Journal of Chemical Health Risks

www.jchr.org

JCHR (2023) 13(4), 236-249 | ISSN:2251-6727

Biotic and Abiotic Interactions of Diverse Organisms Acting as Biofertilizer and their Role in Soil Enrichment

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(Received: 04 August 2023 Revised: 12 September Accepted: 06 October)

KEYWORDS

Biofertilizer,
PGPR,
Agrochemicals,
Stress management,
Soil improvement

ABSTRACT:

In response to world's rapidly increasing population from 6.1 billion in 2000 to 8 billion in 2022, global demands for food and food security is multiplying by folds every year. Also due to factors like deforestation, urbanization, soil pollution etc., the land available for the agricultural purposes is shrinking. To cope up with the increasing demand of agricultural end products i.e. grains, fruits, vegetables, pulses etc. farmers need to increases the production of plants for which they rely on synthetic or chemical fertilizers. These chemicals boost the yield by over providing the nutrients to plants and maximizing their yield. The nutrients are present naturally in the soil but get depleted when crops are grown on same patch of land without following crop rotation or inter cropping. Agrochemicals have adverse effect on the physiochemical properties of soil that is reduced soil fertility, soil pH imbalance, depletion in beneficial micro-organisms etc. Rain and floods of fields washes away these chemicals to water bodies causing water pollution. They do increase the crop growth and development but at the cost of environment. Biofertilizers are living or dormant microbes that promote the growth and development of crops when applied in soil and do not have any harmful effects like that of chemical fertilizers. They improve the growth and development of crops by mechanisms like siderophore production, nitrogen fixation, phytohormone production, potassium solubilization, phosphate solubilization etc., apart from it; biofertilizers are also capable of inducing plant growth promoting activities even under the biotic and abiotic stress. Biofertilizers also provide resistance against many diseases by producing antibiotics. This review sheds a light on biofertilizers, their mechanism and their impact on improving the crop production and soil health.

1. Introduction

Agriculture being one of the most important human activities has been practiced for food production by growing crops or by rearing cattle for centuries. With rapidly increasing population worldwide and to maintain the food production, farmers are dependent on using fertilizers for boosting the productivity of crops. Chemical fertilizers are being extensively used for crops; which no doubt increase the production but may have several adverse effects. The over accumulation of insoluble chemicals acidifies the soil and kills many helpful microorganisms, thus degrading the quality and heath of soil; in addition to getting washed away with rain to water bodies causing water pollution.

Plants require macronutrients and micronutrients for their optimal growth. Nitrogen, Phosphorus and Potassium are the most essential macronutrients for the growth and development of plants. Nitrogen is the main component of amino acids and nucleic acids. It plays a crucial role in synthesizing proteins, DNA, RNA and enzymes [1] and increases the rate of photosynthesis [2]. On the other hand, phosphorus plays a major role in converting light energy into chemical energy and drives biochemical reactions in plants. Potassium is the third most essential nutrient which is essential for osmoregulation, photosynthesis, enzymatic activities, protein synthesis and maintaining plasma membrane [3, 4]. It is the most abundantly present cation in plants and is involved in many physiological processes [5].

Various symptoms are caused because of deficiency of elements like retardation in growth and development of plants and yellowing of stem and leaves because of deficiency in Nitrogen, leaf curl caused because of deficiency of potassium, Adenosine triphosphate is provided as energy for processes like transpiration, photosynthesis and phosphorus is one of main constituents of ATP, deficiency in phosphorus ultimately hinders these processes. Nitrogen being the most vital macronutrients for plants, when deficient leads to changes in leaf and stem size, reduction in leaf area leads to reduction in photosynthetic activity as less chloroplasts will be present, it further leads to reduced Rubisco and PEPcase activity, and causes negative impact on stomatal conductance [6]. In addition, it also affects leaf transpiration leads to retardation in plant growth, yield & development [7] . Phosphorus deficiency tends to inhibit the shoot growth and potassium deficiency inhibits root growth and also reduces the photosynthesis in plants [8]. Deficiency of Potassium severely affect the plant growth by inhibiting the glutamine synthetase, nitrate reductase and glutamate synthase which further hinders the growth of shoots, roots, and reduces the leaf size of plants [9].

