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

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OPINION

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

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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), that is, a large portion (80%–90%) of fresh carbon inputs to soil is subject to rapid mineralization. The short-term mineralization kinetics of organic inputs is 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 recognising 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

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

same time delivering other co-benefits such as reduced soil erosion and enhanced biodiversity.

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 contribute significantly 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.

KEYWORDS

carbon sequestration, climate change, mineralization, soil

1 | 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), that is, 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 SOC do exist.

2 | RAPID MINERALIZATION OF ORGANIC INPUTS IS NOT OVERLOOKED

In brief, after a short review, mainly citing papers that question or criticise the potential of soils to sequester CO_2 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 stabilised 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 as far back as the pioneer work of Hénin and Dupuis (1945). There are numerous long-term field experiments under various environments (e.g., Cardinael et al., 2022; Fujisaki et al., 2018; Kong et al., 2005; Thomsen & Christensen, 2004) and field-isotope studies (e.g., Aita et al., 1997; Voroney et al., 1989), which show that crop residues decompose quickly in soil and that conversion of organic C inputs to SOC is in the range of 10%. The short-term mineralization kinetics of organic inputs is 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 exponential decay rate constants varying between 35 and 0.6 yr^{-1}, depending on the pool and model. First-order kinetics is used, with C flows from those pools to microbial biomass and recalcitrant soil organic matter pools with concomitant production of CO_2 (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 CO_2 to the atmosphere. This is, of course, absolutely true and is actually recognised as a fundamental process of SOC stabilisation. 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. Liang et al., 2019; Six et al., 2006). This is now a well-established pathway of SOC formation and stabilisation (e.g., Cotrufo et al., 2013; Kallenbach et al., 2016; Sokol et al., 2022).

3 | AGRONOMIC PRACTICES TO INCREASE SOIL ORGANIC CARBON

Berthelin et al. (2022) emphasise 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 Mg C ha^{-1} yr^{-1} (Poeplau & 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, for example, 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 (Bruni et al., 2022; Maillard & Angers, 2014), 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 N_2O) has to be carefully accounted for.

Implementing SOC sequestering practices at a scale large enough that significant atmospheric CO_2 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 (Liang et al., 2020; VandenBygaart et al., 2008). Their combined implementation at a 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 CO_2eq removals in soils (Environment and Climate Change Canada, 2021). This is significant relative to approx. 20 Mt CO_2eq emissions of N_2O from soils (application of inorganic and inorganic fertilisers, 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 is crucial to minimise the negative feedback effect of climate change on net primary production and on resulting C inputs to soils (IPCC, 2019; Lal, 2016). 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 the most SOC gains, with steep increments from low initial levels.

4 | 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 greenhouse gases 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 CO_2 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 recognising 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 a Deputy Editor of the European Journal of Soil Science. He played no part in the handling or review of this Opinion.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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