# New model shows global warming accelerates carbon dioxide emissions from soil microbes

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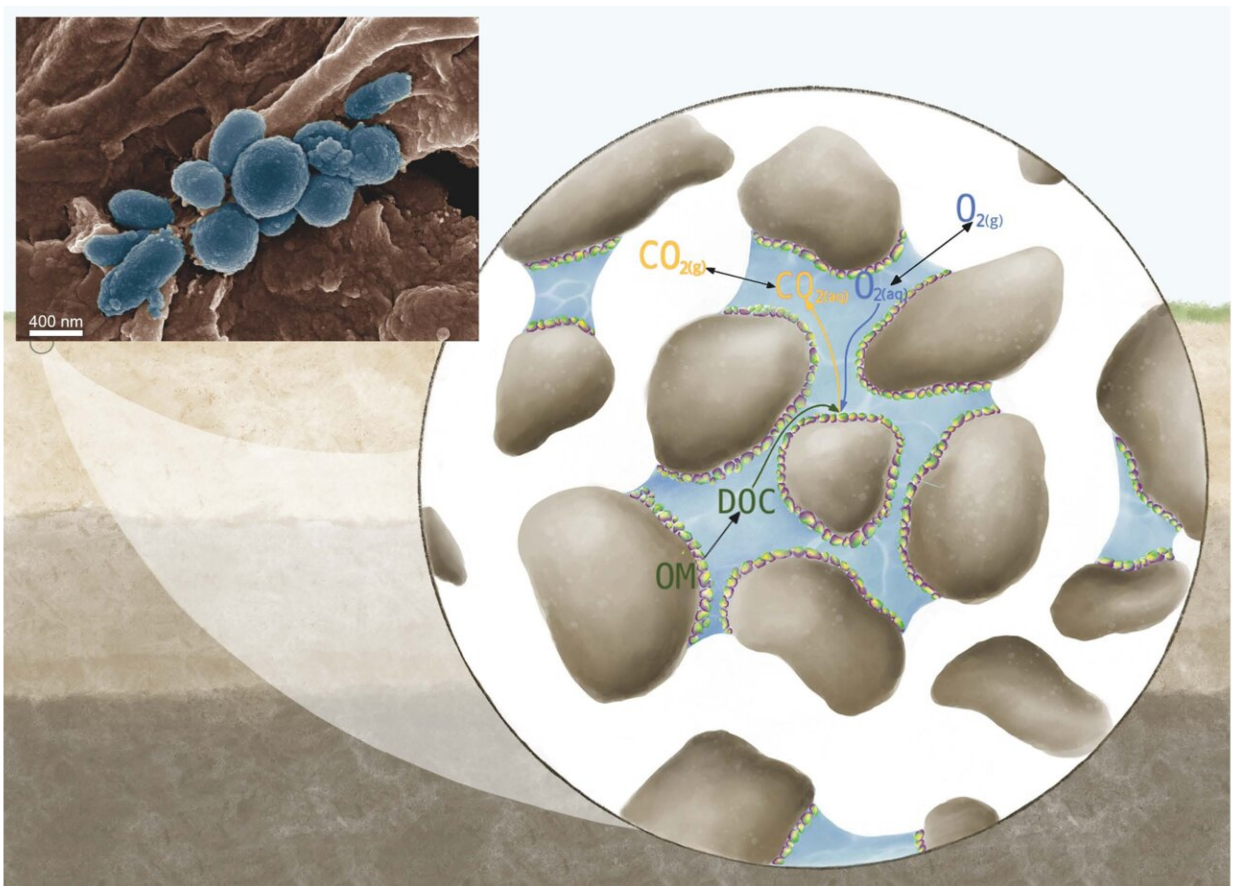


The scanning electron microscope image shows a colony of bacteria (coloured bluish) around a few micrometres small root (brown) in the soil. The image represents how bacteria and microbial communities influence $CO_2$ release from the soil through heterotrophic respiration: The soil contains soil grains to which microbial communities adhere and process dissolved oxygen $O_2$ and organic carbon DOC from organic matter (OM). Credit: Springer Nature / ETH Zurich Institute of Environmental Engineering)

When microorganisms decompose organic material in the soil, they actively release $CO_2$ into the atmosphere. This process is called heterotrophic respiration. A novel model shows that these emissions could surge by up to 40% by the end of the century—most significantly in the polar regions.

The rise in atmospheric carbon dioxide ($CO_2$) concentration is a primary catalyst for global warming, and an estimated one fifth of the atmospheric $CO_2$ originates from soil sources. This is partially attributed to the activity of microorganisms, including bacteria, fungi, and other microorganisms that decompose organic matter in the soil utilizing oxygen, such as deceased plant materials. During this process, $CO_2$ is released into the atmosphere. Scientists refer to it as heterotrophic soil respiration.

