Editorial

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Phosphate-Solubilizing Microorganisms for Agricultural Sustainability

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Phosphorus is the second most vital nutrient required by every existing live on the earth including plants and humans. It is structural element of the plants and humans DNA and RNA and it plays pivotal role such as cell division, and physiological responses. The deficiency of this nutrient may leads to serious problems like; apatite loss, bone pain in humans and growth stagnation in plants. Phosphorus, although is present in the earth in huge amount but not available for the plant and humans. The plant demand of phosphorus earlier fulfilled by using the chemically prepared phosphate fertilizers but its use generally has undesirable effect on the plants, humans and animals as well as environments. Phosphate solubilizing microorganisms under the natural and stressed conditions could be alternative and eco-friendly approach for agro-environmental sustainability. These microorganisms solubilizes inorganic and organic phosphorus both through various mechanism such as production of organic acids, inorganic acid, H_2S, siderophores and protons; excretion of extracellular enzymes; direct oxidation pathway and enzymatic actions. Microorganisms with phosphate-solubilizing activity have been reported from different phyla of all three domain eukarya, archaea, and bacteria from various natural as well as stressful environmental conditions.

Phosphorus, the irreplaceable element is one of the most essential elements and a pillar of food security for every living cells or organism including microbe, plant, animals and humans [1]. It is structural element of RNA and DNA which plays diverse and significant role in the living organism. In plants, phosphorus plays important role in cell division, generation of energy, macromolecules biosynthesis, membrane integrity, photosynthesis, signal transduction, and plant respiration. In leguminous plants this element also helps in the fixing the nitrogen. On the other in humans phosphorus plays pivotal role in skeletal and non-skeletal tissues and it also act as signaling molecules which helps in inducing complex physiological responses [2]. Phosphorus deficiency often occurs in poor, weathering, and calcium carbonate-rich soils. In the case of human, due to phosphorus deficiency human suffer to loss of appetite, anxiety, bone pain, fragile bones, stiff joints, fatigue, irregular breathing, irritability, numbness, weakness, and weight change. In children, decreased growth and poor bone and tooth development may occur [3].

In soil, phosphorus accounts for 50 to 3000 mg kg^{-1}, yet total P mineral available for plants uptake is 0.1%. Consequently, to fulfil the phosphorus demand of plant, huge amount of phosphatic fertilizers were being produced and used. The use of chemical phosphatic fertilizers over the long period of time has resulted in the precipitation of the fertilizer in the soil in huge proportion. With scientific advancements and modernization in agricultural practices, utilization of the agrochemicals to obtain high yield has been increasing over time. So, phosphatic fertilizers are also used in recommended doses to fulfil P requirement the demands. But, production of phosphatic fertilizers requires high cost and their excessive use is unsafe for the environment [4]. Therefore, researchers are focusing to find alternative and eco friendly strategies to deal with the problems of P availability and solubilization [5, 6]. The huge amount of fertilizer accumulation has resulted in the causing

Table 1: World phosphate fertilizer demand (thousand tonnes P_2O_5) forecast.

	2016	2017	2018	2019	2020	2021	2022
World	44481	45152	45902	46587	47402	48264	49096
Africa	1676	1827	1942	2030	214	2194	2274
Americas	12121	12237	12488	12713	12932	13165	13387
North America	5007	502	5135	5183	5220	5261	5294
Latin America & Caribbean	7114	7213	7353	7530	7712	7904	8094
Asia	25445	25719	26100	26357	26774	27217	27662
West Asia	1148	1104	1091	1072	1065	1059	1054
South Asia	8586	8801	9118	9323	9690	10071	10457
East Asia	15711	15814	15891	15962	16019	16087	16151
Europe	4030	4048	4089	4180	4262	4355	4435
Central Europe	793	817	827	843	868	908	940
West Europe	1820	1784	1771	1774	1772	1769	1766
East Europe	1418	1447	1490	1563	1622	1677	1729
Oceania	1208	1322	1283	1307	1321	1333	1337

Source: FAO [11]

deleterious harm to animals, consumer health and soil fertility [7]. Phosphate-solubilizing microorganisms use as a bioinoculants is the sustainable and alternative approach that could help in achieving the same goal as chemical phosphatic fertilizers and phosphate-solubilizing microorganisms as bioinoculants in the fields could help in reducing the fertilizer input [8, 9].

