

Review

Agricultural importance of algae

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Algae are a large and diverse group of microorganisms that can carry out photosynthesis since they capture energy from sunlight. Algae play an important role in agriculture where they are used as biofertilizer and soil stabilizers. Algae, particularly the seaweeds, are used as fertilizers, resulting in less nitrogen and phosphorous runoff than the one from the use of livestock manure. This in turn, increases the quality of water flowing into rivers and oceans. These organisms are cultivated around the world and used as human food supplements. They can produce a clean and carbon-neutral food also and can be grown on abandoned lands and arid desert lands with minimal demands for fresh water. Seaweeds are an important source of iodine. Iodine levels in milk depend on what the cow producing the milk has been fed with. Feeding milk cattle with seaweeds can increase the quantity of iodine in milk, according to Fuzhou Wonderful Biological Technology. Egg-laying rate in hen is also increased by algae feed additives. In this article, we discussed the most important aspects of algae and its agricultural uses to those who work in this area.

Key words: Algae, seaweeds, agriculture, biofertilizer, soil stabilizers.

INTRODUCTION

The assemblage of plant-like forms which are collectively referred to as algae includes a tremendously diverse array of organisms. Algae may range in size from single cells as small as one micrometer to large seaweeds that may grow to over fifty meters (Vymazal, 1995). Many of the unicellular forms are motile, and many integrate the protozoa (South and Whittick, 1987). Algae are ubiquitous; they occur in almost every habitable environment on earth, in soils, permanent ice, snow fields, hot springs, and hot and cold deserts. Biochemically and physiologically, algae are similar in many aspects to other plants. They possess the same basic biochemical pathways; all possess chlorophyll-*a* and have carbohydrate, protein and products comparable to those of higher plants. Furthermore, algae are the major primary producers of organic compounds; and play a central role as the base of the food chain in aquatic systems. Besides forming the basic food source for these food chains,

they also produce the oxygen necessary for the metabolism of the consumer organisms (Lee et al., 1989).

This review intends to reinforce the notion that algae are important components of arid and semi-arid ecosystems. Furthermore, their distribution and condition may indicate the health of the environment. Additionally, the presence of algae leads to reduced erosion by regulating the water flow into soils. Similarly, they play a role in soil fertility, soil reclamation, bio-controlling of agricultural pests, formation of microbiological crust, agricultural wastewater treatment and recycling of treated water. Human civilization depends on agriculture for its existence. The success of agriculture greatly depends on the fertility level of the soil. Like other organisms, algae which are found in different soil types, may help the soil to improve its characteristics such as, carbon content, texture, aeration (Ibraheem, 2007) and also nitrogen fixation (Hamed, 2007). The magnitude of these improvements is greatly dependent on the physical and chemical characteristics of the soil, affecting the composition of the algal population (Abdel-Raouf et al., 2004).

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Marine algae are used as fertilizers on farmlands close to the sea, examples include the large brown and red algae used as organic fertilizers; which are usually richer in potassium but poorer in nitrogen and phosphorus (Waaland, 1981). The weed is usually applied direct and ploughed in, both as solid (processed into a seaweed meal) and/or as liquid fertilizer (concentrated extract of seaweeds) (Round, 1973). Probably the widest use of seaweeds in agriculture is as liquid fertilizers (Povolny, 1981). The positive effect of liquid fertilizers is mainly explained by the high content of trace elements and growth regulatory substances (particularly cytokinins). Calcareous red algae known as maerl, are used in the United Kingdom and France to reduce soil acidity (Blunden et al., 1981). Man's uses of algae, particularly marine algae, are far more diverse and economically important than generally realized (Abbott and Cheney, 1982). They are used as human food, in agriculture (fertilizer, manure, fodder and aquaculture), medicine, textile, paper and paint industries, chemical extracts from larger marine algae (example alginic acid, carrageenan or agar) are used in the manufacture of food industry, and diatomaceous earth (deposits of diatom frustules) is widely used as filtration and polishing materials. Algae are also important surface-binding agents which reduce erosion and can be used for wastewater treatment.

Cyanobacteria are a diverse group of prokaryotes. A common feature is their oxygenic photosynthesis, which is similar to that in algae and higher plants. As sunlight is their energy source and water, they generate oxygen in the light. Energy and reductants generated by photosynthesis are usually used for carbon dioxide reduction. These microorganisms are distributed worldwide and improve the growth and development of the plants, with which they share the habitat, because they: 1) contribute to soil fertility in many ecosystems; 2) produce various biologically active substances and 3) have higher efficiency in biosorption of heavy metals (bioremediation) (Ibraheem, 2007).

