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Review on Blue Green Algae (BGA): Potential Source for Carbon Sequestration in Rice Cultivation Systems

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ABSTRACT

Rice is a stable food for a many of the countries in Asia and Arica. The climatic conditions favour the cultivation of this crop in Asia and African countries. Rice is grown under the anaerobic condition and it is an important point source of greenhouse gases such as Methane, carbon-di-oxide and nitrous oxide. Blue green algae are belonging to cyanobacterial group and application of Blue green algae are emerging trend in rice cultivation which converts the radiant energy into chemical energy and also supplies nitrogen to the crop. It is an eco-friendly sustainable agricultural practice for production of biomass of very high value and emerged potential as biofertilizer which are economical and environment friendly. Application of this blue green algae in agriculture increases the yield of the crop by the addition of nitrogen and also reduce the emission of green house gases in rice cultivation systems.

Key words: *Cyanobacteria, Methane, Calcite, Sequestration*

Introduction

Ricefields are the most extensive freshwater aquatic ecosystem on Earth with more than 1.5 million square km. The submerged parts of rice plant provide a photic and aerobic environment that can be colonized by epiphytic bacteria and algae, and where populations of pulmonate molluscs can also find mechanical support (Roger, 1996). Cyanobacteria are emerging microorganism for sustainable agricultural development. Diazotrophes are cyanobacteria useful for the generation of eco-friendly biofertilizers which are easily available and less costly. They can control the nitrogen deficiency in plants, improve the aeration of soil and water holding capacity (Son *et al*., 2005).

In recent years, the use of N_2-fixing cyanobacteria as biofertilizers in rice cultivation has been popularised, where they contribute significantly to fertility. In addition to N fixation these microorganisms can play a major role in improving the soil environment and also have the capacity to reclaim saline soils (Uma and Kannaiyan, 1999). Cyanobacterial inoculum could supplement upto 20 per cent nitrogen for rice cultivation in saline soils and inoculation of the cyanobacterial inoculums in the saline soil resulted in 80.48 per cent increase in yield over control. They can improve the organic matter content and water holding capacity of soil, and can reduce soil erosion (Azizand Hashem, 2004). They can benefit the rice plants by producing growth promoting substances and by increasing the availability of P by excretion of organic acids. It is estimated that cyanobacteria contribute 20 to 80 kg N ha^{-1} per crop on turnover of their biomass in the rice fields (Whitting, and Chanton, 2001). Blue Green

Algae and *Azolla* are aerobic photosynthetic organisms. In the medium of their growth, they release a lot of O2 during photosynthesis. As a result, when they grow in rice fields they make the standing water highly oxygenated. It directly influences the dissolved oxygen and redox potential ultimately reduces the emission of methane from rice filed (Jeyapandiyan *et al*., 2017).

Blue green algae

Green algae and cyanobacteria comprise a vast group of photosynthetic organisms. They are ubiquitously distributed throughout the biosphere and grow under the widest possible variety of conditions from aquatic (freshwater to extreme salinity) to terrestrial places. Its uniqueness, that separates them from other microorganisms, is due to presence of chlorophyll and having photosynthetic ability in a single algal cell. Cyanobacteria can be subdivided into filamentous (heterocystous and non heterocystous) and unicellular types. All heterocystous types can fix nitrogen aerobically, but only a few non heterocystous filamentous and unicellular cyanobacteria possess this property (Gallon, 1980).

Predominant genera are *Anabaena sp., Nostoc sp., Calothrix sp., Aulosira sp., Aphanothece sp.* and *Gloeotrichia sp.* The cyanobacterial nitrogen fixation has a swich on mechanism which gets activated when the combined nitrogen level falls below 40 ppm which enables algal biomass to produce more of biologically fixed nitrogen as soon as the nitrogen fertilizer level is reduced in the ecosystem due to loss and utilization. It has been observed that the removal of algae from paddy field water greatly reduced the in-situ nitrogen fixation. Application of BGA by farmers can save approximately 40-60 Kg urea as an average consumption of BGA has been found to be 20-30 kg N/ha/season (Khairnar and Thakur, 2011).

First it was reported in a unicellular ensheathed cyanobacterium, assigned to *Gleocapsa* sp., could fix nitrogen aerobically. Besides their well-established role as nitrogen supplements and tolerance to desiccation, cyanobacteria can be the key players in carbon sequestration and improving nutrient use efficiency and crop yields (Rao and Burns, 1990). The major activities of microorganisms in paddy fields include methanogenesis, methane oxidation and biogeochemical cycling of carbon, nitrogen and sulphur (Kazutake, 1995).

