LETTER

Soils can help mitigate CO_2 emissions, despite the challenges

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In their opinion piece, Amundson and Biardeau (1) argue that "values system opposition" between farmers and scientists complicates the use of soils as long-term carbon stores. They imply that storing carbon in agricultural soils is an unrealistic climate mitigation strategy. We agree that implementing restorative soil management practices across the world's >500 million active farms is a formidable challenge. But we fear that the authors are overly dismissive of the broader motivations for, and benefits of, building carbon in our soils. Furthermore, we assert that current agricultural practices are contingent upon, and will be shaped by, transitions in the global energy systems. Therefore, continued soil-restoration efforts may not only contribute to climate mitigation, but may also play a role in supporting energy transitions as well as climate adaptation.

Soil organic matter (SOM) content contributes to soil health and function by supporting crop performance and ecosystem services (2). Soils with higher SOM content tend to be more productive and more capable of retaining water (3); they are also inhabited by more diverse micro- and macrobiomes (4). Although farmers may not describe these processes using the same terminology as scientists, farmers in many locations have long leveraged practices that cultivate soil fertility, beneficial soil–plant–water processes, and intergenerational health of soils (5).

The soil security framework (6) recognizes soil as a primary resource for fundamental human endeavors, which goes beyond "climate-smart soils" (7). Humans are managing over 75% of the global land area, contributing to the decline in soil function in many regions (8). The soil security framework establishes the relationships among soil health, economic value, stakeholders, and environmental sensitivity. This framework draws from growing knowledge of soil systems to posit that practices that restore SOM add value to agricultural lands. This approach bridges social and biophysical sciences, highlighting the importance of policy and legal frameworks pertaining to soil use.

Contemporary farming practices rely on the heavy use of fertilizers, excessive soil tilling, and heavy machinery; these practices are detrimental to soil health and carbon storage, and entrain soil erosion, losses of SOM, and other externalities (9). Despite this, many programs still incentivize such practices. Instead, crop insurance and other programs could base their guarantees and rates on data that reflect soil health, such as SOM enrichment and aggregate stability (10). While federal and global institutions have incentivized energy-intensive agriculture, transformations of energy systems may greatly change this trend. Reducing the reliance on fossil fuel inputs now is important to facilitate broad energy transitions.

Focusing on soil security and actionable valuation of soil benefits such as SOM and carbon accumulation may accelerate soil-health-promoting practices, add economic value in terms of soil performance, maintain food security, and reduce energy needs in agriculture. Institutional obstacles to rapid, wide-scale implementation of altered soil management practices may currently prevent farm-based carbon sequestration as a global climate mitigation strategy, but it provides a framework for considering the variable ways that soil management bridges an array of concerns from the scale of the farm to the planet.

1 Amundson R, Biardeau L (2018) Opinion: Soil carbon sequestration is an elusive climate mitigation tool. *Proc Natl Acad Sci USA* 115:11652–11656.

2 Lal R (2004) Soil carbon sequestration to mitigate climate change. *Geoderma* 123:1–22.

3 Harden JW, et al. (2018) Networking our science to characterize the state, vulnerabilities, and management opportunities of soil organic matter. *Glob Change Biol* 24:e705–e718.

4 Jackson R, et al. (2017) The ecology of soil carbon: Pools, vulnerabilities, and biotic and abiotic controls. *Annu Rev Ecol Evol Syst* 48:419–445.

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5 Sandor JA, Homburg JA (2017) Anthropogenic soil change in ancient and traditional agricultural fields in arid to semiarid regions of the Americas. *J Ethnobiol* 37: 196–217.
6 McBratney R, Field DJ, Koch A (2014) The dimensions of soil security. *Geoderma* 213:203–213.
7 Paustian K, et al. (2016) Climate-smart soils. *Nature* 532:49–57.
8 Bouma J, McBratney R (2013) Framing soils as an actor when dealing with wicked environmental problems. *Geoderma* 200-201:130–139.
9 Montgomery DR (2017) *Growing a Revolution: Bringing Our Soil Back to Life* (W. W. Norton & Co., New York).
10 Woodward JD, Verteramo-Chiu L (2017) Efficiency impacts of utilizing soil data in the pricing of the federal crop insurance program. *Am J Agric Econ* 99:757–772.