IMPROVEMENT OF SOIL FERTILITY

Some cyanobacteria are able to reduce atmospheric nitrogen to ammonia, a process where oxygen evolved by photosynthetic activity in the same cell is detrimental to nitrogen fixation. Strategies to avoid oxygen range from temporal separation of nitrogen fixation and oxygen evolution (in many unicellular and filamentous, non heterocysts strains) to spatial separation and cellular differentiation into nitrogen fixing heterocysts (in filamentous cyanobacteria). Heterocysts are terminally differentiated cells whose interior becomes anaerobic, mainly as a consequence of respiration, allowing the oxygen-sensitive process of nitrogen fixation to continue. The regulation of dinitrogen fixation has been extensively studied in the heterocyst system (Bhme, 1998).

Diazotrophic 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 *Azolla*, has long been recognized (El-Zeky et al., 2005). 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.

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 (Omar, 2000; Ladha and Reddy, 2003). Whereas the incorporation of genes into rice plants by using tissue culture and modern genetic tools remains as an ambitious research goal, the use of cyanobacterial diazotrophic technology in rice agriculture offers an immediate and even long term alternative to synthetic nitrogen fertilizers, particularly in developing countries and the world as a whole. However, one of the weaknesses in the technology is the heavy application of several toxic agrochemicals, especially herbicides, which are reported in most cases as inhibitors of cyanobacterial diazotrophic growth, and in some cases as mutagenic. Therefore, a successful biotechnology requires the selection of suitable diazotrophic strains as biofertilizers that could tolerate the field-dose concentrations of herbicides (Tiwari et al., 1991).

Uptake of P and N

Cyanobacteria also have some soil phosphate-solubilizing species. Phosphorus (P) is the second important nutrient after nitrogen for plants and microorganisms. Most aquatic systems are resource-limited, where P and N are often the primary limiting nutrients. To ensure survival, a competitor must be able to maintain net population growth at resource levels less than those required by other species (Scott et al., 2005; Silke et al., 2007). Algae are particularly adapted to scavenge their environments for resources through structural changes, storage or increased resource utilization efficiency (Singh and Dhar, 2007). Internal adjustments by algae involve biochemical and physiological adaptations, whilst they can also excrete substances to enhance nutrient availability. Algae excrete extracellular phosphatases almost immediately upon the onset of P limited conditions (Healy, 1973). Algae can also excrete other compounds and change the pH of their surroundings, which in turn can render adsorbed P available (Grobelaar, 1983). In addition, algae can store resources like P in excess of their immediate needs. This

excess or "luxury" uptake is clearly distinct from the Michaelis-Menten (Monod, 1950) nutrient uptake kinetics which are based on external resource concentrations. Epply and Strickland (1968) concluded that the growth rate of phytoplankton is more closely related to the cellular nutrient content than to external concentrations. It is, therefore, necessary to establish a relationship between the cell quota of a nutrient and the growth rate of an alga. Such a relationship was given by Droop (1983).

Cyanobacterial fertilization has been compared to inorganic fertilization on rice and lettuce seedlings (Ibraheem, 2007). Biofertilizers are likely to assume greater significance as complement and/or supplement to chemical fertilizers in improving the nutrient supplies to cereal crops because of high nutrient turn-over in cereal production system, exorbitant cost of fertilizers and greater consciousness on environmental protection (Ahmed, 2009).

Nitrogen fixation

Algae, especially cyanobacteria, may be the most important nitrogen-fixing agents in many agricultural soils (Rodrigo and Eberto, 2007). Their importance as nitrogen fixers in rice fields have been studied by several investigators (Hung and Chow, 1988). The great majority of cyanobacteria that fix nitrogen are probably heterocystous (Granhall and Henriksson, 1969); however, non-heterocystous cyanobacteria fix nitrogen as well (Kallas et al., 1983). The nitrogen fixed by the algae is liberated and then re-assimilated by the higher plants (Stewart, 1970). A large variety of cyanobacterial species are known to be nitrogen fixing and their importance in improving soil fertility for sustainable agriculture in submerged and irrigated rice cultivation is well recognized (Saikia and Bordoloi, 1994). The use of cyanobacteria as a biofertilizer for rice fields is very promising but limited due to fluctuation in quality and quantity of inoculum and its physiological attributes in varied agroecological regions. Utilization efficiency of fixed nitrogen by rice plants is often low and efforts are therefore being extended to isolate suitable strains of cyanobacteria that would be prolific not only in fixing atmospheric nitrogen but also in excreting it continuously, thus making it available to the growing rice plants (Boussiba et al., 1984).

