SOIL CRC

Performance through collaboration

YEAR IN REVIEW

2024

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The University of Newcastle Australia
Charles Sturt University
NSW Government Department of Primary Industries and Regional Development
Federation University
Griffith University
Murdoch University
SAGIT
Southern Cross University
University of Southern Queensland
University of Tasmania

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SPAA Society of Precision Agriculture Australia
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wheatbelt natural resource management

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2024 in Review

35 ACTIVE SOIL CRC PROJECTS

11 NEW PROJECTS APPROVED

9 COMPLETED

$4.2m COMMITTED TO NEW PROJECTS

39 PHD STUDENTS CURRENTLY STUDYING

2 NEW REGISTERED TRADE MARKS

6 NEW PHD STUDENTS COMMENCED

About the Soil CRC

The Cooperative Research Centre for High Performance Soils (the Soil CRC) was established in 2017 to give farmers the knowledge and tools they need to make decisions on extremely complex soil management issues.

Through our soil research and innovation program, we are developing new solutions that are unlocking the potential of Australia's agriculture sector.

Our practical, real-world outputs allow farmers to optimise their productivity, yield and profitability, and ensure the long-term sustainability of their farming businesses.

The Soil CRC is the largest collaborative soil research effort in Australia's history, bringing together 8 universities, 4 state government agencies, 7 industry partners and 20 farmer groups.

Our multi-disciplinary research efforts are helping Australian agriculture to reach its target for farm gate output of $100 billion per year by 2030.

Vision

Australian farmers using best practice soil management to underpin a dynamic, sustainable and profitable agriculture sector.

Mission

To contribute new knowledge, tools and practices to help Australia's farmers better manage their soils in order to improve the profitability, sustainability, resilience and well-being of the agriculture sector.

4 PROGRAMS

10 YEARS' FUNDING

CASH AND IN-KIND INDUSTRY SUPPORT **$146m**

$39.5m COMMONWEALTH INVESTMENT

Values

Collaborative

The Soil CRC is a collaborative and inclusive research and adoption organisation, passionate about soil and bold in its approach to delivering outcomes.

End user-driven and focused

The Soil CRC is end user-driven in all things it does. Through farmers and other groups, industry are genuine partners in the CRC, helping to set priorities, develop proposals, undertake research, interpret results and communicate new knowledge.

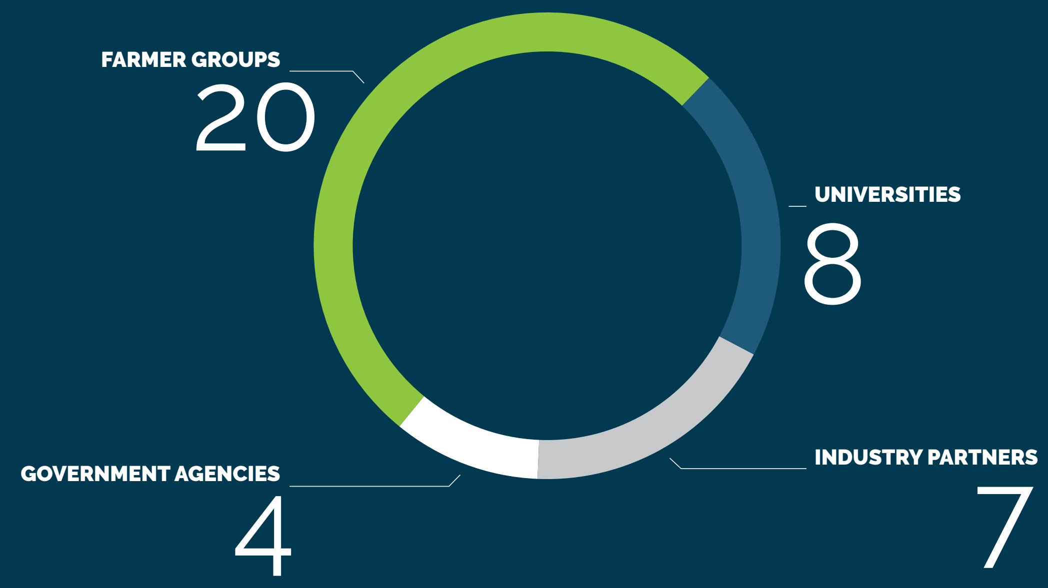
Multidisciplinary

The Soil CRC employs the necessary disciplines and expertise to deliver change during the life of the CRC, while being aspirational in its long-term goals to ensure a continuing legacy.

Research excellence

The Soil CRC is committed to research excellence - in science practice, capacity building, governance, management, integrity and ethics. The CRC is committed to being a national collaborative leader, recognised as an integral part of Australia's agricultural innovation system.

Participants



Message from the Chair and Chief Executive Officer

The Soil CRC has completed 7 years of its 10-year funded life and is at the peak of the organisation's activity and investment. We are now widely recognised as Australia's leading collaborative soil research effort, bringing farmers, industry and research together to deliver practical solutions for Australia's underperforming soils.

The work of the Soil CRC continues to contribute to the three goals of the National Soil Strategy – prioritise soil health, empower soil innovation and soil stewards, and strengthen soil knowledge and capability. The National Soil Action Plan, which outlines priority actions for the next 5 years to improve Australia's soil health and long-term security, was released in late 2023, and the Soil CRC is active in supporting all four priority actions through our investment and delivery.

The revised and refreshed Soil CRC Strategic Plan 2023-2027 was released in November 2023, outlining our strategic priorities for the next 4 years. We now have an increased focus on integration, adoption and outreach, ensuring that the knowledge outputs of the Soil CRC are appropriately disseminated to next users, and ultimately to the farmers and land managers who are dependent on high performing soils.

We are working closely with our grower groups and other delivery partners, including the Regional Soil Coordinators, to ensure our research outputs are made available where they can best be used. In 2024, we have worked with our partners on the development of an Adoption Plan which will guide activities in this area for the remaining 3 years, ensuring that our activities are aligned with those of our partners.

