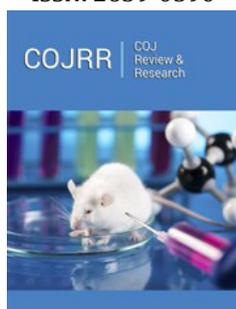


Microbial Mediated Soil Carbon Sequestration and Mitigation of Green House Gases

Pooja Arora* and Smita Chaudhry

Institute of Environmental Studies, India

ISSN: 2639-0590



***Corresponding author:** Pooja Arora, Institute of Environmental Studies, Kurukshetra University, Kurukshetra, Haryana, India

Submission: 📅 July 06, 2021

Published: 📅 August 19, 2021

Volume 3 - Issue 3

How to cite this article: Pooja Arora, Smita Chaudhry. Microbial Mediated Soil Carbon Sequestration and Mitigation of Green House Gases. COJ Rev & Res. 3(3). COJRR. 000562. 2021.
DOI: [10.31031/COJRR.2021.03.000562](https://doi.org/10.31031/COJRR.2021.03.000562)

Copyright@ Pooja Arora, This article is distributed under the terms of the Creative Commons Attribution 4.0 International License, which permits unrestricted use and redistribution provided that the original author and source are credited.

Abstract

Anthropogenic development activities have resulted in rapid global climate change. The effects of increasing surface temperatures are evident from unprecedented loss in plant and animal species. However, microbial life has not been well discussed in context of climate change. The present review has been done to understand the basic processes that soil microbial communities carry out in context of climate change such as microbial mediated soil carbon sequestration and mitigation of greenhouse gases. Soil microbes play a crucial role in decomposition of organic matter and soil respiration processes that are fundamental in sequestering carbon in the soil and CO₂ emissions from the soil. The emissions of other important greenhouse gases such as methane and nitrous oxide are also mitigated by microbial actions. The mitigation of methane is brought about by its oxidation by methanotrophic bacteria while that of nitrous oxide is achieved by manipulating soil microbiome *in situ* along with manipulation in biotic and abiotic factors in soil. Hence, an understanding of the role of soil microbes as both contributors to and reactive components of climate change is much needed to clarify their roles whether they can be used to mitigate the emissions of GHGs or accelerators of climate disaster at the macroscopic level and even at the global scale.

Keywords: Soil microbes; Carbon sequestration; Climate change; Mitigation; Greenhouse gases; Carbon dioxide; Methane; Nitrous oxide

Introduction

Earth's environment has been undergoing changes due to increasing human population and its activities. The most significant change is the increase in concentration of carbon dioxide and other greenhouse gases in the troposphere resulting in increase in average surface temperature of Earth. The change in climate is the result of continuous but non-linear interaction among components of the climate system at varying time scales (minutes to billions of years). But the "enhanced greenhouse effect" and resulting rapid global climate change is posing great threat to the well-being of humankind and other life forms on the earth as evident from unprecedented loss in plant and animal species. By contrast, microbial life has not been well discussed in context of climate change.

Although invisible to the naked eye, the abundance and diversity of microorganisms is very crucial in determining the resilience of many organisms and ecosystems and thereby their ability to respond to changing climate scenarios. A typical soil sample may contain more than 10⁶ individual species-level Operational Taxonomic Units of Bacteria, Archaea, and Fungi Fierer et al. [1]. Estimation of soil microbial communities and biomass is of fundamental importance to study a wide range of soil processes such as nutrient cycling, organic matter decomposition, soil quality, soil respiration and mineralization. Hence, microbes can be viewed as the engines that drive these processes.

Climate Change mitigation necessitates the management of terrestrial carbon (C) by creating new C sinks and also by preserving and enhancing the existing ones. Carbon capture in living biomass, in soil (roots and microbes) and recalcitrant organic and inorganic carbon

all in terms of carbon sequestration is one such option. Even the seasonal variations of soil microbial biomass as a potential stock of carbon reflect the degree of immobilization and mineralization of soil carbon Chaudhry [2]. Microbial diversity in different ecosystem has many contributions in controlling the climate change and combating its negative impacts owing to their amazingly versatile metabolism and ability to flourish in broad environmental conditions.

Microbial Mediated Soil Carbon Sequestration

Soil micro-organisms have a crucial role in cycling of the nutrients, promoting and accelerating the decomposition of the organic matter, the release of nutrients contained therein and précising the processes that control the flow of these nutrients to plants and hydrological & gaseous losses to surrounding environments. The dominating factor in the terrestrial carbon cycle is the balance between two processes of photosynthesis and

respiration. Autotrophic organisms, especially photosynthesizing plants, and also photo and chemoautotrophic microorganisms fix atmospheric carbon dioxide (CO_2) into organic material (Figure 1); [3] which is then returned back to atmosphere via autotrophic and heterotrophic respiration and decomposition pathways. Decomposition is carried out by 'organic carbon-consuming' heterotrophic microorganisms that feed on carbon of either plant, animal or microbial origin as a substrate. Some amount of this carbon is retained in their biomass while the rest is released as metabolites or as CO_2 back to the atmosphere. In this way, soil microorganisms directly regulate the amount of organic carbon stored in soil and released back to the atmosphere. They also indirectly influence carbon storage in plants and soils by providing macronutrients (N & P) to regulate productivity Singh et al. [4], Bardgett [5]. Further, in many ecosystems, mycorrhizal fungi are responsible for substantial amounts of nitrogen and phosphorus acquisition by plants Fellbaum et al. [6].