Cyanobacteria are widely used in rice fields throughout Asia, where their enhancement of soil fertility by means of biological nitrogen fixation (so called algalization) in place of N-rich fertilizers (Halperin et al., 1981), but their beneficial effects is not limited to that. The cyanobacterium *Tolypothrix tenuis* is grown in cultures and added to rice fields. Aboul-Fadle et al. (1967) reported 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 Japan, rice fields are fertilized by water fern *Azolla* which multiplies rapidly and contains the symbiotic blue-green alga *Anabaena* which fixes gaseous N₂.

Source of organic matter

Algae are also important source of organic matter in soil (Shields and Durrell, 1964; Ibraheem, 2007). The organic matter 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). Humus accumulation is also important for moisture retention (Bolshev and Novichkova-Ivanova, 1978). In the U.S.S.R., filamentous forms of the Cyanophyceae, especially *Oscillatoria*, *Schizothrix* and *Plectonema* were found to be important in soil formation (Gayel and Shtina, 1974). In most cases, it is generally accepted that the incorporation of organic carbon via photosynthesis and of organic nitrogen via nitrogen fixation is the most important contributions of algae added to the soil. They also act as a reserve of inorganic nutrients.

Soil reclamation

The difficulties in soil reclamation in arid and semi-arid regions are mostly the salinity conditions of large soil areas. Several studies have been carried out on the effect of salinity on the growth, metabolism and yield of the plants and algae (Ibraheem and Abdel-Raouf, 2001; Tang et al., 2007). Some growth regulators such gibberellic acid (GA₃) were used for improving the salt tolerance of the plants (Ouda et al., 1991). From an economic point of view, growth regulators are expensive and are non-practical especially, when applied in large amounts. Algae play an economic role in soil reclamation increases soil fertility and improve the plant conditions under certain environmental factors (Pandey et al., 2005; Nisha et al., 2007; Prabu and Udayasoorian, 2007).

PRODUCTION OF EXTRACELLULAR SUBSTANCES

Cyanobacteria excrete a great number of substances that influence plant growth and development (Haroun and Hossein, 2003; Rodriguez et al., 2006). These microorganisms have been reported to benefit plants by producing growth-promoting regulators (the nature of which is said to resemble gibberellin and auxin), vitamins, amino acids, polypeptides, antibacterial and antifungal substances that exert phytopathogen biocontrol and polymers, especially exopolysaccharides, that improve

soil structure and exoenzyme activity.

Plant growth substances

While working on the algae of Indian paddy fields, Gupta and Lata (1964) observed that cyanobacteria accelerated seed germination and promoted seedling growth. In addition, they also observed that both the yield and the quality of the grains were improved in proteins content. It seems very likely that the beneficial effect of the algae on the rice crop may not be restricted to their capacity to fix atmospheric nitrogen alone, but also they have additional beneficial roles, such as releasing of bioactive substances. Mechanisms used by microbes to stimulate plant growth include biofertilization (increasing the supply of mineral nutrients to the plant), biological control (elimination of the plant enemies including microbial pathogens, insects and weeds) and direct plant growth production by delivering plant growth hormones (Lugtenberg et al., 1991). Biofertilization techniques using cyanobacteria are recommended for increasing the rate of seed germination and growth parameters of many plants (Strick et al., 1997).

Although microalgae and cyanobacteria are primary microbial photosynthetic agents of the soil, their ecological role is still not fully defined. However, it is obvious that some of their advantageous properties and beneficial effects influence plant/soil-systems. Two important potential uses of soil microalgae in crop production are as biofertilizers or soil conditioners. Recently, there is increasing interest in their antimicrobial- and PGR-compounds (Plant Growth Regulator). The effect of a great varieties of extracellular substances production by algae including cyanobacteria, play a valuable role in water habitats (Fogg, 1971), as well as having a valuable role in enhancing the growth and germination of higher plants (El-Ayouty, 1998). For this reason, cyanobacteria algae were recommended as a biofertilizer (Banerjee and Kumar, 1992) due to the liberation of a very large portion of the bioactive substances from their assimilating nitrogen outside their cells. The previous inductions attributed to nitrogenase and nitrate reductase activities of cyanobacteria are associated with the surface of plants or the amino acids and peptides produced in algal filtrate and/or other compounds that stimulate growth of crop plants (Adam, 1999).

