PNAS LETTER

Reply to Lajtha and Silva: Agriculture and soil carbon persistence of grassland-derived Mollisols

Yichao Rui[a,b,1], Randall D. Jackson[c], M. Francesca Cotrufo[d], Gregg R. Sanford[c], Brian J. Spiesman[e], Leonardo Deiss[f], Steven W. Culman[f], Chao Liang[g], and Matthew D. Ruark[a]

We thank Lajtha and Silva (1) for raising important questions that advance the discussion of our paper (2). However, we disagree with their statement that "grazing cattle, well-managed or not, has no role in enhanced carbon sequestration."

1) Lajtha and Silva suggested a calorie-based soil C calculation, but we need actual carbon (C) sequestration and reductions in greenhouse gas emissions, not reductions relative to calories produced. Calorie-based calculations support the notion that we must produce more calories to "feed the world," a trope that has been thoroughly discredited (3). Currently, most North American Mollisols grow grains that are fed to cattle and other livestock in feedlots or used to create ethanol as a gasoline additive. Both have devastating socioecological consequences (4, 5).
2) Lajtha and Silva suggest restoring the land to natural vegetation. Mollisols developed under grazed and burned grasslands for thousands of years. Well-managed grazed pastures resemble, but are not identical to, bison-grazed tallgrass prairie of North America in many ways (6). By comparing a wide range of cropping systems typically grown on Mollisols, our findings (2) highlight the role of well-managed grazed pastures in the maintenance and restoration of intact grasslands that build soil, retain nutrients, and support biodiversity.
3) Lajtha and Silva argue that the impact of grazing on climate would be much higher than for crops due to methane and manure emissions and animal feed in winter. Life-cycle analyses in the north-central United States show that well-managed grazing systems not only can reduce emissions compared to feedlot systems but also can completely offset emissions from grazing cattle (7, 8). We focused on the changes in soil C in this paper and therefore did not calculate the C budget related to the animal feed in winter. Many graziers in the north-central United States feed their own grass hay to livestock during winter months by rolling out bales in their rotational fields, thereby returning much of the C and nutrients removed in harvest. If well-managed grazed grassland soils accumulate and store C at ∼1.6 $Mg \cdot ha^{-1} \cdot y^{-1}$, we could meet our current beef supply with net zero emissions (6).
4) Lajtha and Silva suggest that understanding of C persistence would require other methods such as radiocarbon dating. Indeed, soil C persistence is a state, not a property, and mounting evidence suggests that soil C persistence is governed by accessibility, not recalcitrance (9), and therefore studying C that is protected in mineral associations can suitably inform C persistence. There is also evidence that mineral-associated organic matter (MAOM) typically has older ^{14}C mean ages than unprotected particulate organic matter (POM) (10). The physical fractionation of soil organic matter (SOM) into POM and MAOM arguably introduces the least methodological artifact of other separation treatments (i.e., chemical) and therefore is a suitable method to study broad-scale SOM dynamics in the context of global change (11). We acknowledge its limitations (e.g., it does not quantify soil organic C occluded within aggregates or entrapped in soil pores, which could confer another level of persistence) and encourage other techniques to be developed and employed to study soil C persistence.

Author affiliations: [a]Department of Soil Science, University of Wisconsin–Madison, Madison, WI 53706; [b]Research Department, Rodale Institute, Kutztown, PA 19530; [c]Department of Agronomy, University of Wisconsin–Madison, Madison, WI 53706; [d]Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523; [e]Department of Entomology, Kansas State University, Manhattan, KS 66506; [f]School of Environment and Natural Resources, The Ohio State University, Wooster, OH 44691; and [g]Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China

Author contributions: Y.R., R.D.J., M.F.C., G.R.S., B.J.S., L.D., S.W.C., C.L., and M.D.R. wrote the paper.

The authors declare no competing interest.

[1]To whom correspondence may be addressed. Email: yichaorui@gmail.com.

Published July 6, 2022.

1. K. Lajtha, L. Silva, Grazing cattle, well-managed or not, is unlikely to increase soil carbon sequestration. *Proc. Natl. Acad. Sci. U.S.A.* **119**, 10.1073/pnas.2203408119 (2022).
2. Y. Rui *et al.*, Persistent soil carbon enhanced in Mollisols by well-managed grasslands but not annual grain or dairy forage cropping systems. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2118931119 (2022).
3. T. G. Benton, R. Bailey, The paradox of productivity: Agricultural productivity promotes food system inefficiency. *Glob. Sustain.* **2**, E6 (2019).
4. L. S. Prokopy *et al.*, The urgency of transforming the Midwestern U.S. landscape into more than corn and soybean. *Agric. Human Values* **37**, 537–539 (2020).
5. T. J. Lark *et al.*, Environmental outcomes of the US Renewable Fuel Standard. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2101084119 (2022).
6. R. D. Jackson, Grazed perennial grasslands can match current beef production while contributing to climate mitigation and adaptation. *Agric. Environ. Lett.* **7**, e20059 (2022).
7. J. E. Rowntree *et al.*, Potential mitigation of midwest grass-finished beef production emissions with soil carbon sequestration in the United States of America. Futur. Food J. Food. *Agric. Soc.* **4**, 31–38 (2016).
8. P. L. Stanley, J. E. Rowntree, D. K. Beede, M. S. DeLonge, M. W. Hamm, Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agric. Syst.* **162**, 249–258 (2018).
9. J. A. J. Dungait, D. W. Hopkins, A. S. Gregory, A. P. Whitmore, Soil organic matter turnover is governed by accessibility not recalcitrance. *Glob. Change Biol.* **18**, 1781–1796 (2012).
10. M. Schrumpf *et al.*, Storage and stability of organic carbon in soils as related to depth, occlusion within aggregates, and attachment to minerals. *Biogeosciences* **10**, 1675–1691 (2013).
11. J. M. Lavallee, J. L. Soong, M. F. Cotrufo, Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century *Glob. Chang. Biol.* **26**, 261–273 (2020).