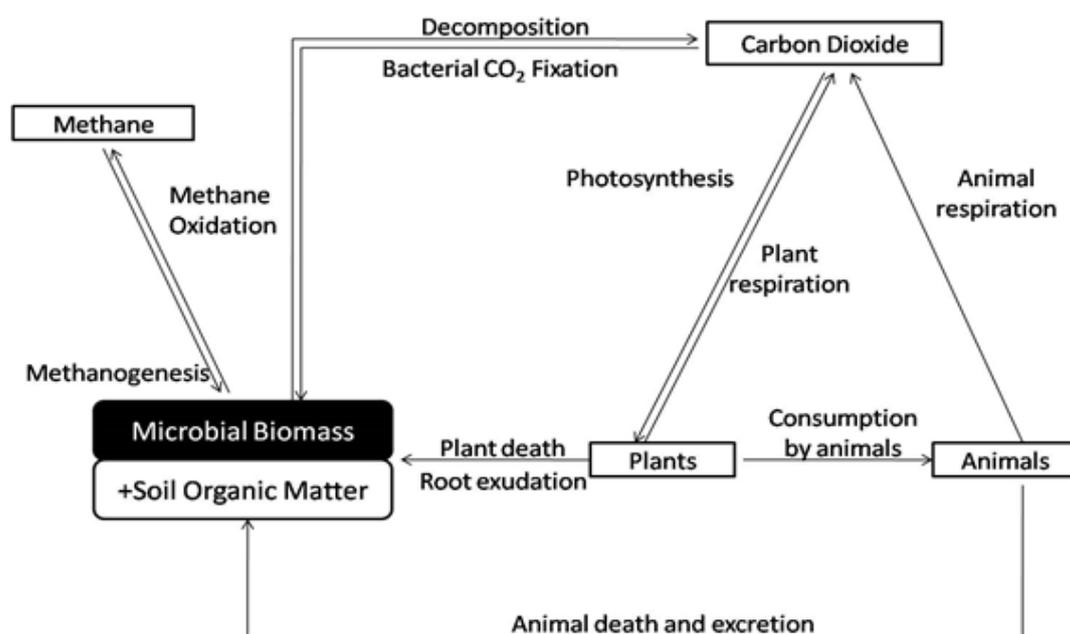


Figure 1: Microbial mediated terrestrial carbon cycle Gouglia C et al. [3].

Therefore, many studies suggest that soil microorganisms have a key role in controlling formation, decomposition and accumulation of Soil Organic Matter Mellado-Vazquez et al. [7]; Liang et al. [8]; Cotrufo et al. [9]; Lange et al. [10]; Balsler [11]; Gleixner et al. [12]. In *vice versa* situation, plant derived C resources largely influence the soil microbial activity apart from other factors such as soil temperature, soil humidity or pH Voroney [13]. Also, the impact of different photosynthetic pathways on the microbial community may be triggered by confounding effects of other environmental parameters Chen et al. [14].

Decomposition of Soil Organic Matter

Soil Organic Matter (SOM) consists of fresh to progressively decomposing plant, microbial and faunal-derived debris and exudates. The microbial biomass, responsible for primary

decomposition of these materials also forms a part of Soil Organic Matter. The process of decomposition starts with complex plant detritus and other organic matter producing carbon gases and humus (Figure 2); [15]. The process can efficiently be characterized by the rate of mass loss, and rates of nutrient immobilization and release into the soil. The decomposition process can be distinguished in three phases: early, late and humus-near stage. In the early stage, decomposition of soluble, unshielded cellulose and hemicelluloses takes place. The process is influenced by climate. In the late stage, the influence of climate on decomposition gradually decreases to essentially zero. Also, negative influence of N on lignin degradation may come into effect through a repression of *de novo* ligninase synthesis. In final, humus-near stage, the decomposition reaches a limit value. From the very onset of decomposition, the concentrations of Nitrogen and lignin increase (Figure 3); [16].

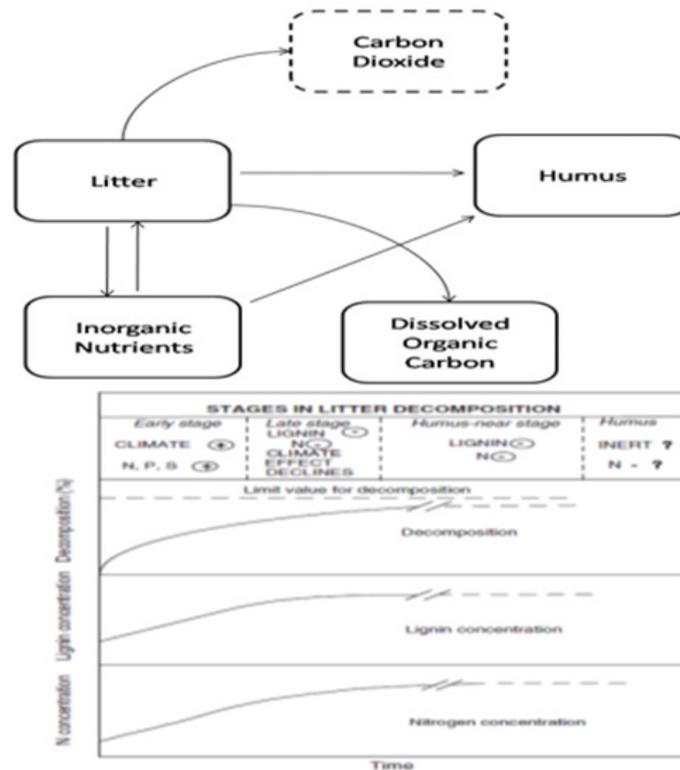


Figure 2: a) Generalized pathways for transformation of litter to humus and inorganic C.

b) Stages in litter decomposition Berg and McLaugherty [15].