Microalgae are a biochemically diverse assemblage of microorganisms amenable to formation and mass culture. Including the cyanobacteria and nearly a dozen of eukaryotic classes, microalgae produce a wide array of compounds with biological activity. These may be nitrogenous (Jones and Stewart, 1969), amino acid (Varga et al., 1999), vitamin B12 and biotin (Misra and Kaushik, 1989). Moreover, cyanobacteria have ability to exude also plant growth hormones including auxins like

substances (Venkataraman, 1981), cytokinin-like substances (Strick et al., 1997) gibberellins or gibberellic-like substances (Shen-Rui and Shen, 1997), antibiotics, algicide, toxins, organic acids (Hellebust, 1974) and pharmaceutically active compounds (Metting and Pyne, 1986). A gibberellin-like substance has been isolated from the cyanobacterium *Phormidium foveolarum* and this is active in GA-bioassays (Gupta and Agarwal, 1973). Moreover, chromatography identification of an excreted substance from *Nostoc muscorum* isolated from Argentine paddy fields revealed auxinic activity and characteristics similar to indole acetic acid (Caire et al., 1979). Growth-promoting substances were also detected by the effect of extracts of *N. muscorum* on seedlings of *Panicum miliaceum*. The height of millet plants as well as their dry weight was also increased by all the extracts (Caire et al., 1976). Information about cyanobacterial biomass or their substances being incorporated to other plants different to rice is scarce (Halperin et al., 1981).

Bently (1958) in studying growth regulator production by phytoplankton showed that some strains of *Anabaena* and *Oscillatoria* exuded auxin-like substances. This was confirmed by the work of Likhitkar and Tarar (1995) who found that presoaked cotton seeds in different concentrations of exudate of *N. muscorum* increased germination rate, total length of seedlings and radicals. Adam (1999) revealed a stimulation effect of the cyanobacterium *Nostoc muscorum* on seed germination of wheat, sorghum, maize and lentil. He also concluded that the germination of seeds of the tested crop plants either in live cyanobacteria inoculum algal filtrate (exogenous) or boiled algal extract (endogenous) was significantly increased. He attributed it to the nitrogenase and nitrate reductase of the alga, or the amino acids and peptides produced in the algal filtrate and/or other compounds that stimulate growth of crop plants.

Moreover, Mahmoud and Amara (2000) revealed that biofertilizers enhanced the growth parameters, fruit yield as well as CO₂ evolution of tomato plant. Germination and related processes in wheat, sorghum, maize and lentil growth parameters and contents of nitrogenous compounds also increased. These reports indicated that the usage of biofertilizers enhances the growth parameters, fruit yield and vitamin C (ascorbic acid) in tomato plants. On the other hand, Tantawy and Musa (2001) studied the effect of cyanobacterial filtrates of *Nostoc calcicola* and *Anabaena flos aquae* on the seed germination and/or plant growth of some wheat, soybean and clover crop cultivars. They found that soaking the seeds for these crops in the filtrates of both cyanobacterial strains increased the germination percentage either in the control treatment (water) and Watanabe medium. In this respect, Aref (2001) reported that soaking of rice seeds cultivar Sakha 102 in *Nostoc sp.* live filtrate had stimulated the seed germination percent age, reaching 90% of germination when compared to water soaked seeds. She also showed similar stimulation

effect with both *N. muscorum* and *Anabaena* sp. (86.8 and 83.3, respectively). Additionally, Mohamed (2001) came to a conclusion that the treatment of rice seedlings with the cyanobacteria filtrates of *Anabaena oryzae*, *N. calcicola*, *Microchaete tenera* or *Cylindrospermum muscicola* had increased both shoots and roots lengths than those treated with water only. He owed this to the growth promoting like-substances secreted by the cyanobacterial strains in their filtrates.

Furthermore, Saffan and Mohamed (2001) studied the beneficial role of some bioactive substances released by cyanobacteria on the rate of germination *Senna* seeds as well as evaluation of the metabolic changes in medicinal plant *Senna alexandrina*. They reported that the exudates of *Nostoc piscinale* and *N. muscorum* increased up the rate of germination of *Senna* seeds, reaching 100 and 90% respectively after 60 h. Also, they found that the cyanobacterial exudates contained variable concentrations of abscisic acid (ABA), gibberellic acid (GA₃) and indole acetic acid (IAA) and other metabolites that might be implicated as allelochemical agents. They had also found out a significantly increased proteins and total soluble sugars in treatments with algal exudates, especially those of *N. piscinale* and *N. muscorum*. The allelopathic effects of cyanobacterial exudates (*N. muscorum*, *N. piscinale* and *Anabaena fertilissima*) on some biochemical constituents of cardon (*Cynara cardunculus*) have also been studied (Saffan, 2001). The quantitative analysis of cyanobacterial exudates revealed the presence of phytohormones, amino acids, total soluble nitrogen and total reducing sugars. In addition, treatment with algal exudates stimulated the germination rate of cardon seeds after 96 h. Furthermore, the data revealed a significant increase in the total soluble sugar and protein contents in germinated seeds treated with different algae exudates.

