

Soil Microorganisms and Global Climate Change

1. Objective

The aim of this paper is to examine two aspects of the relationship between soil microorganisms and global climate change. First, I will explore how soil microorganisms contribute to greenhouse gas emissions and then, conversely, I will examine the possible effects that increased temperature and CO₂ concentrations in the atmosphere may have on soil microbial processes.

2. Introduction

Microorganisms found in the soil are vital to many of the ecological processes that sustain life such as nutrient cycling, decay of plant matter, consumption and production of trace gases, and transformation of metals (Panikov, 1999). Although climate change studies often focus on life at the macroscopic scale, microbial processes can significantly shape the effects that global climate change has on terrestrial ecosystems. According to the International Panel on Climate Change (IPCC) report (2007), warming of the climate system is occurring at unprecedented rates and an increase in anthropogenic greenhouse gas concentrations is responsible for most of this warming. Soil microorganisms contribute significantly to the production and consumption of greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and nitric oxide (NO), and human activities such as waste disposal and agriculture have stimulated the production of greenhouse gases by microbes. As concentrations of these gases continue to rise, soil microbes may have various feedback responses that accelerate or slow down global warming, but the extent of these effects are unknown. Understanding the role soil microbes have as both contributors to and reactive components of climate change can help us determine whether they can be used to curb emissions or if they will push us even faster towards climatic disaster.

3. Discussion

3.1 Microbial contributions to greenhouse gas emissions

Soil microorganisms are a major component of biogeochemical nutrient cycling and global fluxes of CO₂, CH₄, and N. Global soils are estimated to contain twice as much carbon as the atmosphere, making them one of the largest sinks for atmospheric CO₂ and organic carbon (Jenkinson and Wild, 1991; Willey et al., 2009). Much of this carbon is stored in wetlands, peatlands, and permafrost, where microbial decomposition of carbon is limited. The amount of

carbon stored in the soil is dependent on the balance between carbon inputs from leaf litter and root detritus and carbon outputs from microbial respiration underground (Davidson and Janssens, 2006). Soil respiration refers to the overall process by which bacteria and fungi in the soil decompose carbon fixed by plants and other photosynthetic organisms and release it into the atmosphere in the form of CO₂. This process accounts for 25% of naturally emitted CO₂, which is the most abundant greenhouse gas in the atmosphere and the target of many climate change mitigation efforts. Small changes in decomposition rates could not only affect CO₂ emissions in the atmosphere, but may also result in greater changes to the amount of carbon stored in the soil over decades (Davidson and Janssens, 2006).

Methane is another important greenhouse gas and is 25 times more effective than CO₂ at trapping heat radiated from the Earth (Schlesinger and Andrews, 2000). Microbial methanogenesis is responsible for both natural and human-induced CH₄ emissions since methanogenic archaea reduce carbon into methane in anaerobic, carbon-rich environments such as ruminant livestock, rice paddies, landfills, and wetlands. Not all of the methane produced ends up in the atmosphere however, due to methanotrophic bacteria, which oxidize methane into CO₂ in the presence of oxygen. When methanogens in the soil produce methane faster than can be used by methanotrophs in higher up oxic soil layers, methane escapes into the atmosphere (Willey et al., 2009). Methanotrophs are therefore important regulators of methane fluxes in the atmosphere, but their slow growth rate and firm attachment to soil particles makes them difficult to isolate. Further exploration of these methanotrophs' nature could potentially help reduce methane emissions if they can be added to the topsoil of landfills, for example, and capture some of the methane that would normally be released into the atmosphere.

Not unlike their role in the carbon cycle, soil microorganisms mediate the nitrogen cycle, making nitrogen available for living organisms before returning it back to the atmosphere. In the process of nitrification (during which ammonia is oxidized to nitrate), microbes release NO and N₂O, two critical greenhouse gases, into the atmosphere as intermediates. Evidence suggests that humans are stimulating the production of these greenhouse gases from the application of nitrogen-containing fertilizers (Willey et al., 2009). For example, *Nitrosomonas eutropha* is a nitrifying proteobacteria found in strongly eutrophic environments due to its high tolerance for elevated ammonia concentrations. N-fertilizers increase ammonia concentrations, causing *N. eutropha* to release more NO and N₂O in the process of oxidizing ammonium ions. Since NO is

necessary for this reaction to occur, its increased emissions cause the cycle to repeat, thereby further contributing to NO and N₂O concentrations in the atmosphere (Willey et al., 2009).

3.2 Microbial responses to global climate change

Microbial processes are often dependent on environmental factors such as temperature, moisture, enzyme activity, and nutrient availability, all of which are likely to be affected by climate change (IPCC, 2007). These changes may have greater implications for crucial ecological processes such as nutrient cycling, which rely on microbial activity. For example, 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. Due to its importance in the global carbon cycle, changes in soil respiration may have significant feedback effects on climate change and severely alter aboveground communities. Therefore, understanding the response of soil respiration to climate change is of great importance and will be discussed in detail in this report.

