Arrouays Dominique (Orcid ID: 0000-0002-6878-6498) Cardinael Remi (Orcid ID: 0000-0002-9924-3269) Farrell Mark (Orcid ID: 0000-0003-4562-2738) Minasny Budiman (Orcid ID: 0000-0002-1182-2371) Recous Sylvie (Orcid ID: 0000-0003-4845-7811)

Opinion

A well-established fact: rapid mineralization of organic inputs is an important factor for soil carbon sequestration.

Comment on "Soil carbon sequestration for climate change mitigation: Mineralization kinetics of organic inputs as an overlooked limitation"

Denis Angers¹, Dominique Arrouays², Rémi Cardinael^{3,4,5}, Claire Chenu⁶, Marc Corbeels^{3,7}, Julien Demenois^{3, 8,9}, Mark Farrell¹⁰, Manuel Martin², Budiman Minasny¹¹, Sylvie Recous¹² & Johan Six¹³

- 1. Agriculture and Agri-Food Canada and Université Laval, Québec, Canada
- 2. INRAE, InfoSol, 45075, Orléans, France
- 3. AIDA, Univ Montpellier, CIRAD, Montpellier, France
- 4. CIRAD, UPR AIDA, Harare, Zimbabwe

Department of Plant Production Sciences and Technologies, University of Zimbabwe,
Harare, Zimbabwe

6. Université Paris-Saclay, INRAE, AgroParisTech, 78850 Thiverval Grignon, France

- 7. International Institute of Tropical Agriculture (IITA), Duduville Campus, P.O. Box 30772-
- 00100, Kasarani, Nairobi, Kenya
- 8. CIRAD, UPR AIDA, Turrialba 30501, Costa Rica

9. CATIE, Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba 30501, Costa Rica

10. CSIRO Agriculture & Food, Kaurna Country, Locked Bag 2, Glen Osmond, SA 5064,

Australia

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11. School of Life and Environmental Sciences, The University of Sydney, NSW 2006, Australia

12. Université de Reims Champagne Ardenne, INRAE, FARE, UMR A 614, 51100 Reims, France.

13. Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland

Corresponding author: dominique.arrouays@inrae.fr

Abstract

We have read with interest an opinion paper recently published in the European Journal of Soil Science (Berthelin et al., 2022). This paper presents some interesting considerations, at least one of which is already well known to soil scientists working on soil organic carbon (SOC), i.e. a large portion (80-90%) of fresh carbon inputs to soil is subject to rapid mineralization. The short-term mineralization kinetics of organic inputs are well-known and accounted for in soil organic matter models. Thus, clearly, the long-term predictions based on these models do not overlook short-term mineralization. We point out that many agronomic practices can significantly contribute to SOC sequestration. If conducted responsibly whilst fully recognizing the caveats, SOC sequestration can lead to a win-win situation where agriculture can both contribute to the mitigation of climate change and adapt to it, whilst at the same time delivering other co-benefits such as reduced soil erosion and enhanced biodiversity.

Key words: soil, carbon sequestration, mineralization, climate change

Highlights

- Rapid mineralization of organic inputs is an important factor for soil carbon sequestration

- Mineralization kinetics of organic inputs are well-known and accounted for in soil organic matter models

- Many agronomic practices can significantly contribute to SOC sequestration

- SOC sequestration can lead to a win-win situation where agriculture can both contribute to the mitigation of climate change and adapt to it

Introduction

We have read with interest "Soil carbon sequestration for climate change mitigation: Mineralization kinetics of organic inputs as an overlooked limitation" recently published in the European Journal of Soil Science (Berthelin et al., 2022). This paper presents some interesting considerations, at least one of which is already well known to soil scientists working on soil organic carbon (SOC), i.e. a large portion (80-90%) of fresh carbon inputs to soil is subject to rapid mineralization. Here we argue that rapid mineralization of organic inputs is an important factor for soil carbon sequestration, and that agronomic practices to increase soil organic C do exist.

Rapid mineralization of organic inputs is not overlooked

In brief, after a short review, mainly citing papers that question or criticize the potential of soils to sequester CO₂ to mitigate climate change, Berthelin et al. (2022) claim that, for the "very first time", they "analyze in detail" the short-term mineralization kinetics of fresh organic inputs added to soils, which according to them "is occasionally alluded to in the literature, but almost always subsumed in a broader modelling context". However, the authors simply put on the table a fact that has been known for nearly a century, that is, all organic carbon (C) added to the soil is subject to mineralization and is not entirely stabilized or sequestered into the soil, just a small fraction of it is. Clearly, this is not a "blind spot" or "untold story" as the authors write. In fact, the mineralization kinetics of organic inputs have been described and quantified since as far back as the pioneer work of Hénin & Dupuis (1945). There are numerous long-term field

experiments under various environments (e.g., Thomsen and Christensen, 2004; Kong et al., 2005; Fujisaki et al., 2018; Cardinael et al., 2022) and field-isotope studies (e.g., Voroney et al., 1989; Aita et al., 1997), which show that crop residues decompose quickly in soil and that conversion of organic C inputs to SOC are in the range of 10%. The short-term mineralization kinetics of organic inputs are well-known and accounted for in soil organic matter models. Decomposition of added organic material is typically represented by two or more organic matter pools. These are defined as rapidly and slowly decomposing plant fractions, with exponent ial decay rate constants varying between 35 and 0.6 yr⁻¹, depending on the pool and model. First-order kinetics are used, with C flows from those pools to microbial biomass and recalcitrant soil organic matter pools with concomitant production of CO₂ (Corbeels, 2001). The partitioning of C between microbial biosynthesis and mineralization is generally driven by the C-use efficiency ratio (e.g., Manzoni et al., 2018). Thus, clearly, the long-term predictions based on these models do not overlook short-term mineralization.

