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Cyanobacterial Biofertilizer for sustainable agriculture and environment

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Abstract
Cyanobacteria are also know as blue-green algae, invented oxygenic photosynthetic and were responsible for the oxygenation of the Earth's atmosphere. Cyanobacteria require solar radiation as a sole energy source for the fixation of carbon and nitrogen. Therefore, they have great potential as biofertilizers.Cyanobacterial biofertilizers are inexpensive, simple to use and have no problem of environmental pollution. Symbionts such a cyanobacteria increase the efficiency of nutrient acquisition by plants. Cyanobacterial biofertilizers mobilize nutritionally important elements such as P from a non-usable to a usable form through biological processes. Cyanobacteria also involved in sustainable agriculture by the process of soil heavy metal bioremediation. This review is an effort to share the valuable information about of cyanobacteria as biofertilizer and their potential role in the agricultural and environmental for the future welfare of the society.

Key words: Cyanobacteria, biofertilizers, bioremediation, sustainable, agriculture.

Introduction:

Cyanobacteria or blue-green algae are extraordinary, most diverse, and most widely distributed group of photosynthetic prokaryotes **[1].**Cyanobacteria are considered as excellent materials for investigation by microbiologist, ecologists, biochemists, and biotechnologists because they found in diverse habitats. Cyanobacteria belong to the domain Bacteria and they lack nuclear membrane and double membrane cell organelles. Cyanobacteria invented oxygenic photosynthetic and were responsible for the oxygenation of the Earth's atmosphere. According to some palaeobotanist, cyanobacteria were first to appear on the earth for over 2.5 billion years ago **[2]** and dominated the biota in the Proterozoic Era, an Era between 2.5 and 0.5 billion years ago. Proterozoic Era is also known as **"Age of Cyanophyceae" [3].** It is believed that the photosynthetic eukaryotic plant cell evolved through an endosymbiont event during which a cell engulfed a cyanobacteria which subsequently evolved to develop a chloroplast. Some of this cynobacteria can fix atmospheric nitrogen through their specialized cell called heterocyst. Cyanobacteria used as biofertilizers and they are inexpensive, simple to use and have no problem of environmental pollution There is need to adopt such sustainable agricultural practices which are not only eco-friendly, but are also cost- effective, and really help us attain the long-term food security. Cyanobacteria can be potential natural resource positively ensure the sustainable development of agriculture and environment.

Cyanobacteria as the potential biofertilizer:

Cyanobacteria require sunlight as a sole energy source for the fixation of carbon and nitrogen. Therefore, they have great potential as biofertilizers, and their use will decrease fuel demand for fertilizer production. The agronomic potential of heterocystous cyanobacteria, either free-living or in symbiotic association with water fern *Azoll*a, has long been **[4]**. This had led to the development of small scale biotechnology involving the use of paddy soils with appropriate cyanobacterial strains as biofertilizers in rice fields, as has been reported in China, Egypt, Philippines and India. *Aulosira fertilissima***,** *Anabaena* sp., *Nostoc* sp. and *Scytonema* sp.are the most abundant flora in the majority of the rice fields, whereas *Gloeotrichia* sp.,*Cylindrospermum* sp. and *Rivularia* sp. are most common in deep-water rice fields. Cyanobacteria are congenial biofertilizers for rice based cropping systems, being the major components of wetland rice ecosystems which are easily available and serve as the cheapest sources of natural biofertilizers **[5]**. Biofertilizers can fix atmospheric nitrogen for plant use and can mobilize unavailable phosphorous pool which can be used by plants. These biofertilizers are inexpensive, simple to use and have no problem of environmental pollution.

