Title

Studies from global regions indicate promising avenues for maintaining and increasing soil organic carbon stocks

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EDITORIAL

Studies from global regions indicate promising avenues for maintaining and increasing soil organic carbon stocks

The Scientific and Technical Committee of the 4 per 1000 initiative

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In view of the growing global population and increasing meat consumption, food and fibre production on existing agricultural land will most likely have to increase (Blum 2013; World Bank 2018). However, intensive agricultural use has led to a decline in soil quality with a third of all soils now considered degraded (FAO & ITPS 2015). Degraded soils have lower soil organic carbon (SOC) and lower capacity to provide ecosystem services such as biodiversity and water quality benefits (Bunemann et al. 2018; Lehmann et al. 2020). Recognising that the dynamics of carbon in soils, regulated by biological activity not only affects agricultural yields, but is also a major driver of climate change (Lal et al. 2021), the 4p1000 Initiative was launched in 2015 with a vision of supporting healthy and carbon-rich soils to combat climate change and food insecurity. Counteracting negative effects of agriculture through encouraging sustainable practices that preserve and increase soil carbon stocks worldwide can make small changes in the large organic carbon reservoir in soils, and thereby contribute to mitigating climate change (Soussana et al. 2019). Even small increases in SOC content also lead to numerous co-benefits. Restoring

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soil health is critical for sustainable agricultural production and adaptation to climate changes (Rumpel et al. 2022). Implementation of the Initiative requires development and adoption of practices that are environmentally viable, economically sound and socially accepted, and able to provide multiple benefits with no negative impacts. To effectively and sustainably enhance soil quality and SOC sequestration, recommended practices should be region-specific and adapted to local pedoclimatic conditions (Amelung et al. 2020).

Evaluating the potential for SOC preservation or additional SOC storage at the national to the global scale relies on the availability of solid data representing the diversity of pedoclimatic conditions, land uses and management systems at the local to regional scale. This Topical Collection presents such studies. It consists of 20 articles presenting original research based on experimental or modelling work (17 articles) or review of articles (3 articles) on the impact of soil and agricultural system management on SOC sequestration. The papers originate from a wide variety of world regions (Fig. 1), characterised by a multitude of pedoclimatic and socioeconomic conditions, and cover a variety of interventions. While not comprehensive, these studies provide a region-specific overview of SOC sequestration possibilities. They describe adequate and innovative practices and their potential benefits for climate change mitigation.

The temperate climate was covered in eight papers. Whitehead et al. (2022) used a modelling approach and national data from New Zealand to show that SOC losses occurred after land-use change from grassland to forest. The analysis highlights the need for changing land management practices to increase SOC stocks. Matsuura et al. (2021) showed that grassland duration determines SOC stock changes regardless of soil type in Japan. Model simulations showed that low-level farmyard manure applications had positive effects on SOC stocks, which are likely to be maintained under climate change. Similar results were found for grasslands with an oceanic climate in Spain by Doblas-Rodrigo et al. (2022). The authors reported that manure additions helped to preserve SOC stocks. The study by Drexler et al. (2021) in German agricultural landscapes indicated that features such as hedgerows on croplands are effective options to increase SOC while at the same time enhancing biodiversity and soil protection. Tanneberger et al. (2022) introduced paludiculture as an option to reduce carbon loss from drained temperate peatlands through rewetting. The authors found that this practice could be economically viable in Germany. The study by Araujo et al. (2022) in Canada investigated farmers' behaviour leading to adoption of farming practices that can mitigate climate change. They found that climate awareness and appetite for innovation among farmers influence their fertiliser use. Because farmer profiles differ, diverse informational and educational strategies are necessary to foster the adoption of climate smart practices. The paper by Baronti et al. (2022) was addressing grazing management in the Italian Alps. The authors found that rotational grazing is beneficial for SOC sequestration and soil protection in Alpine systems in addition to contributing to climate change mitigation. For the high mountain region of the Andes, large ecosystem variability was found by Alavi-Murillo et al. (2022), requiring specific management strategies. Their results indicated that low temperatures may conserve SOC stocks in these regions and that they are thus endangered by climate change. Moreover, local management strategies based on fallow, crop rotation and terraces might have positive effects on SOC albeit the few available data.