The + and - signs indicate positively and negatively related effects, respectively, to increased concentrations of nutrients and lignin.

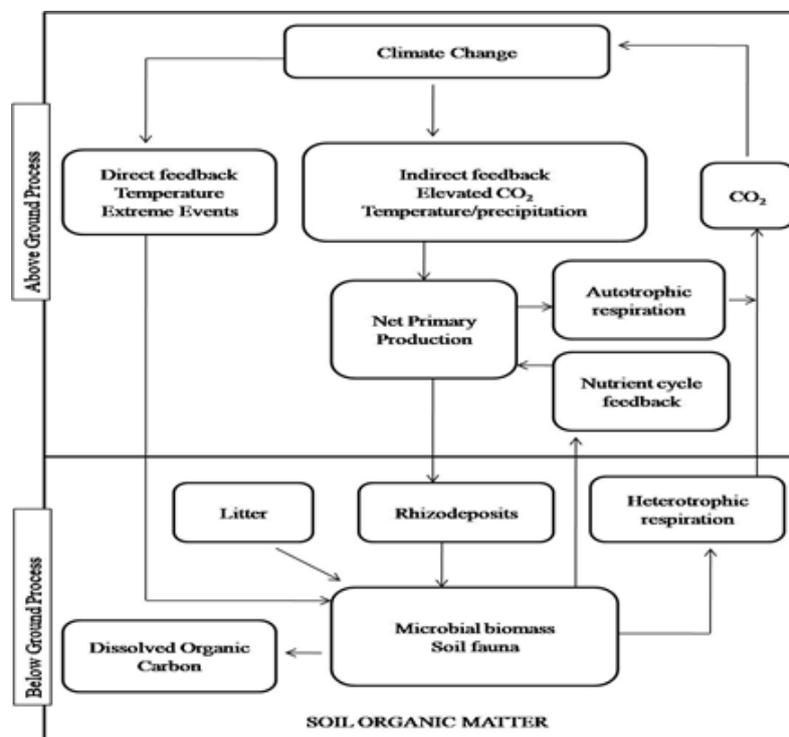


Figure 3: Direct and Indirect effects of climate changes on soil microbial communities and feedback to global warming through carbon dioxide production (Based on Bardgett et al. [16]).

Soil microorganisms act as decomposers and indicators of soil quality by regulating the key process of soil carbon cycling, including lignin and cellulose degradation and soil carbon turnover Lei et al. [17]; Li et al. [18]; Sun et al. [19] and Mele [20]. Complex compounds such as lignin are degraded by enzyme oxidases, which are produced primarily by fungi while cellulose is degraded by hydrolases, produced primarily by bacteria in the soil You et al. [21]. The decomposition of litter and deadwood is a key step in biogeochemical cycling of carbon and nitrogen as it contributes to CO₂ release Van Geffen et al. [22]. Litter and wood decomposition is considered to be mainly carried out by fungi and, to a lesser extent, by bacteria Allmer et al. [23]; Baldrian [24]; Bässler et al. [25]; Purahong et al. [26]; Tlaskal et al. [27]. However, bacteria are able to degrade lignin and catabolize side products being derived from incomplete degradation of litter by fungi Bugg et al. [28,29].

Decomposition proceeds through several steps whereby bacterial community shows a succession of colonizers with most abundant taxa of Proteobacteria, Actinobacteria and Bacteroidetes Purahong et al. [26], Tlaskal et al. [27]; Urbanová et al. [30] over the entire stages of litter decomposition. Similarly, fungal communities also undergo a clear succession process of different taxa which are able to decompose the available biopolymers Fukasawa et al. [31]; Purahong et al. [26], Voriskova [32]. Decomposition stage, type of soil organic matter or quality of litter (lignin or cellulose based), substrate size, physico-chemical properties of soil, soil structure and climate parameters control the decomposition process and hence, play a crucial role in determining the structure and composition of microbial community (bacteria and fungi) and most importantly the decay pattern of organic matter.

Global climate change is likely to intensify the decomposition rates when long-term warming occurs in the absence of moisture constraints. To understand the responses of ecosystems to future climate change in terms of shifts in biodiversity and biogeochemical cycling, it is crucial to understand and quantify the underlying controls on organic matter decomposition Salinas et al. [33].

Soil Respiration

Soil respiration is the production of CO₂ from the soil when plant roots, microbes, and fauna respire. It is the second largest carbon flux between the land and atmosphere Raich [34]; Zhao et al. [35]. The largest share of these fluxes comes from humid tropical forest. It has been suggested that an increase of 3% in a tropical soil respiration of 1500gCm⁻² per year is greater than a 20% increase in a tundra soil-respiration rate of 200gCm⁻² per year Raich et al. [36].

