

Review Article

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Role of Microbial Communities to Mitigate Climate Change in Agriculture

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ABSTRACT

Global warming and climate change are the most prominent issues of the current environmental scenario. These problems arise due to a higher concentration of greenhouse gases in the atmosphere which exerts a warming effect. Although much attention has been given to anthropogenic sources and impacts of these gases, the significance and implications of microorganisms have remained neglected. The present review brings to light this over looked aspect of the causes of climate change. It was then found that microbes play a major role in climate change. Thus, microbes should never be deprived of their due importance in climate change models as well as discussions on the matter. The major feedback response mechanism for climate change by changing their microbial community structure and composition solve this kind of environmental problem, simply using nutrient cycling processes and stimulating their functional genetic material for degrading and eliminating chemicals or gasses which leads to global warming. In addition, the review also identified the necessity of proper research in this aspect as there is a lack of adequate understanding of this facet of climate change. It is well known that beneficial plant associated microorganisms may stimulate plant growth and enhance resistance to disease and abiotic stresses. The effects of climate change factors such as elevated CO₂, drought and raising the temperature on beneficial plant microorganism interactions are being explored to an increasing extent. Overall, this review shows that plant associated microorganisms are an important factor influencing the response of plants to climate change.

Keywords

Climate change,
Drought stress,
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Introduction

The super challenges of the 21st century are climate change, energy supply, diseases and a sustainable environment. World climate change is intensely discussed by the whole society. Microorganisms and biogeochemical cycles are the two sides of the same coin. It takes place inside oceans, soil, open and

closed environment. Both are facilitating the way of making and using greenhouse gases. Microorganisms provide long and short-term encouragement and discouragement feedback responses to global warming as well as climate change (Singh *et al.*, 2010). Microbes play an important role as either generators or users of these gases in the environment as they can recycle and transform the essential

elements such as carbon and nitrogen that makeup cells (Joshi and Shekhawat, 2014). The biological method to control greenhouse gas emissions is invaluable regarding nutrients recycling. Microbial diversity in different ecosystems has many contributions to climate change by controlling and fighting its negative impacts with their metabolism is amazingly versatile and they can grow in broad environmental conditions. Microorganisms perform uptake, storage, and release of gases easily. The review aims to answer the role of microbes to fight climate change, greenhouse gas reduction and how will that role involve in the future as a mitigation option.

Climate change and its causes

Climate is defined as general or average weather conditions of a certain region, including temperature, rainfall and wind. Climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water and living things. The earth's climate is most affected by latitude, the tilt of the earth's axis, the movements of the earth's wind belts, the difference in temperatures of land, sea and topography. The earth is surrounded by a thick layer of gases that keeps the planet warm and allows plants, animals, and microbes to live. These gases work like a blanket without this blanket the earth would be 20-30°C colder and much less suitable for life. Contrary to this, global warming is an increase in the temperature of the earth's atmosphere in the amount over a period. Whereas Green House effect is the phenomenon whereby the earth's atmosphere traps solar radiation and is mediated by the presence in the atmosphere of gases such as carbon dioxide, water vapour and methane that allow incoming sunlight to pass through, but absorb the heat radiated back from the earth's surface. This provides a blanketing

effect in the lower strata of the earth's atmosphere and this blanketing effect is being enhanced because of human activities like the burning of fossil fuels (Olufemi *et al.*, 2014).

Greenhouse gas emission is increased dramatically in recent years due to human activity and natural factors like volcanic eruption. These gases accumulate in the atmosphere and causing concentrations to increase within time. A significant increase in all of these gases has occurred in the industrial era. The major greenhouse gases are carbon dioxide, methane, nitrous oxide and the halocarbons (Abatenh *et al.*, 2018). Carbon dioxide comes from fossil fuel usage, it is also released from natural processes such as the decay of plant matter, respiration, and microbial decomposition of organic matter (Davidson and Janssens, 2006) and also turns out in deforestation. Methane production is the result of anthropogenic day to day activities resemble fossil fuels production, distribution and combustion, landfills and waste, livestock farming, biomass burning and paddy agriculture, natural processes that occur in wetland termites and oceans are unique sources for methane emissions (Singh *et al.*, 2010). Whereas Nitrous oxide is occurred during fertilizer use and fossil fuel burning, on another hand, naturally in soil and ocean is also released (Sanford *et al.*, 2012).

Halocarbon gases quantity is increased primarily due to human and natural processes, these are contained chlorofluorocarbons (CFC-11 and CFC-12) which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere were found to cause stratospheric ozone depletion. These days, the abundance of chlorofluorocarbon gases is decreasing because of international regulations designed to protect the ozone layer. As mentioned above, halocarbons are released by human activities to destroy ozone

in the stratosphere and have caused the ozone hole over Antarctica. Water vapour is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapour. Indirectly, humans have the potential to affect water vapour substantially by changing the climate. For example, a warmer atmosphere contains more water vapour. Human activities also influence water vapour through CH₄ emissions, because CH₄ undergoes chemical destruction in the stratosphere, producing a small amount of water vapour.

