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A Way to Curb Phosphorus Toxicity in the Environment: Use of Polyphosphate Reservoir of Cyanobacteria and Microalga as a Safe Alternative Phosphorus Biofertilizer for Indian Agriculture

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Phosphorus is one of the major elements present in the synthetic chemical fertilizers widely used in agriculture all over the world. India is reported to be the second largest consumer of phosphorus fertilizers after China and utilizes 19% of global consumption.[1] Phosphorus consumption in India exhibited the steepest rise in phosphate use, almost doubling between 2002 and 2009 (80% increase). A recent study[2] found that inorganic mineral phosphate fertilizer accounted for 78% of the phosphorus inputs in Indian Agriculture, while only 20% of the phosphorus applied is recovered in the crop annually. The study predicted, however, that the consumption of phosphorus fertilizer will increase in the future. The chemical inorganic phosphorus fertilizers, available at Government subsidized prices and its unrestrained use in India will contribute toward pollution of the agricultural soil and failure of crop species is often reported due to this phosphorus toxicity. An inexpensive alternative to reduce phosphorus toxicity in Indian agriculture is to substitute the inorganic phosphorus fertilizers with polyphosphate accumulating cyanobacteria and microalga as biofertilizers. Cost effective, commercial scale bioremediation of wastewater by cyanobacteria and microalga, coupled to the biomass harvest and application in Indian agriculture as phosphorus biofertilizer might prove to be a safe alternative for Indian soil.

Most of the common commercial phosphate fertilizers are highly water-soluble and when added to soil, only a small proportion (15−25%) becomes readily available to plants, most is stored between the readily available and less readily available pools and can only be utilized by plants later on. When applied in excess, the amount of phosphate in soluble form increases the risk that phosphorus will be lost via soil runoff or leaching. The potential negative environmental impact due to phosphorus losses from agricultural systems, especially the runoff losses of dissolved phosphorus, is far reaching and is considered as a legitimate environmental concern. Research has established that soils will require several years of continuous cropping without phosphorus additions to effectively reduce very high soil test phosphorus levels. The concept of "critical phosphorus" value for specific crop is the optimum phosphorus requirement that provides highest yield of the crop. But the accumulated excess phosphorus in the soil often exceeds this critical value. This results in environmental pollution and affects crop growth and yield.

A few studies have looked into the contamination of groundwater from overuse of phosphate fertilizers in India. A study[3] on groundwater quality from wells in Palar and Cheyyar River basin, Tamil Nadu, India, reported that 35% of the 43 samples analyzed exceeded the phosphate limit of drinking water standards in this intensive agricultural area. Studies carried out by the Indian Institute of Spices Research (IISR),[4] Kerala, India revealed presence of high levels of phosphorus in the soil samples from Kozhikode and Wayanad districts of Kerala. Overuse of phosphate fertilizers and neglect toward soil test-based fertilizer recommendations has caused alarming rise of phosphorus levels in soils from these regions. Sixty-two percent of the total samples collected from Thirunelli panchayat in Wayanad district recorded a phosphorus level of 40 kg/hectare, and 35% of the samples had more than 100 kg/hectare, well above the standard which led to crop failure.

An efficient alternative to chemical processes for remediation of inorganic phosphates from wastewater is the biological wastewater treatment with aerobically activated bacteria/cyanobacteria/eukaryotic microalgae. The phosphorus removal is effected through its assimilation as the cyanobacteria and microalgae grow and uptake the inorganic phosphorus in excess which become stored within the cells in the form of polyphosphate (volutin) granules. Inorganic polyphosphate (polyP) is a rich source of energy. These internal reserves

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support the prolonged growth and survival of the organism in adversity. PolyP compounds are linear polymers containing tens to hundreds of phosphate residues linked by energy-rich phosphoanhydride bonds. PolyP helps the cyanobacteria and microalgae to adapt to extremes of salinity, osmolarity, desiccation, UV radiation, pH, and temperature[5] in the environment.

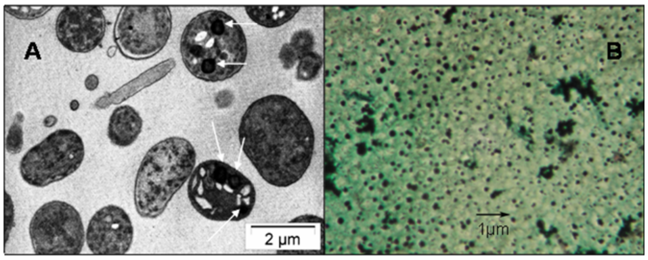

Figure 1. (A) TEM photograph of environmental isolate Fardillapur clone *Cyanobacterium* sp. JX023443 showing presence of large polyphosphate granules in side the cell (shown by arrows). (B) Polyphosphate granules isolated from *Cyanobacterium* sp. JX023443 stained with toluidine blue.

Over the last few decades, microalgal and cyanobacterial species are applied intensively to perform the biological tertiary treatment of secondary effluents. Green alga (*Chlorella* sp. and *Scenedesmus* sp.) and several cyanobacterial species (*Aphanothece* sp., *Spirulina* sp., *Arthrospira* sp., *Phormidium* sp.) have been widely used in wastewater treatment. The present research studies strengthen the concept that the harvested algal and cyanobacterial biomass developed in the biological remediation of phosphorus from wastewater can be applied to soils as slow and moderate release phosphate fertilizers, optimizing the plant growth. The release of plant available phosphate from trapped polyP of the biomass depends on the soil microbial phosphatase activity and hence this process is slow and gradual and possesses high potential of supplying phosphorus amount comparable with the "critical value" for different crops, reducing the probability of excess supply.

Our unpublished data from the experiments done under a closed system revealed that when cyanobacterial or algal biomass equivalent to the amount of chemical super phosphate fertilizer was applied to phosphorus deficient soil for the growth of rice seedlings, within a period of 30 days, the super phosphate released 1.8−2.6 times higher the amount of plant available phosphorus (Modified Morgan's extractant P) than the cyanobacteria and microalgal species. But this released P is 8 times higher than the "critical value" of phosphorus for rice crop, while it is only 3−4.4 times higher in case of the cyanobacterial and microalgal biofertilizer. This study establishes the importance of application of cyanobacterial or algal biomass in Indian agriculture as organic polyphosphate biofertilizer to avoid phosphorus toxicity leading to crop failure.

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Notes

The authors declare no competing financial interest.

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