Role Of Microorganisms In Environmental Carbon Fixation

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Introduction:

The amount of carbon dioxide (0.03%) in the atmosphere is minuscule. Carbon dioxide (CO_2) is important for plants to produce proteins, lipids, and polysaccharides through photosynthesis. It plays a significant role in the carbon cycle. The CO_2 to O_2 ratio in the atmosphere is naturally balanced by the many ecosystems on earth. Carbon dioxide (CO_2) is essential for the cellular structure of living things. The organic carbon molecules from the CO_2 are integrated into the cells. Since photosynthesis is a crucial component of the development of biomass in both plants and animals and is transferred through the food chain, CO_2 is directly impacted by the biosphere's energy budget. Because it is radioactive due to the absorption of infrared rays from solar radiation, CO_2 is crucial for regulating the earth's temperature. But in recent years the CO_2 concentration in the atmosphere has reached approximately 421ppm (Anonymous, 2023).

This abnormal increase in CO_2 results in a tremendous increase in the earth's temperature leading to global warming and in turn climate change. The imbalance in the CO_2 to O_2 ratio disturbs the carbon cycle and other biogeochemical cycles indirectly which in turncauses ozone depletion. In recent days, extensive fossil fuel burning for various purposes like industries, running vehicles, power generation, etc., and deforestation have resulted in an abnormal increase in CO_2 concentration. To overcome these elevated CO_2 levels there is a need to reduce, control or prevent these emissions in to atmosphere. In this discussion let us learn about the sources of CO_2emissions and methods to reduce the emissions.

Sources of CO_2 emission

The emission of CO_2 into the atmosphere occurs in both natural and artificial ways. Among these, the mother earth has the inbuilt capacity to bear and maintain emissions which are resulted by natural processes. Whereas the emissions from artificial sources are so huge that the earth cannot tolerate them.

A. Natural sources: It includes removal of forest covers, volcanic eruption, forest fire, etc., which results in lots of CO_2 emissions into the atmosphere.

B. Artificial sources: These originated as the result of human activities like the burning of fossil fuels in power plants, plastic production, textile industry, paper industry, automobiles running, wood burning, etc., which adds huge amounts of CO_2into the atmosphere (Bazzaz, 1990).

Strategies towards CO_2 reduction:

Improving energy efficiency of existing engine technology and proper fossil fuel utilization

Uses of nonconventional fuels such as bio hydrocarbon, biodiesel, etc.

I. CO_2 sequestration:However, the above strategies when used signally may not be very effective but when used in combination they are very effective in mitigating CO_2 emission (Goeppert et al., 2012).

II. Carbon dioxide sequestration: For the utilization and recycling of atmospheric CO_2, a novel method has been widely used. Both natural and man-made processes are utilized to sequester carbon dioxide. To do this, it is necessary to capture, store, and use atmospheric CO_2 as a raw material for making a variety of carbon-based products. An excellent approach to removing atmospheric CO_2 is CCS- Carbon Capture and Storage technology. Carbon sequestration is the capture and storage of atmospheric carbon dioxide by continual or enhanced biological processes. Also known as Carbon capture. The CO_2, present in the atmosphere should be captured, stored and utilized as a raw material for producing various carbon-based products. Carbon fixation is the conversion of CO_2 to organic compounds by living organisms.

- Artificial method to capture CO_2
- Natural method to capture CO_2

Natural method

Through a series of metabolic events occurring inside the photosynthetic organisms, biomass is created from atmospheric CO2. 12% of the world's energy is currently provided by biomass. By replacing themselves with new plant life, plants serve as an endless natural resource from which to draw energy. In comparison to other renewable energy sources, biomass has the advantage of encapsulating energy in biological bonds. Biomass is used for a variety of things, including wood, agricultural waste, biofuel, and natural gas. An alternative method for storing the acquired CO2 is biomass. The process of turning CO2 into biomass involves a variety of species, including both plants and microscopic creatures like bacteria, fungi, yeast, and algae. Food shortages, land availability, water, manure, and difficulties managing with a limited quantity of resources are disadvantages of the first-generation biofuel crops. It takes a lot of resources, such as biomass and energy from plants, to manufacture these things. The range of algal cultivation has expanded and opened up a key route to producing bioenergy on small ponds, tanks, lakes, seas, etc. using Microorganisms to sequester the carbon dioxide seems very feasible compared to other methods.

Using microorganisms:

Photosynthetic and non-photosynthetic pathways are the microbial mechanisms involved in sequestering atmospheric CO2 into biomass and energy.

Algae: Microalgae are photosynthetic microorganisms and the most prevalent type of plant in the natural world. Chlorophyceae, Rhodophyceae, Phaeophyceae, Cyanophyceae, and Bacillariophyceae are the five primary categories of algae. Despite having no roots, stems, or leaves, microalgae have chlorophyll as their pigment for photosynthetic growth. They are able to transform atmospheric CO2, which serves as their main carbon source, into glucose for growth (Ho et al., 2014).

The light-dependent stage is where microalgae initially take in and store energy from sunlight by converting the energy-carrying molecules ATP and NADP+ from ADP and NADP+. Using the previously produced ATP and NADPH molecules, microalgae will collect organic compounds that produce CO2 by the Calvin-Benson cycle in the second stage of photosynthesis, which is the light-independent reaction (Zhao and Su, 2014). About 1 kg of micro-sized algae can fix 1.84 kg of atmospheric carbon dioxide. Anabaena - 1.46 g/L/d and 6.24 g/L/d by Chlorella vulgaris, Botryococcus braunii, Scenedesmus obliquus, Nannochloropsis oculate, Chlorella vulgaris. Macroalgae or seaweed biomass and energy and they produce high amounts of carbohydrates with low lipid content; hence they are used as feedstock for biofuel production e.g., Ulva and Laminaria.