Aerosols are small particles present in the atmosphere with widely vary in size, concentration, and chemical composition. Some aerosols are emitted directly into the atmosphere while others are formed from emitted compounds (Charu *et al.*, 2014). Aerosols contain both naturally occurring compounds and those emitted because of human activities. Fossil fuel and biomass burning have increased aerosols containing sulphur compounds, organic compounds, and black carbon (soot) (Lal, 2005). Human activities such as surface mining and industrial processes have increased dust in the atmosphere. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans, sulphate and dust aerosols produced by volcanic eruptions (Hasin *et al.*, 2010).

Mechanisms to solve climate change

Microbial processes have a central role in the global fluxes of the key biogenic greenhouse gases (carbon dioxide, methane, and nitrous oxide) and are likely to respond rapidly to climate change. Microorganisms regulate terrestrial greenhouse gas flux. This involves consideration of the complex interactions that occur between microorganisms and other

biotic and abiotic factors. The potential to mitigate climate change by reducing greenhouse gas emissions through managing terrestrial microbial processes is a tantalizing prospect for the future. It is widely accepted that microorganisms have played a key part in determining the atmospheric concentrations of greenhouse gases (Zimmer, 2010). The major feedback response mechanism for climate change by changing their microbial community structure and composition solve this kind of environmental problem, simply using nutrient cycling processes and stimulating their functional genetic material for degrading and eliminating chemicals or gasses which lead to global warming (Zhou *et al.*, 2011). When microbial communities and biogeochemical cycles are linked together act as a good mechanism to solve climate change. Microorganisms are particularly important to use greenhouse gases as energy sources and build their cell (Abatenh *et al.*, 2018).

Some mitigation options used for solving climate change

Minimize introducing synthetic chemical fertilizer in agriculture and using plant promoting microorganisms which act as a biofertilizer in a form of bio inoculation, which can easily stop GHSs emission.

Avoiding the use of fossils raw materials and fuel (wood) through replacement of the use of enzymes and microorganisms helps to make bio-based products in an adverse variety of industry sectors.

Using biofuel and apply bio-based strategies and targets. For example, bioethanol. Biofuels are made from living things or the waste that they produce. One of the most common biofuels is ethanol, it is produced from plants. As a result, biofuels from foodstuffs such as sugar cane are not likely to provide a long-term solution as a replacement to fossil fuels. The sugar can then be fermented (broken down) to ethanol

by microbes such as the yeast *Saccharomyces cerevisiae*, *Sulfolobus solfataricus* and *Trichoderma reesei*.

Using potential bio-based chemicals and plastics can replace their fossil-based counterparts with significant and proven in greenhouse gas emission reduction.

Application of afforestation programs all over the world, to manage carbon sequestration easily

The introduction of novel species in the ecosystem is necessary.

Improving drought tolerance biotic organisms.

Minimizing and reducing water loss from agriculture (Abatenh *et al.*, 2018).

Microbial genetics in changing environment

Climate change is the change in the frequency of weather in a given area for a long time. Climate change could shift in drastic changes in temperature and precipitation leading to extreme heat and flooding, rising sea level, and natural disasters. Adaptation to this changing environment is the best way when change is inevitable. In the previous discussion, it was well discussed that microbes have a significant role in crop production; however, climate change could jeopardize the survivability of microbes. Proper understanding of microbial function could give us lots of insight, and we could exploit it in managing climate change-related situations. A lot of microbes have a short generation time to produce new variants that other eukaryotic and large organisms are unable to do (Bang *et al.*, 2018). Phenotypic plasticity or change in an organism's behaviour develops on them in the changing environment with a change in certain morphological and physiological traits. Bacterial species are found to display extensive phenotypic variability/heterogeneity (Raj and Van Oudenaarden, 2008) building

resilience to environmental changes and adaptation. Phase variation or genetic changes can occur at the individual level of bacterial cells (*e.g.*, Van der Woude, 2011).

However, this beneficial mutation seems to be small, *e.g.*, 2×10^{-9} per genome per replication for *E. coli*. Horizontal gene transfer (HGT) of bacteria is another kind of adaptation that took place through the exchange of genetic material such as plasmids, transposons, and phages. This HGT event occurs between closely related species, allows rapid access to genetic innovations of nonparental lineages, and contributes to the dissemination of beneficial mutations (Aminov, 2011). Overall, the adaptation to extreme environments requires an understanding of the diverse responses within the microbial system. The study of microbial genetics for adaptation gives us the solid foundation of utilizing the role of them in the changing environment.

Rhizosphere microbes improves plant stress tolerance

The plant rhizosphere is occupied with various microbes such as plant growth-promoting bacteria (PGPB) and plant growth promoting fungi (PGPF). Mycorrhizae supply phosphate and nitrate to plants and rhizobacteria play a role in fixing atmospheric nitrogen. Some beneficial microbes can provide resistance to environmental stress factors. Growth of crops under abiotic stress conditions can be improved by different bacterial families (Egamberdieva and Kucharova, 2009). Co-inoculation of *Rhizobium/Pseudomonas* with *Zea mays* can increase its salt tolerance due to decreased electrolyte leakage and balance of leaf water contents (Bano and Fatima, 2009). Various microorganisms produce plant growth hormones such as indole acetic acid and gibberellic acid, which promote root growth.

