Cyanobacteria as potential source to improve yields of crop Production.

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Abstract

Cyanobacteria are group of gram negative prokaryotic organisms that share features with high plants. This organism represent a potential sustainable alternative for agriculture to enhance the growth of crop production. The use of biofertilizer in agriculture can be the solution for Eco-friendly environment to the future agriculture. The use of cellular extract and dry biomass have been report for many researchers to improve the quality of soil and growth of different crops as well increase in yield grain. This review article provide information from different studies, where the use of cyanobacteria in agriculture are a potential biofertilizer to improve soil quality as well as growth and yield of wide range of crops.

Keywords: Biofertilizer, Cyanobacteria, yield, Plant growth.

Introduction

Agriculture plays a significant role in meeting the food demands of a growing human population, this contribute in dependence of chemical fertilizers and pesticides (Santos VB, et al., 2012). In these years the challenge still the production of crops without causing environment degradation (Godfray, et al., 2010; Odegard and van der Vo et., 2014). The use of chemicals to enhance the growth of crops causes air and ground water pollution by eutrophication of water bodies, soil infertility, and biodiversity loss (Youssef MMA, et al., 2014).However organic farming is one of such strategies that not only ensures food safety but also adds to the biodiversity of soil (Megali .L, et al., 2013). The benefit of using biofertilizer is not only to enhance the agriculture production but extent to the cost-effective and also diminish environmental pollution, (Kawalekar, 2013).

Cyanobacteria are photosynthetic blue green algae that share features with bacteria as well with plants. The use of cyanobacteria as a biofertilizer was started long years ago in agriculture. The abilities to fix nitrogen provide adaptability to various soil types, make them ubiquitous. The majority cyanobacteria are capable to use atmospheric dinitrogen as a source of nitrogen. Nitrogen is an essential macronutrient element in plant development and a limiting factor in plant growth, nevertheless, plants cannot directly access dinitrogen gas, which makes up about 80 % of the atmosphere. In plant development, roots are responsible to absorb the available nitrogen in the soil in the form of ammonium and nitrates (Santi.C et al., 2013).

The use of seaweeds are related to brings high quantities of macro and micro-elements, amino acids, antibiotics, and vitamins, needed for adequate plant growth (Tiwaril. P, et al., 2016). Application of seaweed extract in the soil or foliage showed whole range of responses in various plants tested. Raouf. A, et al., 2012, demonstrated in experiments that the use of Algae have been associated with faster seed germination, root development, leaf quality, plant vigor, and higher resistance to pathogens (Waaland. J.R., et al., 1991). Shukla and Gupta in 196, during the experiment in germination of rice seeds using algae extracts has a biofertilizer, found that these organism promote faster germination and add to the final yield content of the cereal grain. They also observed that the quality of the grains were improved in proteins content. Many microalgae species cultivated have capacity to produce Phytohormones such as gibberellins, cytokinin and auxin that can be found in cellular extracts or excreted in growth medium. This secondary metabolites are important in germination and plant development (Tarakhovskaya, et al., 2007).

Microalgae and Cyanobacteria are probably the most photosynthetic agent of the soil and the role of them are not fully understood. However the effect of wide range of varieties of extracellular and intracellular substances produced by this organisms play a valuable in water habitats (Fogg, 1971) as well enhancing the germination and growth of higher plants (El-Ayouty, 1998), some of them also are source of bio pesticide. In this review our aim is to emphasize the importance and role of cyanobacteria as a biofertilizer in improvement of soil quality as well as in growth and yield of crops.

Background

Blue green algae are prokaryotic gram negative bacteria, found in diverse environment condition. They comprise about 150 genera and 2,000 species ranging from unicellular, colonial, filamentous to branched filamentous forms and are divided into 5 subsections: Chroococcales, Pleu-rocapsales, Oscillatoriales Nostocales and Stigonematales (Singh.H et al., 2014). Cyanobacteria are significant sources of various kinds of nutrients and can potentially be used in agriculture, as source to contribute on reduction of nitrogen and phosphorous runoffs, (Tiwari1 et al., 2016). Cyanobacteria, are probably the most important nitrogen-fixing agents in many agricultural soils (Rodrigo and Eberto, 2007). Many species as the ability to survive in extreme adverse condition such as, high temperature, high salinity, presence of pesticides, etc. (Stal, 2007). Blue green algae are organisms important in maintenance of wide range of ecosystems (Whitton, 1992). They can be found in aquatic or terrestrial habitat (Michael J. et al., 1991) .The use of cyanobacteria in agriculture become attractive this days because their use is suitable to the environment. They help to maintain the nature of the soil and add substances that improve the soil fertility. Cyanobacteria as a biofertilizer for paddy began in the 1960s onwards and still today this technology is not much popularized.

