

COMMENTARY

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The misconception of soil organic carbon sequestration notion: When do we achieve climate benefit?

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Abstract

Soil organic carbon (SOC) sequestration is a key function of natural and semi-natural ecosystems. Restoring this property in terrestrial ecosystems has become central to the EU's climate change mitigation and adaptation strategies. However, SOC sequestration is a widely misunderstood concept. The different methodological approaches used to investigate and compare SOC stock under sustainable agricultural practices play a key role in reinforcing misconceptions about this complex process. This commentary paper aimed not only to provide a clear definition of SOC sequestration, but also to interpret the results that can be obtained for SOC stock change estimation using the SOC stock difference and the paired comparison methods, as well as to identify the soil carbon-related processes that achieve climate mitigation. SOC sequestration can be defined as the progressive increase in a site's SOC stock compared with pre-intervention via a net depletion and transfer of atmospheric CO₂ into the soil, where it is retained as soil organic matter (SOM), by plants, plant residues, or other organic solids such as the material derived from the organic fraction of farming solid waste, which can be used as a fertilizer (e.g., manure, compost, biochar, and digestate), and that is produced or derived from that land unit. To date, the most appropriate way to determine whether a land unit's soil is a sink or rather a source of atmospheric CO₂ is to implement the SOC stock difference method, provided the non-occurrence of carbon exchange between ecosystems.

KEYWORDS

climate change mitigation, paired comparison method, sink of atmospheric CO₂, soil organic carbon sequestration, stock difference method

1 | INTRODUCTION

Soil organic carbon (SOC) sequestration has received increased attention worldwide as a possible strategy for

climate change mitigation (FAO, 2019; IPCC, 2019), in light of the fact that soil represents the largest terrestrial carbon pool (Scharlemann et al., 2014). In this paper, we mainly focus on agro-ecosystems since agricultural soil

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has been progressively depleted of its SOC content and thus acts as a net CO₂ source. Therefore, sustainable soil management practices have a large potential to bridge the gap between food provisioning and climate regulation (Sanderman et al., 2017). Particularly, SOC sequestration entails a net removal of atmospheric CO₂ through plant photosynthesis and carbon (C) storage in the soil ecosystem in the form of SOC (Lal, 2004). Net atmospheric CO₂ removal implies a positive difference between the C retained in the soil and the C released from soil heterotrophic respiration. In spite of the fact that most authors agree with this definition, the reported SOC sequestration results usually reflect only reduced SOC losses or differences in SOC stock between paired plots and rarely net SOC sequestration (Olson et al., 2014a, 2014b; Sanderman & Baldock, 2010; Seidel et al., 2023). As already pointed out by several studies (Lal et al., 2015; Lorenz & Lal, 2014; Olson, 2013; Olson et al., 2014a, 2014b, 2016, 2017, Olson & Al-Kaisi, 2015; Powlson et al., 2011; Sanderman & Baldock, 2010; Seidel et al., 2023), the concept of SOC sequestration is widely misunderstood, and this controversy is deeply rooted in the SOC investigation methodology implemented. In fact, considering that direct measurement of CO₂ fluxes between soil and the atmosphere requires sophisticated and expensive technologies (e.g., continuous soil chamber measurements), usually the most used methodology for net SOC sequestration estimation involves soil sampling and SOC stock change measurement (Paustian et al., 2019). The *stock difference method* is the most accepted methodology (IPCC, 2006), by means of which net SOC sequestration is assumed to correspond to the increase in SOC stock observed after the measurements are performed on the same plot at two different times. However, since the *stock difference method* requires time and long-term experiments, this approach is often replaced by the *paired comparison method* (Conteh, 1999; Davis et al., 2004), which compares SOC stock content of two experimental plots, with same site characteristics (soil type, slope, etc.), but with different managements or land cover types, at one point in time. In accordance with the latter method, SOC sequestration corresponds to the relative differences in SOC storage among the two investigated plots. The paired comparison method is also referred to as “space-for-time” (SFT) substitution since the follow-up C stock in the control plot is assumed to correspond to the pre-treatment SOC stock of the treatment plot, under the hypothesis that the SOC stock was in equilibrium state. Most misconceptions about SOC sequestration derive from this empirical assumption, as we are going to demonstrate. In short, while providing a theoretical background, the objectives of this work are (a) to clearly and unequivocally provide a definition of SOC sequestration together with other processes implicated

in carbon dynamics, which are often and erroneously referred to as SOC sequestration (e.g., reduction in soil CO₂ emissions, increase in SOC stock, and reduction in SOC stock losses); (b) to distinguish the two main methods for SOC stock change determination and clarify the interpretation of their respective results; and (c) to identify those soil C-related processes under which climate change mitigation is achieved.

