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Soil Science Challenge Grants Program

The University of Queensland

Phosphorus in long-term agriculture soils: project summary

Project period: June 2022 to December 2025

Introduction

Phosphorus (P) is essential for plant growth, yet many Australian agricultural soils contain concentrations that are severely limiting to plant growth. This not only reduces agricultural productivity but also increases costs for Australian farmers. Furthermore, long-term cropping can potentially cause further P depletion, reduce productivity and further increase the need for fertiliser inputs. Simultaneously, inefficient fertiliser use contributes to national and international environmental problems. This project aimed to understand how long-term cropping and land management practices change the amount, availability and chemical forms of P in soil and associated soil fertility, with knowledge of this being required to improve fertiliser efficiency and sustain Australian agricultural production.

The project combined traditional soil analyses, advanced spectroscopic tools and fieldwork to understand 3 interlinked and critical factors related to increasing efficiency and food production:

1) How P fertilisers behave in Australian soils following their application, with this being essential for developing new types of P fertilisers that are more efficient and effective.
2) Examining how P behaves in long-term agricultural soils.
3) The broader impacts of long-term agricultural management on fertility of Australian soils. For this, soils were sampled that have been used for cropping for up to 100 years, conducted analyses at the Australian Synchrotron, and developed novel approaches to estimate P availability to plants including diffusive gradients in thin films (DGT).

Findings

The project has provided detailed in situ visualisations of how P fertilisers react with Australian soils. Findings show that when P fertiliser granules are added to the soil, they create a small reaction zone called the ‘fertosphere’, where the chemical properties around the granule change markedly. Within this fertosphere, various reactions take place, with much of the P reacting rapidly and being converted into forms that plants cannot readily access.

By mapping these steep chemical gradients, the research has demonstrated where and how these losses of P fertilisers occur within the soil, helping to explain why conventional fertilisers can potentially be inefficient. These findings are important as they demonstrate the chemical processes by which P fertilisers are converted into unavailable forms in Australian soils. This information is critical for future development of the next generation of P fertilisers that can release P more gradually and in forms that

are likely to remain more available within the soil. In a similar manner, strategic placement of this P, such as through deep banding, can help maintain P in plant-available forms.

The research also conducted a unique study in which changes in P were traced for 12 months, a year after their application. This year-long study showed that P becomes profoundly less soluble over time across diverse soils, but the reasons for this differ with soil type. In calcium (Ca)-rich alkaline soils, P quickly forms Ca-phosphate minerals that plants are unable to access, leading to a steady decrease in available P concentrations. In contrast, in the acidic Kandosols and in Vertosols, P initially reacts with aluminium minerals, but a considerable portion remains in forms that plants could still access even after 12 months. Interestingly, co-application of potassium fertilisers together with P fertilisers resulted in additional decreases in P availability to plants. Advanced analyses confirmed these transformations occur slowly but persist over seasons. Thus, this work has demonstrated P fertilisers must be matched to soil type, preventing Ca-phosphate formation in alkaline soils and limiting aluminium-related fixation in acidic soils, to maximise P availability and improve long-term fertiliser efficiency.

The project also examined how this P within the soil changes over the long-term in agricultural systems. The findings demonstrate the potential impact of conventional food production systems on soil P and its behaviour. This demonstrates the urgent need for developing new management approaches that help build soil fertility and resilience, rather than mining the natural capital of soil.

The final component of the project examined how long-term cropping influences soil organic matter (SOM), which plays a key role in storing organic forms of P and other nutrients such as nitrogen. Using highly novel approaches, the project found although long-term cropping markedly reduces organic carbon stocks in SOM, the chemical composition of the SOM remained surprisingly stable. Thus, the findings illustrate losses of SOM in agricultural soils are driven mainly by physical processes (such as aggregate breakdown) rather than by the chemical composition of the SOM itself. The results suggest reducing soil disturbance and improving aggregation are more effective approaches for increasing SOM and for building soil fertility, including for P.

Collectively, this project has provided critical information on P behaviour in Australia's diverse and unique soils, including new mechanistic understanding of how P is stored, transformed, and accessed by plants in our agricultural soils. This knowledge helps identify new approaches to improve land management, increase fertiliser efficiency, and support sustainable production on nutrient-depleted Australian soils.

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.

McKenna, BA, Kopittke, PM, Bell, MJ, Lombi, E, Klysubun, W, McLaren, TI, Doolette, CL & Meyer, G 2024, Phosphorus availability and speciation in the fertosphere of three soils over 12 months, *Geoderma*, vol. 447, 116913, DOI: 10.1016/j.geoderma.2024.116913

McKenna, BA, Lombi, E, McLaren, TI, Doolette, CL, Raymond, NS & Kopittke, PM 2025, Spatially-resolved characterisation of phosphate fertiliser reaction zones for sustainable soil management, *Geoderma*, vol. 463, 117564, DOI: 10.1016/j.geoderma.2025.117564

Zhou, W, McKenna, BA, Bennett-Jones, J, McLaren, TI, Dalal, RC & Kopittke, PM 2025, Functional group composition of soil organic carbon varies between soil organic matter fractions but not with long-term cropping or soil depth, *Pedosphere*, DOI: 10.1016/j.pedsph.2025.12.006

More information

Learn more about the Soil Science Challenge Grants Program.

Contact the project lead, Professor Peter Kopittke.

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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.