factors, instead, are important. Personal beliefs about global warming and perceived scientific agreement, as well as political party identification and political ideology, have a significant impact on whether or not respondents attribute perceived warming to climate change.

These findings have policy implications as political factors can influence whether or not people perceive actual warming. Importantly though, a majority of respondents do perceive winter warming, and this could translate into public support for adaptation policies. However, as attribution of winter warming to climate change is influenced by pre-existing beliefs and political orientation, this could affect the level of public support for mitigation policies, as accepting responsibility for mitigation requires acknowledging the human causes of climate change. This suggests that even experiencing the realities of climate change will not necessarily lead to acceptance that anthropogenic global warming is occurring.

The sociological approach taken by McCright *et al.*[3] emphasizes the role of political orientation in shaping perceptions and beliefs about climate change and thus analyses the social construction of such perceptions and beliefs. Using statistically appropriate empirical modelling techniques, this study both supports previous research that highlights the politicization of climate change and contributes by demonstrating the power of these findings even in the face of real experiences with warming temperatures[7,8]. Although every study has limitations, and this one is no exception, the researchers suggest many directions for future work on how social factors impact perceptions of weather patterns and acceptance of the reality of anthropogenic global warming. Research should continue to build theoretically in these two areas and test for these patterns at different scales and in a range of contexts, using indicators such as variation in rainfall and extreme weather events. Research should also look at different points in time, and at change over time, especially to see if political views — rather than actual experiences — remain a stronger influencing factor of beliefs about global warming. Such research is important for citizen support and pressure for policy decisions regarding adaptation and mitigation of anthropogenic climate change[10]. ❐

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SOIL CARBON

Microbes, roots and global carbon

Interactions between soil microbes, the physical soil environment and vegetation will determine the magnitude of the terrestrial carbon sink under climate change.

William Wieder

Accurate carbon cycle projections are needed to inform climate change adaptation and mitigation strategies. Such projections require understanding of biological responses to environmental change, especially in the world beneath our feet. Globally, soils store more carbon than plants and the atmosphere combined. Soils also provide habitat for a stunning diversity of organisms that are largely responsible for the stabilization and decomposition of soil carbon. Writing in *Nature Climate Change*, Sulman *et al.*[1] present a fresh look at how soil microbial activity can be simulated at global scales and illustrate why such considerations matter. Their findings underscore the need to explicitly incorporate soil microbial response to environmental change in soil biogeochemical models.

Environmental change effectively reshuffles the deck of biological rules that determine how ecosystems function. Most current soil biogeochemistry models that are applied at ecosystem to global scales do not specifically consider soil microbial activity and so fail to represent the 'reshuffling' effect[2]. This raises concerns about the accuracy and certainty of the soil carbon projections derived from these models. Mounting evidence suggests that plants and soil microbes respond in unexpected ways to a variety of perturbations such as changing climate, land use and nitrogen load. For example, increased concentrations of CO_2 in the atmosphere change how and where plants use carbon for growth[3]. In many ecosystems, carbon–nitrogen interactions modulate plant and soil responses under increased CO_2 (ref. 4). These interactions directly influence soil microbial activity in ways that could attenuate potential gains in terrestrial carbon storage in a CO_2-rich world[5]. By omitting these insights, current models potentially misrepresent critical changes in the largest terrestrial carbon pool on Earth.

The work presented by Sulman and colleagues[1], therefore, marks an important development that could help to advance our understanding of the mechanisms that influence soil functioning. Their new model, Carbon, Organisms, Rhizosphere, and Protection in the Soil Environment (CORPSE), explicitly considers interactions between soil microbial activity and the physical soil environment. Microbial activity is simulated for bulk soil and for soil near fine roots, referred to as the rhizosphere (Fig. 1). Rhizosphere soils are characterized by accelerated microbial activity because they receive additional inputs of easily decomposed carbon supplied by fine roots. Experimental