Based on a recent study published in the scientific journal *Nature Communications*, a team of researchers from ETH Zurich, the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, the Swiss Federal Institute of Aquatic Science and Technology Eawag, and the University of Lausanne has reached a significant conclusion. Their study indicates that emissions of $CO_2$ by soil microbes into the Earth's atmosphere are not only expected to increase but also accelerate on a global scale by the end of this century.

Using a projection, they find that by 2100, $CO_2$ emissions from soil microbes will escalate, potentially reaching an increase of up to about 40% globally, compared to the current levels, under the worst-case climate scenario. "Thus, the projected rise in microbial $CO_2$ emissions will further contribute to the aggravation of global warming, emphasizing the urgent need to get more accurate estimates of the heterotrophic respiration rates," says Alon Nissan, the main author of the study and an ETH Postdoctoral Fellow at the ETH Zurich Institute of Environmental Engineering.

## Soil moisture and temperature as key factors

These findings do not only confirm earlier studies but also provide more precise insights into the mechanisms and magnitude of heterotrophic soil respiration across different climatic zones. In contrast to other models that rely on numerous parameters, the novel mathematical model, developed by Alon Nissan, simplifies the estimation process by utilizing only two crucial environmental factors: soil moisture and soil temperature.

The model represents a significant advancement as it encompasses all biophysically relevant levels, ranging from the micro-scales of soil structure and soil water distribution to plant communities like forests, entire ecosystems, climatic zones, and even the global scale.

Peter Molnar, a professor at the ETH Institute of Environmental Engineering, highlights the significance of this theoretical model which complements large Earth System models, stating, "The model allows for a more straightforward estimation of microbial respiration rates based on soil moisture and soil temperature. Moreover, it enhances our understanding of how heterotrophic respiration in diverse climate regions contributes to global warming."

### Polar $CO_2$ emissions likely to more than double

A key finding of the research collaboration led by Peter Molnar and Alon Nissan is that the increase in microbial $CO_2$ emissions varies across climate zones. In cold polar regions, the foremost contributor to the increase is the decline in soil moisture rather than a significant rise in temperature, unlike in hot and temperate zones. Alon Nissan highlights the sensitivity of cold zones, stating, "Even a slight change in water content can lead to a substantial alteration in the respiration rate in the polar regions."

Based on their calculations, under the worst-case climate scenario, microbial $CO_2$ emissions in polar regions are projected to rise by ten percent per decade by 2100, twice the rate anticipated for the rest of the world. This disparity can be attributed to the optimal conditions for heterotrophic respiration, which occur when soils are in a semi-saturated state, i.e., neither too dry nor too wet. These conditions prevail during soil thawing in polar regions.

On the other hand, soils in other climate zones, which are already relatively drier and prone to further desiccation, exhibit a comparatively smaller increase in microbial $CO_2$ emissions. However, irrespective of the climate zone, the influence of temperature remains consistent: as soil temperature rises, so does the emission of microbial $CO_2$.

**How much $CO_2$ emissions will increase by each climate zone**

As of 2021, most $CO_2$ emissions from soil microbes are primarily originating from the warm regions of the Earth. Specifically, 67% of these emissions come from the tropics, 23% from the subtropics, 10% from the temperate zones, and a mere 0.1% from the arctic or polar regions.

Significantly, the researchers anticipate substantial growth in microbial $CO_2$ emissions across all these regions compared to the levels observed in 2021. By the year 2100, their projections indicate an increase of 119% in the polar regions, 38% in the tropics, 40% in the subtropics, and 48% in the temperate zones.

**Will soils be a $CO_2$ sink or a $CO_2$ source for the atmosphere?**

The carbon balance in soils, determining whether soils act as a carbon source or sink, hinges on the interplay between two crucial processes: photosynthesis, whereby plants assimilate $CO_2$, and respiration, which releases $CO_2$. Therefore, studying microbial $CO_2$ emissions is essential for comprehending whether soils will store or release $CO_2$ in the future.

"Due to climate change, the magnitude of these carbon fluxes—both the inflow through photosynthesis and the outflow through respiration—remains uncertain. However, this magnitude will impact the current role of soils as carbon sinks," explains Alon Nissan.

In their ongoing study, the researchers have primarily focused on heterotrophic respiration. However, they have not yet investigated the $CO_2$ emissions that plants release through autotrophic respiration. Further exploration of these factors will provide a more comprehensive understanding of the carbon dynamics within soil ecosystems.

**More information:** Alon Nissan et al, Global warming accelerates soil heterotrophic respiration, *Nature Communications* (2023). DOI: 10.1038/s41467-023-38981-w

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