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Soil Science Challenge Grants Program

The University of Sydney

A soil-plant nexus to maximise organic carbon sequestration in the soil: project summary

Project period: June 2022 to December 2025

Introduction

Research has determined that a major portion of organic matter (OM) in the soil is intimately associated with soil minerals, so-called mineral-associated organic matter (MAOM), where organic compounds are mostly chemically adsorbed onto soil clay minerals and may also be physically trapped in soil aggregates. This project was designed to disentangle key drivers involving soil-plant-microbe nexus that preserve/mineralise organic carbon in soils. Research and findings were delivered under the following 4 activity modules.

Findings

Activity Module 1 - To determine the efficiency of key root exudates of crops and pastures to form microbial products and MAOM

Results included:

- Nitrogen (N) fertilisation increased microbial utilisation of the rhizodeposited carbon (C) and the contribution of in-vivo pathway to mineral-associated organic matter carbon (MAOM-C).
- Data analysis showed the effects of soil texture and clay mineralogy, combined with plant effects, on the quality and quantity of soil organic matter carbon.
- The microbial community composition was affected by plant treatments as well as soil texture, leading to differences in the metabolites available for adsorption to soil minerals or further microbial processing.
- Variation in root biomass, rhizodeposition, and N availability affects the contribution of microbial and plant-derived pathways in the formation of root-derived C in particulate organic matter (POM) and MAOM fractions.

Activity Module 2 - To assess whether organic compounds in MAOM originate directly from plants or from microbially processed matter

Results included:

- Both priming effect (PE) and rhizosphere priming effect (RPE) are affected by the N addition or availability. The RPEs and their responses to N potentially last longer than for PE, due to ongoing root induced destabilization of native soil organic matter by microbes for N mining.

- Through a field study at the Eucalyptus Free-Air CO^2 Enrichment (EucFACE) experiment site, it was observed that 12 years of elevated carbon dioxide (eCO_2) caused significant decreases in MAOM-total C (16%), MAOM-organic N (15%), and MAOM-organic phosphorus (16%) compared to ambient CO2 ($_aCO_2$), but no effects on total C, organic N, and organic phosphorus in POM.
- A growth chamber experiment to determine the effects of the different clay minerals and plant species on MAOM formation revealed that plant species qualitatively affected the amount of OM inputs and dissolved organic matter chemistry, but mineral properties had a greater impact on the total C stock and MAOM formation.

Activity Module 3 - To elucidate how stable the OM in MAOM is with different clay minerals in the presence of plant roots

Results to be published shortly.

Activity Module 4 - Determine the role of iron oxides on carbon sequestration in soils

Results included:

- All extractable forms of iron (Fe) and aluminium (Al) showed significant positive correlations with extractable C, which suggested their role in the preservation of soil organic carbon (SOC).
- Because phosphate and dissolved organic C share similar adsorption mechanisms, the project assessed their competitive interactions in iron-rich soils. Phosphate showed strong adsorption, particularly in soils with higher iron content, and promoted the release of dissolved organic C from mineral surfaces. This finding indicates phosphorus inputs, such as via fertiliser application, may destabilise organic matter in iron-rich soils by displacing previously stabilised carbon.

Publications

This project has published the following papers with additional papers currently in preparation or in review. This section will be updated once additional papers are published.

Amenkhienan, BE, Dijkstra, FA & Singh, B 2025, Competitive adsorption between phosphate and dissolved organic carbon in iron-rich soils, *Frontiers in Soil Science*, vol. 5, 1719389, DOI: 10.3389/fsoil.2025.1719389

Amenkhienan, BE, Dijkstra, FA, Warren, C & Singh, B 2024, Understanding extractable metal species relationships with phosphorus sorption and organic carbon in soils, *Soil Research*, vol. 62, no. 8, SR24118, DOI: 10.1071/SR24118

Bicharanloo, B, Bagheri Shirvan, M, Yang, Z, Yamamoto, R, Keitel, C, Dijkstra, FA, Warren, C & Singh, B 2026, Nitrogen availability alters the contribution of ex-vivo and in-vivo pathways to carbon formation in particulate- and mineral-associated organic matter, *Geoderma*, vol. 468, 117775, DOI: 10.1016/j.geoderma.2026.117775

Favaro, A, Carrillo, Y, Singh, B, Warren, C & Dijkstra, FA 2025, Nutrient-rich mineral-associated organic matter limits carbon storage under elevated carbon dioxide in a low phosphorus Eucalyptus woodland soil, *Global Change Biology*, vol. 31, no. 11, e70585, DOI: 10.1111/gcb.70585

Favaro, A, Singh, B, Warren, C & Dijkstra, FA 2025, Differences between priming and rhizosphere priming effects: concepts and mechanisms, *Soil Biology and Biochemistry*, vol. 205, 109769, DOI: 10.1016/j.soilbio.2025.109769

More information

Learn more about the Soil Science Challenge Grants Program.

Contact the project lead, Professor Balwant Singh.

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Acknowledgement of Country

We acknowledge the continuous connection of First Nations Traditional Owners and Custodians to the lands, seas and waters of Australia. We recognise their care for and cultivation of Country. We pay respect to Elders past and present, and recognise their knowledge and contribution to the productivity, innovation and sustainability of Australia's agriculture, fisheries and forestry industries.