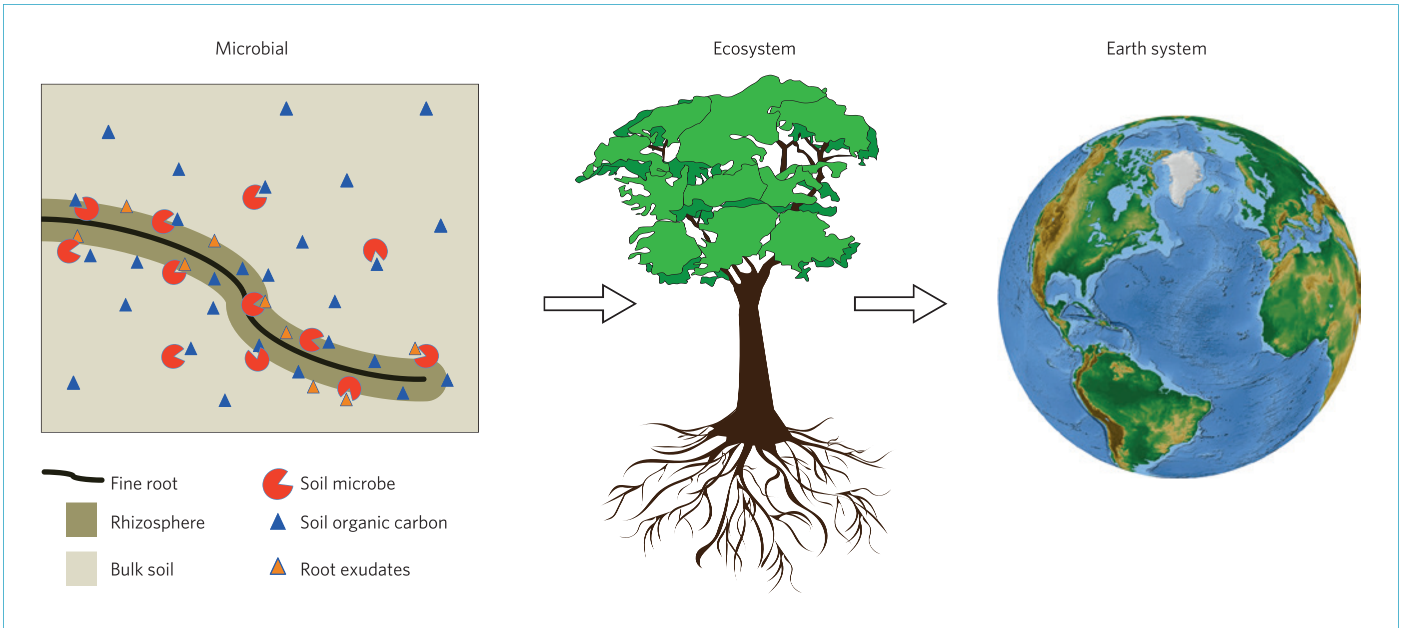

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Figure 1 | Conceptual representation of the processes simulated by the CORPSE model. This model explicitly considers the microbial decomposition of soil organic matter in bulk and rhizosphere soils (near fine root surfaces). Additional inputs of easily decomposed carbon supplied by fine roots accelerate microbial activity and rates of biogeochemical cycling, processes that take place at microbial scales ($<10^{-3}$ m). At ecosystem scales (~1 to 10^6 m^2), increased concentrations of atmospheric CO_2 have been experimentally shown to effectively increase the volume of soils under rhizosphere influence. These insights have now been applied in a land surface model that runs at global scales (grid cell area $>10^{10}$ m^2).

work demonstrates that increased CO_2 increases the volume of rhizosphere soils, thus accelerating the decomposition of soil organic matter[6]. Evaluation of the applicability of these findings is necessary to quantify the broader importance of rhizosphere dynamics across systems, but they present tantalizing new insight into unexplored aspects of the terrestrial carbon cycle.

By applying this understanding of rhizosphere dynamics in a process-based model, CORPSE effectively matches divergent soil carbon responses at two CO_2 enrichment studies[1]. Simpler models that do not consider microbial activity or rhizosphere dynamics could potentially match these results[5], but in ways that do not advance our mechanistic understanding of the processes driving observed ecosystem responses. Insights from CORPSE generate testable hypotheses that can guide experimental work, motivate further model development, and illustrate the value in improving the mechanistic representation in models at multiple scales of interest.

When compared with models that implicitly represent biological activity, those models that incorporate microbial activity make divergent projections about the fate of soil carbon in a changing world. Specifically, when integrated into a global land surface model, CORPSE suggests that accelerated decomposition from rhizosphere expansion provides a significant flux of CO_2 to the atmosphere thereby reducing the strength of the terrestrial carbon sink[1]. Parameter values that generate these results were generated from laboratory incubations and evaluated at two experimental field sites. This level of model validation meets or exceeds the level of scrutiny applied to many global soil biogeochemical models. However greater effort to understand and evaluate the assumptions, strengths and failings of different soil biogeochemical models is necessary to advance our theoretical understanding of soil processes at multiple scales (Fig. 1).

In the real world, ecosystem responses to increased CO_2 are driven by carbon–nitrogen interactions. Currently, ecosystem models are hard-pressed to match experimental results from CO_2-enrichment studies[7]. However, the magnitude of the terrestrial carbon response to increased CO_2 is likely to depend on a myriad of plant–soil feedbacks. Advancements on multiple fronts, however, offer promising inroads into some key uncertainties. For example, new datasets and modelling tools are becoming available online that provide insight into variation in plant carbon allocation strategies, especially fine root production and symbiotic relationships with certain types of fungus[8,9]. A better understanding of plant and microbial functional traits can facilitate the characterization of biotic influence on ecosystem function[10,11]. Applying these insights to models can advance our mechanistic understanding and hopefully improve the accuracy of terrestrial carbon projections. Work presented by Sulman *et al.*[1] marks an important step towards achieving this goal. ❒

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