2 | DISCUSSION

Anthropogenic agricultural activities interacting with soil-atmosphere C fluxes can be characterized according to different perspectives or approaches, answering different research questions: (i) a methodological perspective (e.g., what can be inferred from a methodological point of view?); (ii) an atmosphere-centric perspective (e.g., is the level of CO₂ increasing or decreasing?); and (iii) a soil-centric perspective (e.g., is the soil gaining or losing SOC?).

2.1 | Methodological perspective

In the scientific literature, the SOC stock change (ΔSOC Mg C ha⁻¹) for a given sustainable soil management (SSM) practice is experimentally determined by implementing either one of two different methodologies (Arevalo et al., 2009; Rytter & Rytter, 2020): (1) The SOC stock difference method (Eq. 1 below) and (2) The paired comparison method (Eq. 2 below).

$$\Delta\text{SOC} = (\text{SOC stock } t_1 - \text{SOC stock } t_0) \quad (1)$$

where, ΔSOC : SOC stock change, expressed in megagrams per hectare (Mg C ha⁻¹). SOC stock t_1 : *follow-up* C stock, that is, C stock measured after the experiment, expressed in megagrams per hectare (Mg C ha⁻¹); SOC stock t_0 : *baseline* C stock, that is, C stock measured before the experiment, expressed in megagrams per hectare (Mg C ha⁻¹).

$$\Delta\text{SOC} = \text{SOC stock tr } (t_1) - \text{SOC stock c } (t_1) \quad (2)$$

where, SOC stock tr (t_1): *follow-up* C stock for the treatment plot, that is, C stock measured after the experiment in the treatment plot, expressed in megagrams per hectare (Mg C ha⁻¹); SOC stock c (t_1): *follow-up* carbon stock for the control plot, that is, carbon stock measured after the experiment in the control plot, expressed in megagrams per hectare (Mg C ha⁻¹).

When comparing both methodologies to clarify the different effects of SSM practices on SOC stocks, different

results are obtained (Figure 1). Considering the two equations presented above, it is possible to note that positive ΔSOC values calculated using the “stock difference method” imply SOC pool gain by SSM at year 20, which is an absolute SOC stock increase over time compared with the stock at base period (t_0 ; year 0) (Figure 1a,b,d). In the case represented by Figure 1c, the same methodology shows an absolute decrease in SOC stock compared with the stock at baseline (t_0 ; year 0). In the paired comparison method, the business-as-usual (BAU) trend (blue line) corresponds to the control plot in the experimental design and ΔSOC is calculated as the difference at t_1 (year 20) between the stock in the treatment plot (SSM practices) and the control plot (BAU) of paired sites. Therefore, ΔSOC s represent a relative variation between managements, land uses, or cover types. By implementing paired comparison method, positive ΔSOC s emerge in all 4 cases (Figure 1a–d) even when the soil at t_1 results in a net SOC stock depletion compared with its initial content (t_0) as shown in case Figure 1c.

Therefore, in accordance with FAO (2022) we suggest referring to the ΔSOC calculated by implementing the “stock difference method” as “absolute SOC stock change” ($\Delta\text{SOC}_{\text{ABS}}$) while that calculated by implementing the “paired comparison method” as “relative SOC stock change” ($\Delta\text{SOC}_{\text{REL}}$), in order to avoid any misinterpretation.

