

# Impact of Climate Change on Soil Microbes and their Environmental Management

## Research Article

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**Article Information:** Submission: 01/11/2025; Accepted: 25/11/2025; Published: 29/11/2025

### Abstract

Global climate change, mainly temperature rise and increased carbon dioxide (CO<sub>2</sub>) concentration, is a major concern these days. The inter-annual climatic variability is prominent and significantly influences the agricultural production. Soil productivity is influenced by the amount and activity of beneficial soil microorganisms, which help in degrading the organic matter as well ascertaining the availability of plant nutrients. It is essential to reduce the emission of CO<sub>2</sub> and other major greenhouse gases (GHGs) through the implementation of various strategies in the land use planning and by increasing the soil organic matter by adoption of various techniques which will not only help in reducing the greenhouse gas emissions and mitigating the impact of climate change on beneficial soil microbial community but also allow additional benefits to the farmers in the form of reduced labour, costs, greater efficiency, improved soil quality along with sustainable crop production. Environmental changes are causing shifts in the species distributions on a global scale and can alter the interactions between the microorganisms within ecosystems. Climate change disrupts the delicate balance of plant-soil ecosystems, which significantly affecting plant health and soil fertility. The crucial role of soil microorganisms in nutrient cycling, plant nutrition, facilitation of plant coexistence, and population regulation could have significant consequences for plant community composition and overall ecosystem function. This study focuses on climate-changes, which directly and indirectly have effects on soil microbes and their interactions with plants. Overall, this study has the potential to contribute to our understanding significantly of climate-changes effects on ecosystem.

**Keywords:** Ecosystem, Microbial Communities; Heat Waves; Flooding; Drought; Climate Change Ghgs Mitigation Strategies

### Introduction

Environmental changes are causing shifts in the species distributions on a global scale and can alter the interactions between the microorganisms within ecosystems. The ecosystem comprised a complex web of species with diverse life history strategies and varying dispersal capabilities. Therefore, it is improbable that all species respond to climatic changes identically. Climate change disrupts the delicate balance of plant-soil ecosystems, which significantly affecting plant health and soil fertility. Life as we know it has been transformed due to climate change. The heavy impact of climate change has taken its toll on everything. The rate and extent of damage are expected to become worse each year. Climate change impact has been the center of attention during the past few years. The use of mineral fertilizers has strongly increased the flow of nitrogen (N) and phosphorus (P)

in agricultural systems worldwide and altered global biogeochemical cycles. A significant part of the N and P contained in the fertilizers is lost from agro-ecosystems via leaching, causing serious groundwater pollution and eutrophication (Galloway et al., 2003). The amount of nutrients applied in agricultural systems is not expected to decline in the coming decades and models predict a global increase of N and P excess of 23% and 54%, respectively, with a major intensification in developing countries (Bouwman et al., 2013; McIntyre, Herren, Wakhungu, & Watson, 2009) Earth maintains a delicate balance of incoming and outgoing radiation (He et al., 2023). However, human activity has disrupted this equilibrium by releasing greenhouse gases (Joly et al., 2023). This amplified greenhouse effect pushes global temperatures higher, a seemingly small rise of 1°C masking a cascade of consequences (Peng et al., 2023). The soil microbial community is an important biological component of soil function, valued for its

role in improving soil quality and regulating nutrient availability, and thereby influencing plant production for agriculture and other purposes (Kennedy & Smith 1995, Papendick & Parr 1992). The soil microbial community is expected to be impacted by various facets of global climate change, such as increased atmospheric CO<sub>2</sub>, altered temperature and precipitation patterns, and increased frequency of extreme climate events (IPCC 2007). We must focus on developing strategies to mitigate climate change damage and reinforce plant tolerance and resilience in the face of this intensifying stress to ensure global food security and sustainable production. This review aims to provide a comprehensive overview of the influence of climate change on soil microorganisms.

