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Solubilization of Phosphorus and Potassium by Soil Microorganisms

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Microorganisms play a crucial role in plant health and growth by solubilizing, or making available, essential nutrients like phosphorus and potassium that are often locked up in the soil. Bacteria are more effective in phosphorus solubilization than fungi. The principal mechanism is the production of mineral dissolving compounds such as organic acids, siderophores, protons, hydroxyl ions and CO_2. Potassium promotes the activation of enzymes, the utilization of nitrogen and the syntheses of sugars and protein. Among the different organic acids involved in the solubilization of insoluble K, tarteric acid, citric acid, succinic acid, α-ketogluconic acid, and oxalic acid are the most prominent acids released by KSB.

Phosphate Solubilization by Soil Microorganisms

Phosphorus is an important nutrient for plants. The dynamics of phosphorus in soil is closely related to the dynamics of the biological cycle in which microorganisms play a central role. Microorganisms affect the amount of phosphorus accessible to plants by means of mineralization of organic phosphorus compounds, immobilization of available phosphorus and solubilization of non-soluble phosphorus minerals such as tri-calcium phosphate. Organic phosphorus compounds in soil are an important supply of this plant nutrient but only after they have been mineralized. Bacteria like *Pseudomonas striata*, and *Bacillus megaterium* are also important phosphorus solubilizing soil microorganisms. Many fungi like *Aspergillus* and *Penicillium* are potential solubilizers of bound phosphates(Stamenov *et al*., 2012). They solubilize the bound phosphorus and make it available to the plant, resulting in improved growth and yield of crops. Many Phosphate Solubilizing Bacteria (PSB) including species of *Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Alcaligenes, Arthrobacter, Burkholderia, Bacillus, Rhizobium* and *Serratia* have been reported to enhance plant growth in many commercially important crops.

The commonly reported genera include *Achromobacter, Aereobacter, Agrobacterium, Bacillus, Burkholderia, Erwinia, Flavobacterium Micrococcus, Rhizobium and Pseudomonas*. The microbial fungi that function similarly include strains of *Achrothcium, Alternaria, Arthrobotrys, Aspergillus, Cephalosporium, Cladosporium*.In addition, approximately 20% of actinomycetes could solubilize P, including those in the genera *Actinomyces, Micromonospora,* and *Streptomyces*. Algae such as cyanobacteria have also been reported to show P solubilization activity. However, the most efficient phosphate-solubilizing microorganisms (PSM) belong to the bacterial genera Bacillus and Pseudomonas and the fungal genera *Aspergillus* and *Penicillium* (Alori *et al.*, 2017).

The principal mechanism is the production of mineral dissolving compounds such as organic acids, siderophores, protons, hydroxyl ions and CO_2. The organic acids are produced in the periplasmic space by the direct oxidation pathway and results in released by substitution of H^+ for Ca^{2+} discovered that no correlation exists between the pH and the amount of P solubilized. An alternative mechanism to organic acid production for solubilization of mineral phosphates is the release of H^+ to the outer surface in exchange for cation uptake or with the help of H^+ translocation ATPase. It was also reported that the assimilation of NH^{4+} within microbial cells is accompanied by the release of protons and this results in the solubilization of phosphorus without the production of any organic acids. Of all the organic acids, gluconic acid is the most frequent agent of mineral phosphate solubilization; it chelates the cations bound to phosphate, thus making the phosphate available to plants (Pereira, 2019).

Other mechanisms of mineral phosphate solubilization by microorganisms are the production of inorganic acids (such as sulphuric, nitric, and carbonic acids) and the production of chelating substances. It has, however, been reported that the effectiveness of the inorganic acids and the chelating substances in the release of phosphorus in soil is less than that of the organic acids. Furthermore, Mycorrhizal fungi effectively extend plant roots, aiding crop phosphorus nutrition by increasing the volume of soil from which phosphate may be absorbed.