Phytopathogen biocontrol

Application of chemical pesticides

Soil is a dynamic system in which the physical, chemical and biotic components are in a state of equilibrium. Application of insecticides without considering the other soil constituents, disturb this equilibrium which adversely affects the productivity of the soil. Maintenance of the soil biota other than the harmful pests helps in better crop nutrient management and maintenance of soil health. Insecticides frequently exert inhibitory or stimulatory effects on the growth or other activities of microorganisms, either in pure culture or in the field. Few works on pesticides distributions, types, toxicity, mechanism of actions, degradations, their tolerance by the organisms and other physiological processes were reviewed and summarized (Duke, 2002). Ghosh and Saha (1988) suggested that some pesticides actually are

highly phytotoxic, such as carbaryl. The toxicity of carbaryl was studied also by Peterson et al. (1994). Ibraheem (2002) found that Larvin and Sevin when applied in Egyptian soils have very toxic effects on nitrogen fixing cyanobacteria *Anabaena subtropica* and *A. variabilis*. Blue-green algae, especially the nitrogen-fixers cyanobacteria, represent the major microorganisms which contribute soil fertility. These organisms play an important role in this system by providing a steady input of fixed nitrogen (Roger et al., 1986) and other beneficial roles as previously discussed (Omar, 2000). Most of the soil and aquatic microscopic algae are sensitive to insecticides due to the fact that algae are engaged in photosynthesis and that many insecticides interfere with the process.

Until now many pesticides from different chemical and artificial sources were used as acaricidal, fungicidal and insecticide agents (Banerjee and Banerjee, 1987). These pesticides affect the distribution of fauna in their natural ecosystems. Also, the unjustifiable and unsafe applications of these pesticides on soils and plants cause accumulation of different undesirable chemicals in the crop, which may be a bigger un-direct factor in human diseases.

Biological control

In the last decades, different researchers have studied the replacement of chemical pesticides by natural components of different plant and microalgal sources as insecticide agents (Nassar et al., 1999), acaricide agents (Amer et al., 2000; Sanchez-Ramos and Castanera, 2001; Duke, 2002) and fungicidal agents (Safonova and Reisser, 2005; Volk and Furkert, 2006; Ibraheem and Abdel-Raouf, 2007; Hassan, 2007). These natural materials in addition to their lethal activities on pests, preserves the environment of pollution, maintain the equal distribution of fauna and also to keep the beneficial animals. Fungi and bacteria are the main biological agents that have been studied for the control of plant pathogens, particularly soil-borne fungi.

Cyanobacteria have received little attention as potential biocontrol agents of plant diseases (Hassan, 2007). Kulik (1995) published a literature review summarizing the potential for using cyanobacteria and algae in the biological control of plant pathogenic bacteria and fungi. Caire et al. (1997) reported that different concentrations of dilute aqueous extract from nitrogen-fixing cyanobacterium *N. muscorum* Ag. were efficient in the control of a damping-off. Also, it was found that the growth of the plant pathogens *Sclerotinia sclerotiorum* and *Rhizoctonia solani*, damping-off causal agents, was inhibited by extracts from cells of *N. muscorum* or by extracellular products of this cyanobacterium (Zaccaro et al., 1991). With additional research, it should be possible to develop thin film formulations (polymers) of bactericidal and

fungicidal cyanobacterial products that would confer protection against soil-borne pathogens that attack seeds and seedlings, when applied to high volume seeds and remain competitive (Kulik, 1995). One of the modern and advanced biotechnological researches is that conducted on the using of different algal taxa of different habitats (marine, fresh and soil) as a biological control for many animal or plant diseases and also against agricultural pests. Some of these researches studied the anti-microbial activities against some human pathogenic bacteria, fungi and toxic micro-algae (Noda et al., 1990). Others were conducted on the study of toxic effects of some algal metabolites against insects (Nassar et al., 1999). For example, Mulla et al. (1977) found that a free floating unicellular *Chlorella ellipsoidea* produces some substances which affect the development and immature stages of mosquitoes. Similar results were obtained by Nassar et al. (1999) who found that some cyanobacteria and green algae produce substances that inhibited larval development and delayed the survival and development of the adult female of mosquitoes. Van-Der Westhuzen and Eloff (1983) noticed that toxicity of *Microcystis aeruginosa* against the larvae of *Culex pipiens* increased gradually during the first days of exponential phase to the maximum and then gradually decreased at the beginning of the stationary phase.