Soil respiration is one of the largest elements of carbon cycling in forests Hashimoto et al. [37], main component of ecosystem respiration Granier et al. [38]; Janssens et al. [39], an important aspect of soil quality and an indicator of soil fertility Staben et al. [40]. These facts emphasize the accurate measurement of soil respiration as an essential component for understanding the carbon cycle in any ecosystems since small changes in soil respiration may strongly affect soil carbon sequestration. The rate of soil respiration is affected by many factors such as soil moisture and temperature,

physico chemical properties of soil, soil microbial composition, vegetation composition and site productivity. For instance, in case of sufficient water availability, higher temperatures lead to faster decomposition of soil organic matter, less storage of carbon in the slow and passive pools, and greater loss of carbon through respiration Canadell et al. [41]. The type of vegetation alters the rate of soil respiration by influencing the quantity and quality of litter input into the soil that causes variations in soil metabolism.

Climatic factors such as temperature and rainfall also influence the rates of soil respiration. Soil respiration increases quickly following rain events in dry climates; however, temperature sensitivity of soil respiration helps in describing the changes in CO₂ flux with respect to change in temperature Arora [42]. Soil respiration is often considered as the measure of total microbial activity in soil. Many studies have reported a significant correlation between soil respiration and soil microbial biomass carbon pool Dube et al. [43]; Iqbal et al. [44]; Wang et al. [45]. It is an important indicator of soil health because it represents the diversity of organisms occupying microhabitats throughout the soil profile, level of microbial activity, SOM content and its decomposition.

These microbial mediated decomposition and respiration pathways act as positive feedback to global warming and may also in turn be accelerated as a response to increase in atmospheric temperature. Since, soil respiration is considered to be the sum of heterotrophic and autotrophic respiration, the combined effect of microclimatic factors and anthropogenic activities can be modeled to advance the understanding of the concept. The merits of these estimations will be helpful in reflecting the important soil-to-atmosphere CO₂ efflux Chaudhry [42]. Increased flux of carbon to roots and soil due to elevated carbon dioxide can stimulate microbial activity. This stimulation intensifies the degradation of organic matter, thereby leading to carbon loss from soil.

Mitigation of Green House Gases

There are innumerable ways that soil microbes and their metabolic activity can affect climate change through land-atmosphere carbon exchanges. These can broadly be divided into two categories

- a) the ways that affect ecosystem carbon dioxide and methane uptake, and
- b) the ways that control carbon loss from soil through respiration and production of methane.

Also, changing climate influences soil microbial activity. Climate change has both direct and indirect effects on the activities of soil microbes. Direct effects include the influence on soil microbes, greenhouse gas production under variable conditions of temperature, precipitation and extreme climatic events. Indirect effects are climate-driven changes in plant productivity and diversity which alter soil physicochemical characteristics, carbon supply to soil, structure and activity of microbial communities involved in decomposition processes and carbon release from soil (Figure 3); [16].

The three most important greenhouse gases, CO₂, CH₄ and N₂O occur naturally in the atmosphere and are produced in soils, sediments and waters through various microbiological processes. But due to anthropogenic developmental activities, the concentration of GHGs has increased substantially in the atmosphere resulting in accelerated climate warming. Microbial mediated mitigation of carbon dioxide can well be understood through the processes of organic matter decomposition and soil respiration as discussed earlier.

The major source of Methane is landfills where it is produced through the decomposition of organic wastes. Soil microbial activity acts as a sink for methane gas. The process follows the oxidation of CH₄ into other forms of carbon by a class of microorganisms specifically bacteria known as methanotrophs. These methanotrophs utilize CH₄ as its sole carbon and energy source in the presence of O₂. It has been estimated that methanotrophic bacteria oxidize 10 to 100 % of the CH₄ generated in landfills Borjesson et al. [46]; Chanton & Liptay [47]; Chanton et al. [48]; Czepiel et al. [49]; Liptay et al. [50] and Whalen et al. [51] making landfills to act as sink of CH₄ rather than as its source Bogner et al. [52,53]. Hence, it can be inferred that stimulating the activity of these bacteria in landfill cover soils could possibly reduce emission of CH₄ from landfills.

The stimulation of methane oxidation can be achieved through the application of nitrogen-based fertilizers Bodelier et al. [54]; De Visscher et al. [55], Mohanty et al. [56] as the nitrogenous fertilizers are used as nitrogen sources by the soil microorganisms. However, the drawback of this application is the production of yet another

greenhouse gas, N₂O. Methane-consuming microorganisms are actually capable of extracting atmospheric methane even at very low concentrations Zimmerman [57]. These microorganisms are found both in soil and also in aquatic habitats and at home. Hence, microbes contribute toward controlling methane emission which in turn regulates climate change.

Bacterial and fungal-mediated nitrification and denitrification are the key processes that account for approximately two-third of total N₂O emissions from the soil predominantly due to the application of nitrogenous fertilizers Zhu et al. [58]. The abundance, diversity, community structure and biological pathways of the soil microbial communities (including ammonia oxidizers, bacterial and fungal denitrifiers) are affected by a wide range of biotic, abiotic and emerging global change factors and their interactions. Hence, any strategy that can enhance the plant capacity to readily uptake nitrogen from the soil and making it unavailable to microorganisms can substantially add to the mitigation of soil N₂O emissions. The aim can be achieved through the development of three categories of technologies

- physicochemical technologies (by manipulating soil abiotic factors),
- plant community-based technologies (by manipulating soil biotic factors) and
- microbiome-based technologies (by manipulating soil microbiome *in situ*) for future mitigation of climate change (Figure 4); [59].