In April 2024, the Soil CRC announced funding for 9 new research projects, with a cash investment of $4.2 million and $8.8 million of in-kind contributions from participants. This investment brings the total spending on projects to more than $40 million since the CRC commenced in 2017. This has been supplemented by a number of externally funded projects, providing an additional $10 million in funding to date.

Six new students joined our PhD cohort in 2023–24. With another 3 students completing their PhD this financial year, it brings the total number of completions to 7. Enrolled at 12 universities across Australia and representing a wide range of disciplines, our students are a key part of the contribution that the Soil CRC is making to Australia's future capacity in soil research.

We continued to take advantage of the opportunity for face-to-face networking with many in person meetings and workshops, headlined by our 2023 Soil CRC Participants Conference. Over 140 delegates joined us in Launceston in August last year to hear about the Soil CRC's work, and to network and collaborate. We incorporated a series of field trips into the conference to continue the hands-on learning experience in the field.

In May 2024, Soil CRC Patron, the Honourable Ms Penny Wensley AC was awarded the Distinguished Services Medal by the International Union of Soil Sciences at the Centennial Congress in Florence, Italy. This was in recognition of Penny's significant contribution over many years to promoting and reinforcing public policies for soil resource protection. We are honoured that Penny continues to serve as the Patron of the Soil CRC and advocate for us in so many forums, nationally and internationally.

In June 2024, one of our inaugural Directors, Professor Roger Swift, stepped down after 7 years on the Board. Roger has made a tremendous contribution to the Soil CRC, drawing upon his decades of research leadership experience and his depth of soil science knowledge. He chaired the Research and Adoption Committee since the early days of the CRC and his guidance and wisdom will be missed.

We thank all the members of the Board, management and staff of the Soil CRC for their continued contribution to the organisation's operation. We extend our gratitude to all Soil CRC participants, researchers and students who are working together to deliver the outcomes of the Soil CRC.

We look forward to the final 3 years of the Soil CRC where we will focus on ensuring that the Soil CRC leaves a legacy that will be recognised for years to come.

Dr Paul Greenfield AO FTSE, Chair, Soil CRC

Dr Michael Crawford CEO, Soil CRC

The story so far

Over $40 million cash committed to projects

Over $10 million additional investments

45 projects completed

43 Commonwealth milestones achieved

57 PhD student commencements

7 PhD student completions

7 registered trade marks

Highlights and achievements

- **We approved funding for 9 new research projects** with a cash investment of $4.2 million and a further $8.8 million of in-kind contributions from participants. This brings the total spending on projects to more than $40 million since the CRC commenced in 2017.
- **We welcomed 6 new PhD students in 2023-24 and saw 3 students complete their PhD,** taking the total number of active students to 39 and the total number of completions to 7.
- **We registered 2 new trade marks with IP Australia** – one for the BANDICOOT® all-in-one soil profiling tool and one for the QUOLL® electronic nose. Registration assists in commercialisation of these products.
- **Soil CRC PhD student Reuben Mah (University of Tasmania) was announced the winner of Cooperative Research Australia's 2024 Early Career Researchers competition (top right).** This is the third year in a row that Soil CRC student researchers have been finalists in this competition.
- **We received a $3.94 million grant from the Australian Government's Future Drought Fund** to help Australia's farmers prepare for future drought. The grant will enable us to extend our long-term trials beyond our funded lifetime of June 2027.
- **We received funding from the NSW Department of Climate Change, Energy, the Environment and Water** through the Primary Industries Productivity and Abatement Program to deliver soil carbon capacity building resources for farmers and advisors.
- **Soil CRC Patron, The Honourable Penny Wensley AC was awarded the Distinguished Services Medal** by the International Union of Soil Sciences (middle right), recognising her contribution to promoting and reinforcing public policies for soil resource preservation.
- **Soil CRC researcher Laureate Professor Ravi Naidu (University of Newcastle and crcCARE) was announced as the winner of the 2023 Glinka World Soil Prize** in recognition of his contribution to the scientific community's understanding of soil science and management.
- **Over 140 Soil CRC participants and stakeholders gathered in Launceston, Tasmania, for our 2023 Soil CRC Participants Conference.** The conference highlighted our latest research and provided an opportunity for delegates to network and collaborate.
- **We released a new webinar series and 28 supporting fact sheets on priority soil management issues** aimed at building the technical capacity of natural resource management agencies, Landcare and grower groups. These resources were jointly funded by the Australian Government's National Landcare Program as part of our 'Building technical capacity for improved soil management' project.
- **We were a Lead Supporter of the Parliamentary Friends of Soil World Soil Day event** at Canberra's Parliament House (bottom right). The event sought to focus attention on the importance of healthy soil and to advocate for its sustainable management.
- **Our CEO Dr Michael Crawford showcased the work of the Soil CRC to an international audience,** presenting at the International Union of Soil Sciences Centennial Congress in Florence, Italy, the 'High Level Dialogue' section of the Global Forum on Soil Health in Yangling, China, an industry conference in Hanoi, Vietnam and the International Conference on Decarbonizing Agriculture in Mangalore, India.
- **We continued to support implementation of the National Soil Strategy** with contributions to steering and working groups, and to research which supports its 3 goals – prioritise soil health, empower soil innovation and stewards, and strengthen soil knowledge and capability.

Program 1
Investing in high performance soils

Program Leader: Professor Catherine Allan, Charles Sturt University

Research activities in Program 1 are focused on social and economic aspects of soil stewardship. The distinction between 'researcher' and 'participant' has blurred, as diverse forms of collaborating emerge, including farmer-group-led research projects. Across the program, collaborations happen among researchers and practitioners from 11 grower groups, 7 universities and 5 industry partners. Six PhD students/graduates are contributing knowledge and expertise to this area of work.

Program 1 participants are developing an extensive 'public good package' of information and capacity building activities for researchers, farmer groups and Soil CRC partners. The 3 related outputs in the package will support and enable opportunities to accelerate change and build adaptive capacity in soil stewardship.

