ROLE OF BLUE GREEN ALGAE IN SOIL FERTILITY IMPROVEMENT

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Abstract

A kind of photosynthetic bacteria known as blue-green algae (BGA) can fix atmospheric nitrogen and are crucial for increasing soil fertility. Increased nitrogen, phosphorus, and other important nutrient availability to plants due to the presence of BGA in the soil can result in better plant development and greater yields. Despite the fact that cyanobacteria and microalgae are common in soil, little attention has been given to their potential. The indiscriminate application of several pesticides to increase agricultural output has major side effects, including structural instability, the buildup of hazardous pollutants, and an imbalance in the ecology of the soil, plants, and microbiota. The purpose of the present critical review is to highlight the significance of this particular group of microorganisms in terms of maintaining soil fertility and soil health. Beneficial soil ecological applications of these two groups in enhancing plant growth, establishing interrelationships among other microbes, and detoxifying chemical pollutants have been demonstrated. The advantages and disadvantages of various such cutting-edge methodologies for utilizing the biotechnological potential of these photosynthetic microorganisms for sustainable agriculture were also covered. Recombinant technology involving genomic integration favors the development of useful traits in microalgae and cyanobacteria for their potential application in improving soil fertility and health. We also talk about potential future research paths as well as the difficulties that come with using BGA in agriculture.

Introduction

By 2050, there will probably be over 9 billion people on the planet, which might lead to a 70% increase in the need for food production [1]. The issues facing scientists in the 21st century have been the development and use of sustainable farming from the standpoint of ecological and nutrient balance to feed the human population [2]. The development of intensive agriculture for increased productivity was made possible by the absence of desire to comprehend the natural phenomena of sustainable farming [3]. The deficiency of important elements including nitrogen, phosphorus, potassium, and iron in many agricultural soils leads to the need of 200 million metric tons of artificial fertilizers [4,5]. As a result, producing the necessary quantities of fertilizers will need a substantial investment in fossil fuels, which is both time-consuming economically and damaging to the environment. In recent years, there has been a lot of emphasis focused on the overwhelming support for sustainable agriculture, which uses minimal inputs to maintain soil fertility and a healthy environment. The foundation of sustainable agriculture is soil, which is both a vital resource for growing crops and a complex reservoir of life that requires nutrients to be stable and productive throughout time [6]. Understanding soil ecology is crucial for the sustainability of ecosystems and the restoration of habitats because soil acts as the greatest sink for organic carbon and aids in the management of greenhouse gas fluxes [7]. Increases in organic molecules including carbon, nitrogen, phosphates, and potassium are a function of the soil microbiota and lead to an improvement in the health and quality of the soil [8].

Recently, Locey and Lennon's [9] prediction that the Earth is home to more than 1.0 trillion microbial species combines the scaling rule with the lognormal model of biodiversity. These organisms particularly bacteria, fungus, actinomycetes, microalgae, and cyanobacteria, are closely linked and flourish in the biological soil crust (BSC), the topmost region of the soil that contributes significantly to increasing soil fertility and agricultural production [10].These crusts include a variety of microorganisms, including microalgae, cyanobacteria, fungus, lichens, and plant growth-promoting bacteria (PGPB). Microalgae and cyanobacteria are the main producers in the food chain among the various microbiota in the soil and may thrive in hostile conditions such dry, semi-arid, and wetland habitats. The two-billion-year evolution of cyanobacteria is what leads to photogenic oxygenation. Some cyanobacteria that do not have heterocysts may also fix nitrogen, and some of these are chemoheterotrophs.

In the soil, cyanobacteria and microalgae produce nutritive, organic, and active substances that may be consumed by bacteria, fungi, and invertebrates as food. A key element in agriculture, soil fertility is essential to the sustainability of food production systems. Numerous elements, such as nutrient availability, soil structure, and soil microbes, can affect soil fertility. Cyanobacteria, sometimes referred to as blue-green algae (BGA), are a kind of photosynthetic bacteria that can fix atmospheric nitrogen and are crucial for increasing soil fertility. BGA have been discovered in a variety of soil conditions, including agricultural soils, and it has been demonstrated that they increase soil fertility by giving plants vital nutrients. In this review paper, we examine the effect of BGA in enhancing soil fertility, including soil colonization, nitrogen fixation, and other soil health-promoting processes.

