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Editorial

Soil organic matter in a stressed world

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Soil organic matter (SOM) is quantitatively a minor component (by mass and volume) of most soils, yet it is responsible for facilitating or moderating many key soil ecosystem services that affect agricultural food security, biodiversity and environmental quality. Its constituents range in mean residence times from <1 min for some low molecular weight (LMW) compounds, through to >10 000 years for charcoal-like materials. It is these somewhat enigmatic aspects of SOM that not only provoke such interest from the research community, but also drive the need for applied research that enables custodians of the landscape to effectively manage SOM in a way that limits its loss and maintains or enhances its stock and function.

This special issue of *Soil Research* arises from the 7th International Symposium on Soil Organic Matter, which was held in Adelaide, South Australia, 6–11 October 2019. The theme of the conference was 'Soil Organic Matter in a Stressed World', reflective of the many challenges facing SOM, particularly the effects of climate change and over-exploitation by agriculture, as well as the role that SOM can play in mitigating some of the adverse effects of a stressed world. This overarching theme allowed a broad swathe of sessions and keynote topics framed to address the grand challenges of understanding and better managing SOM in our changing environment. Many of the conference topics/sessions are captured in the collection of papers published in this special issue.

The symposium itself opened and closed with perspectives of some of the traditional custodians of Australia and Aotearoa New Zealand. Following the traditional Welcome to Country from Kaurna (pronounced gar-na) elder Uncle Rodney O'Brien, Robert McGowan delivered an inspiring talk on the perspectives of indigenous Māori people of New Zealand on managing their soils, waters and lands. Of note was the philosophy the Māori apply to the management of Papatuanuku (Earth Mother), in so much as it is not management but more of a partnership approach (McGowan 2021). To close the conference, Kaurna elder Mickey Kumatpi Marrutya O'Brien spoke powerfully about the >60 000 years of land management undertaken by Australia's traditional indigenous owners. This management was far more than hunter-gathering, and included active management of the landscape to encourage important species for food, including grains for the production of damper (Coles and Hunter 2010; Gammage 2012; Pascoe 2018). There is a wealth of information and wisdom held by First Nations people that complements 'western' science, and in some countries such as New Zealand, there are examples of this informing policy (McGowan 2021). Indeed, Te ao Māori—the Māori worldview—is explicitly considered in a recent transdisciplinary review of regenerative agriculture (RA) research in New Zealand (Grelet *et al*. 2021).

There is an acute need for SOM scientists to communicate with policymakers to inform policy development with robust scientific evidence and to dispel misconceptions. For compelling arguments to be made, transdisciplinary approaches that explicitly consider the social impacts of recommendations such as '*quatre pour mille*' (4 per mille; United Nations/Framework Convention on Climate Change 2015) should be considered. In his review in the present issue, Aitkenhead (2021) emphasises that such approaches, also taking into account the many ecosystem services that SOM delivers, can be employed to both inform and bring the public 'along the journey'. He uses the Scottish Government's interactions between policy makers and researchers as a case study to explore these concepts. While there is a clear attraction to focus on the risk and potential that SOM presents from a climate change perspective, it is the wider impact that changes in SOM can have on both soil functions and the wider landscape, including on nutrient and water dynamics, that may be of greater interest to land holders.

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The need to consider the dynamic state of SOM in land management systems and as a driver for informing policy decisions clearly emerged as a key priority for future research and stakeholder engagement. Such need is of particular importance for the management of soils and SOM in agricultural systems. These soils have been both a major contributor to the loss of antecedent SOM levels across the globe and, as a consequence, offer enormous potential for restoration of SOM as a means to mitigate climate change and enhance food security. Central to this being realised is the need to understand the spatial and temporal aspects of SOM dynamics in relation to soil conditions and farming practices, as was highlighted in many papers presented at the symposium. The importance of understanding cross-seasonal fluctuations in the microbial component of SOM (biomass per unit of SOM) and its associated metabolic activity in relation to soil depth (to 1 m) is discussed in the paper by Polain *et al*. (2021). Spatial and temporal effects were clearly more important to microbial function than the effects of cropping systems (continuous vs rotational cotton). This is of significance given the role of microorganisms in conversion of particulate organic matter (POM) in soil, their contribution to the pool of more stabilised and mineral associated organic matter (MAOM) (Cotrufo *et al*. 2019; Coonan *et al*. 2020) and the importance microorganisms in the mineralisation and dynamics of SOM. The relevance of spatial and temporal effects in SOM dynamics are also highlighted in the paper by Carmona *et al*. (2021). Using a mesocosm system with simulated irrigated or dryland conditions for pasture production, this paper showed that the transfer and storge of photosynthetic-derived ^{13}C into fine POM and clay sized fractions was promoted under summer irrigation. Understanding how farm systems practices affect SOM stabilisation is also investigated in the paper by Masilionytė *et al*. (2021), building on the data obtained from long-term crop rotation and fertilisation management treatments applied in an organic vs sustainable agricultural management system trial. The addition of farmyard manure in combination with green manure crops had a positive effect on the levels of stable SOM (as measured by humic and fulvic acid fractions), with greater potential for net humification being evident in the soil with lower historical SOM content. Such examples, as presented in the aforementioned papers and more generally throughout the symposium provide collective and compelling evidence of the need for a wider and more integrative systems-based approach to elucidate the drivers of SOM dynamics.