Cyanobacteria produce different substances which play role in plant growth, development and yield (Haroun and Hossein, 2003; Rodriguez et al., 2006). These micro- organisms have been reported to benefit plants by producing, vitamins, growth promoting factors, polypeptides, amino acids , antibacterial and antifungal substances that exert phytopathogen bio control.

Many studies mention that the biofertilizer technique using cyanobacteria are the potential source to increase the rate of seed germination and growth parameters of many plants (Strick et al., 1997). Number of studies have been report good results on the use of dried biomass of cyanobacteria to inoculate soils as a resource to enhance the fertility. The effect of adding cyanobacteria to soil on rice yield was first studied in the 1950s in Japan, and are the classical example of effect of cyanobacteria in agriculture field (Mishra U and Pabbi S, 2004). Algalization is the term introduced to designate the use of a defined mixture of cyanobacteria species to inoculate soil. Today algalization became the interest in major rice producing countries. This interest is because the use of defined mixture of cyanobacteria exhibited higher grain yield of 15-20% (Mishra U and Pabbi S, 2004).

1.1 The nature of Cyanobacteria

The habitat of cyanobacteria varies from species to species from garden soil, rock, and desert to marine water bodies, freshwater bodies, lakes, rivers, salt marshes, swamps.

In marine environments they grow along the shore as a benthic vegetation in the zone between high and low tide marks. Furthermore they flourish in water that is salty, brackish or fresh, in cold and hot springs, and in environments where no other microalgae can exist, (Humm and Wicks, 1980). Cyanobacteria comprise a large component of marine plankton with global distribution (Gallon et al., 1996).

Cyanobacteria can form a dense and stratified mats in soil or water bodies. These organisms can tolerate hyper saline habitats as well adverse conditions, (Javor and Catenholz 1984; Cohen 1989; Farmer 1992).In natural environment the life processes require only water, carbon dioxide, inorganic substances and light. Photosynthesis is their principal mode of energy metabolism, they have chlorophyll a and photosystems I and II that allow them to perform oxygenic photosynthesis. Most species lack the enzyme α-ketoglutarate dehydrogenase and therefore do not use the citric acid cycle for carbohydrate metabolism, but the pentose phosphate pathway. In the natural environment, however, it is known that some species are able to survive long periods in complete darkness, (Issa et al., 2014).

Cyanobacteria can grow as aerobic or as anaerobic, photoheterotrophs, chemoheterotrophs and as anaerobic or aerobic nitrogen fixers (Allen, 1956). The cyanobacteria has capability to survive in adverse conditions using the amelioration of the salt affected soils, they reduce the salt content and promote levels of Carbon , Nitrogen, and Phosphor, including moisture content of the salt affected soils. Singh SJ et al., 2016, showed that cyanobacteria can induce soil aggregation and water permeability, and are quite useful in improving quality of poor structured soils of arid or sub arid areas.

The Bergey's Manual has divided the organism into five subsections based on their diversity. The classical taxonomy of cyanobacteria divides these organisms into five orders two for heterocystous types and three for non-heterocystous types (Castenholz, 2001; Castenholz and Waterbury, 1989). The non-heterocystous cyanobacteria comprise Subsection I (Chroococcales), which are unicellular cyanobacteria that reproduce by binary fission; Subsection II (Pleurocapsales) are unicellular cyanobacteria that produce daughter cells smaller than the parent; and Subsection III (Oscillatoriales) consists of cyanobacteria that produce filaments of cells known as trichomes. All three subsections have N2-fixing representatives (Bergman et al., 1997).

Rogers and Burns in 1994 conducted experiments where the inoculation of cyanobacteria showed to enhance the stability of soil aggregate (important characteristics of good soil) and noticed the resistance of aggregates to wetting and physical disruption); that improved aeration in soils and reduce the compaction and sodicity of soils through improvement in the level of organic carbon and support the biodiversity of other microflora.

Cyanobacteria have an impressive ability to colonize infertile substrates such as volcanic ash, desert sand and rocks (Issa et al., 2014). They also survive during the biotic stress such as nutrient limitation, pesticides, pollution, drought, salinity, temperature, pH, light intensity and quality, etc. (Herrero et al., 2001). But thylakoid membranes was identified as a sensitive protein to environmental stress conditions that influence the turnover of protein (Giardi et al., 1997).

The abiotic stress, affecting the distribution of algae in soils is solar radiation, moisture, temperature, and pH, organic matter content and soil texture are less insignificant. Pesticides are another factor affecting the distribution and activity of cyanobacteria. Most pesticides, herbicides, fungicides, and soil fumigants can affect the distribution, activity of cyanobacteria or can be toxic, whereas insecticides are less dangerous (Issa et al., 2013).