Colonization of soil by blue-green algae

BGA may colonize soil in a number of ways, including the development of biofilms, which are microscopic bacterial coatings that adhere to surfaces. These biofilms can strengthen BGA's tolerance to environmental stress and aid in their ability to live in hostile situations. Root exudates, which are organic substances generated by plants and can draw in and promote the development of BGA, are another way that BGA can colonize soil. Additionally, BGA and plants can develop symbiotic partnerships that can enhance nutrient intake and increase yields.

Nitrogen fixation

BGA are able to fix atmospheric nitrogen, which plants may utilize for development and growth. BGA achieve this by using specialized organisms known as heterocysts, which can fix nitrogen in anaerobic environments. By increasing the amount of nitrogen that is available in the soil through nitrogen fixation, BGA can boost plant growth and yields. BGA can also increase soil fertility by releasing additional minerals through their metabolic activities, such as phosphate, potassium, and iron.

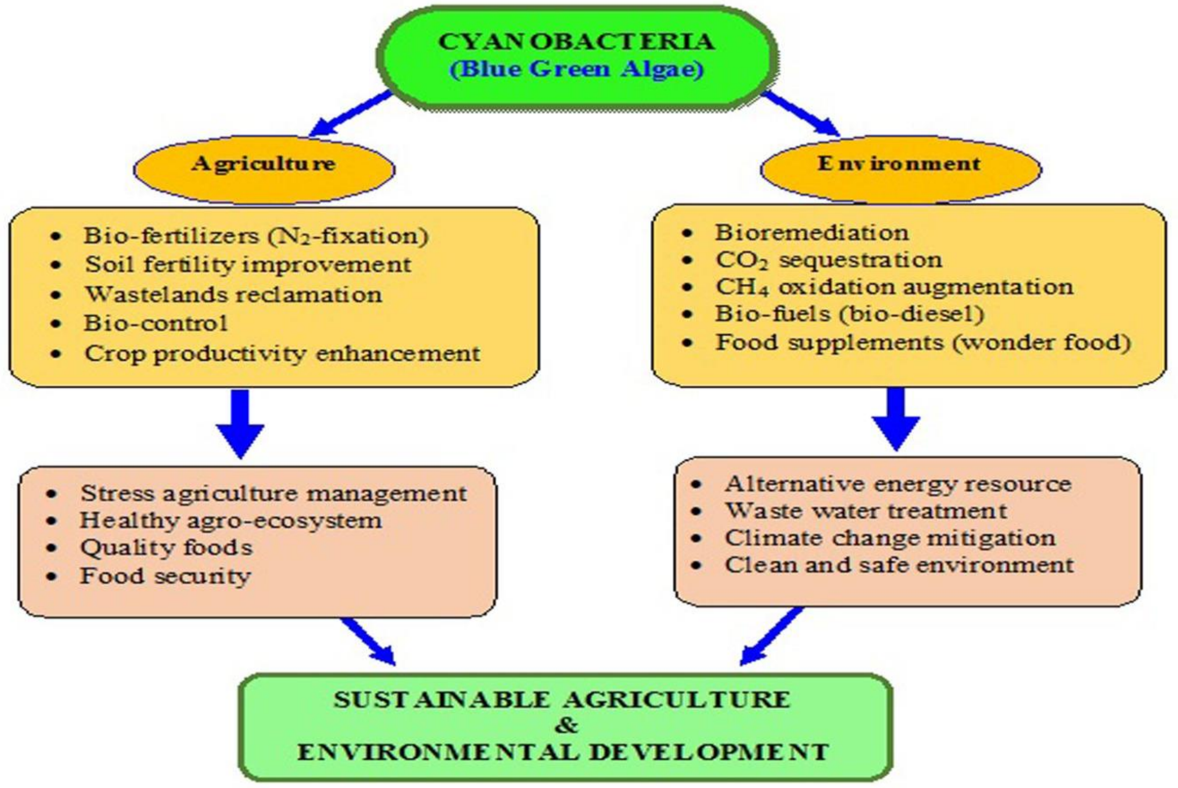

Figure 1. A hypothetical model exhibiting the potential roles of cyanobacteria in sustainable agriculture and environmental management.