Biofertilizers are the living microbial community which is obtained from the soil. Biofertilizers fix the atmospheric nitrogen to avail the plant in the form of nitrate ion and phosphorus in the form of $H_3PO_4^-$ by solubilizing the insoluble phosphorus present in soil. It improves the chemical as well as biological aspects of the soil by restoring soil fertility. Roots surrounded by a narrow zone of soil where soil and microbes interact with each other known as a rhizosphere [10]. In the rhizosphere microbes are in a symbiotic relationship with plants and provide several benefits like nitrogen fixation and nodulation and such microbes as called Plant Growth Promoting Rhizobacteria (PGPR) [11, 12]. PGPR plays an important part in several biotic activities in the soil and promote crop production by producing various enzymes such as siderophore, indol-3-acetate, lytic enzymes and antibiotics [13]. Furthermore, it has specific characteristics like bio-control of pathogens, heavy metal detoxification and salinity tolerance [14].

PGPR can be classified into two main categories based on their association range in the degree of bacterial proximity to root and intimacy of the associations- intracellular plant growth promoting rhizobacteria (iPGPR) and extracellular plant growth promoting rhizobacteria (ePGPR). ePGPR are present in the rhizosphere, either on rhizoplane or in the voids between root cortex cells. Bacterial genera *Agrobacterium, Arthobacter, Azotobacter, Azospirillium, Bacillus, Burkholderia, Caulobacter, Chromobacterium, Erwinia, Flavobacterium, Micrococcous, Pseudomonas and Serratia* belongs to ePGPR [15]. iPGPR is present in dedicated nodular structure in root cells [16]. iPGPR belongs to family *Rhizobiaceae* that includes *Allorhizobium, Bradyrhizobium, Mesorhizobium and Rhizobium* [17].

For 2020-21 the volume of biofertilizers used in India was 3.879 million metric ton and chemical fertilizers used were 23.294 million metric tonnes and has been shown in Fig. 1.

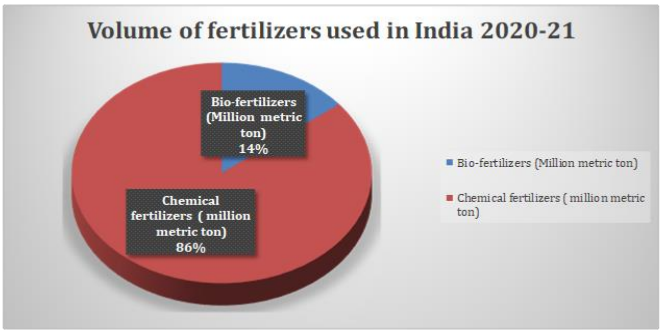

Fig. 1: Volumes of fertilizers used in India 2020-21

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JCHR (2023) 13(4), 236-249 | ISSN:2251-6727

2. Forms of PGPR

Based on the mode of action, PGPR can be classified into three types (Fig. 2) [18].