Nine papers covered the tropical region. In the tropical mountain area of Madagascar, Rakotovao et al. (2022) showed that SOC stocks were maintained thanks to agroforestry systems but increased only when exogenous organic

Fig. 1 Origins of the papers presented in this Topical Collection

matter was added. Koutika et al. (2021) found that the integration of N_2 fixing trees in agricultural and forest landscapes of African Congo improves SOC sequestration and other ecosystem services. Koné (2022) found similar beneficial effects of legumes in Ivory Coast. He reported that mixed legume fallows have benefits on soils, although SOC stock changes may be more related to site history. In addition to land-use history, baseline SOC stocks may be important to consider as shown by Chopin and Sierra (2021) in Guadeloupe. These authors reported only small relative increases of SOC following conservation agricultural practices and use of locally produced compost due to high baseline SOC contents of volcanic soils in the Caribbean.

In Brazil, deforestation was reported by Damian et al. (2021) to contribute to climate change not only through removal of the forest biomass but also due to SOC losses. Two studies highlighted agricultural practices able to increase SOC storage of degraded pastures in Brazil. De Oliveira et al. (2022) reported that appropriate stocking rates and weed control as well as simple practices, such as fertilisation or liming could increase SOC stocks of degraded pastures. The recovery of degraded pastures may have the potential to increase C stocks by up to 23%. Hernandes et al. (2022) showed that green-harvested sugarcane establishment on degraded pastures could lead to positive long-term soil C budget. Likewise, Ramos et al. (2022) indicated that conservation agricultural practices increase C and N stocks in the cerrado ecosystem. In addition, the latter two studies highlighted the importance of directed public policies and region-specific land-use planning to implement such practices. Socioeconomic factors may indeed be important as shown be Leopold et al. (2021) for the Maré Loyalty Island in New Caledonia. Their study indicated that the socioeconomic evolution of agricultural systems impact SOC stocks, as traditional slash and burn agriculture maintained SOC stocks, while the new market-oriented avocado plantations depleted them.

Two papers addressed SOC sequestration strategies in subtropical and semiarid regions. Biala et al. (2021) reported benefits of exogenous organic matter additions for SOC sequestration in Queensland, Australia. The authors identified a set of research priorities to allow for accurate assessments of SOC sequestration potential to inform policy makers. The study by Malou et al. (2021) indicated that livestock manure fosters SOC in sandy soils in Senegal independently from clay content but determined by distance to the village. These two studies again show the importance of taking into account socioeconomic and political factors in addition to biophysical constraints when managing SOC sequestration.

The paper by Anton Sobejano et al. (2021) investigated different climate zones within the region of Navarre in Spain. The authors found that exogenous organic matter additions are beneficial for SOC storage in all climates. Uneven effects were observed for conservation agriculture, irrigation and crop rotations, which could show contrasting results highlighting the need for site-specific assessment of the impact of agricultural practices. SOC was therefore suggested as suitable indicator for regional adaptation practices.

Six main conclusions may be drawn from these studies:

- It is important to consider the site history and baseline evolution of SOC stocks. The latter are often declining under current management. Increases with regard to business as usual are thus relative rather than absolute.
- A great diversity of management options allows for relative increases in SOC stocks. They often are very specific to the climatic and socioeconomic context, which may vary even within one region.
- Nutrient management and soil cover are essential to reverse soil degradation and for positive effects on SOC stocks.
- Inputs of exogenous organic matter such as manure are widespread in application and lead to positive effects on SOC stocks across regions.
- Traditional agricultural systems and smallholder farm practices have the potential to increase SOC stocks by implementing management options that avoid soil degradation.
- Technical advice and policy frameworks are important and should be improved to support farmers to implement SOC-fostering practices

Studies like those presented in this Topical Collection are excellent contributions to global efforts, such as the FAO agroecological approach (GAEZ), or the Foodscape approach (Bossio et al. 2021), which provide frameworks to understand the relevance of local and regional studies to other areas. These global efforts are necessary to define sustainable practices able to be applied in specific agroecological zones and/or foodscapes, as the basis of an agroecological transition.

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