From a positive ΔSOC value calculated using the “paired comparison method,” it is possible to infer only that the sustainable management is slowing SOC losses (Figure 1c) compared with the BAU trend, which is taken as a benchmark, unless there is evidence that the SOC stock in the BAU management maintained an equilibrium state during the experiment (e.g., neither losing nor gaining C, Figure 1a). In the other conditions (see “Figure 1b–d”), without the initial SOC level measurement, it is not possible to determine whether a positive $\Delta\text{SOC}_{\text{REL}}$ is connected to an increase in SOC stock or to a reduction in carbon losses. Moreover, for these scenarios the magnitude and the sign (positive or negative)

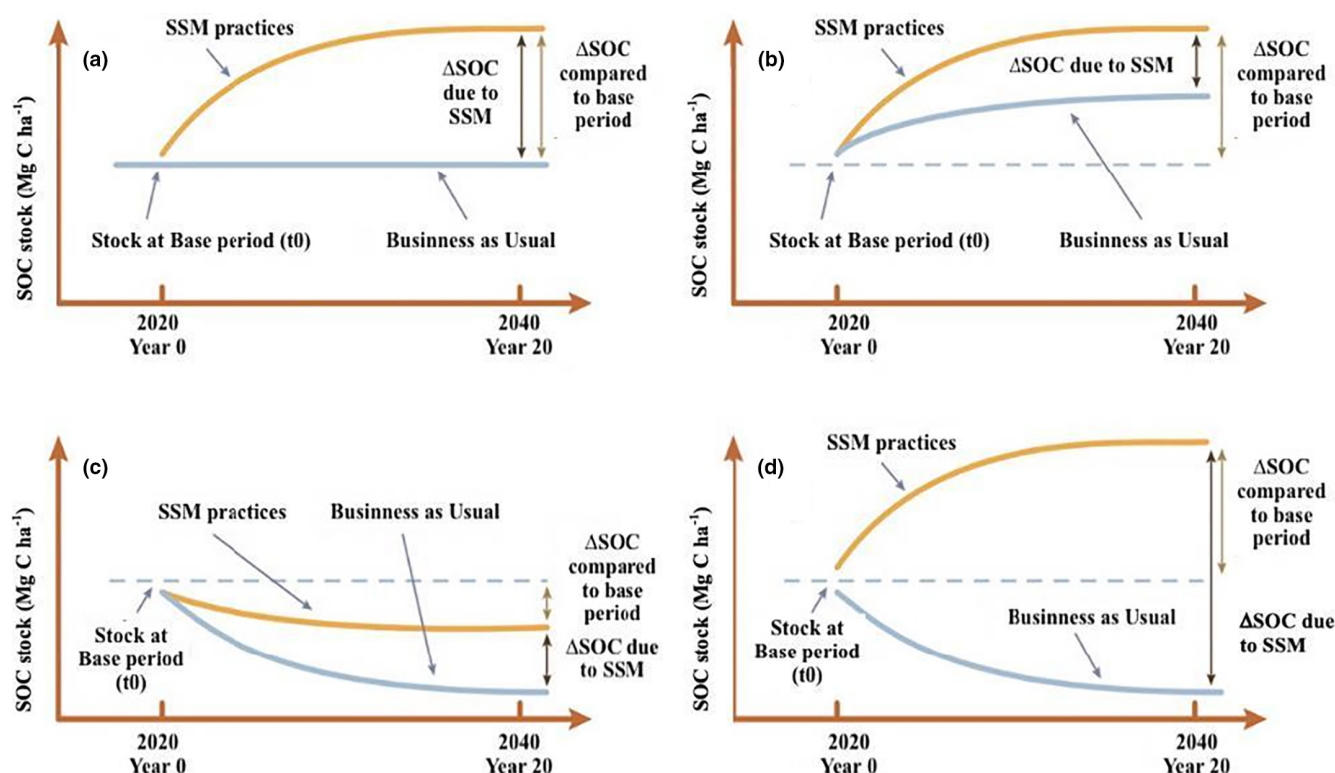


FIGURE 1 Soil organic carbon theoretical evolutions under business-as-usual (BAU) practices as compared to the adoption of sustainable soil management (SSM) practices. The x-axes represent time, expressed in years. The y-axes represent SOC stock, expressed as Mg C ha^{-1} . ΔSOC represents the variation in SOC stock content of a land unit induced by SSM after 20 years with respect to the baseline SOC stock content (according to the stock difference method) or the difference in SOC stock content at one point in time (year 20) between a treatment plot where SSM is applied and a control plot (according to the paired comparison method). Every graph represents a different scenario: (a) lands where SOC levels have reached equilibrium and it is possible to increase levels through SSM; (b) lands where SOC is increasing but can be further increased through SSM; (c) lands where SOC is decreasing and it is possible to stop or mitigate losses in SOC levels; or (d) even reverse such fall through SSM. Source: FAO, 2022. Global Soil Organic Carbon Sequestration Potential Map – GSOCseq v.1.1.1. Technical report. Rome. <https://doi.org/10.4060/cb9002en>

of relative SOC stock change differ from absolute SOC stock change.