PGPBs can also promote the plant's immune system to fight with many pathogens. Certain PGPF, such as mycorrhizal and endophytic fungi, significantly enhance stress tolerance of the plants against a variety of conditions, *i.e.*, drought, heat, pathogens, herbivores, or limiting nutrients (Rodriguez *et al.*, 2008). Some PGPF can have beneficial effects on certain host plants and exerts pathogenicity to nonhost plants, for example, *Colletotrichum acutatum*, which is a pathogenic ascomycete for strawberry but beneficial when colonizing with pepper, eggplant, bean, and tomato. Microbes help to improve plant stress responses to an abiotic environment by influencing plant physiologically (De Zelicourt *et al.*, 2013).

Microorganisms in Controlling Carbon Emission

Carbon sequestration by microbial processes is yet to be explored. Two important sinks of carbon are soil and the ocean can play a major role to mitigate anthropogenic carbon emission (Menon *et al.*, 2007). There is a huge potential of the carbon sequestration process which can be modified by microbial community engineering, *i.e.*, a shift in land use from arable land to grassland entails an average 18% higher carbon sequestration, with a yearly carbon input of 0.75 tonnes C/ha/year (Kampf *et al.*, 2016). A limited degree of soil manipulation could bring a higher degree of microbial homeostasis for sequestration. The addition of charcoal or biochar to the soil as a long-term carbon source improves soil quality and adsorption of nutrients to increase their bioavailability to the plants (Prost *et al.*, 2013). The concept of carbon sequestration can also be approached by using concentrated CO₂ sources. Microbial electro-synthesis generates valuable products from electricity, using CO₂ or other organic feed stocks as carbon sources. In this process, acetate butyrate and other commodity

chemicals (Arends *et al.*, 2017) have been produced. These chemicals can be converted to medium-chain fatty acids like caproate and caprylate that can serve as bio-based building blocks for the chemical industries. An energy efficient harvesting of carbon sources could lead to microbial carbon sequestration.

Improving Salinity Tolerance

Soil salinity could decrease national agricultural crop production in arid and coastal regions in climate change situations. *Azospirillum* inoculation can alter salt-stressed maize variety. Osmotic stress of pepper can be decreased by inoculation with *Bacillus* sp.TW4 (Sziderics *et al.*, 2007). For the salt-stressed plants, secondary inoculation with *Azospirillum* can result in prolonged root exudation of plant flavonoids following inoculation with *Rhizobium* (Dardanelli *et al.*, 2008). Thus, co-inoculation of plants with various bacterial species can improve abiotic stress tolerance.

Drought Stress Tolerance

The drought stress on plants can result in stomatal closure to minimize water loss by increased abscisic acid (ABA) levels in leaves with some other compounds such as ethylene, salicylic acid, etc. PGPR has a beneficial effect on plant's drought tolerance caused by changes in hormonal contents, mainly of ABA, ethylene, and cytokinins. *Azospirillum lipoferum* strains when inoculated with wheat seedlings can reduce drought stress (Arzanesh *et al.*, 2011). Root morphology can be changed by beneficial bacteria and hormone-like matters produced to excite the endogenous plant hormones (Dobbelaere *et al.*, 1999). It was also evident that a significant amount of nitric oxide is produced as a diffusible gas by *A. brasilense* in aerobic conditions signaling an IAA-induced pathway for root growth. Inoculation of plant species

with certain bacterium species can increase its drought stress tolerance by isolating its drought-responsive gene, ERD15, from *A. thaliana* when inoculated with *Paenibacillus polymyxa* (Timmusk and Wagner, 1999).

It can be concluded, the climate change is a real thing, and it is already marking its harmful impact on Earth. The future of climate change will be more harmful, and we need to act immediately. Among various adaptation methods on climate change, microbial mitigation and adaptation are the latest additions here. The role of microbes is least known among the scientific community. Various promising aspects of microbes have been discovered to cope with the changing environment due to climate change. Microorganism genetic resources for agriculture carry out many of the vital functions that underpin the ecosystem services that sustain life. Their role is vital to nutrient cycling, supporting the soil food web, imparting resilience, transforming and protecting food from spoilage, and controlling pests, diseases and weeds. Generally, microorganisms through nutrient cycling act as a break down organic matter release greenhouse gases and speed up global climate change. On another side, it minimizes or compromises the emission of different gases and slows down or prevents climate change by converting to an organic form usable for themselves and others. In ecological processes, microbes have significant value in the consumption/transformation and production of gases. Biological mechanisms are regulating carbon and nitrogen exchanges between the land, water and atmosphere. Microbial ecology to assess the terrestrial carbon cycle plays an important role in balance the ecosystem and stabilizes the atmospheric condition. Methylophs can use greenhouse gases as substrates to fulfill their energy and carbon needs. Greenhouse gases are moving forward to the atmosphere during

respiration (breathing), decay and combustion (burning). Nature also by itself does a great job of balancing the carbon and nitrogen within biogeochemical nutrient cycling.

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