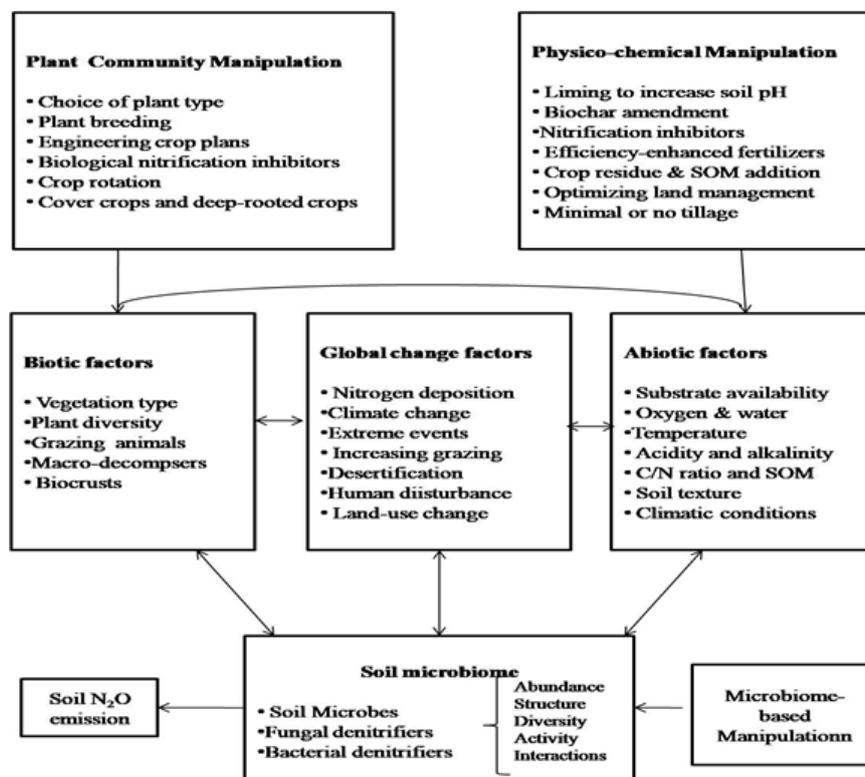


Figure 4: The relationships and interactions among N-cycling microorganisms, biotic factors, abiotic factors, global change factors, mitigation strategies and dryland N₂O emissions Redrwan from Hu et al. [61].

Conclusion

Climate change and warming have direct and indirect consequences on soil microbial communities Castro et al. [60] through modifications in various factors simultaneously. Such immense alterations can have considerable impacts on the soil microbiome as well as on plants and ultimately soil carbon balance. Soil microorganisms contribute significantly to the production and consumption of greenhouse gases, such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and nitric oxide (NO). This contribution towards production of GHGs by microbes is further stimulated by anthropogenic activities such as waste disposal and intensive agriculture. The feedback responses of soil microbes to increasing GHGs concentration in atmosphere can accelerate or slow down global warming up to different unknown extent.

Hence, an understanding of the role of soil microbes as both contributors to and reactive components of climate change can help us determine whether they can be used to mitigate the emissions of GHGs or they will accelerate the speed of climate disaster at the macroscopic and even the global scale. Although various ecosystem specifically agriculture sector where productivity is very much dependent on soil microbial activity has been predicted to combat the adverse impacts of climate change till now, but in near future this situation may get reversed. Arora et al. [61]. This necessitates the implementation of appropriate measures to deal with the problems of changing and climate and their aftereffects on soil microbiome.

Microbes are involved in many processes, such as the carbon and nitrogen cycles, and are responsible for both the production and consumption of greenhouse gases such as carbon dioxide and methane. Microbes could have various positive and negative feedback responses to temperature, but the extent of these is not completely understood. The reason is that microbes live in very diverse communities that interact with other organisms and the environment in complex ways, which makes it difficult to make predictions about the effects of microbes on climate change, but scientists are trying to include microbial activity in climate change models. What is certain is that human activities have helped to increase the production of greenhouse gases by microbes.

Microorganisms have been changing the climate, and have been changed by the climate, throughout Earth's history. As we experience unprecedented environmental impacts from climate change, microorganisms will respond, adapt, and evolve in their surroundings. Because they have generation times as short as a few hours, they will do so at higher rates than most other organisms. This makes microbes ideal sentinels for understanding the effects of climate change on biological systems and the global biogeochemical cycles that microbes mediate. Scientists can study the effects of climate change on microbes to both understand and hopefully predict the future effects of climate change on all forms of life. This colloquium brought together members of the American Society for Microbiology and the American Geophysical Union because understanding climate change impacts requires experts from many scientific disciplines. The collaboration between

these two societies intermingled scientists knowledgeable about microbial contributions and responses to climate change across global settings (terrestrial polar regions; soil, agriculture, and freshwater; oceans) and able to think broadly about the functions of microbiomes. Although scientists have been studying microbial ecosystems for many years, we realize we have much more to learn and understand about complex and interconnected microbial functions. The information in this report reflects the current understanding of microbes and our changing climate, as well as gaps and priorities for future study.