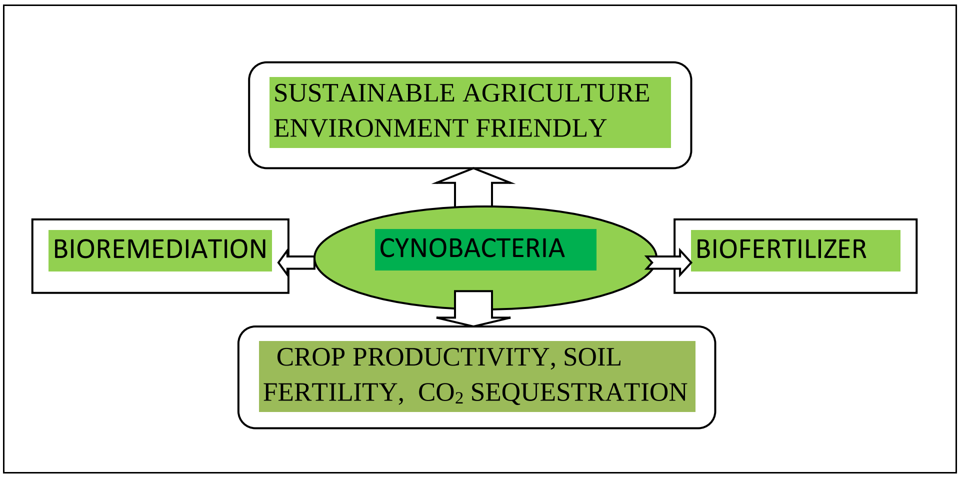

FIG-1 Role of Cyanobacteria for the development of sustainable agriculture and environment.

Need of Biofertilizer for sustainalble agriculture :

Sustainable crop production depends upon the rational use of chemical fertilizers and pesticides along with organic manures for better soil health. Some of the major objectives of sustainable agriculture include production of safe and healthy foods, conservation of natural resources, economic viability, restoration and conservation of ecosystem services. Owing to the constant production of crops from the soil, the latter is being depleted gradually of its nitrogenous and other nutrients. Moreover, in recent years increasing fertilizer costs, and concern for sustainable soil productivity and ecological stability in relation to use of chemical fertilizers, have emerged as issues of vital Concern and considered as harmful to environment. These microorganisms are distributed worldwide and improve the growth and development of the plants, with which they share the habitat, as they contribute to soil fertility in many ecosystems. They also produce various biologically active substances and have higher efficiency in biosorption of heavy metals that means they involve in the process of bioremediation **[6]**. Besides above facts, the long term use of bio-fertilizers is economical, eco-friendly, more efficient, productive and accessible to marginal and small farmers over chemical fertilizers **[7].** The Comparison between the Cyanobacterial biofertilizer and chemical fertilizer are depicted in table 1 **[8].**

Table 1: Comparison between Cyanobacteria biofertilize and chemical fertilizer.

Sl. no.	Disadvantages of using chemical fertilizer	Advantages of using Cyanobacterial biofertilizers
1	Disturb the plant-microbe associations and inhibit symbiotic nitrogen fixation by suppressing the beneficial soil microflora.	Enhance the diversity of beneficial soil microflora, plant-microbe associations and soil nitrogen fertility.
2	Softening of plant tissue resulting in increased susceptibility to diseases and pests.	Help to suppress certain soil-borne plant pathogens and parasites and protect from diseases
3	Nutrients are easily lost from soils through fixation, leaching or GHGs emission.	Nutrient supply is more balanced due to enhanced microbial activities
4	Enhance the decomposition of soil, which leads to soil acidification or alkalization, reduction in soil fertility. All of which cause irreparable damage to the overall ecosystem.	Increase the organic matter content of the soil, improve soil nutrient status and buffering the soil against acidity, alkalinity, salinity and restore soil fertility.
5	Suppress the soil methanotrophs number and Suppress the soil methanotrophs number and CH_4 sink potential.	Enhance the soil methanotrophic diversity and CH_4 sink strength in long-term.

Practice of cyanobacteria for sustainable agriculture :

The major role of biological management of soil fertility is to utilize farmer's management practices to influence soil microbial populations and processes in such a way as to achieve beneficial effects on soil productivity. Cyanobacterial as well as other soil microbial populations influence soil fertility and structure in a variety of ways, each of which has an ameliorating effect on the main soil-based constraints to productivity. Symbionts such a cyanobacteria increase the efficiency of nutrient acquisition by plants. A wide range of microbial community participates in decomposition, mineralization, and nutrient availability (microbe-mediated unusable P-availability), and therefore influence the efficiency of nutrient cycles. Soil microbial communities mediate both the synthesis and decomposition of soil organic matter and therefore, influence cation exchange capacity, the soil N, S, P reserve, soil acidity and toxicity and soil water holding capacity. Use of successful indigenous strains of cyanobacteria as the potential biofertilizer not only improves the physico-chemical and biological properties of the soil but also helps in promoting yield of various agricultural crops such as rice, wheat and pearl millet under saline, drought and contaminated agro-ecosystems. Regular application of cyanobacterial strains adapted to various extreme environments seems promising for wasteland management and improvement of soil stability, nutrient status, soil microbial activities, nutrient mineralization and crop growth in ecologically sustainable manner. Cyanobacterial biofertilizers mobilize nutritionally important elements such as P from a non-usable to a usable form through biological processes **[9]**. Cyanobacteria play an important role in various chemical transformations of soils and thus, influence the bioavailability of major nutrients like P to plants. Cyanobacteria and PSB have been used as biofertilizer to increase crop production **[10]**. Cyanobacteria can play a major role in improving the soil environment in addition to N fixation. They have the capacity to reclaim saline soils **[11]**. They can improve the organic matter content and water holding capacity of soil, and can reduce soil erosion. They can benefit the rice plants by producing growth-promoting substances, and by increasing the availability of P by excretion of organic acids **[12]**.