Phosphorus is mostly found in the atmosphere as small dust particles. In soil, phosphorus is present in the two forms i.e., 30-65% organic P (Inositol, phosphate, phospholipid and nucleic acid) and 35-75% inorganic P (Ca, Fe and Al phosphates). Phosphorus enters into soil through chemical fertilizers (inorganic sources), compost, biosolids, or dead plant or animal debris (organic sources), it cycles between several soil pools through the processes such as mineralization, immobilization, adsorption, precipitation, desorption, weathering, and dissolution [10]. Consequently, there has been an increase over the years in the demand for and use of phosphatic fertilizers to maintain a continuous supply of phosphorus in plants (Table 1) [11]. Humans have a substantial impact on the phosphorus cycle due to a variety of human activities, such as the use of chemical fertilizer, food distribution, and artificial eutrophication. Excessive use of these fertilizers reduces soil fertility and is harmful to soil microorganisms. When these flow into the surrounding water bodies, they pose a threat to the flora and fauna of the ecosystem. Thus, human activities tend to damage aquatic ecosystems whenever excess amounts of phosphorus are released into the water.

Phosphate solubilizing microorganisms solubilizes phosphorus for their own requirement and use which also fulfil the P mineral demand of the plants. Phosphate-solubilizing microorganisms disseminate phosphorus by three predominant ways i.e. mineralization, solubilizing and immobilization [12]. Phosphate solubilizing microorganism follows exhibits different mechanism for the solubilization of inorganic and organic phosphorus minerals present in soil (Figure 1). Inorganic phosphate including Fe-P, Ca-P and Al-P, solubilization is achieved by the microorganisms by mechanism such as production of organic acids, inorganic acid, H_2S, siderophores and protons; excretion of extracellular enzymes; and direct oxidation pathway. On the other hand, the organic phosphate is solubilized *via* enzymatic action of non-specific acid phosphatases, C–P lyases, phytases, and phosphonatases. Phosphate solubilization through the organic acid productions is one of the most known mechanisms of soil and plant allied microorganisms. Microorganisms produced different types of organic acid namely, oxalic acid, tartaric acid, citric acid, gluconic acid and 2-ketogluconic acid. These organic acids helps in the cation and complexation of chelation and metal ions bound to phosphate, lowering of pH which avail the P for the uptake [13].

In the strategy of inorganic acid production, phosphate-solubilizing microorganisms produce acids like carbonic acid, nitric acid, sulfuric acid and hydrochloric acid, but these acids have low efficiency of P solubilization as compared to organic acid [14]. In the mechanism of proton extrusion from ammonium, phosphate-solubilizing microorganisms produce