More than 30 microbiologists from 9 countries have issued a warning to humanity -- they are calling for the world to stop ignoring an 'unseen majority' in Earth's biodiversity and ecosystem when addressing climate change. 'Scientist's warning to humanity: microorganisms and climate change' was published today in the journal *Nature Reviews Microbiology*. Professor Rick Cavicchioli, microbiologist at the School of Biotechnology and Biomolecular Sciences at UNSW Sydney, has led the global effort. With their statement, the researchers are hoping to raise awareness both for how microbes can influence climate change and how they will be impacted by it -- calling for including microbes in climate change research, increasing the use of research involving innovative technologies, and improving education in classrooms. "Microorganisms, which include bacteria and viruses, are the lifeforms that you don't see on the conservation websites," says Professor Cavicchioli.

"They support the existence of all higher lifeforms and are critically important in regulating climate change.

"However, they are rarely the focus of climate change studies and not considered in policy development."

Professor Cavicchioli calls microbes the 'unseen majority' of lifeforms on earth, playing critical functions in animal and human health, agriculture, the global food web and industry. For example, the Census of Marine Life estimates that 90% of the ocean's total biomass is microbial. In our oceans, marine lifeforms called phytoplankton take light energy from the sun and remove carbon dioxide from the atmosphere as much as plants. The tiny phytoplankton form the beginning of the ocean food web, feeding krill populations that then feed fish, sea birds and large mammals such as whales.

Sea ice algae thrive in sea ice 'houses'. If global warming trends continue, the melting sea ice has a downstream effect on the sea ice algae, which means a diminished ocean food web. "Climate change is literally starving ocean life," says Professor Cavicchioli. Beyond the ocean, microbes are also critical to terrestrial environments, agriculture and disease. "In terrestrial environments, microbes release a range of important greenhouse gases to the atmosphere (carbon dioxide, methane and nitrous oxide), and climate change is causing these emissions to increase," Professor Cavicchioli says. "Farming ruminant animals releases vast quantities of methane from the microbes living in their rumen -- so decisions about global farming practices need to consider these consequences.

“And lastly, climate change worsens the impact of pathogenic microbes on animals (including humans) and plants -- that’s because climate change is stressing native life, making it easier for pathogens to cause disease. “Climate change also expands the number and geographic range of vectors (such as mosquitos) that carry pathogens. The end result is the increased spread of disease, and serious threats to global food supplies.” Greater commitment to microbe-based research needed. In their statement, the scientists call on researchers, institutions and governments to commit to greater microbial recognition to mitigate climate change. “The statement emphasizes the need to investigate microbial responses to climate change and to include microbe-based research during the development of policy and management decisions,” says Professor Cavicchioli.

Additionally, climate change research that links biological processes to global geophysical and climate processes should have a much bigger focus on microbial processes. “This goes to the heart of climate change, so if micro-organisms aren’t considered effectively, it means models cannot be generated properly and predictions could be inaccurate,” says Professor Cavicchioli. “Decisions that are made now impact on humans and other forms of life, so if you don’t take into account the microbial world, you’re missing a very big component of the equation.” Professor Cavicchioli says that microbiologists are also working on developing resources that will be made available for teachers to educate students on the importance of microbes. “If that literacy is there, that means people will have a much better capacity to engage with things to do with microbiology and understand the ramifications and importance of microbes.”