Physico-chemical alterations in the environment may benefit the abundance of some species or affect the presence and growth of other species, which leads to the succession of several species in a course of time (Muthukumar et al., 2007). High temperatures favor both the phytoplankton productivity and blue green algae (Roger and Reynaud, 1979).

1.2 Nitrogen fixation Cyanobacteria

Cyanobacteria belong to restrict group of organisms that have the ability to utilize N2 through the process of biological nitrogen fixation, (Prasanna et al., 2013).

Prasanna et al., 2012, reported that the Inoculation soil with cyanobacteria enhanced the es tablishment and N2-fixation of the soil surface population under a rice and wheat crop.

Most cyanobacteria species can fix nitrogen, some have the specialized cells known as heterocyst, where the nitrogen are fixed by nitrogenase enzyme. The enzyme is involve a complex pathway that catalyzes the conversion of the molecular N_2 into reduced form like ammonia (Singh et al., 2011), either by secretion or by microbial degradation after the cell death (Subramanian and Sundaram, 1986). But both heterocystous cyanobacteria (Nostoc, Anabaena, Aulosira, etc.) but also by several non-heterocystous (Gloeocapsa, Aphanothece, Gloeothece, etc.) was found to fix nitrogen.

The filamentous cells differentiate into heterocysts when the cells are deprived of dissolved inorganic nitrogen. A heterocyst consists of a thick cell wall and only contains photosystem I for ATP production. Photosystem II is degraded to prevent O2 production. O2 inhibits nitrogenase, the enzyme responsible for N2-fixation. Heterocyst formation is an important aspect to nitrogen fixation.

In non heterocystous forms, the oxygenic photosynthesis was found to be separated from nitrogen fixation either temporally or spatially. In temporal separation, nitrogen fixation predominantly occurs during the dark period and photosynthesis during the light; in these forms in terms of energy the anaerobic dark conditions are not very favorable for the process of nitrogen fixation. (Issa et al., 2013).

The nitrogen fixation by cyanobacteria occurs only in deficient conditions and in the presence of combined nitrogen source the enzyme nitrogenase remains repressed which, similar to oxygen effect, is a reversible inhibition.

The cyanobacteria biomass supply approximately 4 kg N ha-1 to the standing crop of rice and their nitrogen fixing capability has been studied by various investigators (Vaishampayan et al., 2001). Issa et al., 2014, mention that the cyanobacteria can contribute about 20-30 kg N ha−1 season−1 as well as organic matter to the soil which is quite significant for the economically weak farmers who are unable to invest on costly chemical nitrogen fertilizer.

1.2.1 Cyanobacteria that can fix N2 aerobically

1. Cyanobacteria that separate N2 fixation from oxygenic photosynthesis in space. Includes heterocystous genera, for example, Anabaena.
2. Cyanobacteria that separate N2fixation from oxygenic photosynthesis in time. Includes non-heterocystous genera, such as Gloeothece, Cyanothece and Lyngbya
3. Cyanobacteria that separate N2 fixation from oxygenic photosynthesis both in space and in time. Includes non-heterocystous genera, such as Trichodesmium and Katagnymene

1.2.3 Cyanobacteria that can fix only N2 either anaerobically or micro aerobically

1. Many non heterocystous cyanobacteria, for example, Plectonemaboryanum

2. Cyanobacteria and Plant interaction

Cyanobacteria are known to possess the ability to form associations with vascular/nonvascular plants. The presence of cyanobacteria in rhizosphere can help in assimilating organic compounds and their association with crop plants is advantageous for establishment, acceleration of germination, growth and yield of crops (Prasanna et al., 2013).The discovery of agronomic potential of cyanobacteria started probably with the paddy fields (Hung and Chow, 1988). Abd-Alla and Issa, 1994; Abd-Alla et al., 1994 found that effect of cyanobacteria are also notable on other crop plants like vegetables, wheat, sorghum, maize, cotton, sugarcane, etc. Fertilization with cyanobacteria has been compared to inorganic fertilization on rice and lettuce seedlings (Ibraheem, 2007).

Raouf et al., 2012, in experiment noted that inoculation at about 250 g dry mass ha-1 of the same species resulted in a 19.5% increase in rice yield as compared with 16.6% produced by a dressing of 25 kg ha-1 of ammonium sulfate. In addition to contributing nitrogen, cyanobacteria benefit crop plants also by producing various extra- and intra-cellular polysaccharides like xylose, galactose, fructose, etc. Moreover, chromatography identification of an excreted substance from Nostoc muscorum isolated from Argentine paddy fields revealed axenic activity and characteristics similar to indole acetic acid, (Caire et al., 1979).

