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Soil Science Challenge Grants Program

The University of Melbourne

Soil organic carbon decline in Australian grain cropping: project summary

Project period: June 2022 to December 2025

Introduction

Soil organic carbon and soil organic nitrogen are closely connected. Together, they help keep soil productive, resilient and able to support sustainable grain production over the long term.

Many Australian broadacre grain farms do not replace all the nitrogen removed when grain is harvested. Over time, this leads to soil nitrogen depletion (nitrogen mining), which also contributes to soil organic carbon decline.

The project focused on the relationship between soil carbon and nitrogen, the risks linked to current farming practices, and management options that could improve long-term soil health.

The project aimed to:

- measure the extent, rate and impacts of soil nitrogen depletion across the Australian grain growing systems
- understand the environmental and economic causes and consequences of soil nitrogen depletion
- identify whether declining soil organic carbon can be reversed and test management practices that could improve soil carbon and nitrogen levels.

The project investigated:

1) how much soil nitrogen is declining across Australia’s grain growing regions
2) what is causing the decline
3) what the impacts are for farming systems.

Findings

The research confirmed that declining soil organic carbon is closely linked to soil nitrogen depletion. Laboratory studies found that soil carbon and nitrogen are strongly influenced by:

- fertiliser history
- temperature
- soil moisture
- crop residue management.

An analysis of 8,029 field observations from the Making Better Fertiliser Decisions for Cropping Systems in Australia database found that soil nitrogen depletion is already widespread. More than 76% of recorded experiments showed evidence of nitrogen depletion.

Modelled simulations across 1,002 representative grain-growing sites showed that if current average fertiliser application rates continue, soil organic carbon, total soil nitrogen and grain yield are likely to decline over time.

The greatest risks were identified in:

- south-west Western Australia
- inland parts of the grain belt
- the models also showed these declines can be reduced, although the effectiveness varies between regions and climate conditions.

The project found risks can be reduced by increasing nitrogen inputs and returning more residue to enhance soil carbon and nitrogen levels. The greatest improvements to soil carbon levels occurred when both practices were used together. However, the effects varied across regions and different climate scenarios. Field studies in the southern Mallee showed that more strategic nitrogen management can reduce the risk of soil nitrogen depletion while maintaining farm profitability.

Translating these findings for on-farm practices requires addressing several factors that influence fertiliser decisions, such as:

- production and input costs
- cash flow
- concerns about production risk
- the assumption that pre-sowing soil nitrogen reserves are sufficient to meet crop demand.

Management options

The project reviewed published management options. These were grouped into three tiers based on costs, effort and the support needed for adoption.

1) Tier 1 - Practices that require little labour, cost, or changes to current farming operations. These are the easiest options for farmers to adopt.
2) Tier 2 - Practices that require moderate operational changes or additional investment.
3) Tier 3 - Practices that are more complex, knowledge-intensive or costly, and require greater resources and capacity to implement.

The estimated cost of implementing practices to prevent nitrogen mining and soil organic carbon decline varied considerably. Tier 1 practices were the most affordable, with estimated implementation costs ranging from tens to hundreds of dollars per ha. Tier 2 practices required greater investment, with implementation costs at least doubling. Tier 3 practices involved the highest costs because they require more specialised knowledge, planning and capital investment. These findings highlight the importance of selecting management options that balance effectiveness with available resources.

The project developed soil natural capital distance functions, a new method for measuring the gap between current soil condition and an estimated benchmark for healthy, productive soil. The analysis found the application rate of nitrogen fertiliser applied was the strongest predictor of both soil organic carbon and total soil nitrogen.

Farm profitability was the second most important predictor, showing that both farming practices and financial considerations play a major role in maintaining healthy soils. By combining field experiments, large datasets, process-based modelling and socioeconomic analysis, this project provides a strong evidence base for monitoring soil decline and guiding future investment in soil management.

The findings show that optimising nitrogen input and returning crop residues to the soil can help maintain healthier, more productive and resilient grain growing systems. However, management strategies will need to be tailored to different regions, particularly areas that are more vulnerable, such as western and inland grain-growing regions.

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 Deli Chen.

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