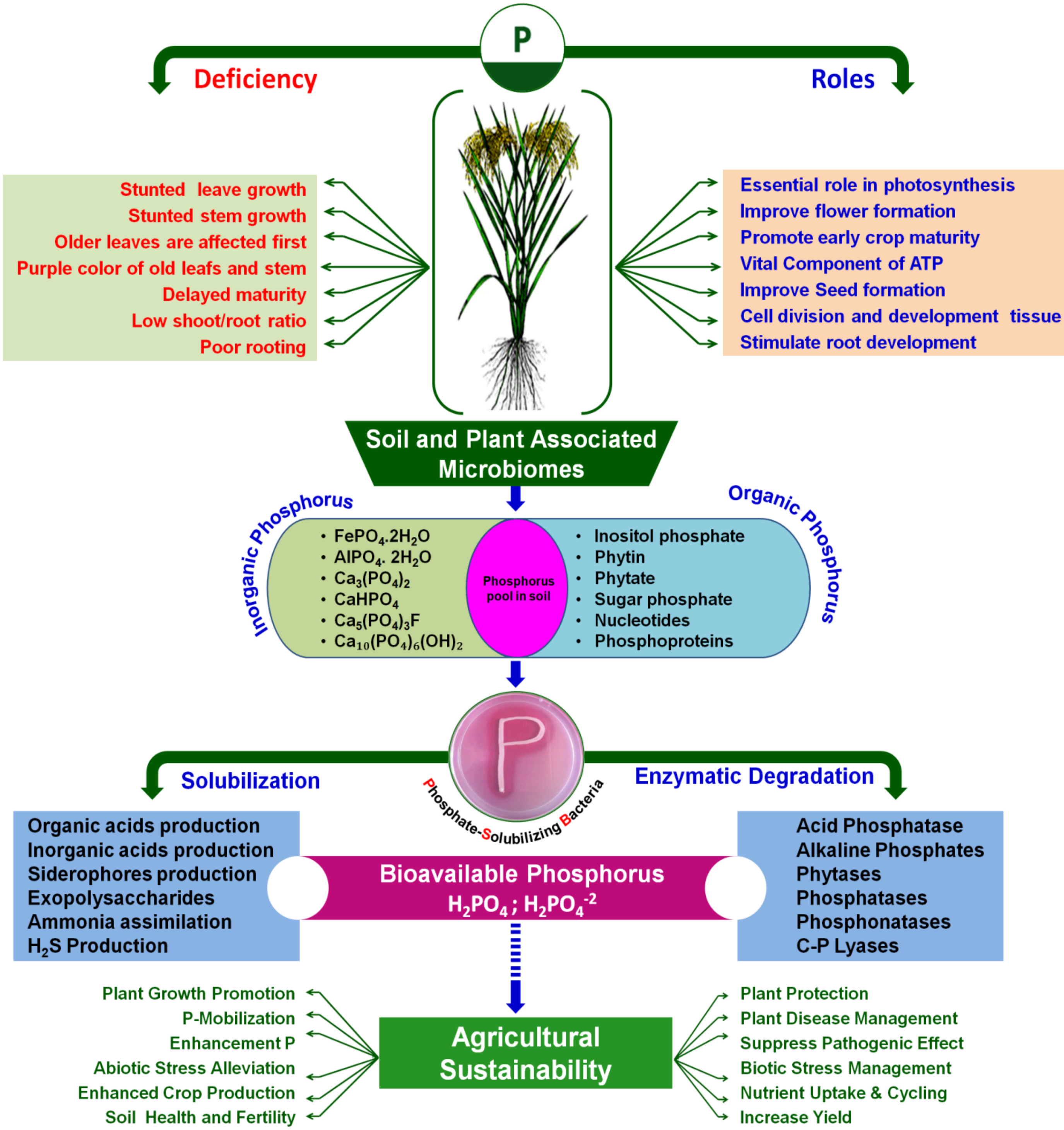

Figure 1: Schematic presentation of phosphate solubilization by phosphate-solubilizing microorganisms and their role for agricultural sustainability