Another mechanism of microbial phosphate solubilization reported in the literature is the liberation of enzymes or enzymolysis, the mechanism of P solubilization by PSM in a medium containing lecithin where the increase in acidity is caused by enzymes that act on lecithin and produce choline. The major source of organic phosphorus in soil is the organic matter, largely in the form of inositol phosphate (soil phytate). Most of the organic compounds are high molecular-weight materials that are generally resistant to chemical hydrolysis and must therefore be bio-converted to either soluble ionic phosphate (Pi, HPO_4^{2-}, H_2PO^{4-}), or low molecular-weight organic phosphate, to be assimilated by the cell.

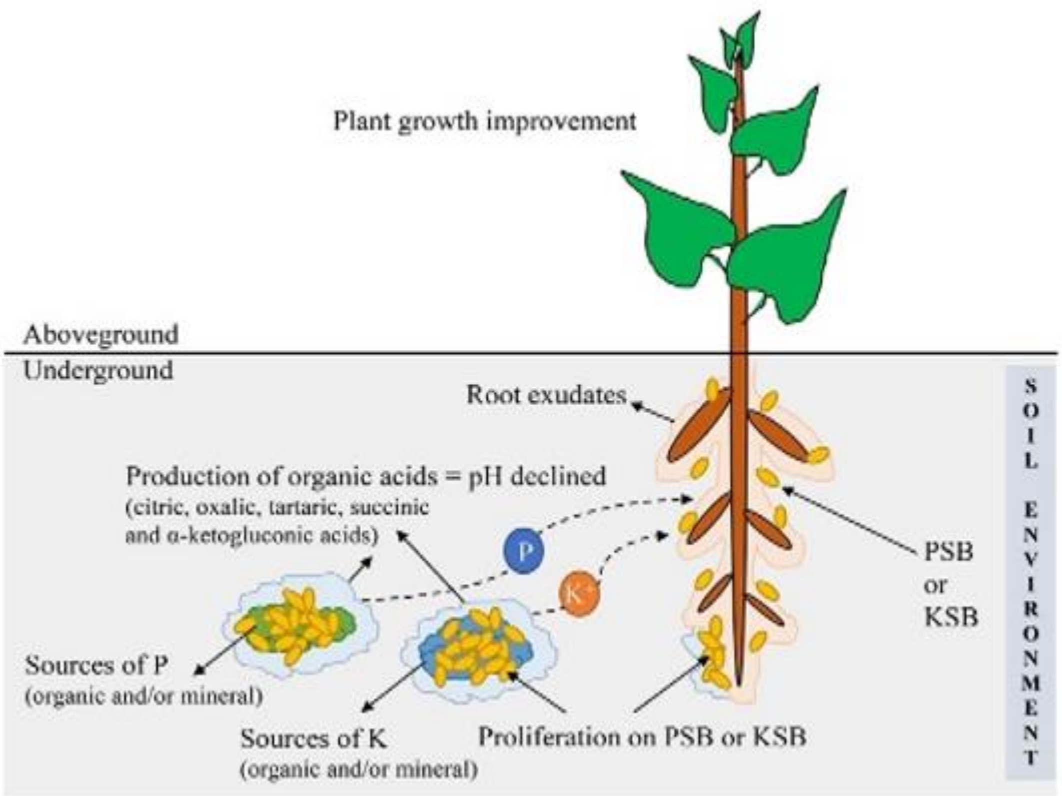

Fig. 1: Schematics representation of the interaction between potassium-solubilizing bacteria (KSB) or phosphate-solubilizing bacteria (PSB) and plant root (Adapted from Bakhshandeh *et al.*, 2017)).

