LINK TO ORIGINAL ARTICLE
LINK TO AUTHORS' REPLY 1
LINK TO AUTHOR'S REPLY 2

Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy

Chao Liang and Teri C. Balser

In their recent article (Microbial production of recalcitrant dissolved organic matter: long-term carbon storage in the global ocean. *Nature Rev. Microbiol.* **8**, 593–599 (2010)), Jiao *et al.*[1] propose a conceptual framework — the microbial carbon pump (MCP) — to address the processes and mechanisms involved in the generation of the recalcitrant organic matter that is stored for millennia in the ocean. The MCP provides a formalized focus for understanding the role of microbial processes in the production of recalcitrant organic matter in marine systems, and it also stresses the proposition that the part that the ocean plays in global climate change is largely driven by microorganisms. This nevertheless draws attention to microbial production of recalcitrant organic matter in global terrestrial systems, which cover about 30% of the Earth's surface, as another major global carbon pool.

Studies of carbon bio-sequestration in both oceanic and terrestrial systems have dramatically increased owing to growing interest in understanding the global carbon cycle as it pertains to climate change[2]. Consequently, much impressive research has shown microbial carbon stabilization in oceans[1,3–6], but somewhat less effort has focused on soils, particularly regarding microbial biomass incorporation into the soil recalcitrant carbon pool, which nevertheless lies at the root of two issues of global concern — maintaining agricultural productivity and controlling atmospheric carbon dioxide levels.

Even currently, microbial contributions to long-lived soil carbon pools are often regarded as low to negligible, because the carbon in living microbial biomass is less than 4% of soil organic carbon[7,8]. However, microorganisms add to soil carbon in a continuously iterative process of cell generation, population growth and death. "The inability to sum up the effects of a continually recurrent cause has often retarded the progress of science." (REF. 9.) In recent years there has been a greater recognition that microbial necromass may dominate inputs into those soil organic matter pools that have longer turnover times[10–14]. Thus, in spite of severe ignorance about this microbial carbon sequestration and the lack of a meaningful way to measure the magnitude of this very large pool of dead microorganisms, understanding the microbial role in soil carbon stabilization will undoubtedly advance the current state of knowledge of global carbon-cycling models.

The recent novel conceptual model using Absorbing Markov Chains represents a first step in attempting to quantify the flow of carbon through microbial pathways in terrestrial systems[15]. Based on rough data in an ideal scenario, the model simulation suggests that the size of the microbial necromass carbon pool could be about 40 times that of the living microbial biomass carbon pool in soils. Assuming microbial living biomass carbon is 2% of the total soil organic carbon, carbon in the necromass would account for 80% of the organic carbon in soil. Considering that the model parameters were generated from divergent sources under condition-specific studies, an accurate estimation of the properties and dynamics of the soil microbial necromass depends on additional research. We are eager to provoke increased discussions and inspire new studies related to the role of microbial necromass in soil carbon stabilization.

Chao Liang and Teri C. Balser are at the US Department of Energy Great Lakes Bioenergy Research Center, 1550 Linden Drive, Madison, Wisconsin 53706, USA, and the Department of Soil Science, University of Wisconsin–Madison, 1525 Observatory Drive, Madison, Wisconsin 53706, USA.

Correspondence to C.L.
e-mail: chaoliang@wisc.edu

1. Jiao, N. *et al.* Microbial production of recalcitrant dissolved organic matter: long-term carbon storage in the global ocean. *Nature Rev. Microbiol.* **8**, 593–599 (2010).
2. US Department of Energy. Carbon cycling and biosequestration: integrating biology and climate through systems science. Report from the March 2008 workshop. *US Department of Energy Office of Science* [online], http://genomicscience.energy.gov/carboncycle/ (2008).
3. McCarthy, M. D., Hedges, J. I. & Benner, R. Major bacterial contribution to marine dissolved organic nitrogen. *Science* **281**, 231–234 (1998).
4. Ogawa, H., Amagai, Y., Koike, I., Kaiser, K. & Benner, R. Production of refractory dissolved organic matter by bacteria. *Science* **292**, 917–920 (2001).
5. Tremblay, L. & Benner, R. Microbial contributions to N-immobilization and organic matter preservation in decaying plant detritus. *Geochim. Cosmochim. Acta* **70**, 133–146 (2006).
6. Hedges, J. I. *et al.* Evidence for non-selective preservation of organic matter in sinking marine particles. *Nature* **409**, 801–804 (2001).
7. Anderson, T.-H. & Joergensen, R. G. Relationship between SIR and FE estimates of microbial biomass carbon in deciduous forest soils at different pH. *Soil Biol. Biochem.* **29**, 1033–1042 (1997).
8. Sparling, G. P. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Aus. J. Soil Res.* **30**, 195–207 (1992).
9. Darwin, C. *The Formation of Vegetable Mould Through the Action of Worms With Observations on their Habits* (Murray, London, 1881).
10. Kiem, R. & Kogel-Knabner, I. Contribution of lignin and polysaccharides to the refractory carbon pool in carbon-depleted arable soils. *Soil Biol. Biochem.* **35**, 101–118 (2003).
11. Kindler, R., Miltner, A., Richnow, H.-H. & Kastner, M. Fate of gram-negative bacterial biomass in soil-mineralization and contribution to SOM. *Soil Biol. Biochem.* **38**, 2860–2870 (2006).
12. Liang, C. & Balser, T. C. Preferential sequestration of microbial carbon in subsoils of a glacial-landscape toposequence, Dane County, WI, USA. *Geoderma* **148**, 113–119 (2008).
13. Potthoff, M., Dyckmans, J., Flessa, H., Beese, F. & Joergensen, R. Decomposition of maize residues after manipulation of colonization and its contribution to the soil microbial biomass. *Biol. Fertil. Soils* **44**, 891–895 (2008).
14. Simpson, A. J., Simpson, M. J., Smith, E. & Kelleher, B. P. Microbially derived inputs to soil organic matter: are current estimates too low? *Environ. Sci. Technol.* **41**, 8070–8076 (2007).
15. Liang, C, Cheng, G., Wixon, D. & Balser, T. An Absorbing Markov Chain approach to understanding the microbial role in soil carbon stabilization. *Biogeochemistry* 17 Sep 2010 (doi:10.1007/s10533-010-9525-3).

Competing interests statement
The authors declare no competing financial interests.