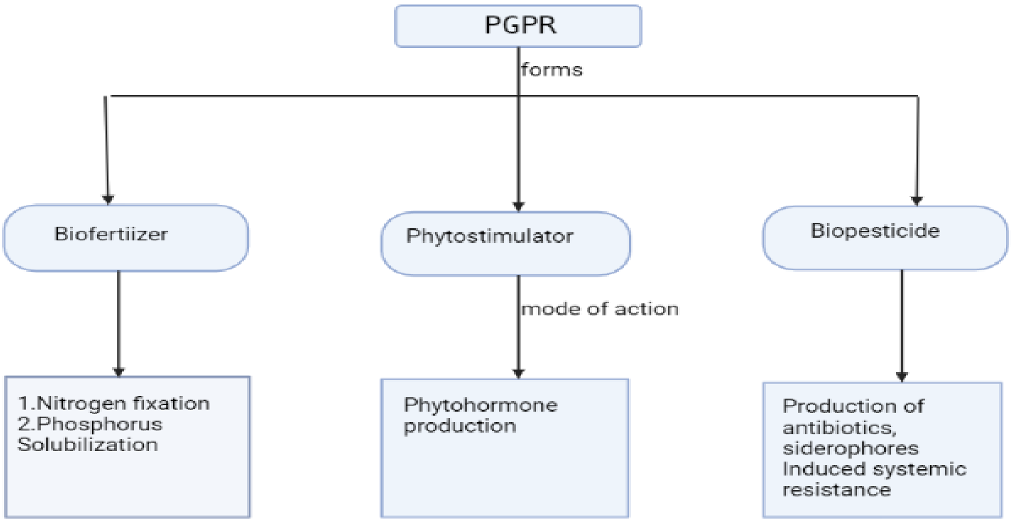

Fig. 2: Classification of Plant Growth Promoting Rhizobacteria

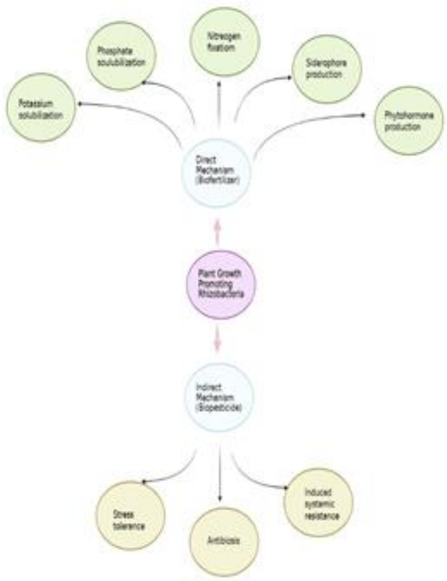

Fig.. 3

Biofertilizers living microbial community used as fertilizers because of their ability to perform various mechanisms which enhance to development and growth of plants by providing them with nutrients and fixing insoluble ones to soluble forms for plants.

Phytostimulators they enhance the soil microbial activity for degradation and breakdown of organic content. Biopesticides these are the natural materials derived from microbes, plants and animals that are used to control pest, they are safer and approach than chemical pesticides with less towards environment and humans.

3. Mechanism of Plant Growth Promoting Rhizobacteria

Rhizobacteria uses various mechanisms to enhance plant growth in different conditions. PGPR facilitated plant growth promotion is transpired because alteration of microbial community in rhizosphere by production of various substances [19]. They usually promote the plant growth directly by easing nutrient plant growth directly by easing nutrient acquisition (phosphorus, nitrogen, potassium and other nutrients) or by regulating the hormone levels of plants, known as Biofertilizer activity method. In addition, they also indirectly promote the plant growth by reduction of inhibitory effect of pathogens on plant growth and development in form of biocontrol, root colonizer agents, known as Biopesticide activity method [20]. The various mechanisms of plant

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JCHR (2023) 13(4), 236-249 | ISSN:2251-6727

growth promoting rhizobacteria have been depicted in Fig. 3.

3.1 Direct Mechanism

PGPR have certain mechanisms that directly facilitate the growth and development of plants such as phosphate solubilization, nitrogen fixation, siderophore production, potassium solubilization, and phytohormone production [21].

3.1.1. Nitrogen fixation

Nitrogen is the most important macronutrient required by plants. Although our atmosphere comprises of 78.7% but it remains unavailable to the plants, as plants are only capable of using Nitrogen in Ammonia (NH_3) form. Biological N_2 fixation is a process by which atmospheric nitrogen is converted into ammonia by nitrogen fixing microbes using nitrogenase enzyme [22]. PGPRs are capable of fixing atmospheric nitrogen into ammonia and provide it to plants by two different mechanisms viz. symbiotic associations or by non-symbiotic associations between microbes and the plant roots [23]. In symbiotic nitrogen fixation the microorganisms enters the roots and forms root nodules in which fixation of nitrogen occurs and formed ammonia is available for the plants [24]. They include strains of *Azoarcus sp., Beijerinckia sp., Bradyrhizobium, Sinorhizobium, Mesorhizobium, P. agglomerans* [25]. Inoculating these species in soil improves the quality of soil and nodule formation. Nitrogen fixation is carried out by 'nif' gene which is involved in activation of ion protein, biosynthesis of Fe-Mo co factor and electron donation [26].

Free living diazotrophs carry out non-symbiotic nitrogen fixation and can stimulate plant growth in non-leguminous plants such as *Oryza sativa*, *Azotobacter, Acetobacter, Azospirillum, Pseudomonas, Enterobacter* and *Gluconabacter* are the rhizobacterial sp. playing a role in non-symbiotic nitrogen fixation [18]. Rhizobium are bacteria which form symbiotic association with leguminous crops and then fixes the atmospheric nitrogen, rhizobacteria enters roots of these crops and causes nodule formation on roots, which inhibits rhizobia and fixes atmospheric nitrogen and supplies the plants with NH_3 continuously.