BGA as a factor for soil fertility

Due to intensive farming methods, which may cause 30% of the cultivable area to be exposed to soil degradation, agricultural lands are vulnerable to the loss of soil fertility. Microalgae make about 27% of the total biomass of agricultural land, among other soil microorganisms [11]. Cyanobacteria are the best class of microbes to take into account as a soil bioindicator of land use, as shown by their reaction in various agro-ecosystems [12]. The research indicates that microalgae and cyanobacteria have the ability to enhance a number of soil fertility and health-related indices. (Table 1). Particularly during times of climatic change, cyanobacteria and green algae tend to boost organic plant output [13]. The release of exopolysaccharides after the lysis of algal cells also results in an increase in oxidizable C, which in turn increases soil organic matter [14]. The easiest source of carbon for the formation of soil bacteria is soil organic matter [15]. The topsoil's overall nutrient availability can be improved by the cyanobacterial inoculation by increasing soil organic carbon (SOC). In contrast to seeded pots, it has been shown that cyanobacteria inoculated in a pot without seeding had a greater amount of carbon, nitrogen, and minerals [16]. Due to variables that affect plant development, the plant can also stimulate the mineralization of soil organic matter (SOM) [17]. However, a complex SOM fraction's bioavailability to support the development of microbiota is limited because of how its solubility and reactivity rely on the environment. Algae are also thought to compete with higher plants, stop mineral leaching, and preserve bioavailability reserves [18]. Cyanobacteria, including *Nostoc* sp., may invade plant root systems and, by close interaction and hormogonia, enhance the flow of nutrients and metabolites [19]. The improvement in rice output was achieved by using natural cyanobacterial strains as a substitute for nitrogen supplements [20]. Similar to this, using cyanobacterial biofilms in non-flooded environments enhanced N_2 fixation and phosphate solubilization, resulting in an increase in crop plant growth [21]. Not only did cyanobacteria boost paddy production, but postharvest soil demonstrated the largest increase in oxidizable and soluble C relative to preharvest soil [22]. Cyanophyceae genera promote retention of silt and clay in harsh settings while increasing organic C (300%) and N (400%) levels [23]. In addition to leaving C residues that can improve plant development without the use of manure, cyanobacterial inoculation increases grain yield [24]. It's interesting to note that the abundance of local algae can boost nitrogen fixation while reducing the variety of other diazotrophic organisms [25]. In nutrient-limited semi-arid soil, Mayland *et al.* [26] observation of a two-fold increase in nitrogen concentration points to the importance of cyanobacteria with active heterocyst.

Soil type	**Major soil characteristics**	**Cyanobacterial/ microalgal inoculants**	**Soil fertility improvement**
Sandstone, granite, schist and lime	Poor micronutrients	*Oscillatoria* sp., *Nostoc* sp. and *Scytonema* sp.	Formation of microbial crusts with high carbon and nitrogen content
Silt loam soil	Poor micronutrient availability	*Anabaena* sp. and *Providencia* sp.	Iron concentration in soil was >2–3 folds.

Desert soil	Low organic carbon and total nitrogen	*Microcoleus vaginatus* Gom. and *Scytonema javanicum*	>5-Fold increments of soil organic carbon and nitrogen.
Sterile soil	Low nutrients	*Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., and *Chroococcus* sp.	Microbial biomass carbon.
Clay loam	Low nitrogen	*Chlorella vulgaris*	Improved nitrogen and soil enzyme activities.
Semi-arid soil	Organically poor	*Anabaena doliolum* HH-209, *Cylindrospermum sphaerica* HH-202, and *Nostoc calcicola* HH-201	Improved carbon and nitrogen mineralization by promoting soil microbial activities.
Ferruginous tropical soil	Poorly aggregated soils	*Nostoc* sp.	Improvement of aggregate stability.