Diversity of cyanbacteria in rice fields

The utility of cyanobacteria in sustainable agriculture and environment can be enhanced by the healthy agro-ecosystem and gain sustainability in the true sense in order that it conserves the nature and natural resources, and also maintains the complexity and diversity of the ecosystems. The presence of cyanobacteria in rice paddy fields are reported form many countries such as Australia, Egypt, India, Indonesia, Iraq, Japan, Morocco, Philippines, and South-east Asia **[13]**.The occurrence of blue green algae in Indian paddy fields studied by several workers[**14, 15]**.Cyanobacterial diversity occurring in some local rice fields of Orissa, India has been studied and it has been found altogether 58 taxa belonging to 20 genera were obtained and characterized **[16]**. Out of these 19 forms were heterocystous and 39 were non-heterocystous. Highest abundance of cyanobacteria was reported in order Nostocales which was represented by 15 species. Among the species relative abundance of *Oscillatoria chalybea* (9.90%) was found to be highest followed by *Phormidium purpurascens* (8.49%), *Cylindrospermum muscicola* and *Oscillatoria chlorina* (8.01%). Cyanobacteria are the primary producers and the ultimate source of atmospheric oxygen. The rice fields are agronomical managed wet land ecosystem, well known for the rich diversity of cyanobacteria most paddy soils have a natural population of cyanobacteria which provides a potential source of nitrogen fixation at no cost. The paddy field ecosystem provides a favorable environment for the growth of cyanobacteria with respect to their requirements for light, water, high temperature and nutrient availability. This could be the reason for more abundant cyanobacteria growth in paddy soils than in upland soils. Cyanobacteria are ubiquitous in nature covering almost all adverse climatic conditions. Counts in 396 soils of ten countries ranged from 10 to 10^7 g^{-1}dry soil (median: 2 x 10^4) **[17]**.In rice fields, cyanobacteria are subjected to large diurnal and seasonal variations in temperature (5–60ºC), pH (5–10), O_2 concentration (0–30 ppm), and nutrient status. In arid tropics, high light intensities and temperatures may inhibit their growth at the beginning of the crop cycle. In wet monsoonal zones, they may develop early in the crop cycle during the dry/warm season, but can be inhibited during the wet season because of light deficiency and disturbance by heavy rain. The abundance of N_2-fixing forms is positively correlated with soil pH and available Phosporous. The algal flora appears to be more abundant in cultivated soils than in uncultivated one. The alga flora could be used as an indicator of soil type and condition in various habitats. In Paddy field soils species,*Anabaena circinalis*, *Nostoc muscorum*, Oscillatoria species and *Westiellopsis prolifica* are usually abundant. The ecology of paddy field environment has been relatively studied but the effect of cultivation and physicochemical conditions the effect of these on the growth of different algal species and the interrelations between the various microorganism and the plants are all undoubtedly complex. Blue green algae (BGA) are the most promising biological systems, adding the nitrogen to the paddy fields **[18].** Some of the common type of cyanobacteria present in the agriculture soil are depicted in the table no.2 **[19].**

Table 2: Common type of cyanobacteria present in the agriculture soil.

Type I Unicellular forms	(E.g**.** *Aphanorhece* and *Gloeocapsa***)** that can fix nitrogen both in aerobic and anaerobic (microaerophilic) conditions.
Type II Filamentous non-heterocystous forms.	(E.g**.** *Oscillaroria and Plectonema***)** that can fix nitrogenonly under microaerophilic conditions but not when grown in air.
Type III Filamentous heterocystous forms.	(E.g. *Anabaena, Aulosira, Calorhrix, Cylindrospermum, Gloeotrichia, Nostoc and Scyronema* that can fix nitrogen both aerobically and anaerobically.