3.1.2. Phosphate Solubilization

After nitrogen, phosphorus is 2nd most crucial macronutrient required by the plants. Apart from growth and development, phosphorus plays a vital role in metabolic processes such as respiration, energy transfer, signal transduction, photosynthesis and macromolecular biosynthesis of the plant [27]. In soil, phosphorus is available in both organic and inorganic forms; however 94-98% of phosphorus in soil is in insoluble, immobilized or precipitated form which cannot be absorbed by the plants [28]. Plants are only capable of absorbing phosphates in their monobasic (H_2PO4^-) and dibasic (HPO_4^{-2}) ionic forms [17].

PGPR in soil uses different methods to make unavailable phosphorus available to plants by converting them to soluble forms. Mechanisms used by the PGPRs to solubilize phosphate include Releasing complex or mineral dissolving compounds like protons, organic acid anions, carbon dioxide and hydroxyl ions, liberating the extracellular enzymes (biochemical phosphate mineralization) and release of phosphate during substrate degradation (biological phosphate mineralization) [29]. PGPR capable of solubilizing phosphate are included in genera *Rhodococcus, Arthobacter, Beijerinckia, Burkholderia, Serratia, Erwinia, Microbacterium, Flavobacterium, Pseudomonas, Rhizobium, Bacillus, And Enterobacter* [30].

3.1.3. Potassium solubilization

Potassium is 3rd most essential macronutrient for plants after nitrogen and phosphorus. Since 89% of the potassium is present as silicate minerals and insoluble rocks, the concentration of soluble potassium that can be utilized by plants is very low in soil [31]. Moreover because of unsupervised and imbalanced applications of fertilizers, potassium deficiency has become one of major restrictions in crop production. Deficiency of potassium leads to plants having poor root development, lowered production of seeds, retarded growth and lower yield.

PGPR can solubilize potassium rocks by breaking them with the help of production and secretion of organic acids. *Bacillus edaphicus, Acidothiobacillus sp., Burkholderia sp., Ferrooxidans sp., Pseudomonas sp., Bacillus mucilaginosus* and *paenibacillus sp.*, are Rhizobacteria species which are reported to be capable

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www.jchr.org
JCHR (2023) 13(4), 236-249 | ISSN:2251-6727

of releasing potassium in accessible forms in soil by breaking down potassium bearing minerals present in the soil [32]. Thus, the application of Potassium Solubilizing PGPR as a biofertilizer can help in improving agriculture and also lower the use of agrochemicals [33].

3.1.4. Siderophore Production

Iron (Fe) is an essential micronutrient for all the living organisms. Despite being the fourth most abundant element on earth, iron is unavailable for plants because it is not readily assimilated by plants or by rhizobacteria [34]. Microbes have developed certain special mechanisms for assimilation of Iron, which includes production of light molecular weight Fe chelating compounds- Siderophores [35]. They are minute organic molecules that are produced by microbes under Fe restrictive conditions and they improve the Fe uptake capacity [36]. PGPR such as *Streptomyces sp., Azadirachta, Bacillus, Azotobacter, Burkholderia, Aeromonas, Pseudomonas* and *Rhizobium* are capable of producing siderophores and provide plants with the required Iron.

3.1.5. Phytohormone production

Plant growth regulators or phytohormones are organic substances, which when present in lower concentration (<1mM) plays a role in promoting, inhibiting or modifying the growth and development of the plants [37]. PGPR produces phytohormones such as cytokinin, auxin, gibberellins, abscisic acid, ethylene and brassino steroids that can be proliferated by the root cells by overproduction of root hairs and lateral roots with uninterrupted increase in nutrient and water uptake [38].

Root invigoration: It is made up of several hormone-mediated pathways that connect to and interact with pathways that detect and react to signals from the environment [39]. These hormones can be produced by PGPR such as *Agrobacterium chroococcum, Klebsiella oxytoca, Pseudomonas putida and Paenibacillus polymyxa.* They produce hormones like auxins, kinetin and gibberellins [40, 41]. Auxins like Indole Acetic Acid (IAA) has a positive effect on cell division, extension and differentiation, increased rate of xylem and root development [42].

Shoot invigoration: Cytokinins help in inducing the shoot development in higher plants. Microbes that encourage hormone production also have an important role in shoot invigoration. It is observed in PGPRs like *Azotobacter sp., Pseudomonas sp., Rhizobium leguminosarum* and *Bacillus subtilis* [43].