Further studies by other workers were conducted on the possibility of prevention of carcinogenesis by some algal products (Mokady and Ben-Amotz, 1991). There is much evidence that the production of extracellular substances by blue-green algae is widespread and sometimes quantitatively important (Fogg, 1970). The enhanced research activity on the subject of biological control is in line with increased effort and determination by microbiologists to adapt to the conceptual scheme of integrated pest management as an acceptable ecosystem approach to disease control and to realize that biological control must become one of the basic components in pest management practices (Hassan, 2007).

Exopolysaccharide

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). Maintenance of adequate levels of soil organic matter is essential for a sustainable and high production of crops. Cultivation alters the structural stability of soil and reduces the amount of N and soil organic matter.

The nature of this labile organic matter is not fully known, but a major portion of it could be microbial biomass (Singh and Singh, 1995). Reducing the amount of organic matter affects the stability of soil aggregates.

Incorporation of organic materials in soil promotes microbial growth and enzymatic activity in the soil. Some cyanobacteria excrete slime or mucilage that becomes dispersed around the organism and, to an extent, partially dissolves in the culture medium or in the soil solution. One way to positively affect nutrient content and soil structure is to add cyanobacteria (Rogers and Burns, 1994).

Application of algal biofertilizers is also useful for the reclamation of marginal soils such as saline-alkali and calcareous soils (Hedge et al., 1999). *N. muscorum* can improve the aggregate stability of a saline soil, where the increase in soil aggregation is mainly due to exopolysaccharide secreted by microorganisms or exopolysaccharide added to soil after death and cellular lysis (Caire et al., 1997). Cyanobacteria can be incorporated into soil as organic matter and also as a source of enzymes as they produce acid and alkaline extracellular phosphatases that are active in solution or located in the periplasmic space of the cell wall. Both biomass and exopolysaccharides incorporated into soil induce a growth promotion of other microorganisms and increased the activity of soil enzymes that participate in the liberation of nutrients required by plants (Caire et al., 2000).

TREATMENT OF HEAVY METALS

A large number of microorganisms, including cyanobacteria, are able to concentrate metal ions present in their environment (Mohamed, 1994; Khalifa, 1999; Abdel-Raouf and Ibraheem, 2001; Shaaban et al., 2004; Samhan, 2008). Mechanisms of cyanobacterial and microalgal resistance to heavy metals involve: 1) environmental factors; 2) non-specific protective mechanisms of the cell; and 3) specific protective mechanisms developed in response to the impact of a toxic metal species in the cell. In addition to intracellular protective mechanisms in which the main mechanism of biosorption of heavy metals is ion exchange in the cyanobacterial outer cell wall, there are mucilaginous sheaths that behave as an "external vacuole". The metal-binding properties are probably due to a high density of anionic charges, especially carboxyl, identified in the capsular polymer. This group of microorganisms could have a higher efficiency in the biosorption during its growth in polluted environment or in the use dried non-living biomass for the removal of heavy metals (Gloaguen et al., 1996).

Moreover, some of them are able to fix atmospheric nitrogen. The use of selected diazotrophic cyanobacteria that accumulate heavy metals would decrease the cost of production of biomass to use as inoculum in processes of environmental remediation. *M. tenera* could be used for remediation of lead contaminated soils and waters (Zaccaro, 2000).

SOIL CONSOLIDATION AND DUST CONTROL

Crust formation

Soil microorganisms commonly aggregate soil particles to form biological soil crusts, particularly in harsh environments where vascular plant distributions are patchy and water is limited (Hawkes and Flechtner, 2002; Ibraheem, 2003; Abdel-Raouf et al., 2004). Biological crusts consisting of algae, cyanobacteria, lichens, microfungi, bacteria, and mosses are common in habitats where water and nutrients are limited and vascular plant cover is discontinuous. Crusts alter soil factors, including water availability, nutrient content, and erosion susceptibility, and thus are likely to directly and indirectly affect plants (Hawkes and Flechtner, 2002; Stal, 2007; Bhatnagar et al., 2008).