Symbiotic cyanobacteria :

The symbiosis between cyanobacteria and plants of agronomic significance is that between *Anabaena azollae* and the freshwater fern *Azolla*. The endophytic *Anabaena* resides within a basal cavity of each leaf of *Azolla*. The association may proliferate without mineral N. *Azolla* has been used as green manure in rice fields for centuries, in North Vietnam and South China, because of its ability to grow rapidly together with wetland rice and its high N content. It prefers areas and seasons with a cool temperature (daily average around 25°C), because at higher temperatures *Azolla* growth is reduced and damage by insect pests is severe. Cool weather is a key to successful *Azolla* cultivation. *Azolla* grows optimally at pH 4.5–7.0 and survives within a range of pH 3.5–10. Azolla N becomes available to rice upon decomposition and mineralization. Nitrogen recovered by rice from ^{15}N-labeled *Azolla* ranged from 20 - 34% and was higher when *Azolla* was incorporated into the soil. *Azolla* decreases weed incidence and water evaporation. It improves soil structure as do most organic manures; that become important when an upland crop is grown after rice. ***Azolla*** is used as biofertilizer for wetland rice and it is known to contribute 40-60 kg N/ha per rice crop **[20].** Cyanobacterial biomass can be used for the production of food, energy, biofertilizers, secondary metabolites of nutritional, cosmetics, and medicinal importance. Therefore, cyanobacterial farming is proposed as environment friendly sustainable agricultural practice which can produce biomass of very high value **[21].**

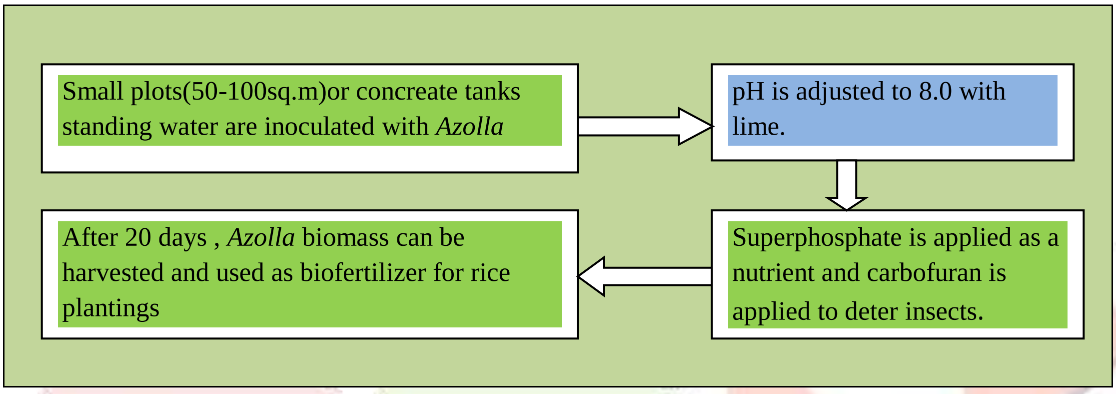

Fig -2 Mass cultivation of *Azolla* as biofertilizer

Soil heavy metal bioremediation by cyanobacteria :

Cyanobacteria also involved in sustainable agriculture by the process of soil heavy metal bioremediation. Several chemicals are released into the soil ecosystem either as a method of disposal or as a consequence of the technology of their utilization. The application of pesticides, many of which are toxic or contain toxic contaminants, which may hamper the yields in modern agriculture. With the advances in biotechnology, bioremediation has become one of the major developing research areas of environmental restoration, utilizing microorganisms to reduce the concentration/toxicity of various chemical pollutants such as heavy metals, dyes pesticides, etc. Biological treatment especially using cyanobacteria, for treatment of water bodies has many advantages over conventional methods, as cyanobacteria are cosmopolitan in environment and known to accumulate high levels of metal/pollutant; therefore, the process involved is relatively cheap and environment friendly. Cyanobacteria occurring in contaminated environments (with salts, heavy metals, pesticides and other potential toxicants) have tendency to take up and accumulate the toxicants intracellular. The pollutant level in cyanobacterial cells can even be used as the pollution indicator. Cyanobacteria are the principal primary producers of diverse type of ecosystems. Therefore tolerance of such organisms to diverse extreme environments (salinity, drought, contaminated soils, etc.) is relevant from an ecological view point. Some efficient cyanobacteria reported for the remediation of heavy metals polluted soils has been depicted in table 3. **[22].**

Table 3- Soil heavy metal bioremediation by Cyanobacteria.

