic phosphate. Phytates account for a large component of the organic P, some 20-50 % of the total soil organic P. yet appear to be only poorly utilized by plants [34].

## 8.12 Designing of Medium:

### 8.12.1 Agricultural Wastes as Raw Materials of Medium:

The Synthetic media cost increases very rapidly these days. It is only used for lab purposes. But in the field application, synthetic media is not compatible. So this problem can be solved by agricultural waste media. Agricultural wastes contain lots of organic components. They increase the fertility of soil and soil quality. Agricultural wastes and organic wastes are highly nutritious and found all types of nutrients for microbial and plant growth.

For this property of agricultural wastes can be used as microbial growth media. They are cost effective and we easily get the agricultural wastes left after crop harvesting. Their use does not cause any kind of environmental pollutions. Agricultural wastes contain organic components that increase the water holding capacity in the soil. Agricultural waste media can be used in the place of synthetic media or chemical media due to the presence of excessive nutrients in it.

Sugarcane bagasse contain high amount of sugar and other essential nutrients, which are mostly used in making agricultural wastes media. The process of photosynthesis in sugarcane plant is very fast and their dry matter per hectare is approximately 60 tones. Sugarcane is used by many industries to make products.

After which a large amount of sugarcane waste is obtained as sugarcane bagasse. In which there is still a lot of nutrients left. So that it is used in making media [35].

Rice straw represents an important crop product in India. About 10 million tons of rice straw was produced every year from the rice fields. Using rice straw as agricultural media for agriculture production is one of the proposed practical uses. The use of compacted rice straw as organic media in open field production is a new approach. Rice straw pulp contain good source of N and C [36].

## 8.13 Effect of Phosphate Solubilizing Microorganisms on Crops:

Microorganisms have enormous potential in providing soil P for plant growth. The phosphate solubilizing bacteria as inoculants simultaneously increases P uptake by the plant and crop yield. These PSMs effect directly and indirectly on plant growth. Direct effects include the increased solubilization and uptake of nutrients or production of plant growth regulators, while the indirect effects include suppression of pathogens and producing metal binding molecules, known as siderophores. In most bacteria, mineral phosphate dissolving capacity has been shown to be due the production of organic acids.

The chemical messengers by producing hormones, which are effective at very low concentration. They are synthesized in one part of the plant and are transported to another location and affect a plants ability to respond to its environment. Phosphate solubilizing bacteria assist in good supply of nutrients to plants, improve soil structure and also help in the bio accumulation or microbial leaching of inorganic compounds [37]. The plant microbe interaction by PSMs in the rhizosphere play a vital role in transformation pathways, mobilization of nutrients and solubilization processes of nutrients from limited nutrient pool and subsequently uptake of essential nutrients by plants to realize their genetic potential.

## 8.14 Application of PSB in Crop Production:

Phosphate solubilizing microorganisms play an important role in enhancement of growth and yield of crop plants by providing them phosphorus, which is otherwise unavailable to plants. These microorganisms can directly or indirectly affect the plant growth.

Considerable success was acclaimed in increased yield and quality of crops due to increased phosphate uptake by inoculating seeds with efficient phosphate solubilizers. Statistically significant increase in yield of the order of 5 to 10% has been recorded in about 30% of large number of inoculation experiments with phosphate solubilizing Microorganisms [38]. PSMs are environmental friendly they reduce environmental problems and maintain soil health.

They produce many types of organic acids and secondary metabolites which mineralize plants. PSMs increase bioactivity in rhizospheric regions of soil, which affect plant productivity and crop yield. Increasing soil microbial activities, bioavailability of P in a bioactive soil was remarkably enhanced.

Such a phenomenon inspires the application of a similar principle on the bio activation of relatively nonreactive rock phosphate. The fact that certain soil microorganisms are capable of solubilizing relatively insoluble phosphatic compounds has opened the possibility for inducing microbial solubilization of phosphates in soil.