Since scale measurements differ (i.e., absolute and relative), Δ SOC calculated by means of these two different methodologies cannot be assumed to be equivalent, unless the equivalence is appropriately verified through simultaneous implementation of both methodologies on the same experimental site. Moreover, the measured Δ SOC might not correspond to the net C removal from the atmosphere and storage into soil, therefore to SOC sequestration. In fact, Δ SOC_{REL} and Δ SOC_{ABS} are methodological-centred perspective definitions and do not explain the processes implicated in determining Δ SOC stocks. To identify these processes, we need to introduce other three terms linked to the atmosphere-centric perspective: *SOC sequestration*, *SOC accumulation*, and *soil CO₂ emission reduction*.

2.2 | Atmosphere-centric perspective

“SOC sequestration” has been defined by Olson (2013) and Olson et al. (2014b), as the “[...] process of transferring CO₂ from the atmosphere into the soil of a land unit through unit plants, plant residues and other organic solids, which are stored or retained in the unit as part of the Soil Organic Matter (SOM). [...] The sequestered SOC process should increase the net SOC storage during and at the end of a study to above the previous pre-treatment baseline.”

A land unit is an ecologically homogeneous tract of land (Zonneveld, 1989), whose dimensions and boundaries are set by the researcher with the aim of identifying a representative sample of the object of investigation. Therefore, it could be anything from an experimental plot, parcel, or field to a whole farmland or portion thereof or even a forest, pasture, or landscape (Olson, 2013).

In light of the above definition, for *SOC sequestration* to happen, the following conditions must be jointly satisfied:

1. There has been an increase in a land unit's SOC stock compared with pre-treatment levels;
2. Plants, plant residues, and other organic solids responsible for such increase derive from that same land unit;
3. A net reduction in atmospheric CO₂ is achieved, contributing to climate change mitigation.

Condition (A) excludes the paired comparison method as the increase in SOC using this method may result from a reduced emission (see Figure 1c,d), while condition (B) excludes the contribution of organic solids and plant residues produced out of the boundaries of

that land unit. Condition (C) instead excludes the reduction in soil CO₂ emissions from the definition of SOC sequestration, which, however, delivers climate change mitigation.

When condition A is satisfied, but B is not, the SOC stock increase mechanism should be termed “SOC accumulation.” In this case, there is no climate change mitigation benefit neither with *SOC sequestration* nor with *reduction in soil emissions*. In accordance with Lorenz and Lal (2014), Lal et al. (2015), and Powlson et al. (2008, 2011), although external organic C inputs might increase SOC stock over time, there is still no net C removal from the atmosphere but rather a transfer of organic C from one biogenic pool to another (Olson et al., 2014b). We propose the term *SOC accumulation* to describe absolute SOC stock increase linked to external C inputs not coupled with *SOC sequestration*. This often is linked to organic amendment (OA) application to a land unit, which delivers high quantities of C ultimately deriving from carbon fixation by plants grown out of that land unit boundaries. *SOC accumulation* is therefore the effect of a C exchange between production systems/land units rather than a SOC sequestration process. The definition of the land unit boundaries may change the results of the assessments: at the regional/national level, the application of OA produced within regional/national boundaries could be considered as *SOC sequestration*, while this could not be the case when the system boundaries are defined at the farm level and the OA is purchased on the market. On the contrary, OA delivers *SOC sequestration* when organic compounds are produced and applied within the same land unit while determining an increase in SOC stock. In the case of grazed pasture land, we advance the hypothesis that *SOC sequestration* is occurring: vegetation grown on that land unit is returned to that land unit in the form of fresh manure, after undergoing a process of digestion (e.g., bacterial/microbial) and transformation by gut microbiome. Moreover, in mixed farms, if animal feed and bedding materials (e.g., hay and straw) are produced within the farm boundaries and farmyard manure is applied and redistributed within farmland, we suggest that *SOC sequestration* is still occurring. The same criteria could be applied to compost, biochar, slurry, and anaerobic digestate: whatever the process plant biomass may undergo (pyrolysis, composting, and digestion), if its by-products are applied to the same land unit in which it grew, any increase in SOC stock should be recognized as *SOC sequestration*. Another case in which *SOC accumulation* occurs is when, through erosion and water runoff, SOC is transferred from a land unit to a depositional site out of that land unit. This phenomenon may alter SOC stock of both land units (e.g., eroded