The first output involves using markets to reward farmers for improved soil stewardship. In 2023-24, our work has highlighted large global variation in how the costs and benefits of soil stewardship are understood and measured. Researchers explored the implications of this with agri-finance providers and worked towards developing customised co-learning activities with this sector.

The essential elements of stewardship verification approaches to meet the needs of consumers and financial markets were also articulated in the past year, complemented by a thorough review of legal aspects as part of a PhD study. Education materials for use in high schools were also developed to contribute to addressing a previously identified poor understanding by many of Australia's consumers of how soil management relates to food and fibre.

The second output relates to acceptance and use of approaches to soil stewardship among farmers. The first round of 6 social benchmarking surveys was completed in 2023–24, and the next round of surveying commenced. At the same time, other projects considered the benefits and risks of on-farm soil management in detail, specifically related to regenerative agriculture and organic fertilisers.

Part of the work of these projects has been to reframe the narrow, short term economic lens traditionally used for agriculture, to capture a more complete range of risks and benefits. This work is supported by 2 PhD students. Our understanding of best practice knowledge sharing was also enhanced with the completion of a knowledge sharing project. Progress was made in 2 projects led by a farming systems group that built on the lessons from that project by co-creating tools to help groups and other advisors assess potential innovations and share them effectively.

The third output relates to innovative and effective ways of operating and collaborating in complex and uncertain situations. A project of supporting farmer groups' innovations was completed in 2023-24, and the lessons from that experience will add to the growing, comprehensive portfolios of support for soil stewardship.

A highlight of 2023-24 was the graduation of one PhD student, and submission of 3 other theses by students within Program 1.

Although the work in Program 1 is framed as 3 outputs, and separate projects, there are many linkages across the program. In 2023-24, various streams of activity, building on the outputs from previous projects, and complemented by PhD research, were drawn together. This was possible because of the strong networks developed among researchers in this program.

Consolidation of the information in portfolios that are accessible and relevant will continue in 2024-25 and beyond. Much of the learning from Program 1 activities is contributing to the development and implementation of the Soil CRC Adoption Plan.

Program 2
Soil performance metrics

Program Leader: Associate Professor Richard Doyle, University of Tasmania

Program 2 seeks to better understand indicators of soil performance and how these can be used to enhance soil productivity. Twenty grower groups, 5 universities, 2 government research partners and 11 PhD students are developing tools linked to soil management products that will help farmers better manage their soils for increased productivity and profitability.

Program 2 researchers are developing a range of technologies that will enable farmers to cost-effectively collect data for monitoring soil performance. They have progressed development of the BILBY® underground communication node, the BANDICOOT® soil moisture and strength probe and the QUOLL® soil electronic nose. The Soil CRC secured a registered trademark for the latter 2 devices in 2023-24, enabling future commercialisation of the technology.

Our work to commercialise the BILBY® is making steady progress and field trials are underway with interested industry collaborators. The device has undergone redevelopment based on industry feedback to ensure a market-ready and saleable product.

The QUOLL® has undergone a redesign to decrease faults and improve air flow and capability for broader sensing of CO2 and other gases emitted from the soil. Following on from glasshouse trials in 2023-24, the device will now undergo field testing.

A project to commercialise the BANDICOOT® is well underway. The device is undergoing refinement of the sensor tip design to determine the best configuration for build capability and eventual manufacture. Both durability along with the ability to replace tips is being investigated.

Significant progress has been made on the Soil CRC's Lab-on-a-Chip technology, which integrates a 3D-printed microfluidic device with a smartphone app to measure soil nutrients.

Researchers are working with interested research and industry partners to prepare the device for commercialisation. Work also continues to expand the capabilities of this technology to measure soil biological properties. The major focus of testing and research is on assessment of urease, phosphatase, and labile organic carbon.

A project dedicated to matching soil performance indicators to farming systems was completed in 2023-24, providing insights into which soil indicators are most trusted and utilised and which work best for different users. This research will continue as part of a new Soil CRC project to examine the interdependencies between indicators and how they are used in decision making. This is key to the more widespread use and application of farming system appropriate soil testing.

Wrapping up in July 2024, the second phase of the *Visualising Australasia's Soils* (VAS) project has involved working with farmer groups to advance the use cases and load broader datasets into the soil data portal, including 6 million soil moisture data points. A third phase of VAS was approved in 2023-24 and aims to transform VAS into an enduring component of an Australasian soils knowledge system that is self-sustaining and inherently useful for research and education. This phase will harness artificial intelligence to add value to soil performance data, and enhance the reporting of soil quality, function and target values for high performance soils.

Work concluded on surveying and enhancing research data management across the Soil CRC. The project assessed the awareness of data management processes and responsibilities using some key data rich projects across the CRC. The project team developed a research data management guide, templates and training materials to help increase knowledge and responsibility for the development of metadata information on critical datasets.

A project investigating the best soil biological indicators for farmers completed its final field trial sampling and testing in 2024. The assessment of the number and diversity of nematodes emerged as a reliable indicator of soil health. Nematodes account for 80% of all animals on earth by number, so it is reassuring to know that their heathy ecology in soils is an important broad biological indicator for farmers.

Two PhD candidates from Program 2 completed their theses in 2023-24, and 9 more are at various stages of their candidature. Their research is contributing to a number of our projects and helping advance our understanding of soil biological indicators, build our remote sensing capabilities, develop machine learning for better soil moisture monitoring, and create innovative technologies to monitor soil performance.

Case study 1

Matching soil performance indicators to Australian farming systems

Australian farmers and their advisers use a range of tests, observations and other assessments to evaluate the health of their soils. *Matching soil performance indicators to farming systems* (2.1.006) provides new insights into which of these soil indicators farmers are using, and why. The project has addressed knowledge gaps for researchers, providing important context around how farmers are choosing to monitor soil health.

Researchers from Federation University, the University of Newcastle and Charles Sturt University surveyed Australian farmers, agronomists and industry stakeholders to determine which soil indicators they use, how often, what information they provide and why they choose to work with them.