The use of cyanobacteria are correlates to the development of root, shoot, increase of grain weight, etc, (Venkataraman and Neelakantan, 1967; Singh and Trehan, 1973; Jacq and Roger, 1997). The use of cyanobacteria also contribute bioavailability of phosphorus to the plants by solubilizing and mobilizing the insoluble organic phosphates present in the soil with the help of phosphatase enzymes (Singh et al., 2016).Fuller and Roger (1952) observed that uptake of phosphorus by plants from algal materials was greater than that from the inorganic phosphates, when both were provided in equal amounts over a longer period of time. The availability of nitrogen as well as the biologically fixed nitrogen becomes available gradually through exudation and decomposition of these algae. The nitrogen fixation by cyanobacteria depends upon the various biotic and abiotic factors. Efficiency of fixed nitrogen is very promising but limited due to fluctuation in quality and quantity of inoculum and its physiological attributes in varied agro ecological regions (Raouf et al., 2012).

3. Cyanobacteria and soil Interaction

Cyanobacteria not only fix carbon in CO2 through photosynthesis, but they can also fix atmospheric nitrogen. Both of these processes also play an important role in humus formation. Algae are also important source of organic matter in soil formed from the death and decay of algae may get mixed in the soil and mucilage acts as binding agent for soil texture, thereby increasing the humus content and making it more habitable for other plants after some years (Marathe and Chandhari, 1975). This is essential for the maintenance of the soil organic matter and enhance of crop growth.

Cyanobacteria produce extracellular polymers of diverse chemical composition, especially exopolysaccharides that enhance microbial growth and as consequence, improve soil structure and exoenzyme activity (Ibraheem, 2007; Hamed, 2007). Also play a significant role in water storage due to the hygroscopic properties of polysaccharides and contribute to increased water retention capacity of the soil. However, has been observed increase of 50-70% in soil aggregation capacity due to algal inoculation. Subsurface soil cyanobacteria are also known to associate with plant roots, producing hormones that stimulate root growth and enhance the activities of other beneficial root-associated microorganisms (Issa et al., 1994).

After blue green algae dead serves has a food source for many important bacteria and fungi in soils. Among soil properties, pH is a very important factor in growth, establishment and diversity of cyanobacteria, which have generally been reported to prefer neutral to slightly alkaline pH for optimum growth (Koushik, 1994). In the Arctic, cyanobacteria are the primary source of newly fixed nitrogen (Hobara et al., 2006; Solheim et al., 2006) and form many associations with vegetation including epiphytic and endophytic facultative associations with bryophytes (Turetsky, 2003) and the lichen symbioses and soil surface colonies that are components of Biological Soil Crusts (Belnap et al., 2001).

The cyanobacteria *Alosira ferrilissitiia* and *Calothrix brevessima* have been reported to be ubiquitous in Kerala rice fields with pH from 3.5 to 6.5. Subhashini and Kaushik 1981, reported that the pH of the alkaline soil decreased when treated with cyanobacteria.

Singh SJ et al., 2016, reported that cyanobacteria also helps to control salinity in soil. These gram negative bacteria have been found not only to grow in highly saline-alkali soils, but also improve the physicochemical properties of the soil by enriching them with carbon, nitrogen and available phosphorus (Kaushik, 1994).

The species with highest potential bio fertilization are the heterocystous filamentous forms in which the nitrogenase activity and oxygenic photosynthesis are separated spatially and nitrogenase activity is usually light-dependent. Cyanobacteria inoculation to soil increased 13-14% of N content under field conditions and cyanobacteria amended soil released 50% of ammonium N at 50 days of flooding (Singh et al.,1981). The rate of N released by cyanobacteria was 12 and 35% after 7 and 35 days of flooding (Saha et al., 1982) respectively.

Conclusion

The Cyanobacteria extract, dry biomass and growth medium is an emerging approach for Eco- friendly environment in agriculture field. The identification of more strains that have efficiency on different crops, is the most importance to reduce our dependence on chemical fertilizers and pesticides.

Many studies have mentioned the potential of this organisms in improvement of soil quality and growth of crop, without disturbance on the environment. But the cost of this procedures still unclear. For instance the next step is the production in large scale in way that can be implemented stepwise in local village cultivars.

Biofertilizer keep the soil environment rich in all kinds of micro and macro nutrients via nitrogen fixation, phosphate and potassium solubalization or mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter in the soil. Nevertheless, the progress in biotechnology related to manipulation of genes to increase the yield of particular strain will be the main advance in this area. The use of cyanobacteria as a biofertilizer has the potentiality to eliminate chemical fertilizers upon development of large scale production of the cyanobacteria stains capable to promote faster germination, improve in pant growth and high yield in short time. Create an Eco friendly environment is another goal in implementation of cyanobacteria as a biofertilizer This review summarize the application of cyanobacteria as a potential source to contribute to the organic matter to the soil and improve the agriculture crops during the germination, growth as well in final yield.

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