### Impact Of Climate Change on Microbial Community

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Microbial processes are dependent on environmental factors such as temperature, moisture, enzyme activity and nutrient availability, all of which are affected by climate change. Soil respiration is dependent on soil temperature and moisture and may increase or decrease as a result of changes in precipitation and increased atmospheric temperatures. Climate change may be due to natural internal processes or external force or due to persistent anthropogenic changes in the composition of the atmosphere or in land use.

### Impact Of Heatwaves on The Soil Microbiota

Climate change is already causing significant impacts on plant diseases worldwide. In the USA, warmer temperatures have contributed to the northward expansion of corn diseases like northern corn leaf blight. In Europe, the incidence of late blight on potato crops is expected to increase significantly with rising temperatures. Understanding this intricate interplay between temperature and fungal phytopathogens is key to developing effective disease management strategies (Cruz-Paredes et al., 2023) [10]. This knowledge empowers us to protect precious crops and gardens from the silent threat of these microscopic pathogens, ensuring a bountiful harvest and a flourishing landscape (Nottingham et al., 2021).

### Impact Of Droughts on The Soil Microbiota

Microbial life depends critically on water availability. Beyond its role as a solvent, water acts as a reactant in numerous metabolic pathways, directly influencing cellular processes such as photosynthesis and respiration (Siebielec et al., 2020 and Veach and Zeglin, 2020). Water abundance correlates with increased metabolic activity and growth (Peng et al., 2023). Decomposition is a key process for releasing nutrients from dead organic matter, which slows down, leading to nutrient deficiencies for plants (Qu et al., 2023). This could create a vicious cycle, as stressed plants are more susceptible to drought in the first place (Bogati and Walczak, 2022). Microbes play a crucial role in biogeochemical cycles, like carbon and nitrogen cycling (Wang et al., 2023a). Droughts could disrupt these cycles, leading to changes in greenhouse gas emissions and influencing the overall health of the planet.

### Impact Of Flooding on The Soil Microbiota

Increased rainfall and extreme weather could lead to soil saturation (Arnell and Gosling, 2016). This flooding disrupts oxygen availability, favoring anaerobic microbes like methanogen that contribute to greenhouse gas emissions. Additionally, it could cause the elimination of microbes, further disrupting community composition (Chung and Lee, 2020) [1]. Flooding, an increasingly frequent natural disaster due to climate change, significantly impacts plant health and agricultural productivity (Duan et al., 2019). This effect is often amplified by the rise of phytopathogens, microscopic organisms that grow in wet environments and cause devastating diseases (Moche et al., 2015). Understanding the complex interplay between floods and fungal phytopathogen is crucial for mitigating their destructive potential and ensuring food security (Jones et al., 2019) [2]. The influx of water displaces oxygen, creating an anaerobic environment (Gschwend et al., 2020). The floodwaters can wash away certain microbial groups, disrupting the delicate balance of the soil micro biome.

### Impact Of Increased Co<sub>2</sub> on Microbial Community

The present atmospheric CO<sub>2</sub> increase is caused by anthropogenic emissions of CO<sub>2</sub>. Table 1 show that the atmospheric CO<sub>2</sub> levels are increasing at a rate of 0.4% per year and are predicted to double by 2100 largely as a result of human activities such as fossil fuel, combustion and land-use changes. An estimated 30-40% of the CO<sub>2</sub> released by humans into the atmosphere dissolves into oceans, rivers and lakes (Feely et al. 2004, Millero 1995), which contributes to ocean acidification. The direct effect of elevated CO<sub>2</sub> in stimulating above-ground biomass production has been extensively studied (Pan et al. 1998). This increase in above-ground net primary production (ANPP) has been shown to increase C supply below-ground and stimulates soil biological activity (Pendall et al. 2004) [3].