The phosphate solubilizing microorganisms onto rock phosphate or reacting the rock phosphate with a liquid culture supernatant may be considered a better means to overcome the low solubility problems of rock phosphate. Such an approach may eliminate factors inhibiting a successful interaction between phosphate solubilizing microorganisms and rock phosphate under field conditions. This approach will also make the production of single soluble phosphate possible without the use of chemical acidulation.

## 8.15 Field Inoculation in Combination with PSM and Application of RP:

The microorganisms have enormous potential in providing soil P for plant growth. Combined application of rock phosphate and PSMs has produced mixed results on plant growth responses, which were perhaps attributed to differences in microbial strains and soils. There are some species of microorganisms which have the potential to mineralize and solubilize organic and inorganic phosphorus in soils.

The genera *Pseudomonas, Bacillus* and *Rhizobium* are among the most powerful phosphate solubilizers. Phosphorus solubilizing activity is proved by the ability of microbes to release metabolites such as organic acids. These organic acids chelate the cations bound to phosphates and thereby resulting in the conversion of the later to soluble forms.

Combine inoculation of PSMs, RP and agricultural wastes as raw materials 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. Since not many reports are available on the use of RP with PSMs as fertilizer, which is a cheap, consistent and environment friendly source of phosphate fertilizer, this is an attempt to isolate efficient phosphate solubilizers and inoculating them in the field with RP amended soils to increase the P levels [39].

## 8.16 Concluding Remarks and Future Perspectives:

Phosphate-solubilizing microbes (PSM) play an important role in P supply to plants. Their use as a biofertilizers can help in reducing dependence on chemical phosphatic fertilizers. Biofertilizers are the formulations containing viable microbial cells that are applied to soil for growth promotion of plants through direct or indirect mechanisms. They are usually prepared as carrier based inoculants containing effective microorganisms.

They settle in plant roots actively and promote plant growth by increasing nutrient uptake from rhizospheric soil. Phosphate solubilizing microbes are more significant because they are the natural source of fertilizers that improve the efficiency of soils and plants. PSMs have a great potential for phosphorus management and disease suppression in P deficient soils. Therefore, the use of environmentally friendly microorganisms is needed for plant growth promotion and disease control in sustainable agriculture.

As a result, the concept of eco-friendly agriculture is getting to be a new field of interest to diminish the harmful outcomes of commercialized farming presently being experienced.

## 8.17 References:

1. Ahmed, N., Johri, S., Sultan, P., Abdin, M. Z., & Qazi, G. N. (2011), Phylogenetic characterization of archaea in saltpan sediments. Indian Journal of Microbiology, 51: 132-137.
2. Hou, E., Chen, C., Wen, D., & Liu, X. (2015), Phosphatase activity in relation to key litter and soil properties in mature subtropical forests in China. Science of the Total Environment. 83-91.
3. Tomar, N.K., Khanna, S.S. and Gupta, A.P. (2014), Transformation of phosphates varying in citrate and water solubility in calcareous soils after incubation with cattle dung. Journal of Indian Society of Soil Science. 32: 421-426.
4. Vora, M.S., Shelat, H.N. (2017), Impact of addition of different carbon and nitrogen sources on solubilization of rock phosphate by phosphate-solubilizing micro-organisms. Indian Journal of Agricultural Science. 68: 292–294.
5. Peng, Y., He, Y., Wu, Z., Lu, J., & Li, C. (2014), Screening and optimization of low-cost medium for *Pseudomonas putida* Rs-198 culture using RSM. Brazilian Journal of Microbiology. 45(4): 1229-1237.
6. Sen, M., & Joshi, H. (2015), Study of phosphate solubilizing activity of lead tolerant *Pseudomonas aeruginosa* HMT 51 isolated from Zawar mines, Udaipur, India. Research Journal of Recent Sciences. 4: 280-282.
7. Jones, D. L., & Oburger, E. (2011), Solubilization of phosphorus by soil microorganisms. In E. K. Benemann, Phosphorus in action, Soil Biology. 169-198.
8. Khan, M. S., & Zaidi, A. (2014), Phosphate solubilizing microorganisms. (M. S. Khan, A. Zaidi, & J. Mussarrat, Eds.) Singapore: Springer International Publishing.
9. Vassilev, N., Eichler-Lobermann, B., & Vassileva, M. (2012), Stress-tolerant Psolubilizing microorganisms. Applied Microbiology and Biotechnology. 95: 851-859.