Findings from the survey showed that:

- Chemical tests and visual appraisal of crops and soil are widely used in all agricultural enterprises.
- Biological tests are the least used, with farmers expressing concerns and uncertainties about the use and interpretation of biological tests.
- Farmers conduct soil tests regularly and see a value in testing.
- Farmers' choice of soil indicators is largely driven by in-person interactions such as those with advisors and agronomists, at field days, and staff at farmer groups.
- Tests and assessments are chosen for their relevance to the farming enterprise, ease of sampling and assessment, and suitability to land use.
- Farmers that are not soil testing said barriers include cost, and not knowing how to undertake the tests or use the results.
- Advisors are highly influenced by education and training.

Matching survey results to broader datasets

The project team examined data from the *Visualising Australasia's Soils* (VAS) portal to see if it could be matched to survey results, providing broader insights.

The review revealed that VAS contains vast sets of data that can be used in assessments of soil health and performance. Most soil data in the VAS portal is from topsoil observations and laboratory analysis assessments as part of agronomic research trials, soil monitoring, soil type, and general soil fertility and health assessment.

Researchers cross-analysed survey responses with data in the VAS portal to explore which indicators best suited specific management goals in different landscapes and agricultural systems.

Use case shows potential of data to improve soil performance

The team did a more detailed assessment and produced a use case for how this data could help to better understand farmers' use of soil indicators when managing grasslands for soil performance. Publicly available soil data from two adjacent southeast Australian river catchments was used to develop a spatial data-driven framework that identifies the soil groups associated with pasture health and soil performance.

"The use case showed that soil data can provide valuable insights into soil performance and indicators in use across Australia," said Project Leader Dr Nathan Robinson, a Senior Research Fellow at Federation University's Centre for eResearch and Digital Innovation.

The project team developed a novel framework in the assessment of soil performance, potentially valuable to widespread areas of Australia's agricultural zones. The Digital Soil Mapping approach proved an effective framework for identifying key soil attributes that affect agricultural productivity (e.g. net primary productivity) – pinpointing critical locations for highly productive or less productive soils.

"Using publicly available data means the framework can be scaled across vast areas of Australia's agricultural zones," Dr Robinson said.

Next steps to provide soil indicator guidance

This project has addressed existing research gaps about soil indicators in Australian agriculture. Findings from the project have contributed new insights from the perspective of farmers and other stakeholders in the agriculture sector. These could be used to develop relevant and locally tailored soil quality assessment schemes.

Dr Robinson said the foundational information and findings gathered by the project can help growers, advisers and scientists identify what soil indicators work best and where.

"The research is being extended as part of a new Soil CRC project aimed at producing an enduring resource on key soil indicators," he said.

This phase will deliver co-design workshops with project members from West Midlands Group, AIR EP, Holbrook Landcare Network, Southern Farming Systems and Central West Farming Systems.

"Members will work together to identify combinations of soil type, climate, land use and management practices that will inform soil performance metrics, corrective actions, and management options," Dr Robinson said.

Domain experts, leading agronomists and farmers will be critical to developing fit-for-purpose soil indicators tailored for their region.

A key part of the next project phase will be linking soil indicators to actionable decisions and leveraging existing research and development (including that of the Soil CRC), to provide farmers with guidance for maintaining and improving soil health and performance.

Program 3
New products for soil fertility and function

Program Leader: Professor Megharaj Mallavarapu, University of Newcastle

Program 3 aims to develop new fertiliser formulations, pesticide delivery systems, soil enhancements, microbial carrier products and improved mechanisms for delivering these solutions to farmers. These pursuits collectively aim to enhance soil performance and productivity for farmers. This program brings together 7 grower groups, 7 universities, and 3 industry partners. There are 12 active projects and 8 completed projects, with 12 current PhD students and 6 PhD completions.

Our researchers have made significant contributions to the field, with the successful synthesis of micro-lime and micro-gypsum products, along with the creation of innovative biochars and biochar-clay composites, microbial carriers and high moisture retention products.

A few studies focus on extracting high-grade fertilisers, especially phosphorous, from waste streams. The successful synthesis of novel biochar from the waste streams highlights the program's commitment to resource recovery for potential fertiliser applications, helping to develop the circular economy and reduce the reliance on chemical or synthetic fertilisers.

Key achievements in 2023–24

Biochar-clay innovations

- Designed surface-engineered carbon (biochar) clay-based nanocomposites.
- Completed synthesis and characterisation of various formulations
- Commenced glasshouse experiments, showing potential as potent phosphorous fertilisers for agricultural crops.

Plant growth and manure studies

- Ongoing glasshouse and field trials to evaluate manures as phosphorous fertilisers.
- Investigating the impact of raw versus treated manures on both plant growth and organic matter degradation.

Slow-release pesticide delivery systems

- Developed clay and polymeric beads loaded with pesticide imidacloprid developed as low-residual pesticide delivery system.

Enhancing soil structure

- Progressing development of nanostructured lime and gypsum products.
- Established superior reactivity, dissolution rates, and mobility of these products into subsoil.

Nano-lime and nano-gypsum application

- Demonstrated significant potential for addressing subsoil acidity and sodicity with surface applications.
- Achieved higher use efficiency and reduced application rates by up to 25%.

Moisture retention products

- Developed high moisture retaining organic-based and clay-based materials.
- Positive effects on wheat growth, indicating potential for commercialisation.

Microbial carrier products

- Innovations in moisture retention and microbial carrier products designed for rhizobia.
- Enhancing efficacy of beneficial soil microbes, contributing to nitrogen fixation, root disease protection, and symbiotic interactions with plants.
- Field trials underway across various locations in Australia.

Program 4 Integrated soil management solutions

Program Leader: Dr Lukas Van Zwieten, NSW Department of Primary Industries and Regional Development

Program 4 aims to develop cost-effective and sustainable soil management solutions to build more productive and resilient soil. This will underpin a dynamic, sustainable, and profitable Australian agriculture sector. The projects within Program 4 engage with 15 grower groups, 7 universities, 2 government research partners and 8 current PhD students.

The program is delivering a suite of tools, including nature-based solutions such as cover and intercropping, a better understanding of regenerative farming and soil resilience to drought, and the use of traditional and novel amendments to improve surface and subsurface soils.