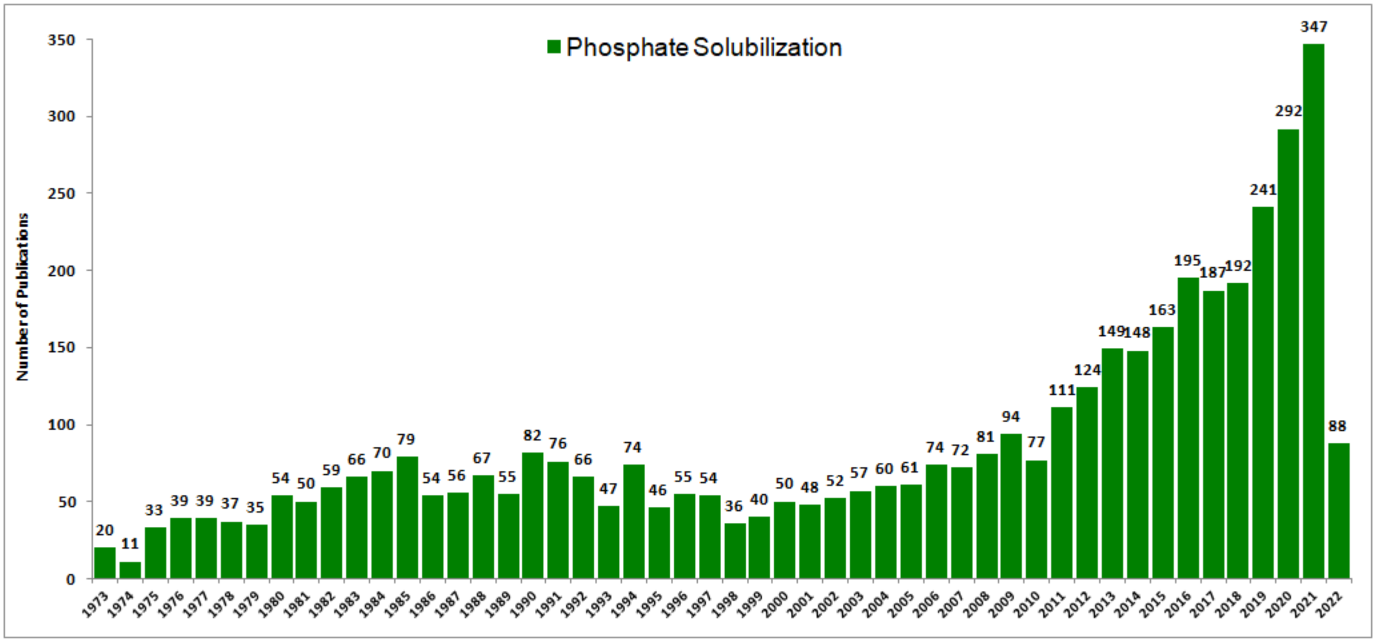

Figure 2: Number of research publications on phosphate solubilization [Source-PubMed]**.**

amino acids and which is assimilated by the ammonium ion present in soil that converted into ammonia. The excess of proton H^+ present in the microbial cell is released into the cytoplasm. The ion released in soil lowers the pH and dissolute the insoluble phosphate [15]. Another mechanism of P-solubilization i.e. direct oxidation pathway releases inorganic P bound with Ca^{2+} and Fe^{2+}. In this mechanism glucose is converted into gluconic acid in the presence of enzyme glucose dehydrogenase. The gluconic acid is further oxidized into 2-ketogluconic acid with help of gluconate dehydrogenase. The 2-ketogluconic acid act as chelators of Ca^{2+} and Fe^{2+} and which chelates them releases P mineral [16]. In the mechanism of EPS production, the microbial released EPS form the complex with metal ions and helps the release of P [16]. Mechanism of siderophores production helps in the release of P bound with Fe, as siderophores are the chelator of iron [17]. All these mechanism of phosphate solubilization is governed by the various sets of glucose dehydrogenase gene (*gcd*), pyrroloquinoline quinine (*pqq A-F*) genes and enolase gene (*eno*) [18].

Phosphate-solubilizing microorganisms have been reported from various habitats and have capability to solubilize in stressful conditions including biotic and abiotic. Various microbes have been reported so far that have capability to solubilize P in the biotic and abiotic stressful conditions [19]. In a report, plant growth promoting bacteria *Streptomyces* was reported for solubilizing phosphorus under the biotic stress of panicle blight disease in rice plant [20]. Under the rain-fed conditions, *Pseudomonas libanensis* [21], *Streptomyces laurentii*, *Penicillium* sp. [22], and *Acinetobacter calcoaceticus* [23] was reported for solubilizing P mineral. In a report, *Bacillus megaterium* and *B. subtilis* was reported solubilizing phosphorus under salinity stress [24]. Heavy metal is also known as major abiotic stressor and microbes have also been reported for solubilizing phosphorus under heavy metal stressed conditions [25]. Phosphate-solubilizing microorganisms additionally possess other plant growth promoting capabilities. They enhance growth by producing plant growth regulators such as indole acetic acid, gibberellins and cytokinins; synthesizing siderophores, solubilizing K, Zn and Mn and showing bio-control activity against plant pathogens. Phosphate solubilizers also help the plant to withstand abiotic stress conditions of drought, salinity, high and low temperature, as well as heavy metal by synthesizing ACC deaminase and preventing oxidative damage [26]. Biofertilizers are living cells of plant associate and soil microorganisms that could be used in various types of bio-formulations. Biofertilizers come in two types of bioformulations i.e., liquid and powder, both of which are commercially available in the market. As a result, scientists and biofertilizer manufacturers must to work together to resolve bottlenecks in the bacterial bioformulation process [27]. There are huge and vast varieties of finding as phosphate solubilization for agricultural sustainability (Figure 2)

In conclusion, the scientific community is greatly focusing on more utilization of phosphate solubilizers with multifarious PGP attributes. Phosphate-solubilizing microorganisms can thus be utilized as bioinoculants to enhance the availability of P and to promote the growth of the plants and restore the fertility of the soil. It not only plays structural role in plant but also controls the metabolic functions of the plants. Phosphate-solubilizing microorganisms could be applied to crops to promote the growth or enhance P-availability simultaneously to reduce the dependence on chemical phosphatic fertilizers and restore soil fertility. Further understanding and study of genetics behind the phosphate solubilization would also be very beneficial. Lastly, the transfer of knowledge from the scientific community to farmers to appreciate and more utilization of bio based inoculants are of major importance.

CONFLICTS OF INTEREST

Author declares that there are no conflicts of interest.

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