High CO<sub>2</sub> concentrations accelerate average growth rate of plants, thereby allowing them to sequester more CO<sub>2</sub>. This growth of plants was coupled with an increase in soil respiration due to the

**Table 1:** Year-wise data for global carbon emissions (fossil fuels, combustion and land-use change)

S. No.	Year	CO <sub>2</sub> concentration in atmosphere(ppm)	Remarks
1.	2014	398.55	Copenhagen Accord
2.	2013	396.48	
3.	2012	393.82	
4.	2011	391.63	
5.	2010	389.85	
6.	2009	387.37	
7.	2008	385.59	
8.	2007	383.76	
9.	2006	381.90	
10.	1997	356.38	Kyoto Protocol
11.	1992	356.38	Earth Summit in Rio de Janeiro
12.	1987	349.16	The last year when the annual CO <sub>2</sub> level was less than 350 ppm
13.	1959	315.97	The first year with a full year of instrument data

increase in nutrients available for decomposition by releasing more CO<sub>2</sub> into the atmosphere. Increased levels of CO<sub>2</sub> quantitatively and qualitatively alter the release of labile sugars, organic acids and amino acids from plant roots, and this can stimulate microbial growth and activity. In the long term, it is argued that the increase in microbial biomass as a result of increased carbon release by the roots can lead to immobilization of soil N, thereby limiting the nitrogen available for plants and creating negative feedback that constraints future increase in plant growth. This, in turn, may lead to an increased soil carbon to nitrogen ratio, which favour higher fungal dominance and diversity. Global carbon flux between the atmosphere and terrestrial ecosystems is depicted in (Figure 1)

Fungi generally have higher carbon assimilation efficiencies (they store more C than they metabolize) than bacteria, and fungal cell walls mainly consist of carbon polymers (chitin and melatin) that are much more resistant to decomposition than those in bacterial cell membranes and walls (phospholipids and peptidoglycan). As a result, in eco systems dominated by fungi, soil respiration rates are typically low, which increases the potential for carbon sequestration. An increase in atmospheric CO<sub>2</sub> may be one of the effects of climate change, can significantly change soil environment mainly by modifying the distribution of above and below-ground nutrients. For example, an increase of atmospheric CO<sub>2</sub> could lead to an increased plant growth, since CO<sub>2</sub> is the molecular building block for photosynthesis. This may lead to an increase in litter production rate and a modification in litter chemical composition, which may in turn lead to a change in its digestibility. Such modifications will then influence the nature of organic matter available for soil microorganisms (Zak et al. 2000).

**Result and Analysis**

**Outcome and Discussion**

As climate change due to increasing concentrations of GHG

effect on soil microbes which lead to environmental management. for its improvement following strategies would be beneficial which are as

**Mitigation Strategies**

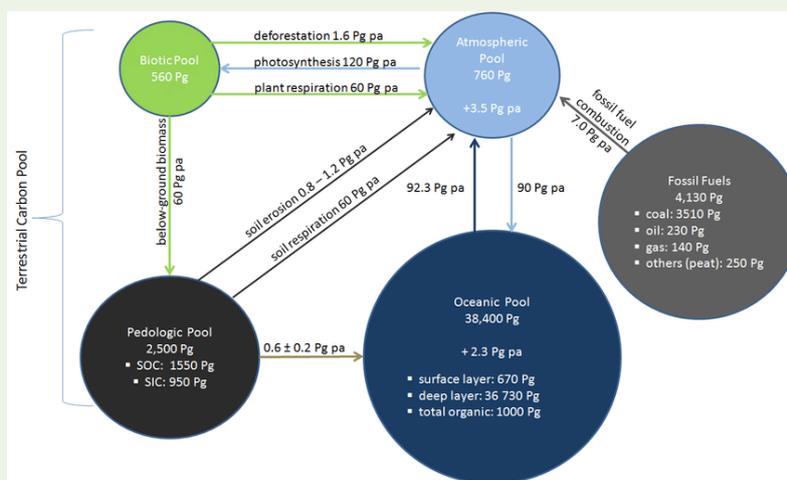
To a large extent, the same practices that increase productivity and resilience to climate change also provide positive co-benefits with respect to agricultural mitigation of GHGs. There are three main mechanisms for mitigating GHGs in agriculture: a) reducing emissions, b) enhancing removal of carbon from the atmosphere and c) avoiding emissions through the use of bio energy or agricultural intensification rather than expansion (Smith et al. 2007). There is a positive correlation between soil organic carbon and crop yield, practice that increase soil fertility and crop productivity also mitigate GHGs emissions, particularly in areas where soil degradation is a major challenge (Lal 2004) [5]. There is little research to date on the synergies and tradeoffs between agricultural adaptation, mitigation and productivity impacts.