fields lose SOC and depositional plots gain SOC) with no implications for climate change. In fact, SOC lost from eroded fields is not released into the atmosphere as CO₂, and SOC gained in depositional fields is not sequestered C, as it derives from another land unit (Olson et al., 2016). However, if eroded and depositional plots belong to the same land unit, the net SOC stock balance results unaltered, with no implications neither from a soil-centric perspective nor from an atmosphere-centric perspective. The latter phenomenon, which should be termed “horizontal redistribution within a land unit,” does not change the net SOC balance therein.

In contrast, the term “soil CO₂ emission reduction” should be used for reduced soil CO₂ emissions from SOC as consequence of sustainable management practices compared with a BAU scenario, when soil acts as source in both managements or when—in the best-case scenario—soil in SSM delivers zero net soil CO₂ emissions, although never transforming into a sink. Cases c and d in Figure 1 reflect soil CO₂ emission reduction through SSM compared with BAU. Soil CO₂ emission reduction is therefore the result of an inhibition of SOC mineralization, photochemical decomposition, oxidation and/or biodegradation, or even wildfire, which, according to Pellegrini et al. (2022), could result in loss or accumulation of soil carbon depending on the ecosystem. Mineralization is a biological process operated by soil heterotrophic organisms, which obtain energy from SOM with production of CO₂ re-emitted to the atmosphere. Generally, mineralization rate is positively correlated with oxygen concentration in soil, nitrogen and water availability, soil temperature, and labile SOC components (Paustian et al., 1997; Stockmann et al., 2013). Oxygen infiltration in soil can be minimized by reduced soil disturbance, such as reduced intensity tillage, no till, and minimum till, and also increased soil compaction. In this latter case, the scientific literature on the topic suggests positive and negative effects on SOC mineralization Beylich et al. (2010). Soil temperature in hot season may be diminished by mulching practice and shadowing. Enhanced oxidation and mineralization may be a consequence of soil water and wind erosion and surface runoff, which is likely to occur in sloped fields intensively tilled with bare soil. Notwithstanding negative agricultural and environmental externalities such as land degradation and soil loss driven by erosion, only avoided emissions by soil

erosion prevention through SSM from a land unit should be accounted as soil CO₂ emission reduction.

2.3 | Soil-centric perspective

From a soil-centric perspective, SOC stock levels either increase over time (i.e., SOC stock gain) or decrease over time (i.e., stock losses) or neither (i.e., stock equilibrium state). However, SOC gain and losses do not necessarily affect climate change since they might be the result of SOC accumulation, SOC transport through erosion within the same land unit (horizontal redistribution), or erosion and transport through another land unit. These SOC dynamics should not be confused with the sink or source function of soils, which are functions related to the effect on atmospheric CO₂ concentration (i.e., atmosphere-centric concepts). In this context, the term SOC retention should be used when the rate of SOC loss is decreased with respect to BAU, by reduction in mineralization/oxidation rates and/or surface runoff, erosion, and leaching. SOC retention should not be confused with soil CO₂ emission reduction, since SOC retained not necessarily derives from reduced mineralization, photochemical decomposition, oxidation, and biodegradation only, which are the processes responsible for soil CO₂ emissions, but may be the result of the combination of reduced mineralization, surface runoff, erosion, and leaching. Therefore, SOC retention is defined from a soil-centric perspective (i.e., SOC is less depleted) and does not necessarily have an impact on climate change. Soil acts as C sink only when net SOC sequestration is occurring and as C source when net release takes place (Table 1).

3 | CONCLUSIONS

We attempted to clarify the contribution of processes and practices on the C cycle by reinforcing the definition of three different terms: *SOC sequestration*, *SOC accumulation*, and *soil CO₂ emission reduction*. These definitions reflect an atmosphere-centric perspective and identify real climate change mitigation deriving from net atmospheric C removal (i.e., SOC sequestration), climate change mitigation through decreased soil CO₂ emissions (i.e., soil CO₂ emission reduction), and no climate change mitigation

TABLE 1 Climate mitigation effect of SOC processes.