10. Gaonkar, T., & Bhosle, S. (2013), Effect of metals on a siderophore producing isolate and its implications on microbial assisted bioremediation of metal contaminated soils. Chemosphere. 93(9): 1835-1843.
11. Bajpai, P. D., & Rao, S. (2015), Phosphate solubilizing bacteria. Soil Science and Plant Nutrition. 46-53.
12. Sagervanshi, A., Kumari, P., Nagee, A., & Kumar, A. (2012), Media optimization for inorganic phosphate solubilizing bacteria isolated from Anand agriculture soil. International Journal of Life Science & Pharma Research. 2(3): 245-255.
13. Gaonkar, T., Nayak, P. K., Garg, S., & Bhosle S. (2012), Siderophore producing bacteria from a sand dune ecosystem and the effect of sodium benzoate on siderophore production by a potential isolate. The scientific World Journal. 1-12.
14. Dastager, S. G., Deepa, C. K. and Pandey, A., (2011), Potential plant growth promoting activity of *Serratia nematodiphila* on black pepper (*Piper nigrum* L.). World Journal of Microbiology and Biotechnology. 27: 259-265.
15. Sekhar, D. M. R., Dassin, Y., Momani, L. and Hamatteh, A. (2013), Phosphate rich organic manure as fertilizer. Current Science. 80(9): 72 – 80.
16. Hassan, T., & Bano, A. (2016), Biofertilizers: A novel formulation for improving wheat growth, physiology and yield. Pakistan Journal of Botany. 48(6): 2233-2241.
17. Patel, B. B., Patel, B. B., & Dave, R. S. (2011), Studies on infiltration of salinealkali soils of several parts of Mehsana and Patan districts of north Gujrat. Journal of Applied Technology in Environmental Sanitation. 1(1): 87-92.
18. Swarnalakshmi, K., Prasanna, R., Kumar, A., Pattnaik, S., (2013), Evaluating the influence of novel cyanobacterial bio filmed biofertilizers on soil fertility and plant nutrition in wheat. European Journal of soil biology. 55: 107-116.
19. Arora, N. K., Khare, E., & Maheshwari, D. K. (2010), Plant growth promoting rhizobacteria: Constraints in bio formulation, commercialization, and future strategies. In D. K. Maheshwari (Ed.), Plant growth and health promoting bacteria, Berlin, Heidelberg: Springer. 97-116.
20. Netik, A., Torres, N.V., Riol, J.M., Kubicek, C.P., (2016), Uptake and export of citric acid by microorganisms is reciprocally regulated by manganese ions. Biochimicaet Biophysica Acta. 1326: 287–294.

21. Parewa, H.P., Rakshit, A., Rao, A.M., Sarkar, N.C. and Raha, P. (2010), Evaluation of maize cultivars for phosphorus use efficiency in an Inception. International Journal of Agriculture Environment & Biotechnology. 3(2): 195-198.
22. Ghosh, P. K., Manna, M. C., Mandal, K. G. and Acharya, C. L. (2013), Effectiveness of phosphocom post application on Groundnut in vertisol of central India. International Arachis Newsletter. 21: 51-53.
23. Jha, Y., & Subramaniam, R. B. (2014), Characterization of root-associated bacteria from paddy and its growth promotion efficacy. *3 Biotech.* 4: 325-330.
24. Sharma, A., Shankhdhar, D., Sharma, A., & Shankhdhar, S. C. (2014), Growth promotion of the rice genotypes by papers isolated from rice rhizosphere. Journal of Soil Science and Plant Nutrition. 14: 505-517.
25. Mirhadi, B., Mehdikhani, B., & Askari, N. (2011), Synthesis of nano-sized betatricalcium phosphate via wet precipitation. Processing and application of ceramics. 5(4): 193-198.
26. Patil, G. B., Lakshman, H. C., Mirdhe, R. M. and Agadi, B. S. (2013), Effect of co-inoculation of AM fungi and two beneficial microorganisms on growth and nutrient uptake of *Eleusine coracana* Gaertn. (Finger millet). Asian Journal of Plant Science and Research. 3(1): 26-30.
27. Saharana, K., Sarma, M. V., Srivastava, R., Sharma, A. K., Johri, B. N., Prakash, A., et al. (2010), Development of non-sterile inorganic carrier-based formulations of fluorescent pseudomonads R2 and R81 and evaluation of their efficacy on agricultural crops. Applied Soil Ecology. 46: 251-258.
28. Hilda, R., and Fraga, R., (2012), Phosphate solubilizing bacteria and their role in plant growth promotion. Biotechnology Advances. 17: 319–339.
29. Spohn M., Treichel, N. S., Cormann, M., Schloter, M., & Fischer, D. (2015), Distribution of phosphatase activity and various bacterial phyla in the rhizosphere of *Hordeum vulgare* L. depending on P availability. Soil Biology and Biochemistry. 44-51.
30. Trivedi P., & Sa. T. (2008), *Pseudomonas corrugate* (NRRl B-30409) mutants increased phosphate solubilization, organic acid production and plant growth at lower temperatures. Current Microbiology. 56: 140-144.

