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RESPONSE

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Refining stoichiometric approaches to trace soil organic matter sources

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KEYWORDS
meta-analysis, mineral-associated organic matter, particulate organic matter, plant carbon, soil carbon, soil organic matter dynamics

We appreciate the kind words and thoughtful comments by Liu and Chen (2024) regarding our recent stoichiometric approach to assess plant and microbial contributions to mineral-associated organic matter (MAOM; Chang et al., 2024). We support Liu & Chen's idea to build on our approach and develop a Bayesian framework that incorporates more nuanced variations in the stoichiometry of different contributions to the MAOM pool.

We offer two points of clarification. Firstly, Liu and Chen (2024) suggest that our use of particulate organic matter (POM) as a single plant source of MAOM ignores the role of plant-derived dissolved organic matter (DOM) that contributes to MAOM through direct adsorption. We fully agree that it is important to consider another type of organic matter, especially one commonly neglected by most fractionation procedures. We did test the sensitivity of our approach to the inclusion of plant DOM in MAOM and our main findings were robust (see Figure S3 in our original paper), though more data would certainly help to further constrain the role of DOM.

Secondly, Liu and Chen (2024) highlighted the use of a constant C/N in our model, arguing that C/N ratios for plant litter and microbial sources vary over time. Plant litter C/N ratios do change during decomposition. However, we used POM (not fresh plant litter) as the end-member for the plant contribution to MAOM because plant litter mostly passes through POM prior to forming MAOM (Cotrufo & Lavallee, 2022). Accordingly, using litter as the end-member would overestimate the C/N of plant source in MAOM and finally underestimate plant contribution to MAOM. We are not aware of studies showing substantial temporal variation in the C/N ratio of POM. Moreover, soil microbial biomass C/N generally remains relatively stable due to stoichiometric homeostasis (Cleveland & Liptzin, 2007; Spohn, 2016).

Although we estimated average microbial contributions to MAOM of 34–47%, this does not suggest that microbial contributions to MAOM are universally lower than plant contributions. Indeed, microbial and plant contributions depend on ecosystem types, soil properties, and climate factors (Figure 1). Microbial contribution increased with soil depth, clay content, and mean annual temperature and precipitation. Moreover, grassland soils had a lower microbial contribution to MAOM than forest or cropland soils (Figure 1).

This article is a Response to a Letter to the Editor by Liu and Chen, https://doi.org/10.1111/gcb.17384 regarding Chang et al, https://doi.org/10.1111/gcb.17092.

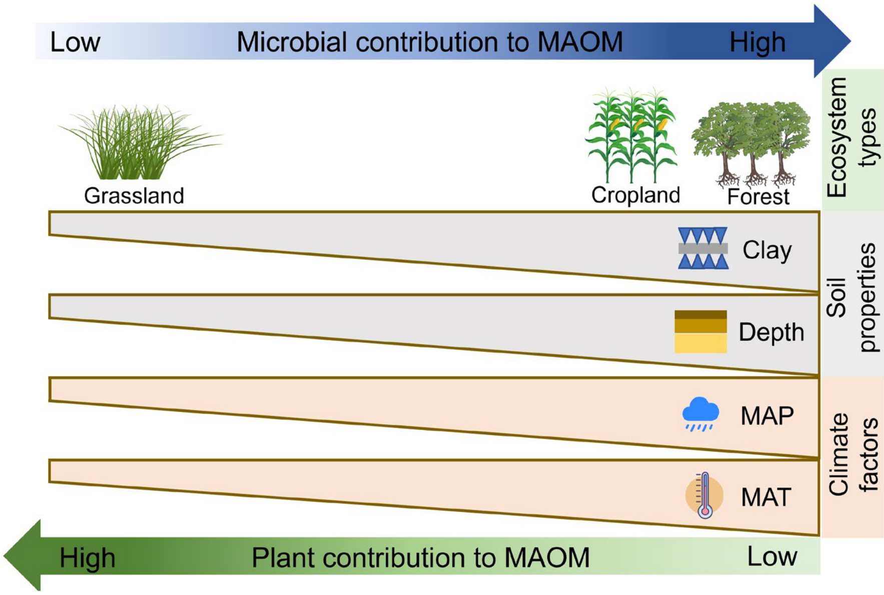

FIGURE 1 Plant and microbial contributions to MAOM depend on ecosystem types, soil properties, and climate factors. The dependences were modified on figures 4 and 5 in Chang et al. (2024); MAP, mean annual precipitation; MAT, mean annual temperature.

As research on this topic advances, we must stay aware of methodological benefits and limitations of each approach, and further develop and compare multiple methods to develop a clearer picture of where and to what extent MAOM is formed from direct vs. indirect (via the microbial funnel) plant inputs. Liu and Chen (2024) contribute ideas that may help t refine the ecological stoichiometry approach we introduce, and we look forward to seeing them tested.

AUTHOR CONTRIBUTIONS

Yi Chang: Visualization; writing – original draft. **Dechang Ji:** Visualization; writing – review and editing. **Noah W. Sokol:** Writing – review and editing. **Kees Jan van Groenigen:** Writing – review and editing. **Mark A. Bradford:** Writing – review and editing. **Thomas W. Crowther:** Writing – review and editing. **Chao Liang:** Writing – review and editing. **Yiqi Luo:** Writing – review and editing. **Yakov Kuzyakov:** Visualization; writing – review and editing. **Jingkuan Wang:** Supervision. **Fan Ding: Conceptualization;** Visualization; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable—no new data were generated.

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REFERENCES

Chang, Y., Sokol, N. W., van Groenigen, K. J., Bradford, M. A., Ji, D., Crowther, T. W., Liang, C., Luo, Y., Kuzyakov, Y., Wang, J., & Ding, F. (2024). A stoichiometric approach to estimate sources of mineral-associated soil organic matter. *Global Change Biology*, *30*(1), e17092. https://doi.org/10.1111/gcb.17092

Cleveland, C. C., & Liptzin, D. (2007). C: N: P stoichiometry in soil: Is there a “Redfield ratio” for the microbial biomass? *Biogeochemistry*, *85*(3), 235–252. https://doi.org/10.1007/s10533-007-9132-0

Cotrufo, M. F., & Lavallee, J. M. (2022). Soil organic matter formation, persistence, and functioning: A synthesis of current understanding to inform its conservation and regeneration. *Advances in Agronomy*, *172*, 1–66. https://doi.org/10.1016/bs.agron.2021.11.002

Liu, J., & Chen, J. (2024). Developing an ecological stoichiometry-based framework for tracing the sources of soil organic matter. *Global Change Biology*.

Spohn, M. (2016). Element cycling as driven by stoichiometric homeostasis of soil microorganisms. *Basic and Applied Ecology*, *17*(6), 471–478. https://doi.org/10.1016/j.baae.2016.05.003

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