Cyanobacteria: Cyanobacteria are blue-green, prokaryotic bacteria or algae that operate as a bridge between green plants and bacteria. They are gram negative photoautotrophic bacteria that can be found in both microscopic and macroscopic forms. For carbon fixation, they have carboxysomes in their cytoplasm. Bacteria and all cyanobacteria, which are photoautotrophs and chemoautotrophs, are examples of microorganisms that have carboxysomes. It is connected to the Calvin-Benson cycle (CBB). The cytoplasm of bacteria contains micro compartments termed carboxysomes, which are home to the two enzymes RuBisCO and carbonic anhydrase. Alpha and beta carboxysomes containing RuBisCO form IA and IB, respectively, are the two different forms of carboxysomes (Rosgaard et al., 2012). The majority of chemoautotrophs, all alpha-cyanobacteria, and some purple bacteria all have alpha carboxysomes. Order Nostocales, Anebaena are important representative of carbon capture and storage. Can absorb a large amount of carbon (1.2 gCO2/Lday) and store this as exopolysaccharides The CBB is the primary carbo fixation cycle utilized for gross primary productivity and contribute nearly one-fourth of the global carbon fixation.

Archaea: The following archaeal groups are typically found in the majority of coastal sedimentary microbiomes: Bathyarchaeota, Thermoprofundales, Thaumarchaeota, Woesearchaeota and Lokiarchaeota. Over 95% of all archaeal populations are normally accounted for by their relative abundance. A global survey of the 16S rRNA genes of Woesearchaeota suggests that they are more abundant in mangrove and saltmarsh than in other ecosystems total archaeal population, as evidenced by the fact that Bathyarchaeota is the most dominant archaeal group widely distributed in many coastal areas, with the relative abundance of up to 60%

(Huang et al., 2021). They are chemolithoautotrophic ammonia-oxidizing archaea (AOA), which generate energy during ammonia oxidation and use the hydroxypropionate/ hydroxybutyrate (HP/HB) cycle to form biomass from CO2 fixation. The methanogens produce biofuel-methane under an anaerobic environment by utilizing CO2, energy obtained from hydrogen. The most energy-efficient aerobic autotrophic process is the Thaumarcheotal HP/HB cycle, which uses one-third less energy than the Calvin-Benson-Bassham (CBB) cycle and 3-hydroxypropionate cycling.

Fungi: The eukaryotic, multicellular organism with a stiff cell wall is known as a fungus. They are primary decomposers and the main organisms responsible for capturing carbon in the terrestrial ecosystem. They are heterotrophic. They are divided into two classes, saprophytic fungus and mycorrhizal fungi, based on the decaying organic materials. Mycorrhizal fungi's ability to degrade materials like cellulose, hemicellulose, pectin, and lignin, which are essential for mineralization and the carbon cycle, is limited by a shortage of enzymes produced by saprophytic fungi. There are three types of mycorrhizal fungi, including ectomycorrhizal, arbuscular, and ericoid mycorrhizas, which are only found in plants in the order Ericales. These fungi live in symbiotic relationships with plants.

When compared to bacteria, fungi facilitate soil carbon sequestration by creating organic humus and maintaining the carbon balance, which contributes significantly to CCS in the terrestrial ecosystem. There are three methods for storing carbon in soil: producing soil aggregate, recalcitrant biomass and their secondary products, and incorporating atmospheric CO2 into fungal biomass. The carbon is kept in storage by the mycelium. Thus, effectively integrating CO2 at a larger percentage results in the production of a huge amount of biomass.

Mycelia, the vegetative tissue produced by fungi, has a quick rate of growth and spreads in the soil much more quickly by making it easier to access nutrients and water. By producing biomass, and secondary products, and degrading their necromass, fungi contribute to the sequestration of carbon from CO2. The type of fungi in the soil and the amount of biomass they produce will determine the rate of carbon sequestration. For example, the more mycelia that are produced, the higher the percentage of carbon that is incorporated, so the more fungal biomass that is produced, the higher the percentage of CO2 that is utilized.

Bacteria: These are unicellular, microscopic organisms with 19 groups. Bacteria, just like other microbes, can produce a broad range of bio-alcohols and fatty acids for oil production which are essential industrial compounds. Bacteria are capable of synthesizing intracellular as well as extracellular fatty acids. Intracellular fatty acid is used by bacteria as precursor molecules for the biosynthesis of their own cell envelopes. Bacteria synthesize fatty acids similar to plants, using acetyl-CoA with ATP as the source of energy and NADPH as the source of reducing equivalents.

Pseudomonas fluorescents is a plant growth-promoting bacterium that has the potential to be an effective tool for storing carbon and reducing climate change. Specifically, in high-CO2 habitats, the findings of this study show that this microbial inoculant boosted plant productivity and had the ability to reduce high atmospheric CO2 levels by enhancing terrestrial carbon sequestration. These results may highlight the potential for microbial inoculants that promote plant development as a means of capturing atmospheric CO2 (Nie et al., 2015).

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