Rice cultivation and Greenhouse gas emissions

Climate change is one of the most pressing modern day environmental issues. Natural shifts in global temperatures have occurred throughout human history. However, the 20th century recorded a rapid increase in global mean surface temperature by 0.8 °C as a result of increased greenhouse gas emissions (GHGs) through various anthropogenic sources (IPCC, 2007). This phenomenon of increased global mean temperature is termed as "enhanced greenhouse effect". Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are important drivers of this anthropogenic greenhouse effect Agricultural practices release significant amounts of Greenhouse gases (GHGs) like carbon di oxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are implicated in global warming phenomena and these play a major role in climate change.

It is estimated that agriculture accounts for 10 to 12 per cent of total global anthropogenic emissions of GHG, which amounts to 50 per cent and 60 per cent of global CH_4 and N_2O emissions, respectively (Smith *et al*., 2007). The concentrations of CH_4 and N_2O are lower than CO_2 but their global warming potential are 23 and 296 times as strong as that of CO_2 respectively. The concentration of CH_4 increase is 4.9 ppb yr^{-1} and N_2O increase is by 0.8 ± 0.2 ppb yr^{-1}. N_2O is a more potent GHG than CH_4 with a radiative forcing potential that is approximately 12 times larger. Increasing atmospheric N_2O concentration may also be detrimental to the stratospheric ozone layer.Rice fields are an important atmospheric methane (CH_4) source, contributing about 5 to 19 per cent of total global CH_4 emissions to the atmosphere (IPCC, 2007). The 18th century Italian physicist Alessandro Volta first identified methane from a waterlogged marsh (Reay *et al.*, 2010).

Blue Green Algae and Carbon precipitation

Microbial based technologies, specifically those utilizing photoautotrophs, represent a promising solution once methods of carbon uptake and disposition by the cell are determined. Microorganisms have been agents for geochemical change for over 85 per cent of the earth's history, and linkages between the geochemical and biological evolution of the earth are profound. It is widely accepted that microorganisms were largely responsible for production of oxygen in the earth's atmosphere and that through their metabolism they can dramatically alter elemental distributions. Interactions between the biosphere and geosphere are complex because organisms are able to transform the chemistry of their environment (Satpathy, 1997).

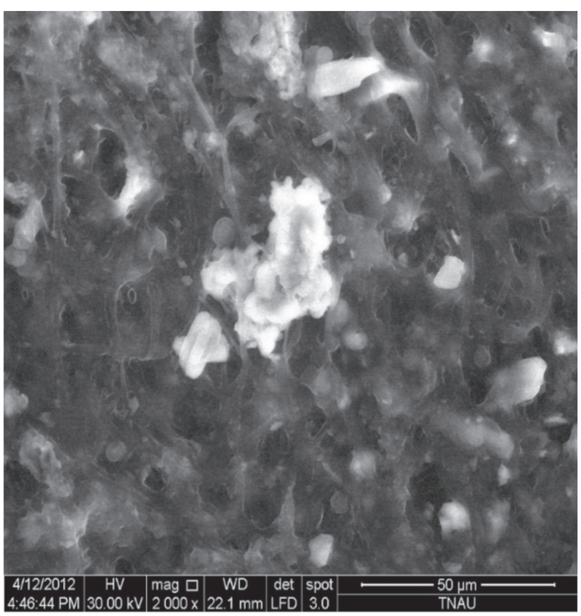
In considering the earth's carbon distribution, it is relatively easy to ascertain that much of the carbon that is represented in the global carbon cycle is sequestered primarily as calcium and calcium– magnesium carbonates (Ehrlich, 1996). In many cases, the carbonates are of biogenic origin, some precipitated by bacteria, cyanobacteria and fungi. Actinomycetes cultures were also observed to precipitate Calcite ($CaCO_3$). Calcium or Calcium– Magnesium Carbonates are precipitated by numerous mechanisms, one of which is photo and chemosynthetic autotrophy in the presence of Ca and Mg counter (Saadatnia and Riahi, 2009).

Calcium is abundant in many terrestrial, marine and lacustrine ecosystems. By using halophilic cyanobacteria, seawater or brines, for example agricultural drainage water, or saline water produced from petroleum production or geological CO_2 injections, can serve as potential calcium sources for the calcification process. Calcification can further be boosted by supplying calcium from gypsum or silicate minerals, possibly in connection with biologically accelerated weathering $CaCO_3$ precipitation is one of the fundamental processes in the carbon cycle on both global and regional scales (Ridgwell and Zeebe, 2005). Microbially mediated precipitation of $CaCO_3$ was first investigated a century ago,Indeed, some bacteria and fungi can induce precipitation of calcium carbonate extracellularly through a number of processes that include photosynthesis, ammonification, denitrification, sulphate reduction and anaerobic sulphide oxidation (Riding, 2000).

