July 2026

Soil Science Challenge Grants Program

University of New South Wales Sydney

Engineering novel soil amendments: project summary

Project period: June 2022 to December 2025

Introduction

This collaborative research program focused on developing engineered soil amendments that enhance carbon storage without the environmental trade-offs associated with conventional land management practices. Combining materials engineering with soil science and microbiology, this project explored how functionalised carbon mineral materials capture and stabilise carbon within soil systems. The project's 4 research components were:

1) **Functionalised nano-clay–biochar composites**

To design and synthesise amine-functionalised nano-clays and biochar hybrids with tunable porosity and surface chemistry to maximise carbon dioxide (CO_2) adsorption and conversion to stable carbonates in soils.

2) **Functionalised biochar and graphene-based composites**

To design and synthesise functionalised biochar composites to capture and store CO_2 while improving soil carbon storage. A key focus was to modify biochar surfaces and create composites through the addition of iron-based compounds. This study also explored the development of graphene oxide-based materials as substrates to trap CO_2.

3) **Soil carbon cycling and stabilisation mechanisms**

To quantify how engineered amendments affect soil organic and inorganic carbon sequestration and resolve carbon flow pathways and stabilisation mechanisms (including microbial contributions) across several representative Australian soils.

4) **Climate response and system-level carbon fluxes**

To determine how these amendments influence soil carbon dynamics under future climate conditions (e.g. elevated CO_2 levels), including carbon fluxes, stability and feedback to plant-soil systems.

Findings

This project showed increasing soil carbon storage is not simply a matter of adding more carbon, but of controlling how carbon is stabilised in soil. Engineered biochar mineral materials can improve both CO_2 capture and soil carbon retention, but their performance depends on how they are designed and the soils they are applied to. Surface structure (porosity and surface area) and surface chemistry both played key roles, working together to control carbon capture and stabilisation.

Iron-modified biochars emerged as the most effective materials for promoting long-term carbon storage, particularly where they enhanced organo-mineral interactions and redox processes. However, their

success depended on soil conditions, especially soil pH. In alkaline soils, simpler iron-based minerals sometimes outperformed more complex composites.

The studies also showed the type of carbon entering soil is a major control on its fate and rapid early carbon turnover does not necessarily mean long-term carbon loss. Calcium-based amendments improved soil structure and reduced toxicity but did not reliably increase carbon storage, highlighting trade-offs between soil function and carbon sequestration.

Overall, no single amendment worked in all situations. The key insight is that soil carbon management must be purpose-driven, with materials tailored to soil chemistry, climate conditions and desired outcomes.

Publications

This project has resulted in peer review journal papers currently in preparation or in review. This section will be updated once papers are published.

More information

Learn more about the Soil Science Challenge Grants Program.

Contact the project lead, Professor Paul Munroe.

Acknowledgements

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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.