**Mulching/light soil sealing**

Mulching consists of covering the soil surface to protect against erosion and to enhance its fertility. Mulch is usually applied towards the beginning of the crop growing season, and may be reapplied as necessary. It serves initially to warm the soil through retaining heat and moisture. A variety of materials can be used as mulch including organic residues (e.g. crop residue, hay, bark), manures, sewage sludge, compost and rubber or plastic films.

**Fertilizers**

High levels of some inorganic nitrogenous fertilizers provide microbes nitrogen with easy to use, thereby boosting their activity. This increases the rate of decomposition of low-quality organic inputs and soil organic matter, resulting in less of soil carbon and the continuing decline of soil organic matter content which, ultimately, results in loss of soil structure and water holding capacity.



**Figure 1:** Conceptual diagram of global carbon flux between the atmosphere and terrestrial ecosystems. Transformation of carbon flux from terrestrial to atmospheric C pools by decomposition includes the breakdown of plant residue, litter, and soil organic matter by soil organisms, which is balanced by the net assimilation of carbon via photosynthesis in ecosystems that are in steady state (Wolf & Wagner 2005, Lal 2008) [4]. All units are in Pg C (10<sup>15</sup>g). **Source:** Annual CO<sub>2</sub> Data: NOAA-ESRI data file created (2015).

Table 2

Enzyme	Changes
phosphatase	Rapid phosphorus metabolism
dehydrogenase	Increase microbial respiration
B glucosidase	Improve carbon cycling
ligninase	Increase microbial respiration

Table 3

Condition	Enzyme	Enzymatic activity
Temperature increases	NPK Degrading Enzyme	Increase in mass
Drought	Dehydrogenase	Reduction in microbial biomass
Precipitation	Phosphatase	Increase in enzyme production

Table 4: Impact on Respiration

Microbes	Example	Rate of Respiration
Fungi	Aspergillus, Penicillium	0.5-3.5
Bacteria	Bacillus, Pseudomonas	0.3-4.0
Actino bacteria	Streptomyces	0.5-2.0

Table 5: Rate of Decomposition

Soil organic matter	Rate of Decomposition
Fungi	fast
Bacteria	Moderate slow
Actino bacteria	Slowest

## Crop Management

### Selection of the crop species

The choice of the cultivated crop is important as it defines the kind of habitat available to soil fauna. For example, legumes can act as natural fertilizers, improving the N concentration in soil by establishing symbiotic relationship with rhizobia. Application of nitrate fertilizers as calcium ammonium nitrate in crops with aerobic conditions and ammonium fertilizers as ammonium sulphate, urea, in wetland crops also helping reducing the nitrous oxide (N<sub>2</sub>O) emission (Pathak & Nedwell 2001).

### Crop rotations

Crop rotations can also help to avoid the buildup of pathogens and pests, as the alteration of crops modifies the associated communities of biological regulators. Appropriate crop management practices, which lead to increase N use efficiency and yield, hold the key to reduce nitrous oxide emission.

## Landscape Management

### Hedgerows and grassy field margins

Establishing hedge rows or grassy strips at the edge of arable fields offer a stable habitat, food and a protective environment for soil fauna next to the intensively managed fields. Hedgerows are even more favourable to soil organisms, in particular biological regulators, than grassy field margins, however, due to their low mobility; the soil organisms will have only limited dispersal into the fields. That also counts for field margins, in which 10% of the soil dwelling species present in farmland were found to occur exclusively.