References

- Fierer N, Bradford MA, Jackson RB (2007) Toward an ecological classification of soil bacteria. *Ecology* 88(6): 1354-1364.
- Arora P, Chaudhry S (2015) Carbon sequestration potential of populus deltooides plantation under social forestry scheme in Kurukshetra, Haryana in Northern India. *Journal of Materials and Environmental Studies* 6(3): 713-720.
- Gouglis C, Joanna MClark, Shaw LJ (2014) The role of soil microbes in the global carbon cycle: Tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. *Journal of the Science of Food and Agriculture* 94(12):2362-2371.
- Singh BK, Bardgett RD, Smith P, Reay DS (2010) Microorganisms and climate change: Terrestrial feedbacks and mitigation options. *Nat Rev Microbiol* 8: 779-790.
- Bardgett RD, van der Putten WH (2014) Belowground biodiversity and ecosystem functioning. *Nature* 515(7528): 505-511.
- Fellbaum CR, Mensah JA, Pfeffer PE, Kiers ET, Bücking H (2012) The role of carbon in fungal nutrient uptake and transport Implications for resource exchange in the arbuscular mycorrhizal symbiosis. *Plant Signal Behav* 7(11): 1509-1512.
- Mellado-Vazquez PG, Lange M, Gleixner G (2019) Soil microbial communities and their carbon assimilation are affected by soil properties and season but not by plants differing in their photosynthetic pathways (C3 vs. C4). *Biogeochemistry* 142: 175-187.
- Liang C, Schimel JP, Jastrow JD (2017) The importance of anabolism in microbial control over soil carbon storage. *Nat Microbiol* 2(8): 17105.
- Cotrufo MF, Soong JL, Horton AJ, Campbell EE, Haddix ML, et al. (2015) Formation of soil organic matter via biochemical and physical pathways of litter mass loss. *Nat Geosci* 8(10): 776-779.
- Lange M, Eisenhauer N, Sierra CA, Bessler H, Engels C, et al. (2015) Plant diversity increases soil microbial activity and soil carbon storage. *Nat Commun* 6: 6707.
- Balser TC, Firestone MK (2005) Linking microbial community composition and soil processes in a California annual grassland and mixed-conifer forest. *Biogeochemistry* 73(2): 395-415.
- Gleixner G, Poirier N, Bol R, Balesdent J (2002) Molecular dynamics of organic matter in a cultivated soil. *Org Geochem* 33(3): 357-366.
- Voroney RP, Heck RJ (2015) The soil habitat. In: Paul EA (Ed.), *Soil microbiology, ecology and biochemistry*. (4th edn), Academic Press, Boston, USA, pp. 15-39.
- Chen JR, Wang QL, Li M, Liu F, Li W (2016) Does the different photosynthetic pathway of plants affect soil respiration in a subtropical wetland? *Ecol Evol* 6(22): 8010-8017.
- Berg B, McClaugherty C (2008) *Plant litter: Decomposition, humus formation, carbon sequestration*. (2nd edn), Springer, Verlag Berlin Heidelberg, New York, USA.
- Bardgett RD, Freeman C, Ostle NJ (2008) Microbial contributions to climate change through carbon cycle feedbacks. *ISME J* 2(8): 805-814.
- Lei L, Xiao W, Zeng L, Zhu J, Huang Z, et al. (2018) Thinning but not understory removal increased heterotrophic respiration and total soil respiration in Pinus massoniana stands. *Science of the Total Environment* 621: 1360-1369.
- Li L, Zhu-Barker X, Ye R, Doane TA, Horwath WR (2018) Soil microbial biomass size and soil carbon influence the priming effect from carbon inputs depending on nitrogen availability. *Soil Biology and Biochemistry* 119: 41-49.
- Sun S, Zhao H, Xing F, Bai Z, Gao Y, et al. (2017) Response of soil microbial community structure to increased precipitation and nitrogen addition in a semiarid meadow steppe. *European Journal of Soil Science* 68(4): 524-536.
- Mele PM, Crowley DE (2008) Application of self-organizing maps for assessing soil biological quality. *Agriculture, Ecosystems & Environment* 126(3-4): 139-152.
- You Y, Wang J, Huang X, Tang Z, Liu S, et al. (2014) Relating microbial community structure to functioning in forest soil organic carbon transformation and turnover. *Ecology and Evolution* 4(5): 633-647.
- Van Geffen KG, Poorter L, Sass-Klaassen U, Van Logtstijn RS, Cornelissen JH (2010) The trait contribution to wood decomposition rates of 15 Neotropical tree species. *Ecology* 91(12): 3686-3697.
- Allmer J, Stenlid J, Dahlberg A (2009) Logging-residue extraction does not reduce the diversity of litter-layer saprotrophic fungi in three Swedish coniferous stands after 25 years. *Can J for Res* 39(9): 1737-1748.
- Baldrian P (2016) Forest microbiome: Diversity, complexity and dynamics. *FEMS Microbiol Rev* 41 (2): 109-130.
- Bässler C, Müller J, Dziöck F, Brandl R (2010) Effects of resource availability and climate on the diversity of wood-decaying fungi. *J Ecol* 98(4): 822-832.
- Purahong W, Wubet T, Lentendu G, Schloter M, Pecyna MJ, et al. (2016) Life in leaf litter: novel insights into community dynamics of bacteria and fungi during litter decomposition. *Mol Ecol* 25(16): 4059-4074.
- Taskal V, Voriskova J, Baldrian P (2016) Bacterial succession on decomposing leaf litter exhibits a specific occurrence pattern of cellulolytic taxa and potential decomposers of fungal mycelia. *FEMS Microbiol Ecol* 92 (11): 1-10.

