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Phosphorus Solubilizing Microorganisms (PSMs) and Arbuscular Mycorrhizal Fungi (AMF): A Sustainable Solution for Phosphorus Nutrition in the Crops

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SUMMARY

A large fraction of phosphatic fertilizer gets fixed into the soil and is unavailable to the plants. Various soil microorganisms produce organic acids, siderophores, and many exometabolites, which help in the solubilization of the fixed form of phosphorus into the soil. Furthermore, many microbial enzymes also help in the mineralization of the organic form of phosphorus. We also discussed the on-farm mass production of arbuscular mycorrhizal fungi (AMF) using grasses plant family, which acts as phosphorus mobilizer upon root colonization.

INTRODUCTION

Phosphorus is an essential macronutrient required for the growth and metabolisms of the plants. It is necessary for the root, flower, and seed development, nitrogen fixation, rigidity for plant stalk and stem, crop quality, resistance to plant diseases, and uniform and early crop maturity. It is a vital component of ATP, nucleic acids (RNA and DNA), phospholipids, and acts as a catalyst in the conversion of many biochemical reactions inside the plants. The phosphorus deficiency leads to the yellowing, which is followed by reddish / purpling of older leaf due to anthocyanin pigment, and then necrotic lesions are formed. Purpling is mainly occurring on veins, and it can be differentiated from potassium and magnesium deficiencies, as phosphorus deficiency does not cause interveinal chlorosis. Furthermore, it does not cause general chlorosis in incase of nitrogen deficiency. Other symptoms are curling or malformation of leaves and delay in the development of young roots. When phosphatic fertilizer is applied to soils, approximately 70-90% of them get fixed in the soil. Thereby, the phosphorus use efficiency in the agricultural ecosystem is only 10-20%. In alkaline soil, phosphorus is complexed as calcium and magnesium phosphate and with iron and aluminium phosphate in acidic soils. Thus, only 1 ppm (0.1%) is available for plant growth. The best pH for P availability is 6.5-7.5. The application of phosphatic fertilizers leads to groundwater pollution and eutrophication of water bodies, and possible contaminants in the food chain.

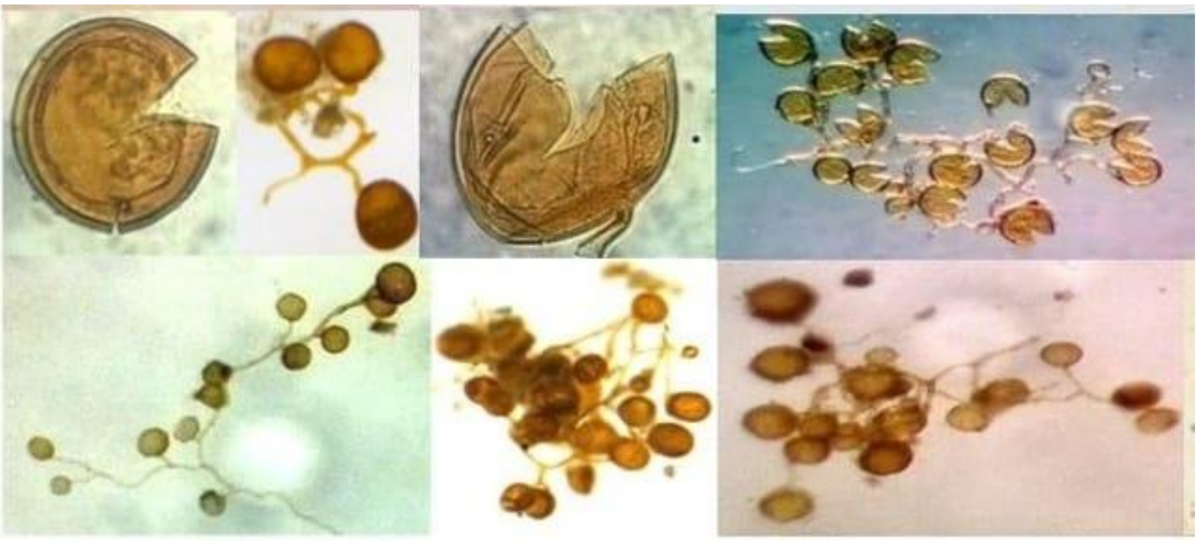

Fig: *Arbuscular mycorrhiza* spores (Source: Agnihotri *et al*., 2018)

Factor affecting phosphorus availability:

- Soil pH: The maximum availability of phosphorus occurs at 6.5-7.5 pH.

- Organic matter: soils rich in organic matter have higher amounts of organic phosphorus, thereby providing phosphorus upon mineralization. Moreover, the organic matter acts as chelating agents that bind with the cations complexed with phosphorus.
- Types of clay material: Soils rich in clay particles such as clay loam soils have higher phosphorus fixation capacity than corresponding light texture sandy soils.
- High rainfall and high-temperature areas generally have acidic soils and thereby phosphorus fixed with iron and aluminium cation.
- The low temperature of soil, compactness, and poor aeration of soil leads to phosphorus deficiency.
- Sulfur application in the soil increases the availability of phosphorus by the formation of sulphuric acid.

Phosphorus solubilizing microorganisms (PSMs)

The PSMs consists of various heterotrophic bacteria and fungi, actinomycetes, and yeasts. These PSMs are isolated from bulk soil or rhizospheric soil by enrichment methods in the Pikovskaya medium or National Botanical Research Institute P (NBRIP) medium. It could be a viable, sustainable, and cheaper option for phosphorus nutrition to the plants. Since these PSMs have several mechanisms to removed, bound cation and release available forms of phosphorus $H_2PO_4^-$ and HPO_4^{-2} into the soil solution.