Potassium Solubilization by Soil Micro-organisms

Potassium (K) is essential to plant growth and development. It is involved in the adjustment of cellular osmotic pressure and the transportation of compounds in plants. It promotes the activation of enzymes, the utilization of nitrogen and the syntheses of sugars and protein. It also boosts plant photosynthesis. A diverse group of soil microorganisms was reported to be involved in the solubilization of insoluble and fixed forms of K in to available forms of K which is taken up by plants. A number of microorganisms namely *Bacillus mucilaginosus, Bacillus circulans, Bacillus edaphicus, Acidothiobacillus ferrooxidans, pseudomonas, Burkholderia* have been report to release potassium in accessible form from K bearing minerals in soil (Etesami *et al.*, 2017). A variety of soil microorganisms have been

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found to solubilize silicate minerals. The potassium solubilizing fungi strains such as *Aspergillus terreus* and *Aspergillus niger* were isolated from various K rich soil samples and observed increase soil fertility.

Soil bacteria are capable of transforming soil K to the forms available to plant effectively. There is considerable population of KSB in soil and in plant rhizosphere. A considerably higher concentration of KSB is commonly found in the rhizosphere in comparison with non-rhizosphere soil. Solubilization of K by KSB from insoluble and fixed forms is an import aspect regarding K availability in soils. The ability to solubilize the silicate rocks by *B. mucilaginosus, B. circulanscan, B. edaphicus, Burkholderia, A. ferrooxidans, Arthrobacter sp., Enterobacter hormaechei, Paenibacillus mucilaginosus, P. frequentans, Cladosporium, Aminobacter, Sphingomonas, Burkholderia, and Paenibacillus glucanolyticus* has been reported. Among the soil bacterial communities, *B. mucilaginosus, B. edaphicus and B. circulanscan* have been described as effective K solubilize (Bashir *et al*., 2017). In general, the microbial solubilization of K is strongly influenced by pH, oxygen, the bacterial strains used, and kind of K bearing minerals; in fact, moderate alkalinity favors the solubilization of silicate.

Currently there is little information available on the mechanisms which by KSB can solubilize K-bearing minerals and release K for improving the growth and yield of plant. It is generally believed that microorganisms contribute to the release of K^+ from K-bearing minerals by several mechanisms. Released H^+ can directly dissolve the mineral K as a result of slow releases of exchangeable K, readily available exchangeable K. As occurs in the case of P solubilization, the major mechanism of K mineral solubilization is by production the organic and inorganic acids and production of protons (acidolysis mechanism) which are able to convert the insoluble K (mica, muscovite, and biotite feldspar) to soluble forms of K, easily taking up by the plant . The types of various organic acids such as oxalic acid, tartaric acids, gluconic acid, 2-ketogluconic acid, citric acid, malic acid, succinic acid, lactic acid, propionic acid, glycolic acid, malonic acid, fumaric acid, etc. have been reported in KSB, which are effective in releasing K from K-bearing minerals. It has also been known that the type of the organic acid produced by KSB may be different. Among the different organic acids involved in the solubilization of insoluble K, tarteric acid, citric acid, succinic acid, α-ketogluconic acid, and oxalic acid are the most prominent acids released by KSB.

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Microorganisms including KSB can have a considerable role in proving K to plant by storing K in their biomass, which is potentially available to plants. The production of various extracellular polymers can also be led to release of K from K-bearing minerals for plant uptake. These substances serve as attachment structures to mineral or rock surface. Solution containing fresh microbial EPS (exopolysaccharides) increases the dissolution rate of feldspars probably by forming complexes with framework ions in solution. KSB also synthesize biofilms, which create controllable microenvironments around microbial cells for weathering and also regulated denudation losses by acting as a protective layer covering the mineral-water-hyphal/root hair interface in the mycorrhizosphere and rhizosphere of vascular plants. In addition, it is known that the release of organic acids from the plant roots can be effective in enhancing mobilization of mineral K. In general, the most important mechanisms known in K mineral solubilization by KSB are (i) by lowering the pH; (ii) by enhancing chelation of the cations bound to K; and (iii) acidolysis of the surrounding area of microorganism.

Conclusion

Overall, the solubilization of phosphorus and potassium by microorganisms is a critical process for healthy and productive plant growth. It promotes efficient nutrient use, reduces reliance on chemical fertilizers, and contributes to a more sustainable agricultural system.

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