Cyanobacteria and other crust organisms stabilize the soil by binding together small particles into larger particles (Shields and Durrell, 1964). This binding is achieved by several mechanisms (Bar-Or and Danin, 1989) including: physical binding of soil particles by entangled filaments, adhesion to mucilaginous sheaths or slime layers excreted by cyanobacterial trichomes and attachment of particles to sites along the cyanobacterial cell walls. This binding increases the organic matter content of the crust (Danin et al., 1989), improving soil's resistance to both wind and water erosion. The importance of micro-organisms for enhancing the stability of soil aggregates is well recognized (Eldridge and Leys, 2003). Bailey et al. (1973) demonstrated enhanced aggregation when soils were inoculated with algae or cyanobacteria. Cyanobacteria and microphytes exude gelatinous materials that adhere or entangle clay particles in sand, and this process concentrates the microorganisms at the soil surface. The crusts are formed by the entanglement of cyanobacteria and algae filaments, lichen and moss thalli and soil particles (Chartres, 1992). Polysaccharides excreted by filamentous algae and cyanobacteria, along with the living organisms themselves, bind soil particles together into a single, consolidated layer to form a crust of the first few centimeters of surface soil (Campbell et al., 1989). The importance of soil crust development in ecological functioning in arid and semi-arid regions is well established (Harper and Marble 1998). In the arid desert regions of China, soil crusts are common once the shifting sand dunes have been stabilized.

Microbiotic crust communities occur throughout arid and semi-arid regions of the world, and an interest in their role in nutrient cycling and the discovery of a rich microfauna and microflora have led to a growing number of ecological, physiological and taxonomic studies (Lewis and Flechtner, 2002). The earliest surveys of microbiotic crust organisms to include algae began in the 1960s with Cameron (1960, 1964), Shields and Drouet (1962) and Friedmann et al. (1967). These studies revealed a very

small number of green algae from a given site. It is important to characterize the spatial distributions of organisms within crusts because of their biotic effects on both physical and chemical soil properties and their potential influence on vascular plants. A variety of biotic and abiotic factors may contribute to spatial heterogeneity of crust organisms (Hawkes and Flechtner, 2002).

Stabilization of soil aggregate

Mucilaginous (palmelloid) green microalgae are as soil-conditioning agents on a very small scale in the United States (Shujinš, 1991). Soil conditioning is any procedure or product that improves not only the physical properties of soil for agriculture, but also the soil structure by genesis and/or stabilization of soil aggregates. Aggregate formation is complex and poorly understood. However, aggregate stabilization is known to be primarily due to adsorption and binding of particulates by polysaccharides or microbial origin together with environment by living microbial filaments (Burns and Davies, 1986). When inoculated on to irrigated sandy soils through center pivot sprinklers, mass-cultured *Chlamydomonas* and *Asterococcus* species (Chlorophyceae) have been shown to significantly improve the integrity of soil aggregates in the face of disruption by wind and slaking in water (Hawkes and Flechtner, 2002).

AGRICULTURAL WASTEWATER TREATMENT

Pollution of agricultural water drains is a man-made phenomenon, arising either when the concentrations of naturally occurring substances are increased or when non-natural synthetic compounds (xenobiotics) are released into the environment. Organic substances released into the environment as a result of domestic, agricultural and industrial activities leads to an inorganic pollution (Mouchet, 1986). There are still a number of cases where municipal and rural domestic wastewater is discharged directly into waterways, often without treatment. These discharges are increasing year after year due to the existing plan for water supply networks set-up in many villages. Also, the present expansion of water networks in several towns without parallel construction of new sewerage systems or rehabilitation of the existing ones aggravate the problems and lead to pollution problems of the water bodies and increasing public health hazards. The constituents of domestic and urban input to water resources are pathogens, nutrients, suspended solids, salts and oxygen demanding materials (Singh and Dhar, 2006).

The agricultural drains sometimes receive the bulk of the treated and untreated domestic pollution load (Abdel-Raouf et al., 2004). As a result, many canals now also are contaminated with wastewater pollutants. Apart from being the largest consumer of water, agriculture is also a

major water pollutant. Saline irrigation return-flows or drainage containing agrochemical residues are serious contaminants for downstream water users. Moreover, agricultural nitrate contaminates groundwater. The disposal of liquid animal waste pollutes surface and groundwater, etc. This means a large number of organic and inorganic substances disturb the water quality, which is the main cause of eutrophication of water body. They also proved to be powerful stimulants to algal growth and consequently formation of "algal blooms". An algal bloom can affect the water quality in several ways.