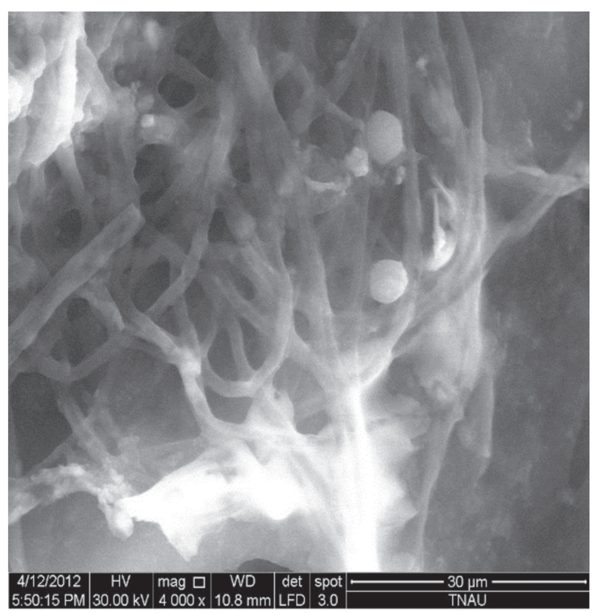
Additionally, the activity of sulphate reducing bacteria has been shown to mediate precipitation of dolomite ($CaCO_3$.$MgCO_3$) (Warthmann *et al*., 2000). The primary role of bacteria in the precipitation process has been ascribed to their ability to create an alkaline environment through various physiological activities.

In addition to field observations, Calcium Carbonate has been formed in the laboratory in association with different bacterial cultures, such as marine bacteria, soil bacteria *Pseudomonas flurescens*, *Myxococcus Xanthus* and various other autotrophic and heterotrophic bacteria (Gonzalaz-Munoz, 2000).

Precipitation of carbonaceous sediments by oxygenic photosynthetic bacteria classified as cyanobacteria is of particular interest because cyanobacteria represent a diverse group of photosynthetic prokaryotes that exhibit versatile physiology and wide ecological tolerance that has allowed them competitive success in a broad spectrum of environments. They are found in numerous terrestrial environments; but, more importantly, they are

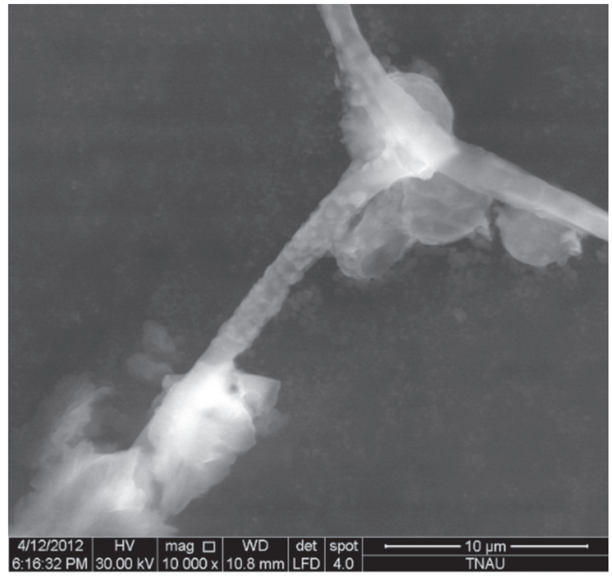


SEM image showing cyanobacterial induced precipitates of calcite (Jeyapandiyan *et al.,* 2017)



SEM image showing the calcite crystals attached to cyanobacterial filaments (Jeyapandiyan *et al.,* 2017)

SEM image showing intracellular calcite precipitation by cyanobacterial strains (2000x) (Jeyapandiyan *et al.*, 2017)



SEM image showing intracellular calcite precipitation by cyanobacterial strains (10000x) (Jeyapandiyan *et al.*, 2017)

common in freshwater bodies, such as the Great Lakes, and the cyanobacterium, *Synechococcus*, contributes up to 50 per cent of chlorophyll a biomass in oligotrophic oceans. In addition, marine cyanobacteria are responsible for an estimated 20 to 40 per cent of carbon fixation in oceans (Partensky *et al*., 1999). As cyanobacteria are low-light organisms that frequently inhabit environments of high light radiation, a light shading function of the calcified sheath has been proposed for cyanobacteria.