At the landscape scale, numerous processes affect the soil organic carbon (SOC) dynamics and C sequestration. In this special issue three such processes are explored, namely grazing (Sainju *et al*. 2021), woody encroachment (Mureva *et al*. 2021), and environmental plantings (Amarasinghe *et al*. 2021). In the work by Amarasinghe *et al*. (2021) soil microbial activity (heterotrophic respiration), total organic carbon (TOC), total nitrogen (N) and plant-available phosphorus (P) were quantified both under and beyond the canopy of trees in mixed species woody plantings. Importantly, this work focused on two species: a N-fixing tree (*Acacia pendula*) and a non-N fixing tree (*Eucalyptus camaldulensis*). Soil N, P, TOC and heterotrophic respiration were greater under the N fixing tree, and decreased with depth (down to 50 cm). This work adds further evidence that the floristic composition of mixed woody plantings, and especially the inclusion of N-fixing species, can have positive impacts on soil C stocks and nutrient availability (Hoogmoed *et al*. 2014*a*, 2014*b*; Sainju *et al*. 2021). The importance of climate to affecting change in SOM was also highlighted at the conference. For example, Mureva *et al*. (2021) report that mean annual precipitation is important to moderating the rate and extent of change in SOM during shrub encroachment onto grassland in South Africa. The potential to reduce soil C loss where sheep grazing is used for weed management in an organic cropping system is highlighted in the paper by Sainju *et al*. (2021). In comparison to conventional cropping and minimum tillage with chemical treatment, the retention of SOC with sheep grazing is attributed to the return of livestock excreta (urine and faeces). Taken together, these studies highlight that land management and landscape scale processes have the capacity to impart significant effects on SOM stocks and cycling in terrestrial environments. Where trees and shrubs are returned to the environment either through planting or regeneration/encroachment, increases in OM and SOC are likely, albeit that these increases are moderated by vegetation community architecture and climatic conditions.

Another important aspect of the conference was the presentation of methodological innovations that should serve to advance the research community's capability to understand the mechanisms that control SOM dynamics. Two areas of methodological advance are included in this special issue of *Soil Research*: improved insight through higher-resolution analysis, and improved throughput at reduced cost to facilitate prediction of difficult to measure attributes of SOM. Warren (2021) used liquid chromatography–mass spectrometry (LC-MS) to examine the association between intact lipid composition and position along two altitudinal transects in Australia, identifying 174 intact lipids across the nine sites studied. This study identified that pH was among the properties most strongly related to lipid composition, making the observation that the accumulation of diacylglycerol at lower pH may be indicative of retarded hydrolysis or microbial utilisation towards the lower end of the pH range (Malik *et al*. 2018). Conversely, the advance in chemometric analysis of spectral data from nuclear magnetic resonance (NMR), and near- and mid- infrared (NIR, MIR) presented by Baldock *et al*. (2021) identified that the decomposition characteristics of a wide variety of organic amendments can be predicted by spectral techniques. While solid state NMR was able to deliver insight into the main chemical components responsible for an organic amendment's decomposition behaviour, this is still a specialised technique limiting its application. Importantly however, both MIR and NIR provided mostly comparable predictive capacity and NIR in particular, shows great promise for rapid and *in situ* prediction of compost and potentially SOM quality.

Finally, the conference moved beyond the purely terrestrial for the first time in its series, to the discussion of advances in our understanding of organic matter processes in aquatic systems, with a dedicated session and keynote. Blue carbon

ecosystems (including tidal marshes, mangroves, seagrass meadows and other soft sediment habitats) play an important and dynamic role in global biogeochemical cycles. These systems are incredibly efficient at accumulating OM and storing it for long periods of time, highlighting their value as natural C sinks. However, through both natural and anthropogenic induced disturbance, the OM stored in these anoxic environments is being threatened by exposure and these vital C sinks could destabilise and become C sources (Spivak *et al*. 2019). The magnitude of this postulated disturbance in blue C decomposition is massively variable with ranges of 25–100% of buried SOC potentially destabilising via decomposition and released as CO_2 (Spivak *et al*. 2019). There is a paucity of data on the drivers and preservation mechanisms in blue C ecosystems and while they have similarities with both terrestrial and ocean systems, they are very distinct environments and are heavily influenced by local hydrological conditions over different temporal and spatial scales. Quantifying SOC stocks across different blue C habitats is critical to determine how changes in habitat types (i.e. mangrove to tidal marsh) can affect SOC stocks at the large estuarine scales (Bulmer *et al*. 2020). However, Asanopoulos *et al*. (2021) highlight that the local hydrology, geomorphic setting and soil type have a greater influence on surface (top 10 cm) SOC stocks than aboveground vegetation when comparing tidal marsh and mangrove ecosystems. These authors identified over large spatial scales (i.e. state-wide) in South Australia that vegetation has a little impact on the surface SOC stocks. Over smaller spatial scales, there is intrinsic site-specific variability which is currently not captured in blue C modelling of SOC stocks. Asanopoulos *et al*. (2021) highlight the need to consider small scale spatial variability in SOC stocks in order to improve estimates of the vulnerability of blue C systems to future disturbance.

In conclusion, the 2019 International Symposium on Soil Organic Matter provided researchers from many fields with an interest in SOM a comprehensive update on the latest advances in SOM science. Attendees with soil science, agronomy, ecology, terrestrial and aquatic biogeochemistry backgrounds converged to exchange ideas and deliver their findings. The following papers in this special issue only scratch the surface of the topics discussed at the conference.

Conflicts of interest

All authors were guest editors and handled one or more papers submitted for consideration in this special issue.

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