3.1.6. Composting microorganisms

These are microorganisms that break down agricultural waste, twigs, leaves, branches, roots, dead plants etc. into simpler forms which can be absorbed by plants and provide them with nutrients for their optimal growth, and microorganisms undergoing this breakdown are known as composting microorganisms.

3.2. Indirect Mechanism:

Pathogenic bacteria pose a serious threat to agricultural and economic sustainability as they disrupt the ecology of soil and the environment, degrade soil fertility and have harmful impact on plants. Indirect mechanism consists of processes by which PGPR neutralizes the harmful effect of pathogens on plants, by the production of recessive substances that boosts natural resistance of the host [44]. It can also be defined as the mechanism that helps plants to grow under abiotic and biotic stress [45]. Use of PGPRs is an environment friendly approach for obtaining soil fertility and sustainable plant growth. This approach of using PGPR has led to reduction in the need of use of agrochemicals for improving fertility of soil by mechanisms such as antibiotic production, siderophore production, induced systemic resistance, hydrolytic enzymes production [46].

3.2.1. Stress Management

Stress is any factor having negative impact on the development and growth of the plant. Stress leads to increased formation of reactive oxygen species- OH^-, O^{2-} and H_2O^{2-} radicles. Excessive production of reactive oxygen species causes oxidative stress by oxidizing membrane lipids, nucleic acids, proteins and photosynthetic pigments and thus damages the plants [47].

Abiotic stress tolerance: Factors like extreme temperature, salinity, drought etc. have a damaging impact on biomass and crop production, which is a threat to food security worldwide. Aridity stress caused by abiotic factors is most dominant form of stress

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JCHR (2023) 13(4), 236-249 | ISSN:2251-6727

inhibiting growth of plants [48]. Bacterial strains such as *Pseudomonas fluorescens* and *Pseudomonas putida* have been studied for their role in plant abiotic stress management when used as a PGPR. Plant growth promoting rhizobacteria has been reported to be used for crops like chickpea, wheat and soyabean as it provides drought resistance [49].

Biotic stress tolerance: Biotic stress is caused by living organisms (viruses, bacteria, insects, fungi, protists, viroids and nematodes). Their effect on crops and plants leads to reduction in overall yield. It has hostile impacts on plants including nutrient cycling in ecosystem, plant health and population dynamics [50]. These problems can be solved by the use of PGPRs such as *P.flouresence, B. licheniformis, B. subtilis, B. thuringiensis, P. favisporus, B.amyloliquefaciens* etc. Plants when inoculated by soaking their roots in the cultures of plant growth promoting rhizobacteria show massive resistance to biotic stress [19].

3.2.2. Antibiosis

As an alternative to chemical pesticides the use of microbial antagonists against plant pathogens in agriculture has been proposed. PGPR such as *Bacillus sp*. and *Pseudomonas sp*. plays an important role in inhibiting pathogens by producing antibiotics [51]. Most species of pseudomonas produces a variety of antibacterial (pseudomonic acid, andazomycin), antifungal (phenazines, phenazine-1-carboxylic acid, phenazine-1-carboxamide, pyoluteorin, 2,4diacetylphloroglucinol, pyrrolnitrin, rhamnolipids, oomycin A, cepaciamide A, ecomycins, viscosinamide, butyrolactones, N-butylbenzene sulfonamide, pyocyanin) and antiviral antibodies (Karalicine) [52]. *Bacillus sp*. also produces a wide variety of antifungal and antibacterial antibiotics [53]. These antibiotics produced by PGPRs are further classified into volatile (ketones, alcohols, sulphides, hydrogen cyanide, aldehydes etc.) and non-volatile antibiotics (aminopolyols, heterocyclic nitrogenous compounds, cyclic lipopeptides etc.) [54].

3.2.3. Induced systemic resistance (ISR)

Induced systemic resistance is a physiological state of boosted defence capacity aroused in response to a certain environmental stimulus. PGPR induces systemic resistances in plants in response to various environmental factors [55].

Certain signals are produced by plant when they are exposed to specific environmental stressor biotic or abiotic stresses, like pathogen attack, wounding or necrosis. Defensive mechanism gets activated when attacked by pathogens through the vascular system of the plant during invasion of pathogens which lead to the activation of defensive enzymes like β-1, 3-glucanase,lipoxygenase,phenylalanine ammonia lyase, peroxidase and polyphenol oxidase, induced systemic resistance in unspecific for a particular pathogen but helps in controlling several number of diseases in a plant [56]. It involves the use of jasmonate and ethylene hormone signalling and helps in inducing the defensive response of a plant against various pathogens [57].