Many investigations have been conducted and concerning the distribution and species composition of fresh water algal communities in different water supplies in Egypt in response to the impact of some environmental stresses (Abdel-Raouf et al., 2004). The polluted rivers, lakes and seas, were aesthetically displeasing also by man, which importantly were a public health hazard, since they harbored human pathogens and increased the risk of spreading excreta-related diseases through the water-borne route. In order to prevent such problems, the sewage treatment systems were designed. Through most of human history, agriculture has been in effect a major form of biological water treatments through its use of the potential pollutants of human and animal wastes to support plant growth. Municipal sewage, for example sometimes after treatment is applied as a source of nutrients over land occupied by natural vegetation or various crops (Wood-Well, 1977). Such wastes are still important in world agriculture, especially where commercial fertilizers are not readily available (Tourbier and Pierson, 1979).

The history of the commercial use of algal cultures spans about 55 years with application to wastewater treatment and mass production of different strains such as *Chlorella* and *Dunaliella*. Currently, significant interest is developed in some advanced world nations such as Australia, USA, Thailand, Taiwan and Mexico (Renaud et al., 1994). These are due to the understanding of the biologists in these nations for the biology and ecology of large-scale algal cultures, as well as in the engineering of large-scale culture systems and algal harvesting methods, all of which are important to the design and operation of high rate algal cultures to produce high-value products, such as Pharmaceuticals and genetically engineered products (Javanmardian and Palsson, 1991). These include antibacterial, antiviral, antitumor/anti-cancer, antihistamine, antihyperlipidemic and many other biologically valuable products (Abdel-Raouf and Ibraheem, 2008; Abdel-Raouf et al., 2011).

Some industrial and agricultural wastewaters show total nitrogen and phosphorus concentrations up to three orders of magnitude higher than natural water bodies (de la Noüe et al., 1992). The normal primary and secondary treatment processes have been introduced in a growing number of places, in order to eliminate the easily settled materials (primary treatment) and to oxidize the organic

material present in wastewater (secondary treatment). The final result is a clear, apparently clean effluent which is discharged into natural water bodies. This secondary effluent is, however, loaded with inorganic nitrogen and phosphorus and causes eutrophication and more long-term problems because of refractory organics and heavy metals that are discharged.

Tertiary treatment process removes all organic ions. It can be accomplished biologically or chemically. The biological tertiary treatment appears to perform well compared to the chemical processes which are in general too costly to be implemented in most places and may lead to secondary pollution. However, each additional treatment step in a wastewater system greatly increases the total cost; the relative cost of treatment doubles for each additional step following primary treatment (Oswald, 1988a). A complete treatment of wastewater from different sources process aimed at removing ammonia, nitrate and phosphate (Oswald, 1988a). Microalgal cultures offer an elegant solution to tertiary and quinary treatments due to the ability of microalgae to use inorganic nitrogen and phosphorus for their growth (Oswald, 1988a, b; Tam and Wong, 1995) and also for their capacity to remove heavy metals (Hammouda et al., 1995), as well as some toxic organic compounds (Redalje et al., 1989). Therefore, it does not lead to secondary pollution. Amongst beneficial characteristics, they produce oxygen and have a disinfecting effect due to increase in pH during photosynthesis (de la Noüe and De Pauw, 1988).

CONCLUSION

In this review, an attempt was carried to throw some light on the different beneficial roles of algae in agriculture, with regard to the relationship between algae and crop plants. Algae are important components of arid and semi-arid ecosystems. Furthermore, their distribution may indicate the health of the environment. In recent years, much considerations were sent towards the possibility of using algae as biological conditioners instead of any artificial or chemical conditioners, where algal use reduces the resultant pollution to soil and plants together, in addition to their ability to improve both soil and plant properties.

Algae, especially microalgae and cyanobacteria are ubiquitous in the world soils. Although they are the primary microbial photosynthetic agents of the soil, their ecological role is still not fully defined. In this study, emphasis was laid on the role of algae, especially microalgae in soil fertility and reclamation and some of their advantageous properties and beneficial effects influence the plant/soil system, such as:

- (1) Excretion of organic acids that increase P-availability and P-uptake,

- (2) Provision of nitrogen by biological nitrogen fixation,
- (3) Increased soil organic matter,
- (4) Production and release of bioactive extracellular substances that may influence plant growth and development. These have been reported to be plant growth regulators (PGRs), vitamins, amino acids, polypeptides, antibacterial or antifungal substances that exert phytopathogen biocontrol and polymers, especially exopolysaccharides, that improve soil structure and exoenzyme activity.
- (5) Crust formation
- (6) Stabilization soil aggregation by extracellular polysaccharides of soil aggregate
- (6) Concentrate metal ions present in their environment.

This review also reinforced the role of algae in the treatment and agricultural recycling of wastewater. A complete treatment of wastewater from different sources process aims at removing ammonia, nitrate, phosphate and some heavy metals.

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