Cyanobacteria	Toxicants
Spirulina platensis	Cu, Pb, Zn, Ni, Cd and Cr.
Nostoc calcicola	Cu
Microcystis sp	Ni and Cd
Oscillatoria anguistissima	Cu, Pb, Zn, Ni, Cd and Cr.
Microcystis aeruginosa f.flosaquae strain C3–40	Cd, Cu, Pb, Mn and Zn
Synechococcus sp.	Cu, Pb, Ni and Cd
Phormidium limnetica	Hg
Nostoc calcicola	Cr
Lyngbya sp	Cr

Role of Cyanobacteria in sequestering carbon:

The utilization of Cyanobacteria as a biofertilizer for rice is highly promising as the rice field ecosystem provides congenial environment for this self-supporting diazotroph. Cyanobacteria efficiently harvest solar energy and convert it into biomass by simple utilization of CO_2, water and nutrients. During conversion of radiant energy into chemical energy, these biological systems produce oxygen as a by-product. Besides nitrogen fixation, these photosynthetic algal systems can also be employed for sequestering atmospheric carbon in paddy soils. Cyanobacteria are attractive organism in carbon sequestration as they are fast growing and easier to manipulate in paddy fields and open ponds. They possess an essential biophysical mechanism (Carbon Concentrating Mechanism, CCM), which concentrates CO_2 at the site of photosynthetic carboxylation **[23].** Cyanobacterial populations occupy an important place in both aquatic as well as terrestrial ecosystems and achieve net photosynthesis event. The CCM raises the CO_2 concentration around the active site of ribulose bisphosphate carboxylase/ oxygenase (Rubisco). The enzyme uses CO_2 as the substrate but it does so with very poor efficiency. This system has the effect of increasing the photosynthetic affinity for CO_2/HCO_3^- well above the relatively poor affinity of cyanobacterial Rubisco for CO_2 **[24].**

Cyanobacteria in Reduction of Methane Emissions:

Cyanbacteria may possibly minimize the emissions of CH_4 from flooded rice soils at the levels of production,transport,and consumption. Cyanobacteria could be a big prospect to overcome the global warming problem caused by the green house gases generated from anthropogenic activities. It is assumed that cyanobacteria may enhance the oxygen concentration in rhizosphere of paddy and consequently may enhance the methane uptake activity of methanotrophs. In addition, these biological agents can minimize the global warming potential from flooded paddy apart from their ability to fix the atmospheric N_2 in the paddy soils. The O_2, released during photosynthesis by cyanobacteria into the flooded soils, can liberate into the soil and create anaerobic environment, not friendly for CH_4 genesis **[25].**

Conclusion and future prospects:

Cyanobacteria are an ancient group of unique prokaryotic organisms with the ability to perform mutually compatible functions like nitrogen fixation and photosynthesis. The capacity of several cyanobacteria to fix the atmospheric nitrogen is a significant biological process of economic importance. Members of cyanobacteria also possess a central position in the nutrient cycling largely dueto their inherent capacity to fix atmospheric N_2 through which nitrogen enters into the food chain. Estimates vary as to the contribution of biological nitrogen fixation to the global nitrogen cycle, but according to one assumption cyanobacteria fix over 35 million tons of nitrogen annually, which is thus available for use by higher plants. Cyanobacteria are cosmopolitan microorganisms, which play significant roles in diverse ecosystems. The favorable conditions provided by the rice fields for nitrogen fixation by these organisms leads to enhanced plant-available N in soil and yield improvement of rice. Therefore, the sustenance of productivity of rice fields has been attributed to their adaptation to the unique soil - water ecology, their widespread temporal and spatial distribution and diverse metabolic activities. Cyanobacteria liberate extracellular substances and modulate pH, temperature and redox activity, besides playing a role in the volatilization of ammonia and methane generation; therefore, are directly or indirectly implicated in the management and productivity of rice ecosystem. Cyanobacteria inoculation popularly known as "Algalization" helps to provide an environmentally safe agro-ecosystem contributing to economic viability in paddy cultivation, reducing cost and energy inputs. The presence of diverse forms of cyanobacteria indicates a good balancing of the ecosystem. An unbalanced ecosystem or a polluted environment may have led to the reduction in the number of species and an increase in the number of individuals into a bloom. Cyanobacterial biomass can be used for the production of food, energy, biofertilizers, secondary metabolites of nutritional, cosmetics, and medicinal importance. Since the use of cyanobacteria to produce valuable chemicals including food supplements is still little explored, there seems a long way to go. In addition to product developments, future research must address the strain improvement of useful cyanobacteria to achieve high quality food and fuel products, maintain high growth rates and survival under harsh environmental conditions. These will be the key factors to leap from laboratory studies to large-scale and profitable bio-fuel production for sustainable agriculture, ecosystem and environmental development.Therefore,cyanobacterial biofertilizer are considered as environment friendly sustainable agricultural practice which can produce biomass of very high value in low cost. Cyanobacterial biofertilizer in agriculture helps in decreasing the level of greenhouse gas, such as CO_2, and it can be also used for removing various contaminants from wastewater and soil and for betterment of healthy and sustainable agro-ecosystems.

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