3.2.1 Microbial response to increased temperatures:

One of the major uncertainties in climate change predictions is the response of soil respiration to increased atmospheric temperatures (Briones et al., 2004; Luo et al., 2001). Several studies show that increased temperatures accelerate rates of microbial decomposition, thereby increasing CO₂ emitted by soil respiration and producing a positive feedback to global warming (Allison et al., 2010). Under this scenario, global warming would cause large amounts of carbon in terrestrial soils to be lost to the atmosphere, potentially making them a greater carbon source than sink (Melillo et al., 2002). However, further studies suggest that this increase in respiration may not persist as temperatures continue to rise. In a 10-year soil warming experiment, Melillo et al. (2002) show a 28% increase in CO₂ flux in the first 6 years of warming when compared to the control soils, followed by considerable decreases in CO₂ released in subsequent years, and no significant response to warming in the final year of the experiment. The exact microbial processes that cause this decreased long-term response to heated conditions have not been proven, but several explanations have been proposed. First, it is possible that increased temperatures cause microbes to undergo physiological changes that result in reduced carbon-use efficiency (Allison et al., 2010). Soil microbes may also acclimate to higher soil temperatures by adapting their metabolism and eventually return to normal decomposition rates. Lastly, it can

be interpreted as an aboveground effect if changes in growing-season lengths as a result of climate change affect primary productivity, and thus carbon inputs to the soil (Davidson and Janssens, 2006).

The effects of increased global temperatures on soils is especially alarming when considering the effects it has already begun to have on one of the most important terrestrial carbon sinks: permafrost. Permafrost is permanently frozen soil that stores significant amounts of carbon and organic matter in its frozen layers. As permafrost thaws, the stored carbon and organic nutrients become available for microbial decomposition, which in turn releases CO₂ into the atmosphere and causes a positive feedback to warming (Davidson and Janssens, 2006). One estimate suggests that 25% of permafrost could thaw by 2100 as a result of global warming, making about 100 Pg of carbon available for microbial decomposition (Davidson and Janssens, 2006; Anisimov et al., 1999). This could have significant effects on the global carbon flux and may accelerate the predicted impacts of climate change. Moreover, the flooding of thawed permafrost areas creates anaerobic conditions favorable for decomposition by methanogenesis. Although anaerobic processes are likely to proceed more slowly, the release of CH₄ into the atmosphere may result in an even stronger positive feedback to climate change (Davidson and Janssens, 2006).

3.2.2 Microbial response to increased CO₂

Atmospheric CO₂ 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 (Lal, 2005; IPCC, 2007). Increased CO₂ concentrations in the atmosphere are thought to be mitigated in part by the ability of terrestrial forests to sequester large amounts of CO₂ (Schlesinger and Lichten, 2000). To test this, an international team of scientists grew a variety of trees for several years under elevated CO₂ concentrations. They found that high CO₂ concentrations accelerated average growth rate of plants, thereby allowing them to sequester more CO₂. However, this growth was coupled with an increase in soil respiration due to the increase in nutrients available for decomposition by releasing more CO₂ into the atmosphere (Willey et al., 2009). This suggests that forests may sequester less carbon than predicted in response to increased CO₂ concentrations, however more research is needed to investigate this hypothesis.

3.2.3 Soil-borne pathogens and climate change

According to the IPCC (2007) report, climate change will alter patterns of infectious disease outbreaks in humans and animals. Soil pathogens are no exception: case studies support the claim that climate change is already changing patterns of infectious diseases caused by soil pathogens. For example, over the last 20 years, 67% of the 110 species of harlequin frogs (*Atelopus*) native to tropical regions in Latin America have gone extinct from chytridiomycosis, a lethal disease spread by the pathogenic chytrid fungus (*Batrachochytrium dendrobatidis*) (Willey et al., 2009). Research suggests that mid- to high-elevations provide ideal temperatures for *B. dendrobatidis*. However, as global warming progresses, *B. dendrobatidis* is able to expand its range due to increasing moisture and warmer temperatures at higher elevations (Muths et al., 2008). This expansion exposes more amphibian communities in previously unaffected or minimally affected areas, specifically at higher elevations, to chytridiomycosis. As seen in the case of *Atelopus* harlequin frogs, the spread of soil pathogens due to climatic changes can significantly affect life at the macro scale and ultimately lead to species extinction.

4. Conclusion

The complexity of microbial communities living belowground and the various ways they associate with their surroundings make it difficult to pinpoint the various feedback responses that soil microbes may have to global warming. Whether a positive feedback response results, in which microbial processes further contribute to climate change, or whether a negative feedback response slows its effects, it is clear that microbes can have a huge impact on future climate scenarios and ecosystem-level responses to climate change. Soil respiration plays a pivotal role in these effects due to the large amount of CO₂ and CH₄ emissions produced during respiration, the reliance of carbon stocks in soils on rates of respiration, and the initial sensitivity of soil respiration to increased atmospheric temperatures. Further studies in long-term feedback effects of soil respiration on climate change can contribute to our understanding of the overall impacts of climate change, including the ability of terrestrial forests to uptake excess CO₂ from the atmosphere. As we attempt to mitigate greenhouse gas emissions and adapt to predicted climate change effects, turning towards microscopic life that lies below the surface can perhaps help us to become better equipped for future changes at the macroscopic and even global scale.

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