SOC process	Climate change mitigation	Notes
Sequestration	Yes	Soil is a net CO ₂ sink
CO ₂ emission reduction	Yes	Soil is a net CO ₂ source or in equilibrium state
Accumulation	No	SOC stock increases, yet CO ₂ sequestration is performed outside the system boundaries

effect when C is transferred from one terrestrial pool to another (i.e., SOC accumulation). To clarify the temporal dynamics of organic C for a specific land-use category or management, both the paired comparison method and the SOC stock difference method should be implemented in experimental studies. The SOC stock difference and the paired comparison methods are not equivalent but are both useful and can be considered complementary tools to investigate and achieve a wider understanding of the research object. The paired comparison method detects improvements in SOC in a sustainable management scenario compared with a dynamic BAU, that is, when it is expected that the SOC is not in a steady state but it is undergoing an increasing or decreasing trend over time (provided that the counterfactual site has the same biophysical characteristics than the test site). The SOC stock difference method provides more precise net stock change because of a variation in agricultural management over a land unit over time, on the basis of the assumption that the initial SOC would not have changed over time; moreover, provided that no *SOC accumulation* occurs, this method is the only one capable of unequivocally proving SOC sequestration from the atmosphere.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing financial interests.

DATA AVAILABILITY STATEMENT

This is a commentary paper and does not include additional data. The data that support the findings of this study are available in the reference list.

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REFERENCES

- Arevalo, C. B., Bhatti, J. S., Chang, S. X., & Sidders, D. (2009). Ecosystem carbon stocks and distribution under different land-uses in north Central Alberta, Canada. *Forest Ecology and Management*, 257(8), 1776–1785. <https://doi.org/10.1016/j.foreco.2009.01.034>
- Beylich, A., Oberholzer, H.-R., Schrader, S., Höper, H., & Wilke, B.-M. (2010). Evaluation of soil compaction effects on soil biota and soil biological processes in soils. *Soil and Tillage Research*, 109(2), 133–143. <https://doi.org/10.1016/j.still.2010.05.010>
- Conteh, A. (1999). *Evaluation of the paired site approach to estimating changes in soil carbon. Discussion paper 3, of Appendix 6 to Technical Report No 2.* Australian Greenhouse Office.
- Davis, M., Wilde, H., & Tate, K. (2004). Using paired plots to verify soil carbon change associated with land-use change as predicted from historical soil inventory. SuperSoil 2004: 3rd Australian New Zealand soils conference, University of Sydney, Australia, 5–9 Dec 2004.
- Food and Agriculture organization of the United Nations (FAO). (2019). Recarbonization of Global Soils-A dynamic response to offset global emissions, FAO. Available from: <http://www.fao.org/3/i7235en/i7235EN.pdf>
- Food and Agriculture organization of the United Nations (FAO). (2022). Global Soil Organic Carbon Sequestration Potential Map – GSOCseq v.1.1.1. Technical report. Rome.
- IPCC. (2006). Guidelines for National Greenhouse gas Inventories. Prepared by the National Greenhouse gas Inventories Program. Vol. 4. Published: IGES. Japan. AFOLU. 2006. Chapter 2 P. 2.29.
- IPCC. (2019). In P. R. Shukla, et al. (Eds.), *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* Intergovernmental Panel on Climate Change (IPCC). Available from: <https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf>
- Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1–2), 1–22. <https://doi.org/10.1016/j.geoderma.2004.01.032>
- Lal, R., Negassa, W., & Lorenz, K. (2015). Carbon sequestration in soil. *Current Opinion in Environmental Sustainability*, 15, 79–86. <https://doi.org/10.1016/j.cosust.2015.09.002>
- Lorenz, K., & Lal, R. (2014). Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development*, 34, 443–454. <https://doi.org/10.1007/s13593-014-0212-y>
- Olson, K. R. (2013). Soil organic carbon sequestration, storage, retention and loss in U.S. croplands: Issues paper for protocol development. *Geoderma*, 195–196, 201–206. <https://doi.org/10.1016/j.geoderma.2012.12.004>
- Olson, K. R., Al-Kaisi, M., Lal, R., & Cihacek, L. (2016). Impact of soil erosion on soil organic carbon stocks. *Journal of Soil and Water Conservation*, 71(3), 61A–67A. <https://doi.org/10.2489/jswc.71.3.61A>
- Olson, K. R., Al-Kaisi, M., Lal, R., & Lowery, B. (2014a). Examining the paired comparison method approach for determining soil organic carbon sequestration rates. *Journal of Soil and Water Conservation*, 69(6), 193A–197A. <https://doi.org/10.2489/jswc.69.6.193A>