Phosphorus and potassium are the other critical elements needed to boost crops after nitrogen. Typically, the top layer of soil contains organic phosphorus, which makes about 20–80% of the overall amount of phosphorus [27]. Additionally, in highly worn soils, phosphorus availability to plants reduces and is strongly reliant on microbial activity in such soils [28]. Numerous investigations shown that the conversion of insoluble phosphate to soluble phosphorus is largely mediated by phosphate-solubilizing bacteria [28]. But soil microalgae store inorganic phosphate and create polyphosphates, which are the phosphate form that plants may readily use [29]. In order to boost the bioavailability of inorganic phosphate to plants, cyanobacteria can also release enzymes to break it down in the soil [30]. When phosphate is scarce, cyanobacteria can produce phthalic acid, which can dissolve phosphate-containing mineral rock [31]. While insoluble phosphate served to sustain the rate of nitrogen fixation, soluble phosphate caused cyanobacteria to stop fixing nitrogen [32]. Chelation and the solubilization of phosphate by cyanobacteria's production of organic acids are two more potential processes [33].

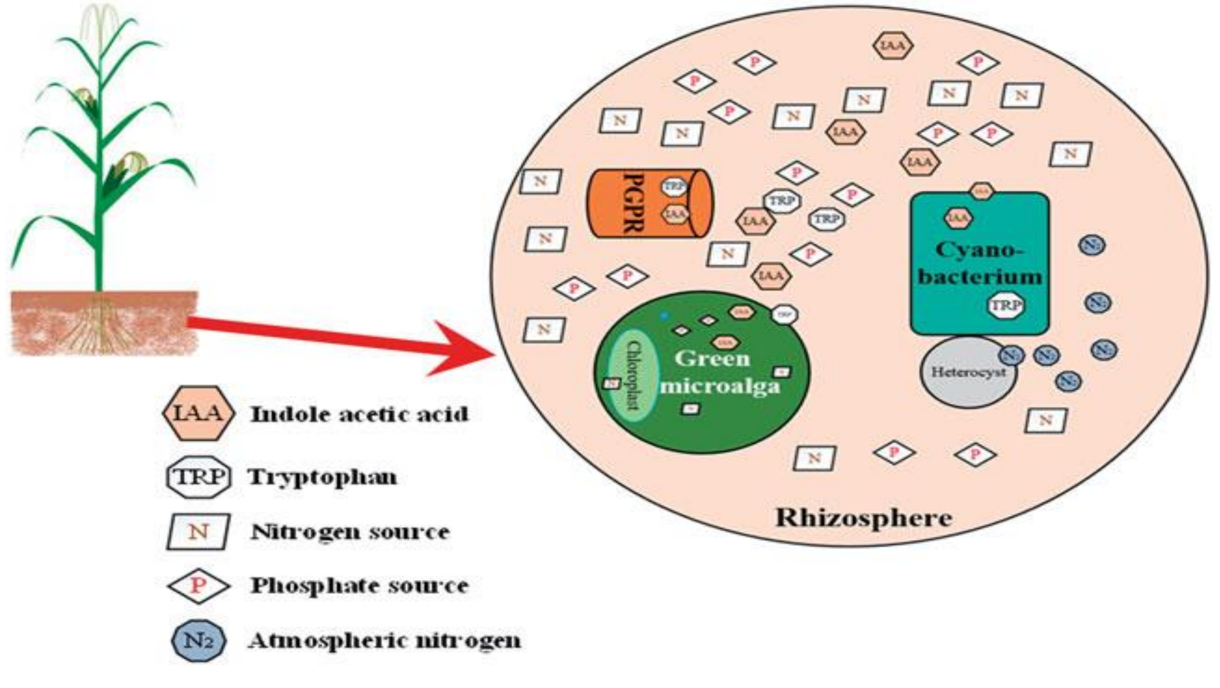

Figure 2. Symbiotic relationship between a microalga, cyanobacterium, and PGPR in plant rhizosphere