28. Bugg TD, Ahmad M, Hardiman EM, Rahmanpour R (2011a) Pathways for degradation of lignin in bacteria and fungi. *Nat Prod Rep* 28(12): 1883-1896.
29. Bugg TD, Ahmad M, Hardiman EM, Singh R (2011b) The emerging role for bacteria in lignin degradation and bio-product formation. *Curr Opin Biotechnol* 22(3): 394-400.
30. Urbanová M, Šnajdr J, Baldrian P (2015) Composition of fungal and bacterial communities in forest litter and soil is largely determined by dominant trees. *Soil Biol Biochem* 84: 53-64.
31. Fukasawa Y, Osono T, Takeda H (2009) Dynamics of physicochemical properties and occurrence of fungal fruit bodies during decomposition of coarse woody debris of *Fagus crenata*. *Journal of Forest Research* 14(1): 20-29.
32. Voriskova J, Baldrian P (2013) Fungal community on decomposing leaf litter undergoes rapid successional changes. *ISME J* 7: 477-486.
33. Salinas N, Malhi Y, Meir P, Silman M, Cuesta RR, et al. (2010) The sensitivity of tropical leaf litter decomposition to temperature: Results from a large-scale leaf translocation experiment along an elevation gradient in Peruvian forests. *New Phytologist* 189(4): 967-977.
34. Raich JW, Schlesinger WH (1992) The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus* 44 B (2): 81-99.
35. Zhao Z, Peng C, Yang Q, Meng F, Song X, et al. (2017) Model prediction of biome-specific global soil respiration from 1960 to 2012. *Earth's Future* 5(7): 715-729.
36. Raich JW (2017) Temporal variability of soil respiration in experimental tree plantations in lowland Costa Rica. *Forests* 8(2): 40.
37. Hashimoto S, Tanaka N, Suzuki M, Inoue A, Takizawa H, et al. (2004) Soil respiration and soil CO₂ concentration in a tropical forest, Thailand. *Journal of Forest Research* 9(1): 75-79.
38. Granier A, Ceschia E, Damesin C, Dufrene E, Epron D, et al. (2000) The carbon balance of a young beech forest. *Functional Ecology* 14(3): 312-325.
39. Janssens IA, Lankreijer H, Matteucci G, Kowalski AS, Buchmann N, et al. (2001) Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. *Global Change Biology* 7(3): 269-278.
40. Staben ML, Bezdicsek DF, Smith JL, Fauci MF (1997) Assessment of soil quality in conservation reserve program and wheat-fallow soils. *Soil Science Society of America Journal* 61(1): 124-130.
41. Canadell JG, Kirschbaum M, Kurz WA, Sanz MJ, Schlamadinger B, et al. (2007) Factoring out natural and indirect human effects on terrestrial carbon sources and sinks. *Environmental Science and Policy* 10: 370-384.
42. Arora P, Chaudhry S (2017) Dependency of rate of soil respiration on soil parameters and climatic factors in different tree plantations at Kurukshetra, India. *Tropical Ecology* 58(3): 573-581.
43. Dube F, Zogal E, Stolpe N, Espinosa M (2009) The influence of land use change on the organic carbon distribution and microbial respiration in a volcanic soil of the Chilean Patagonia. *Forest Ecology and Management* 257(8): 1695-1704.
44. Iqbal J, Hu R, Feng M, Lin S, Malghani S, Ali IM (2010) Microbial biomass and dissolved organic carbon and nitrogen strongly affect soil respiration in different land use: A case study at three gorges reservoir area, South China. *Agriculture, Ecosystems and Environment* 137(3-4): 249-307.
45. Wang Q, Xiao F, He T, Wang S (2013) Responses of labile soil organic carbon and enzyme activity in mineral soils to forest conversion in the subtropics. *Annals of Forest Science* 70(6): 579-587.
46. Borjesson G, Chanton J, Svensson BH (2001) Methane oxidation in two Swedish landfill covers measured with carbon-13 to carbon-12 isotope ratios. *Journal of Environmental Quality* 30(2): 369-376.
47. Chanton J, Liptay K (2000) Seasonal variation in methane oxidation in a landfill cover soil as determined by an *in situ* stable isotope technique. *Global Biogeochemical Cycles* 14(1): 51-60.
48. Chanton JP, Rutkowski CM, Mosher B (1999) Quantifying methane oxidation from landfills using stable isotope analysis of downwind plumes. *Environmental Science & Technology* 33(21): 3755-3760.
49. Czepiel PM, Mosher B, Crill PM, Harriss RC (1996) Quantifying the effect of oxidation on landfill methane emissions. *Journal of Geophysical Research-Atmospheres* 101:16721-16729.
50. Liptay K, Chanton J, Czepiel P, Mosher B (1998) Use of stable isotopes to determine methane oxidation in landfill cover soils. *Journal of Geophysical Research-Atmospheres* 103(D7): 8243-8250.
51. Whalen SC, Reeburgh WS, Sandbeck KA (1990) Rapid methane oxidation in a landfill cover soil. *Applied and Environmental Microbiology* 56(11): 3405-3411.
52. Bogner J, Spokas K, Burton E, Sweeney R, Corona V (1995) Landfills as atmospheric methane sources and sinks. *Chemosphere* 31(9): 4119-4130.
53. Bogner JE, Spokas KA, Burton EA (1997) Kinetics of methane oxidation in a landfill cover soil: Temporal variations, a whole landfill oxidation experiment, and modeling of net CH₄ emissions. *Environmental Science & Technology* 31(9): 2504-2514.
54. Bodelier PLE, Hahn AP, Arth IR, Frenzel P (2000) Effects of ammonium-based fertilisation on microbial processes involved in methane emission from soils planted with rice. *Biogeochemistry* 51: 225-257.
55. De Visscher A, Cleemput O (2003) Induction of enhanced CH₄ oxidation in soils: NH₄⁺ inhibition patterns. *Soil Biology & Biochemistry* 35(7): 907-913.
56. Mohanty SR, Bodelier PLE, Floris V, Conrad R (2006) Differential effects of nitrogenous fertilizers on methane-consuming microbes in rice field and forest soils. *Applied and Environmental Microbiology* 72(2): 1346-1354.
57. Zimmerman L, Labonte B (2015) Climate change and the microbial methane banquet. *Climate Alert* 27(1).
58. Zhu YG, Wang XH, Yang XR, Xu HJ, Jia Y (2014) Key microbial processes in nitrous oxide emissions of agricultural soil and mitigation strategies (in Chinese). *Environ Sci* 35(2): 792-800.
59. Hu HW, Trivedi P, He JZ, Singh BK (2017) Microbial nitrous oxide emissions in dryland ecosystems: mechanisms, microbiome and mitigation. *Environ Microbiol* 19(12): 4808-4828.
60. Castro HF, Classen AT, Austin EE, Norby RJ, Schadt CW (2010) Soil microbial community responses to multiple experimental climate change drivers. *Appl Environ Microbiol* 76(4): 999-1007.
61. Arora P, Devi R, Chaudhry S (2019) Impact of climate change on the production of major food and commercial crops in India: A five decadal study. *International Journal of Environment and Climate Change* 9(9): 477-485.

For possible submissions Click below:

Submit Article