Soil biogeochemistry

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Subsoil carbon loss

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A field-based study of 4.5 years of whole-soil warming reveals that warming stimulates loss of structurally complex organic carbon at the same rate as that for bulk organic carbon in subsoil.

Soils store significantly more carbon than the atmosphere or vegetation. Global warming can stimulate losses of soil organic carbon (SOC) through increased microbial respiration, which potentially accelerates warming via positive carbon–climate feedback[1]. However, the magnitude of microbial and SOC responses to warming remains very uncertain[2]. This is due partly to the knowledge gap in our understanding of the decomposition response of different compounds in bulk SOC. For example, organic carbon with complex molecular structures is expected to be relatively more stable under warming, as it needs more energy than simple organic carbon for decomposition[1]. In *Nature Geoscience*, however, Zosso et al. show that warming stimulates rapid losses of plant-derived complex polymers and pyrogenic carbon in subsoil, suggesting a greater feedback of SOC with climate change[3].

Subsoil stores the majority of soil carbon. To investigate the response of SOC to warming, field-based warming experiments are conducted worldwide[4,5], including open-top chambers, infrared heaters, curtains, heating cables, greenhouses and transplanting. However, most of the experiments are focused on topsoil and the response of bulk SOC.

Zosso and co-authors conducted a whole-soil warming experiment at the University of California Blodgett Experimental Forest, Sierra Nevada, California. Soils were sampled at 0–20 cm (topsoil) and 20–90 cm (subsoil) after 4.5 years of experimental warming. The complex soil carbon examined includes pyrogenic carbon, lignin and suberin and cutin content. The authors find that losses of these complex structures are approximately at the same rate as those for bulk SOC. The result challenges the long-standing consensus that complex molecular structures are more stable, and shield bulk SOC from degradation. This suggests that molecular structure alone may not protect SOC from degradation by warming.

The rapid decomposition of complex organic carbon may be linked to microbial responses to warming (Fig. 1), including shifts in soil microbial community composition, physiology, extracellular enzyme activity and gene abundance[6]. The shift in composition is also closely associated with changes in extracellular enzyme activity[7], an important but understudied microbial function in modulating SOC dynamics. Recent meta-analyses have shown that warming-induced changes in soil extracellular enzyme activity may favour the decomposition of soil organic carbon with complex molecular structures[4,8].

However, Zosso et al. did not observe carbon losses from complex molecular structures in topsoil[3]. This suggests that decomposition of SOC in topsoil and subsoil are regulated by different biotic and abiotic

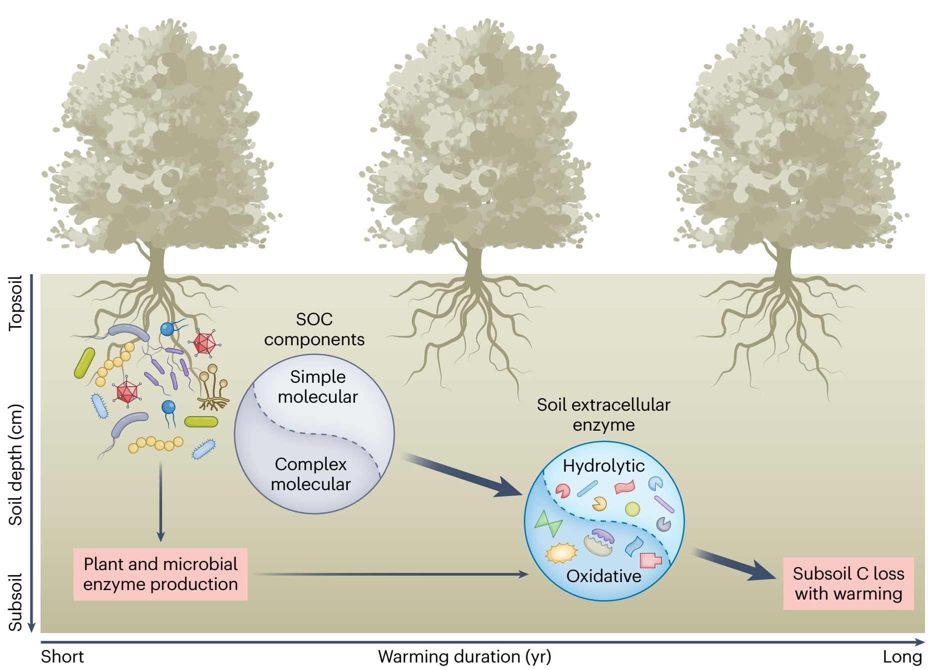

Fig. 1 | Effects of warming on soil carbon dynamics. Zosso et al. show that warming stimulates loss of subsoil complex molecular structures at the same rate as those for bulk soil organic carbon, indicating larger warming-induced soil carbon losses than previously thought.

factors[9]. One possible explanation is that greater reductions in soil moisture in topsoil, relative to subsoil, may limit the microbial decomposition of complex substances. Alternatively, continued litter inputs to topsoil could offset the losses of readily accessible SOC pools at the study site, such that soil microorganisms do not necessarily directly use resources from complex soil carbon.

The duration of experimental warming can affect the trajectory of SOC responses (Fig. 1). Owing to the short duration of experimental warming, many previous field-based experiments were only able to observe the decomposition of SOC from readily accessible pools[5,7]. This leads to the accumulation of complex soil carbon pools and the limitation of microbial-available carbon. However, as warming continues, microbial community composition and physiology may shift towards degradation and consumption of previously underused carbon sources – such as complex soil carbon – to support the microbes' metabolic activities[10]. Such shifts in microbial carbon use strategies may underlie the similar carbon loss rates of complex structures and bulk SOC observed by Zosso et al. in subsoils after their 4.5 years of warming experiments.

However, 4.5 years may not be long enough to capture the long-term shifts in microbial community composition, physiology and carbon use strategies. Globally, there is a very limited number of long-term warming experiments due to the length constraint of the projects.

To fill in the knowledge gaps that impede a general model for the response of SOC to warming, more research will be needed, including investigating the long-term responses across ecosystems and the responses over different spatial and temporal scales. In addition, we need to better understand the exchange of carbon between atmosphere and subsoil and the mechanisms underlying the different responses of various molecular structures and compositions of SOC to warming. Fortunately, recent advances in both experimental and data-analytic technologies and interdisciplinary collaborations will help close these knowledge gaps.

Zosso et al. report that complex soil organic compounds are as vulnerable to warming as bulk SOC. If this response extends broadly across biomes, the amount of SOC losses due to warming would be larger than we thought. However, there are few comparative studies at present, and warming responses may vary across soils, depending on inputs of microbial, plant and pyrogenic compounds and their interactions with soil minerals and moisture availability. Thus, we highlight the urgency of more research on the degradation of different SOC constituents as well as their warming responses across soil profiles.

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Competing interests

The authors declare no competing interests.