31. Theunissen, J. Ndakidemi, P.A. and Laubscher, C. P. (2010), Potential of vermiform post produced from plant waste on the growth and nutrient status in vegetable production. International Journal of Phys. Science. 5(13): 1964-1973.
32. Sekhar, D. M. R., Dassin, Y., Momani, L. and Hamatteh, A. (2013), Phosphate rich organic manure as fertilizer. Current Science. 80(9): 72 – 80.
33. Meena, M. D. and Biswas, D. R. (2015), Effect of rock phosphate enriched compost and chemical fertilizers on microbial biomass phosphorus and phosphorus fractions. African Journal of Microbiology Research. 9(23): 1519-1526.
34. Kpomblekou, K., Tabatabai, M.A. (2014), Effect of organic acids on release of phosphorus from phosphate rocks. Soil Science. 158: 442–453.
35. Gerke, J., Romer, W., Beibner, L. (2018), the quantitative effect of chemical phosphate mobilization by carboxylate anions on P uptake by a single root. I. The basic concept and determination of soil parameters. Journal of Plant Nutrition and Soil Science. 163: 207–212.
36. Beura, K.S., Pradhan, A. K., Ghosh, G.K. and Kohli, A. (2019), Combined Effect of Enriched Compost and Microbial Inoculants on Soil Nutrients and Phosphorus Uptake by Rice. International Journal Current Microbiology and Applied Science. 8(2): 176-181.
37. Rajan, S.S.S., Watkinson, J.H., Sinclair, A.G., (2006), Phosphate rock for direct application to soils. Advances in Agronomy. 57: 78–159.
38. Song, J. S., Walpole, B. C., Chung, D. Y., & Yoon, M. H. (2012), Heavy metal resistant phosphate solubilizing bacteria. Korean Journal of Soil Science and Fertility. 817-821.
39. Khan, M. S., & Zaidi, A. (2007), Synergistic effects of the inoculation with plant growth promoting rhizobacteria and an arbuscular mycorrhizal fungus on the performance of wheat. Turkish Journal of Agriculture and Forestry. 31: 355-362.
40. Yadav BK, Verma A (2012), Phosphate solubilization and mobilization in soil through soil microorganisms under arid ecosystems, the functioning of ecosystems. In: Ali M (Ed) In Tech. ISBN: 978-953-51-0573-2.
41. Khan MS, Ahmad E, Zaidi A, Oves M (2013), Functional aspect of phosphate-solubilizing bacteria: importance in crop production. In: Maheshwari DK et al (Eds) Bacteria in agrobiology: crop productivity. Springer, Berlin. 237–265.

42. Mendes GO, Dias CS, Silva IR, Junior JIR, Pereira OL, Costa MD (2013), fungal rock phosphate solubilization using sugarcane bagasse. World J Microbial Biotechnology. 29:43–50.