Fifteen field trials across Australia are delivering information that is being used in the development of models to predict the impacts of soil constraints and their amelioration. A number of these field sites are led by grower groups with support from research organisations, leading to new networks that will help to strengthen research and development in future years.

Program 4 has 3 key outputs that will collectively deliver innovative soil management techniques, products, data and models that can be used by farmers to better manage their soils.

Output 1: Novel plant and systems-based solutions to improve soils

A broad interest in cover cropping, mixed species cropping, intercropping and regenerative agriculture practices has stemmed from the knowledge that ground cover and plant species diversity have multiple benefits. These include maximising carbon inputs into soil, through sustaining the diversity of soil biological communities and functions that they perform, and contributing to soil physical properties, including protecting the soil from erosion.

Field sites in NSW, Victoria and Western Australia are ground-truthing the role of cover crops and are investigating how these systems approaches can build soil carbon and resilience. Our *Regenerative farming systems* project (4.1.004) highlighted the interest and potential outcomes of regenerative farming systems. Key outcomes from this project demonstrated changes in the functionality of carbon in soil, being more labile in regenerative systems, while also shifting the soil microbial community to a potentially more stable less reactive community.

The completion of our *Plant-based solutions to improve soil performance* project (4.1.002), highlighted both the potential benefits and potential risks of cover cropping. In particular, the project showed soil water may be limiting in some seasons following cover cropping, and that species selection and time of termination are critical in preserving water in the soil profile for the cash crop. Temporary intercropping was identified as a potential practical option for increasing plant diversity in cropping systems with minimal cost and deviation from standard farming practice.

Ongoing research continues to support grower group field trial sites investigating cover crops, as well as supporting the assessment of detailed soil water dynamics occurring as part of another project. At the Riverine Plains trial site in Victoria, an extensive array of soil monitoring probes has been used to quantify and model changes to water storage and drainage, and investigate the water dynamics in rotations with cover crops. This work is further supported by a PhD student who continues to refine models for water use in summer rainfall cover cropping scenarios. Cover crops have so far demonstrated benefits to the infiltration of water into soil, likely through improvements to soil physical structure such as aggregation and soil surface properties.

Output 2: Novel physico-chemical based solutions to improve soils

Field sites continue to address a range of vexing constraints to productivity, including sub-soil sodicity and soil structural decline, toxicities associated with alkalinity or acidity, nutrient deficiencies, non-wetting properties and poor water holding capacity. Ameliorating these constraints can provide significant long-term benefits to productivity, and these field sites, many of which are into their third of fourth year of assessment, are well placed to capture these benefits.

The field sites have also been used for farm walks and educational activities, with over 300 farmers, industry professionals, advisors and school students learning from the sites and new soil management techniques.

Field trials in Lockhart, New South Wales and Burdekin, far north Queensland are assessing a range of technologies for enhancing the structure of sodic subsoils to improve root access to water and nutrients. These include the subsoil placement of stoichiometrically balanced organic amendments, gypsum and bespoke carbon-coated minerals.

The 2024 winter crop (canola) at Lockhart experienced a dry start to the season, and continued monitoring of water dynamics at the site will facilitate the understanding of the role of sub-soil moisture on crop yield. The Burdekin sugarcane field site has continued to foster significant interest in the reuse and deep placement of organic residues in an attempt to improve the structure of sodic sub-soil and improvement in soil health. Over 50 people visited the open soil pit to observe changes to the soil profile.

Field trial sites on highly calcareous soils on the upper Eyre Peninsula in South Australia have shown that a package of higher seeding rates, increased fertiliser inputs and a fungicidal seed dressing produced the best growth and highest grain yields. A bespoke carbon-coated mineral fertiliser that delivered slow-release phosphorus also provided significant benefits to crop production.

In contrasting soils in the southeast of South Australia, foliar application of iron minerals to address root uptake deficiency significantly improved legume production, while also addressing challenging weed issues. Field sites at Kweda and Bullaring had low crop yields from the 2023 crop and no treatment differences were detected. The 2024 crop has been sown and good crop establishment has been observed, underpinning a successful assessment of novel soil management options to improve soil carbon and productivity.

Output 3: Soil improvement decision support tools

The Soil CRC has developed novel ways of representing and predicting the impact of soil constraints on crop production in models and decision support tools. Data driven methods for diagnosis of chemical and soil water holding capacity limitations have been developed and how soils respond to traditional and new ameliorants is now being represented in models.

Bringing the Soil CRC efforts in dynamic and data centric soil constraint and amelioration modelling together into a suite of tools will give Australian producers a key resource to use when reengineering soils for higher performance. Workshops with growers identified that tools and apps have become ubiquitous in farm decision-making, meaning that these will be an effective method of bringing the Soil CRC's research and modelling efforts into the hands of growers.

Case study 2

Integrated solutions for accessing soil moisture

Many Australian crops are not reaching the potential yields of the rainfall they receive. That is because the soils in which they grow have physical and chemical components, usually in the subsoil, that are limiting root growth. This limits a plant's usage of available water and reduces nutrient uptake. This reduction in yield represents major opportunity losses for growers.

Integrated solutions for underperforming constrained soils: accessing soil moisture (4.2.004) is quantifying crop responses to different management practices, on key soils across 4 cropping regions. The project is a collaboration between the NSW Department of Primary Industries and Regional Development, Agriculture Victoria, Murdoch University, Charles Sturt University and Burdekin Productivity Services.

Understanding how subsoil affects a crop's ability to access water is an important step in improving both productivity and water use efficiency, as transpiration (water's movement through a plant) is linked to crop yields.

"The ability of roots to grow through soil unhindered by physical or chemical constraints is key to making full use of the available water resources," said Dr Murray Hart, Project Leader and Research Officer at the NSW Department of Primary Industries and Regional Development.

Long-term sites enable testing of multiple variables

The project has established one medium-term and 3 long-term (5 plus years) trial sites: Wonwondah in Victoria (medium-term site), Lockhart in New South Wales, Clare in Queensland and Kweda in Western Australia.