The authors also point out that "perpetually hungry microorganisms" will lead to an inexorable release of CO₂ in the atmosphere. This is of course absolutely true and is actually recognized as a fundamental process of SOC stabilization. Microorganisms have a high turnover rate in soil and generate large amounts of organic molecules and necromass that can contribute to the stable SOC fraction (e.g. Six et al., 2006; Liang et al., 2019). This is now a well-established pathway of SOC formation and stabilization (e.g., Cotrufo et al., 2013; Kallenbach et al., 2016; Sokol et al., 2022).

Agronomic practices to increase soil organic C

Berthelin et al. (2022) emphasize the role that organic inputs can play in storing additional SOC. The impact of crop residue retention on SOC is generally positive but indeed variable depending on soil, climate, and agronomic contexts (e.g., review by Bolinder et al., 2020). Many other agronomic practices (e.g., reviews by Paustian et al., 2016, Chenu et al., 2019) can significantly contribute to SOC sequestration. For instance, a global meta-analysis showed that cover crops increased SOC storage by an average of $0.32 \text{ Mg C} \text{ ha}^{-1} \text{ yr}^{-1}$ (Poeplau and Don, 2015). This is roughly equivalent to 0.6 % per year for a soil initially at 50 Mg C ha⁻¹ until a new equilibrium is reached within a few decades. There are also examples showing that combining cover crops and no-tillage, without exogenous organic inputs, can result in even much larger SOC sequestration rates, e.g., in Southern Brazil (Veloso et al., 2018) or in France (Autret et al., 2016). Other practices or systems that can improve SOC levels include agroforestry systems (Cardinael et al., 2018; Corbeels et al., 2019; Mayer et al., 2022), the addition of available exogenous organic matter that would otherwise not be applied to soil (Maillard and Angers, 2014; Bruni et al., 2022), and finally, the removal of soil constraints that result in increased crop productivity and thus C inputs from the crop itself, including roots (Emde et al., 2021; Ladha et al., 2011). Obviously, the impact of these management practices on other greenhouse gas emissions (particularly N₂O) has to be carefully accounted for.

Implementing SOC sequestering practices at scale large enough that significant atmospheric CO₂ removals are achieved can be challenging but is possible. An example is provided in the semi-arid Canadian Prairies where the elimination of summer fallow and the implementation of no-till practices result in significant SOC sequestration (VandenBygaart et al. 2008; Liang et al., 2021). Their combined implementation at large scale (tens of millions of hectares) over the past several decades has resulted in large quantities of additional C stored in soils. For example, for the year 2018, the increase in no-till and the decrease in summer fallow resulted in approx. 12 Mt CO₂eq removal in soils (Environment and Climate Change Canada, 2021). This is significant relative to approx. 20 Mt CO₂eq emissions of N₂O from soils (application of

inorganic and inorganic fertilizers, and crop residue decomposition) during the same year (Environment and Climate Change Canada, 2021). Another example of large scale C sequestration is in China (Zhao et al., 2018).

We fully agree with Berthelin et al. (2022) when they write: "it is not reasonable to ask of soil carbon sequestration to compensate all of the greenhouse gas emissions of other anthropogenic sectors" and "one should also ensure that soils will be sufficiently resilient to adapt to a rapidly changing climate in the near future, and still be able to fulfill their essential functions, on which humanity depends crucially". Yet, we think it is important to add here that increasing SOC and enhancing resilience to climate change are crucial to minimize the negative feedback effect of climate change on net primary production and on resulting C inputs to soils (Lal, 2016; IPCC, 2019). This is especially the case for the most degraded soils of the planet or soils that are "at risk" (e.g., Mediterranean soils, arid soils, and several soils in sub-Saharan Africa) for which urgent actions need to be taken to ensure food security (IPCC, 2019). These degraded soils are also plausibly the ones where appropriate interventions bring most SOC gains, with steep increments from low initial levels.

Conclusions

Finally, although we also agree that policymakers "should focus on other possible avenues to halt climate change, like transitioning promptly to renewable forms of energy", it is unreasonable to suggest that "SOC sequestration in soils to mitigate climate change is off the table". The great majority of papers about the potential of SOC sequestration do not consider it as a "silver bullet", which will alone solve the current climate crisis. Fossil fuels are the main source of GHGs and climate change. The absolute priority should be to reduce greenhouse gas

emissions from all sectors, including agriculture, and that includes preventing further losses from already C-rich soils. Equally important is to restore the SOC in our croplands. Even in a decarbonized world, some residual emissions will remain, and negative emissions technologies to remove CO₂ from the atmosphere will be needed to reach net zero emissions by 2050 to meet the goal set in the Paris Agreement (Minx et al., 2018). As with many other land-based solutions, SOC can contribute to the partial and temporary mitigation of anthropogenic emissions (IPCC, 2019), and all practical possibilities to partially slow down the effects of climate change should be considered. If conducted responsibly whilst fully recognizing the caveats, SOC sequestration can lead to a win-win situation where agriculture can both contribute to the mitigation of climate change and adapt to it, whilst at the same time delivering other co-benefits such as reduced soil erosion and enhanced biodiversity. We should not miss this opportunity.

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Conflict of interest

Mark Farrell is Deputy Editor of the European Journal of Soil Science. He played no part in the handling or review of this Opinion.

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