The influence of photosynthesis on $CaCO_3$ precipitation in general is based on the uptake mechanism of inorganic carbon. In the case where HCO_3^- is used as a carbon source, calcification and photosynthesis can be linked at molar ratios of about 1:1. Furthermore, particularly in alkaline and nutrient deficient media, microorganisms can profit from calcification because of a facilitated uptake of nutrients and inorganic carbon.Factors important in $CaCO_3$ precipitation are: (1) calcium concentration; (2) dissolved inorganic carbon (DIC) concentration; (3) the pH of the growth environment; and (4) the availability of nucleation sites for the formation of $CaCO_3$ (Hammesand and Verstraete, 2002).

Under low nutrient concentrations and permanent CO_2 supply, photosynthetic uptake of inorganic carbon predominantly uses CO_2 and consequently does not directly influence the nucleation process of $CaCO_3$ at the surface of *Synechococcus leopoliensis* PCC 7942 (Obst., 2009). Furthermore, ion exchange processes did not affect the kinetics, indicating a passive nucleation process wherein the cell surface or extracellular polymers provided preferential sites for mineral nucleation. The catalyzing effect of the cyanobacteria on calcite nucleation was equivalent to a 18 per cent reduction in the specific interfacial free energy of the calcite nuclei.

Some species of cyanobacteria such as *Synechococcus* sp. Strain PCC 8806 and *Synechococcus* sp. strain PCC 8807, in which these strains were tested in microcosm experiments for their ability to calcify when exposed to a fixed calcium concentration of 3.4 mM and dissolved inorganic Carbon concentrations of 0.5, 1.25 and 2.5 mM. *Synechococcus* sp. Strain PCC 8806 removed calcium continuously over the duration of the experiment producing approximately 18.6 mg of solid phase Calcium. Calcium removal occurred over a two-day time period when *Synechococcus* sp. strain PCC 8807 was tested and only 8.9 mg of solid phase calcium was produced. Their experiments revealed that *Synechoccus* sp. PC8806 are able to remove CO_2 from their growth environment by the fixation into cellular biomass or via precipitation of $CaCO_3$ (Lee *et al*., 2006).

The use of photosynthetic microorganisms as microalgae and cyanobacteria to transform CO_2 into valuable products require the selection of adequate strains that can grow fast in outdoor conditions, are little affected by contaminants, and using waste water, but at the same time that must be easy to harvest and contain valuable compounds. In this sense, the cyanobacteria *Anabaena* sp. has been recently patented for this purpose because it meets most of previous requirements. The cyanobacteria *Anabaena* sp. can grow fast in nitrate free medium, because it is a nitrogen fixing microorganisms, is easily recovered by sedimentation and excretes large amounts of exopolysaccharides (Moreno *et al*., 2003). The maximum CO_2 fixation rate of 1.45 g CO_2 L^{-1} day^{-1} was measured experimentally, but it can be increased up to 3.0 g CO_2 l^{-1} day^{-1} outdoors (Gonzalez Lopez *et al*., 2009). The reasonable amount of CO_2 is fixed at 4.0 g l^{-1} day^{-1} using *Chlorococcum littorale* and 7.0 g $l^{1}day^{-1}$ using *Synechocystis* (Zhang *et al*., 2001)

Role of Blue Green Algae in Oxidation reduction

Methane oxidation greatly limits diffusion of methane to the atmosphere. Ammonium ion inhibited methane oxidation in studies with pure cultures of methanotrophs. Up to 60 percent of the methane produced during a rice growing season may be oxidized before it reaches the atmosphere. that The cyanobacterium, *Synechocystis* sp. was the most effective in retarding methane concentration in rice by 10 to 20 fold over that in controls without cyanobacteria. The photo synthetically generated O_2 is of crucial importance in the maintenance of redox potential and oxygenic conditions of soil despite frequent flooding (Prasanna *et al*., 2012)

Conclusion

The higher biomass production of the cyanobacteria in the rice cultivation soils promotes the sequestration of carbon in the soil. This will increase the organic carbon status of the soil and reduction in the emission of carbon compounds to the atmosphere. The BGA also adds nitrogen to soil by the nitrogen fixation. The potential area which was less investigated beneficial effects of cyanobacteria include curbing of ammonia volatilization, suppressing weeds, transformation of P, Fe, Mn, Zn Cu, pesticide degradation and reclamation of wastelands/degraded soil.

Conflict of interest: The authors declare that they have no conflict of interest.

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