New developments are more appealing for scaling heights and achieving more encouraging outcomes, and they are highly beneficial for understanding the mechanism and reaction of algae to soil function. Due to a decrease in the amount of chemical fertilizer used, economic savings, etc., the use of cyanobacterial biofilm fertilizer gauge has gained popularity. Producing maize hybrids with cyanobacterial biofilm formulation of Anabaena-Trichoderma viride led to a 60 kg/ha nitrogen savings and a 20–60 kg/ha improvement in soil nitrogen availability [34]. Under various phosphate regimes, the biofilm of Phormidium sp. displayed greater phosphatase activity [35]. Similar to this, during wheat cultivation, the biofilms of Anabaena-Serratia and Anabaena-Pseudomonas shown strong acetylene reduction and phosphate activity [36]. With the use of the compost (paddy straw and vermiculate as a carrier) and the Anabaena-T. viride biofilm formulation, Prasanna *et al*. [37] found a 12–25% increase in soybean production. By increasing the bioavailability of nitrogen and phosphates to rice plants under the SRI system, cyanobacteria biofilm formulation was able to save 60 kg of nitrogen per hectare each season1 [38]. In comparison to controls, biofilm formation enhanced the levels of soil micronutrients in Oryza sativa, including zinc (15-41%) and iron

(13-46%) [39]. The nitrogenase activity in the biofilms made up of Anabaena laxa and *Rhizobium* sp. was greater, leading to a chickpea yield of 1724 kg/ha [40]. In comparison to other providers, microalgae/cyanobacteria acting as biofilm vectors have a higher degree of nutrient enrichment.

Cyanobacteria in Reclamation of Salt Affected Soils

Cyanobacteria may have a role to play in the restoration of salt-affected, arid or sub-arid soils (usually referred to as Usar land in some regions of India). Chemical techniques that use gypsum, sulfur, or excessive irrigation to treat salt-affected soils are neither cost-effective nor environmentally beneficial. Alfisol, sodic, alkaline, and salt-affected soils are generally less productive, stiff soils that are impervious to water because of the presence of too much salt in the top layers. Depending on the amount of salt in them, they can be categorized as either alkaline or saline. The high pH, high exchangeable Na, detectable carbonate levels, and broad clay dispersion (deflocculation because of the high zeta potential of active Na^+) are characteristics of alkaline soil. The soils are unproductive due to weak hydraulic conductivity and decreased soil aeration. High levels of soluble salts in salty soil (electrical conductivity more than 4 dS cm^{-1}) provide plant roots a high osmotic tension needed to absorb water and nutrients. For the first time, Singh [41] proposed that cyanobacteria may be utilized as a technique for reclaiming Usar soils due to their ability to establish a thick layer on the soil surface, retain moisture and organic C, N, and P, as well as to convert Na^+ clay to Ca^{2+} clay. Organic matter and N added by the cyanobacteria in such soils helps binding of the soil particles and thus, improves soil permeability and aeration Since the cyanobacteria are capable of solubilizing nutrients from insoluble carbonate nodules through the secretion of oxalic acid; they improve the physico-chemical quality of saline and alkali soils such as soil aggregation by lowering the pH, electrical conductivity, and hydraulic conductivity [42].

Challenges

Despite the potential advantages of BGA usage in agriculture, there are a number of drawbacks as well. Toxins that BGA may create may be hazardous to both human and animal health. BGA may also produce toxic algal blooms in aquatic habitats, which can cause environmental impact and a decline in biodiversity. Additionally, BGA might not work well in all soil situations and might be affected by things like soil pH, temperature, and moisture content.

Future directions for research

To create effective usage methods for BGA in agriculture and to better understand their function in improving soil fertility, more study is required. This involves studying the processes by which BGA colonizes soil as well as how BGA affects soil quality and plant development.

Conclusion

The main colonizers that make it possible for other creatures to live and flourish in a variety of climatic and edaphic conditions, from a desert to a wetland, are microalgae and cyanobacteria. Microalgae and cyanobacteria play a significant role in maintaining the soil health and fertility required for continued agriculture, as this review has shown. The balance in the dynamics of nutrients like carbon, nitrogen, and phosphate for the yield of agricultural crops is the main benefit of using microalgae and cyanobacteria.Metabolic processes, such as the production of phytohormones, enzymes, and allelochemicals from microalgae, are essential for promoting plant development, creating partnerships between different microorganisms, and detoxifying toxins like pesticides and herbicides. Furthermore, utilizing microalgae or cyanobacteria as biofertilizers is a beneficial and promising strategy for improving the nitrogen economy in contemporary agriculture, lowering greenhouse gas emissions, and maintaining soil fertility. Therefore, in order to fully use microalgae and cyanobacteria in bio-technological applications, improved molecular insights into these organisms are crucial.

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