- Olson, K. R., Al-Kaisi, M., Lal, R., & Morton, L. W. (2017). Soil ecosystem services and intensified cropping systems. *Journal of Soil and Water Conservation*, 72(3), 64A–69A. <https://doi.org/10.2489/jswc.72.3.64A>
- Olson, K. R., & Al-Kaisi, M. M. (2015). The importance of soil sampling depth for accurate account of soil organic carbon sequestration, storage, retention and loss. *Catena*, 125, 33–37. <https://doi.org/10.1016/j.catena.2014.10.004>
- Olson, K. R., Al-Kaisi, M. M., Lal, R., & Lowery, B. (2014b). Experimental consideration, treatments, and methods in determining soil organic carbon sequestration rates. *Soil Science Society of America Journal*, 78(2), 348–360. <https://doi.org/10.2136/sssaj2013.09.0412>
- Paustian, K., Collier, S., Baldock, J., Burgess, R., Creque, J., DeLonge, M., ... Jahn, M. (2019). Quantifying carbon for agricultural soil management: From the current status toward a global soil information system. *Carbon Management*, 10(6), 567–587. <https://doi.org/10.1080/17583004.2019.1633231>
- Paustian, K. A. O. J. H., Andren, O., Janzen, H. H., Lal, R., Smith, P., Tian, G., ... Woerner, P. L. (1997). Agricultural soils as a sink to mitigate CO₂ emissions. *Soil Use and Management*, 13, 230–244. <https://doi.org/10.1111/j.1475-2743.1997.tb00594.x>
- Pellegrini, A. F. A., Harden, J., Georgiou, K., ... Jackson, R. B. (2022). Fire effects on the persistence of soil organic matter and long-term carbon storage. *Nature Geoscience*, 15, 5–13. <https://doi.org/10.1038/s41561-021-00867-1>
- Powlson, D. S., Riche, A. B., Coleman, K., Glendining, M. J., & Whitmore, A. P. (2008). Carbon sequestration in European soils through straw incorporation: Limitations and alternatives. *Waste Management*, 28(4), 741–746. <https://doi.org/10.1016/j.wasman.2007.09.024>
- Powlson, D. S., Whitmore, A. P., & Goulding, K. W. T. (2011). Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false. *European Journal of Soil Science*, 62, 42–55. <https://doi.org/10.1111/j.1365-2389.2010.01342.x>
- Rytter, R. M., & Rytter, L. (2020). Carbon sequestration at land use conversion—Early changes in total carbon stocks for six tree species grown on former agricultural land. *Forest Ecology and Management*, 466, 118129. <https://doi.org/10.1016/j.foreco.2020.118129>
- Sanderman, J., & Baldock, J. A. (2010). Accounting for soil carbon sequestration in national inventories: A soil scientist's perspective. *Environmental Research Letters*, 5(3), 034003. <https://doi.org/10.1088/1748-9326/5/3/034003>
- Sanderman, J., Hengl, T., & Fiske, G. J. (2017). Soil carbon debt of 12,000 years of human land use. *Proceedings of the National Academy of Sciences*, 114(36), 9575–9580. <https://doi.org/10.1073/pnas.1706103114>
- Scharlemann, J. P., Tanner, E. V., Hiederer, R., & Kapos, V. (2014). Global soil carbon: Understanding and managing the largest terrestrial carbon pool. *Carbon Management*, 5(1), 81–91. <https://doi.org/10.4155/cmt.13.77>
- Seidel, F., Don, A., Chenu, C., Seitz, D., Kätterer, T., & Leifeld, J. (2023). Soil carbon-sequestration and climate mitigation—definitions and their implications (No. EGU23-12579). Copernicus Meetings. <https://doi.org/10.5194/egusphere-egu23-1257>
- Stockmann, U., Adams, M. A., Crawford, J. W., Field, D. J., Henakaarchchi, N., Jenkins, M., ... Zimmermann, M. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agriculture, Ecosystems & Environment*, 164, 80–99. <https://doi.org/10.1016/j.agee.2012.10.001>
- Zonneveld, I. S. (1989). The land unit—A fundamental concept in landscape ecology, and its applications. *Landscape Ecology*, 3, 67–86.

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