Table 1. List of phosphorus solubilizing and mobilizing microorganisms

Bacteria	Fungi and others
• *Pseudomonas striata, P. putida, P. fluorescens* • *Burkholderia sp.* • *Azotobacter chroococcum* • *Bacillus megaterium, Bacillus subtilis, Bacillus circulans, B. cereus, B. pumilus, B. mycoideus, B. coagulans* • *Rhizobium tropici* • *Serratia* • *Pantoea* • *Arthrobacter* • *Klebsiella* • *Enterobacter* • *Rhodococcus* • *Phyllobacterium* • *Chrysobacterium* • *Citrobacter* • Nitrifying bacteria- *Nitrosomonas* sp. • Sulfur oxidizing bacteria – *Thiobacillus* sp. • Sulfur reducing bacteria- *Desulfovibrio* sp.	• *Aspergillus niger, A. awamori, A. nidulans* • *Penicillum digitatum* • *Trichoderma* • *Rhizoctonia solani,* • *Cephalosporium* sp. • Yeasts- *Yarrowia lipolytica* • Cyanobacteria- *Nostoc* sp., *Anabaena* sp., *Calothrix braunii*, and *Scytonema* sp., • Actinomycetes- *Streptomyces, Actinomyces* • Phosphorus mobilizers: Arbuscular mycorrhiza fungi (AMF) - *Glomus, Gigaspora* and *Aculospora*

The following are Mechanism available with PSMs:

- Organic acid production: Many bacteria like *Bacillus* sp., *Pseudomonas sp., Burkholderia sp., Azotobacter sp., Bradyrhizobium, Thiobacillus* are known for synthesizing organic acids during their metabolism. Among fungi, *Aspergillus, Penicillium, and Chaetomium are* mainly involved.
- The chief organic acids are citric, oxalic, malic, fumaric, tartaric, alpha-keto butyric, succinic, and gluconic acid, which acidify the soil and replaces calcium cation with H+ ion. Thus, Tricalcium phosphate first converted into dicalcium phosphate and finally to available phosphate to plants.
- Inorganic acid production mainly sulphuric, nitric, and carbonic acids, which tend to acidify the environment, and by chelating cations, it replaces bound cation and makes P available.

- Siderophore production, which chelates bound cation and make phosphate available for plants.
- Mycorrhizal fungi predominantly include *Glomus*, *Gigaspora*, and *Acaulospora*, known as a mobilizer and provides P nutrition.
- Carbon-dioxide production-This metabolic released CO2 binds with water, forms carbonic acid, and does as other organic acids.

Phosphorus Mineralization:

The organic P present in RNA, DNA, phospholipid cellular membrane layer, phytin, and inositol phosphate form. These are mineralized by phosphatases either by acid or alkaline phosphomonoesterases. These enzymes remove the phosphate group by breaking the ester or anhydride bond. Acid phosphatases play a significant role in mineralizing. Another enzyme is phytases, which mineralize phytate.

Mycorrhiza Production on the Farm:

Since the mycorrhiza, production in the lab is tedious/complex due to its obligate nature. Thus, On-farm production remains a viable and comparatively easier alternative by which mycorrhizal biofertilizers can be produced in large quantities. Depending upon the season, crops such as sorghum, maize, and wheat having extensive root systems are selected. Some horticultural and vegetable crops such as fenugreek and marigold may also be chosen depending upon the season. The field is prepared on slightly elevated land by ridges and furrow method to prevent water stagnation. The soil may be sterilized by solarization with black polyethylene. The mycorrhiza procured from an authentic source is applied below the seed. A culture containing native AMF species also proves efficient for mass multiplication as these species are well acquainted/ adapted to the local soil conditions. Similarly, a patch in the farmland can also be dedicated to mycorrhizal production. Mycorrhiza colonizes the growing plant root, and as the plant matures, roots are harvested, and rhizospheric soil is collected. The roots are then cut into pieces and mixed with rhizosphere soil to prepare the inoculum. The infectivity potential (IP) of the inoculum is then checked by conducting a small experiment diluting the inoculum with sand and organic substrates. The seeds of a mycotrophic plant such as sorghum are sown, and plants are harvested after 16 days. The roots are then stained with AM specific staining techniques and examined for primary infectious points under a compound microscope. The dilutions and number of primary infectious points are used to calculate the IP g-1 soil and, thereafter, the inoculum dosage. The critical factors to be considered while working with AMF cover the following: i) Type of infectious propagule viz., spores (intraradical/extraradical), vesicles, hyphae (intraradical/extraradical) produced by AMF ii) Soil edaphic factors iii) Soil management history iv) Native mycorrhizal species and population. The site dedicated to mycorrhizal production should never be subjected to fallow or planted with non-mycorrhizal crops such as mustard. The field should also be preferably managed without tillage and supplied with organic manures under low P conditions.

CONCLUSION

The use of PSMs and AMF can enhance the phosphorus availability to the crop plants though different mechanisms. It is a cheaper, environmental friendly and sustainable way of applying phosphorus nutrition to the plants.

Disclaimer: The content of this article is a personal opinion and experience of the authors, not necessarily an endorsement or suggestion of the institute where they are associated with.

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