The sites are putting recent advances in soil amelioration (improving quality with either inorganic or organic chemical products) techniques into practice, to enhance understanding of how these techniques can improve crop rooting depth, water use, productivity and ultimately – yield.

The project is also assessing the amelioration strategies from an economic perspective, to help farmers choose the right strategies for them.

"Economic assessments of amelioration strategies will be developed to guide the adoption of better soil management strategies by farmers. By maintaining experiments for more than 5 years, the project will address the most challenging problems of managing hostile soils," said Dr Hart.

Findings from the sites to date have been varied. A benefit of long-term sites is that practices can be tested over multiple seasons, with some ameliorants not showing benefits in their first application. This is often the case for soils with constraints including high sodium or dispersiveness – where soils collapse when wet.

It also allows for techniques to be tested in different weather conditions. High rainfall can reduce the impact of soil constraints, so understanding how soil will respond to these conditions can help growers be more efficient with ameliorant application.

Between them, the sites are testing amelioration effects on sugarcane, and broadacre crops such as barley, lupin, faba bean, canola and wheat.

Sugarcane ameliorants in focus

Burdekin Productivity Services (BPS), a levy-funded sugarcane agronomic service and Soil CRC participant, is managing the Clare site in Queensland. Rob Milla, Manager at BPS, said it's great to be able to test novel soil treatments for sugarcane within the region.

Some soils in the region are quite challenging for growers, including heavy clays that are sodic with a high moisture content.

"The site presents several soil constraints including compacted and structureless subsoil that is sodic and magnesic, making it an ideal candidate for treatment. To assess the extent of these constraints, soil pits were dug prior to establishment, revealing waterlogged soils from approximately 20cm down."

Because of the long growing season for sugarcane, the site has only had one harvest so far – in July 2024. It was a high-yielding season with minimal difference observed from the amendments utilised at the site – different combinations of gypsum, mill mud and ash, compost, reactive silicate and FOGO (food organics and green organics) outputs.

Addressing subsoil amelioration is complex

Climatic conditions have a huge impact on amendments. In dry conditions, especially in early growth stages, a lack of moisture can prevent amendments from improving soils. If conditions are much wetter than average, crops may not be water-limited and can effectively bypass otherwise significant constraints.

Initial results indicate that organic matter has the potential to improve water use and crop productivity for sodic, clay soils in Victoria and New South Wales – provided they have a minimum carbon to nitrogen ratio.

It is too early for the effectiveness of the ameliorants to be attributed to improved nutrition, better physiochemical conditions or a combination, but ongoing testing will provide further insights.

Capitalising on established field sites

Three of the trial sites from this project will be extended, under a follow-on Soil CRC project: *Capitalising on established field trials for ameliorating (sub)soil constraints* (4.2.006). A further 3 sites from other Soil CRC projects will also be extended under the project.

Led by Professor Richard Bell from Murdoch University, the project will continue investigations for 2 more cropping seasons. This will enable the capture of more data on climate variability, as well as economic analysis of outcomes.

Research project updates

Rewarding soil stewardship

Project 1.1.004

Project leader: Dr Nicholas Pawsey, Charles Sturt University

Duration: 2022–2025

Participating organisations:

- Charles Sturt University
- Federation University Australia
- University of Southern Queensland
- Birchip Cropping Group
- Riverine Plains
- Western Australian No-Tillage Farmers Association

Summary

A previous Soil CRC project, *Collaborative approaches to innovation*, identified the level to which banks, agri-investors and other agricultural industry finance stakeholders and growers value soil stewardship, and how it can be encouraged and rewarded.

The current project focuses on activating financial markets to reward soil stewardship and unlock investment in soils. The research aims to demonstrate a stronger link between good soil stewardship and grower financial profitability. This involves improving connections between researchers, growers and financial markets, and translating soil science for the finance sector.

A range of potential mechanisms and pathways have been identified including sustainability-linked loan schemes, risk assessment and other financial decision tools, government programs and policies, and insurance products.

Activities

During 2023-24, the project team:

- Continued to leverage our previous work with the Australian Accountancy Standards Board (AASB) to advance corporate soil reporting.
- Completed a wide ranging, international literature review on the financial viability of soil stewardship, providing insights on the financial implications of a range of soil stewardship practices.
- Completed and analysed on-farm interviews with the project grower group partners to understand their perspectives on the financial costs and benefits of soil stewardship, and alternative modes of rewarding their investments in soil health.
- Prepared a comprehensive report on factors impacting the financial viability of soil stewardship practices in different contexts, and an evaluation of approaches taken by soil scientists to determine the financial costs and benefits of these practices.
- Developed a design protocol for co-design workshops with financial market participants (agri-lenders, argi-investors, agri-advisors, rural land valuers, soil researchers, grower group representatives and leading soil stewards). These workshops will focus on establishing further innovative soil stewardship incentive pilot activities.

Results and findings

- The literature review provided important details on the various dimensions of the financial viability of soil stewardship, including the net present value of the practices and their overall impact on farm gross margins, net profit and risk.
- The grower group interviews supplemented the academic literature review and previously completed interviews with agri-investors and corporate agricultural entities, providing further insights on the financial viability of soil stewardship and appropriate means of incentivising the practices through financial markets.

Next steps

The project team will deliver the co-design workshops in 2024–25 to complement their ongoing work. The intention is to facilitate agri-investment and lending decisions through the promotion of soil reporting by corporate agribusinesses.

Knowledge sharing for good soil stewardship

Project leader: Dr Hanabeth Luke, Southern Cross University

Duration: 2021–2023

Participating organisations:

- Southern Cross University
- Murdoch University
- Federation University Australia
- Agricultural Innovation and Research Eyre Peninsula
- West Midlands Group
- Central West Farming Systems
- University of Newcastle
- Charles Sturt University
- Birchip Cropping Group

Summary

Effective knowledge sharing in agriculture is complex and multifaceted. Farmers often face barriers in accessing and implementing new knowledge, such as geographic isolation, time constraints, and an overwhelming amount of information that may not always be relevant to their situation.