4. Impact of commercial agrochemicals on soil

Agrochemicals are products like pesticides, fertilizers, herbicides and plant growth hormones which are used for increasing the crop yield [58]. Agricultural sector uses agrochemicals at a large scale for meeting the global food demands. However, unmonitored and excessive use of the agrochemicals leads to environmental degradation, poor soil health and also damages ecosystem [59]. Soil degradation due to excessive use of these agrochemicals has become a global problem as they also harm non target organisms like beneficial bacteria, earthworm etc. in soil [60] and also pose risk of contaminating the food chain [61]. Apart from this, agrochemicals also lead to heavy metal accumulation in the soil which gets absorbed by the crops, which when consumed causes many toxic effects including cancer [62].

Soil health is the continuous capacity of soil to function as a vital living system within an ecosystem to sustain biological productivity, to promote plant and animal health and human habitation, maintain environmental quality [58]. Prolonged fertilizer use results in soil becoming acidic and has major impact on long term productivity of soil; it is also responsible for ground water and surface water pollution. These agrochemicals enter soil through foliage spray, washed off from treated foliage and releases by seeds treated by these agrochemicals.

Bacteria are most abundantly present microbe in soil followed by fungi, algae and protozoans [63, 64]. Fungi make 1-5% of organic matter in soil and uncultivated soil is dominated by fungal biomass and cultivated soil is dominated by bacterial biomass [65, 66]. Application of inorganic factors in agricultural land diminishes the ratio of bacterial and fungal biomass [67]. By many experiments it has been proved that by long term use of inorganic fertilizers soil microbial community is changes and there is imbalance in soil nutrient.

Studies reported that there was a significant increase in the microbial count, activities and organic carbon in soils treated with organic fertilizers in comparison to inorganic fertilizers [68]. Furthermore application of chemical fertilizers in a long run adversely affects the gram negative bacterial population, including *Pseudomonas* that is a beneficial microbial species. There is shift in dominant microbe population and structural diversity of soil because of long term use of chemical fertilizer usage [69].

Pesticides undergo several adsorption, degradation and transport processes that modifies bio-chemical and physiological activity of microbes [70]. As the use of pesticides decreases soil organic matter quality and microbial diversity, since these microbes are accompanying various transformations and nutrient cycling processes, reduction in their number ultimately leads to reduction of soil fertility. The biofertilizers when used in agricultural fields enhances bacterial and fungal ratio which ultimately leads to better soil quality and fertility [67, 71].

5. Algal activities in improving soil condition and their application

The algal micro flora is found to be bio-based fertilizer that can be used for agricultural techniques and is environmentally favourable without leading to any sort of pollution [72]. Algae are commonly classified into two groups- macroalgae and microalgae. Macroalgae is large algae growing in fresh water and marine water, commonly known as seaweed [73], [74]. Microalgae are microscopic algae, found in aquatic, sub aerial and terrestrial surfaces and soils as a part of phytoplankton [75].

5.1. Macroalgae

Sea weeds are generally referred to as macro algae. They are used as fertilizer and for waste treatment [76]. Macroalgae are rich in bioactive compounds such as xanthophylls, terpeniods, chlorophylls, carotenoids, phycobilins, polysaccharides, sterols, phycocyanins, tocopherol and vitamins [77]. Fertilizers produced from sea weeds help in enhancing germination, nutrient absorption, root penetration and crop production [78]. Macroalgae helps in boosting the soil's organic content and leads to overall enhancement of soil [79]. Use of sea weeds as a fertilizer also helps in regularizing pH of the soil and also maintains the C/N ratio in the soil [80].

5.2. Microalgae

Eukaryotic green algae, prokaryotic blue algae, diatoms, euglenoids and dinoflagellates are examples of microalgae [81]. One of major reasons of decreased soil fertility is the depletion of the soil carbon content [82]. Through photosynthesis microalgae is able to incorporate organic carbon into soil. Some of strains of microalgae release extracellular polymeric substance that plays a role as a carbon source and sink, further more improves soil aggregation and soil stability [83]. It influences soil microbial population, phytohormone production and several bioactive substances that play a key role in plant growth and pathogens control [84- 86]. It helps in decomposing the biomass by converting it into simpler forms so that it can be absorbed by plants as nutrients [87], [88]. They also fix atmospheric nitrogen, solubilize phosphors and promote plant defence system [89].