## Microbial Communities and Mitigation Options

### Managing microbial communities to reduce carbon dioxide emissions

Currently, soils contain about 2,000 Pg of organic carbon, which is twice the amount of carbon in the atmosphere and three times the quantity found in vegetation (IPCC 2007, Smith 2004) [6]. The capacity of different land types (for example, woodland, pasture and arable land) to store carbon differs, and it has been suggested that land use can be managed to sequester a further 1 Pg of carbon per year in soils (Smith 2004, Houghton 2008) [6], this potential has received considerable scientific attention (Lal 2008, Busse 2009) [4].

### Managing microbial communities to reduce methane emissions

Global emissions of CH<sub>4</sub> are arguably even more directly controlled by microorganisms than emissions of CO<sub>2</sub>. Natural emissions (~250 million tonnes CH<sub>4</sub> per year) are dominated by microbial methanogenesis, a process that is carried out by a group of anaerobic archaea in wetlands, oceans, rumens and termite guts. However, these natural sources are exceeded by emissions from human activities (mainly rice cultivation, land fill, fossil fuel extraction and livestock farming). Methanotrophic bacteria serve as a crucial buffer to the huge amounts of CH<sub>4</sub> produced in some of these environments. The so-called 'low-affinity' methanotrophs (active only at a CH<sub>4</sub> concentration of >40 ppm; also called type I methanotrophs), which mainly belong to the class Gammaproteobacteria, can often consume a large proportion of the CH<sub>4</sub> produced in soils before it escapes to the atmosphere.

## Discussion

Regarding role of microbes in promoting soil management various authors expressed their findings. Allison, S.D., Wallenstein, M.D. and Bradford, M.A. 2010 [7]. Focused on Soil carbon response to warming dependent on microbial physiology, Berntson, G.M. and Bazzaz, F.A. 1997 [8], Pendall, E., Bridgman, S., Hanson, P.J., Hungate, B., Kicklighter, D.W., Johnson, D.W., Law, B.E., Luo, Y.Q., Meconigal, J.P., Olsrud, M., Ryan, M.G. and Wan, S. 2004. observed Below-ground process responses to elevated CO<sub>2</sub> and temperature: a discussion of observations, measurement methods, and models. Nitrogen cycling in microcosms of yellow birch exposed to elevated CO<sub>2</sub>: simultaneous positive and negative below-ground feedbacks. Lal, R. 2008 [4]. Carbon sequestration impacts on global climate change and food security, Jones, P.; Garcia, B.J.; Furches, A. et al. (2019) [2]. Observed Plant host-associated mechanisms for microbial selection. Davidson, E.A. and Janssens, I.A. 2006 [9]. Stated Temperature sensitivity of soil carbon decomposition and feedbacks to climate change., Global Climate Change Impacts in the United States (GCCCI) 2009. Was observed by Karl, T.R., Melillo, J.M. and Peterson, T.C. (eds.) [10]. Cambridge University Press, New York, USA., Akram, M.A.; Zhang, Y.H.; Wang, X.T. et al. (2022) [11]. Phylogenetic independence in the variations in leaf functional traits among different plant life forms in an arid environment, Anjileli, H.; Huning, L.S.; Moftakhari, H. et al. (2021) [12]. Stated Extreme heat events heighten soil respiration. Bardgett, R.D. and Caruso, T. (2020) [13]. Soil microbial community responses to climate extremes:

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### Conclusion

Lastly, it is concluded that the climate change, as noticed through trends of temperature rise, altered precipitation and increased CO<sub>2</sub> concentration, is a major concern to microbial community. Increase in temperature over a long period of time will not affect the microbial population a lot as it will get adapted to it, but it will contribute to increase in CO<sub>2</sub> emission which is a major greenhouse gas. Microbes have emerged as the major contributor as well as consumer for GHGs as the microorganisms are the main intermediaries of C turnover in soil. Climate change is likely to have significant impacts on soils that may affect all of the services provided by soil microbial community; indeed, the quantification of these impacts is needed. In any case, all mitigation and attenuation measures taken to limit global climate change are expected to have a beneficial impact on soil microbial community preservation, soil functioning and associated services.

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