The diversity of farming systems means that a one-size-fits-all approach to knowledge sharing can be ineffective. Each region and community have unique attributes and challenges, such as varying demographics, localised issues and trends in the uptake of innovations. Engaging them effectively requires understanding their context, respecting their experiences, and offering knowledge sharing methods that fit their needs.

This 2-year project aimed to:

- Identify and test knowledge sharing strategies to increase the number of landholders actively engaged in soil health improvement practices across 4 farming regions.
- Identify policies and regulations that enable or constrain knowledge sharing.
- Provide recommendations for training and engagement for others involved in extension.
- Create a knowledge sharing guide for grower groups.

Activities

Tailored knowledge sharing plans were co-developed with project researchers and the 4 participating grower groups: Agricultural Innovation and Research Eyre Peninsula in South Australia, West Midlands Group in Western Australia, Central West Farming Systems in New South Wales and Birchip Cropping Group in Victoria. The groups considered which strategies and approaches were most effective for engaging different target groups in each region, including underrepresented groups such as women and youth.

The knowledge sharing plans were delivered by the relevant grower groups and trialled over a 2-year period. They used a combination of digital, print and face-to-face engagement strategies. Several regions trialled hands-off approaches to engagement, focusing on promoting and supporting farmer-led engagement through a 'sticky beak' type of field event.

The grower groups maintained process diaries, documenting their observations and experiences about what was working and what was not. These were discussed at regular project meetings allowing the groups to learn from each other's triumphs and challenges, fostering a community of practice.

Ongoing discussions about the different engagement approaches helped groups identify the strategies and activities best suited to their local context.

The research also explored the use and effectiveness of digital engagement tools, such as social media, podcasts and e-newsletters. Interviews and analysis of the process diaries were used to assess their effectiveness.

Federal and state-level policies and regulations that either enable or constrain knowledge sharing were thoroughly reviewed and analysed.

Results and findings

- Knowledge sharing experts need to be more than just information sources; they must build relationships, foster collaboration, and create social opportunities for farmers and growers.
- Face-to-face engagement remains the most effective method for knowledge sharing, despite the rise of digital communication. This includes engaging with experts and grower groups, as well as peers.
- Digital communication should be used as a supporting tool, with clear articulation of audience and purpose. Monitoring and reviewing outputs should be utilised to improve engagement.
- Effective knowledge sharing requires understanding farmer needs, engaging respectfully, focusing on quality interactions, and responding with evidence-based solutions.
- Knowledge sharing plans help grower groups have a clear and actionable approach for who they want to engage, why and how.
- While federal and state government policies support better soil management, current top-down, tech-based knowledge sharing is not proving effective. Clearer metrics are needed to assess what truly works.

Next steps

At least 3 of the 4 grower groups plan to continue using the process diaries for ongoing event evaluation and staff training.

The process diaries are also being used in the new *Packaging Soil CRC tools to enhance extension and adoption* project (1.2.008) led by West Midlands Group, focused on improving engagement in soil and land management and informed by the insights gained in this project.

The Knowledge Sharing Guide will become a component of the Soil CRC's Adoption Plan and has been integrated into the *Supporting Change in Regenerative Systems* (ENVR6009) subject at Southern Cross University.

An example of effective face-to-face engagement: Nearly 600 people attending a Birchip Cropping Group event. Photo: Kelly Angel, Birchip Cropping Group.

Agricultural social benchmarking surveys

Project 1.2.007

Project leader: Dr Hanabeth Luke, Southern Cross University

Duration: 2023–2025

Participating organisations:

- Southern Cross University
- Charles Sturt University
- North Central Catchment Management Authority
- Agricultural Innovation and Research Eyre Peninsula
- West Midlands Group

Summary

Farmers and their on-farm management strategies are critical to the ongoing health of Australia's soils, economy, and environment. Continuing on from the Soil CRC's previous research into what drives farm management decisions, this project will help develop a longitudinal understanding of farmer practices, aspirations and motivations across farming regions.

The project team is delivering 3 follow-up social benchmarking surveys of land managers in North Central Victoria, on the Eyre Peninsula in South Australia and in the Northern Wheatbelt in Western Australia.

The information collected will inform the activities of the Soil CRC and participating farming groups, helping to increase stakeholder engagement and adoption.

Activities

- The North Central Victoria survey was co-developed and pre-tested with regional partners and distributed in mid-2024.
- The Eyre Peninsula survey was co-developed and pre-tested with regional partners and distributed in the second half of 2024.
- The Western Australia survey was initiated in September 2024. Meetings were held with regional partners and Wheatbelt farmers to increase connectivity and boost the response rate in this region.

Next steps

As surveys are distributed on the Eyre Peninsula and responses are received from North Central Victoria, we hope to maintain the strong response rate as achieved in the first round of surveys, at 31% and 34% respectively. A 4-page summary of results will be provided to local partners, with a more comprehensive report to follow.

The Western Australia survey will be implemented in early 2025. Survey data from all 3 will be analysed and documented in publicly available reports.

A new Soil CRC project (1.2.009) will complete the follow-up rural landholder surveys in Central West NSW, Tasmania and the Victorian Wimmera region. This longitudinal research will lead to increased farmer engagement and support, with the aim of improving soil management, farming productivity and ultimately, farming system resilience across Australia.

Defining the benefits of regenerative agriculture

Project 1.4.004

Project leader: Dr Christine Storer, Charles Sturt University

Duration: 2021–2025

Participating organisations:

- Charles Sturt University
- Soils For Life
- Federation University Australia
- Harper Adams University (United Kingdom)

Summary

The economic, environmental and social benefits of regenerative agriculture have not yet been fully defined. There is a need to better understand the interactions between the development of healthy ecosystems (such as soil health) and the production of high-quality food and fibre.

This project is developing an integrated framework that can be used to assess a wide range of economic, environmental and social impacts of agriculture, allowing comparisons among different approaches.

The result will be a relevant, practical and usable decision support framework for farmers considering transitioning to regenerative agriculture.