The ability to improve the production of crops by using microalgae as a fertilizer for soil development, crop productivity and crop protection is made possible by the positive impacts that microalgal biomass has on soils and plants. When microalgal biomass is applied to soil it can improve the soil structure and water retention capacity of the soil [90] and because of such properties it acts as soil conditioner [91]. Crops treated with cyanobacteria was able to economize 25-40% of Chemical based nitrogen present in the soil [92].Hence increase the nitrogen content in present in the soil and leading to improve soil fertility.

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Heavy metals get accumulated in the soil because of use of chemical fertilizers and are harmful to the plants if absorbed. Accumulation of heavy metals has increased in the past few years because of their presence in agrochemicals (herbicides and pesticides), mining, electroplating and wastewater treatment [93].

Peptide chains of algae tend to bind with heavy metals and generate special complexes known as organometallic complexes, which enter vacuoles and regulate heavy metal concentration in the cytoplasm of the plants [94]. Microalgal metabolism converts, volatilizes and cleanses these heavy metals and xenobiotic chemicals. Microalgae are non-pathogenic in nature, thus there is no chance of discharge of any sort of unintended pollutants in the environment. Apart from removal of heavy metals from water bodies, bio sorption is also a valid method. Microalgae can absorb waste along with these heavy metals as a source of nutrition and enzymatically destroy these contaminants. Microalgae have certain metal binding capacity which is linked to the presence of polysaccharides and lipids on the surface of the cell wall of microalgae. The cell wall of microalgae includes functional groups- carboxyl, amino, sulphate & hydroxyl which can bind metals and act as metal binding sites. Thus these cell walls of microalgae trap heavy metals, as a result of which biomass of microalgae are extremely effective for removing heavy metals from water bodies. These properties make microalgae a multifunctional polymer that can be used to sequester a wide range of metals through ion exchange and adsorption [95]. Microalgae also promote the mycorrhizal associations which increase the availability of Phosphorus present in the soil, in addition to providing the plants with a constant supply of micronutrients [95].

6. Role of Biofertilizer in Shifting Soil Nitrogen Cycle

With the excess application of synthetic fertilizers on the farm fields, excessive amount of ammonia is emitted from these fertilizers which increase the deposition of Nitrogen (N_2) in the soil.

Bacillus subtilis, when used as a biofertilizer plays an important role in mitigating the agricultural ammonia (NH_3) emissions and also plays an important role in soil nitrogen cycle. B. *subtilis* decreases the NH_3 volatilization by 21% [96]. B. *subtilis* biofertilizer helps in reducing the abundance of ureC gene and boosts abundance of the functional genes and also increases the ammonia oxidising bacteria present in the soil [97].

In an experiment conducted by [97] it was found that the use of *B. subtilis* helped in the conversion of fertilizer Nitrogen to NH_4 i.e. ammonium was reduced and the process of nitrification was increased. Or in other words the application of *B.subtilis* based biofertilizer reduced the source of releasing NH_4 and enhanced the sink or breakdown of NH^{4+}, thereby decreasing the retention of NH^{4+} in the alkaline soil and mitigating the ammonia NH_3 volatilization .

7. Conclusion

Biofertilizer is a promising and better alternative to harmful chemical fertilizers that are currently being used in the agricultural industry. It is eco-friendly and renewable source of nutrition to the plants, as they are capable of transforming or solubilizing nutrients from insoluble form to soluble forms and fix atmospheric nitrogen. Application of biofertilizers plays a major role in maintaining soil fertility, soil quality, soil pH, nutrient level in soil, promotes growth of helpful microbes and has anti-bacterial and anti-fungal properties. Apart from these, they also provide plants with both biotic and abiotic stress tolerance and induce systemic response in plants to fight against pest and any sort harmful microbial invasion. Algae when used as biofertilizer not only provide the plants with nitrogen and other essential nutrients, but also help in cleansing heavy metals and xenobiotic chemicals from the soil. Various other microbes when used as a biofertilizer results in shifting soil nitrogen cycle, soil phosphorus cycle etc.

Conflicts of interest

Authors declare no conflict of interest.

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