Activities

- The project team completed a critique of social benefits literature relevant to regenerative agriculture and are preparing a journal article for submission.
- An online survey was launched to assess the social, economic and environmental preferences of farmers. Follow-up farm visits and interviews have commenced.
- Six selective farm case studies were developed, which examine the economic, social and environmental co-benefits of adaptive regenerative farming management and how they link to healthy soil practices.
- The team has been developing and testing frameworks to assess costs and benefits of regenerative farming.
- Soil CRC PhD student Pradeep Rai from Charles Sturt University joined the project team. His PhD is expanding on the research findings in the longer term.

Results and findings

The project has identified common themes from the case studies, finding that regenerative practices were primarily focused on livestock and pasture holistic farming systems, with trialling of changing management practices such as smaller paddocks for controlled stocking and rotations, maintaining ground cover and living roots, water flow management, nurturing a wider range of plants and microbes, and limiting use of synthetic chemicals and fertilisers.

A diverse range of environmental benefits were reported including increased biodiversity and improved health of soil, pastures, microbes, animals and livestock as well as water infiltration, retention, reduced run off and improved water quality. The social benefits reported were more broadly defined from learning and group activities and support systems to benefit the community, family and work/life balance. The economic benefits were mostly focused on improved production, not so much the flow on impact on costs, income, profit or equity.

Next steps

With another year to go, the project is continuing to develop the decision support framework and define what regenerative agriculture means for Australian agricultural enterprises.

Project 1.4.005

A new tool for assessing the benefits of adopting new farming practices

Project leader: Dr Nathan Craig, West Midlands Group

Duration: 2022–2024

Participating organisations:

- West Midlands Group
- Corrigin Farm Improvement Group
- Central West Farming Systems
- Charles Sturt University

Summary

While profitability is often the driving force behind adoption of new farming practices, there are many other factors. These can include emotional, social, community, environmental and other emerging business risk factors.

This project is creating a reporting tool to communicate the risks and benefits of new farming technologies and practices. The tool will assist grower groups and extension agencies to better reach farmers, enabling informed decision making.

The tool will also enable research outputs to be shared in a standardised way that allows for better evaluation and balance between the short- and long-term soil health benefits and improved farm profitability.

Activities

- A farmer survey was developed and implemented to gain feedback on farmer perceptions of risk and reward in decision making.
- Survey results were cross-referenced with grower group experience to define the most important considerations for farmers when deciding whether to adopt a new farming practice.
- Survey feedback was used to develop a draft report (known as the 'risk/reward tool'), which was then refined by testing with grower groups and farmers.

Results and findings

- User feedback confirmed that the reporting format currently used by the industry is adequate but lacks a robust financial analysis component.
- Grower group feedback indicated that there is significant variability in how innovation is presented to farmers for consideration of adoption.
- The outcome is a suite of reporting tools (a full report template, 4-page report template, and an infographic template) that grower groups and other next users can use to develop communication material for farmers to help them better understand the risk and reward of new farming practices and technologies.

Next steps

- The project team will complete further user testing of the suite of tools to inform the final product.
- Grower group case studies will be developed to highlight the dynamic use of these reporting tools in a range of use-case scenarios, along with user documentation.

Project 2.1.005

Smelling soil: eNose development

Project leader: Dr Shane Powell, University of Tasmania

Duration: 2022–2024

Participating organisation:

- University of Tasmania

Summary

This project continues development of a low-cost electronic smell sensor — or 'eNose' — for measuring soil gas emissions and detecting changes in soil conditions. The aim is to build a useful and useable device that can help growers understand what is happening in their soil.

The eNose will detect the 'aroma' of soil as a rapid test of activity in soil, helping growers make informed decisions about how to best manage their soil to be more productive and resilient to environmental change.

The project focuses on 2 areas: building a robust device suitable for field use and investigating the relationship between eNose data and significant changes in soil biological activity.

Activities

- IP Australia approved the Soil CRC's trademark application for the QUOLL® eNose, enabling future commercialisation of the device.
- The project team continued to test the abilities of the QUOLL® in glasshouse and field trials.
- The user interface was further enhanced, and a user guide was developed to enable users to access and analyse data.
- Further refinements were made to improve the device's useability.
- Discussions with interested industry and research partners are ongoing.

Results and findings

- Glasshouse trials provided a sizeable dataset for continued work to understand the QUOLL® outputs and optimise the data processing.
- The eNose was able to detect changes in activity in the soil but interestingly, the replicates (sub samples) did not respond in an identical manner, which reflected other biological measurements that were made.

Next steps

The research team are continuing field trials and developing the data analysis and modelling to provide clear outputs. The QUOLL® is 2–5 years away from hitting the shelf as a product that farmers can purchase and use on their farms.

While the current project concludes in 2024, the Tasmanian Institute of Agriculture (TIA) has received funding from the Tasmanian Government's Agricultural Development Fund to further develop the QUOLL®. This will allow it to help farmers better understand on-farm carbon sequestration processes.

Project 2.1.007

Affordable rapid field-based soil tests: Phase two – soil organic carbon

Project leader: Dr Liang Wang, University of Newcastle

Duration: 2022–2026

Participating organisations:

- University of Newcastle
- University of Tasmania
- Burdekin Productivity Services
- Herbert Cane Productivity Services

Summary

This project is addressing the issue of costly and time-consuming laboratory soil health measurements, by providing farmers with affordable, rapid and accurate in-field solutions.

It builds on the Soil CRC's *Affordable rapid field-based soil tests* project (2.2.004), which developed the Lab-on-a-Chip – a 3D-printed microfluidic device for rapid in-field measurement of soil chemical properties including soil pH and macronutrients such as nitrogen, phosphorus and potassium.

Phase 2 will extend the functionality of the Lab-on-a-Chip to rapidly determine soluble soil organic matter and key biological functions. When combined with a smart phone app, this new technology will benefit farmers by providing simple, quick and affordable in-field tests to support decision-making.

Activities and results

The team successfully integrated the permanganate oxidisable carbon (POXC) method into the Lab-on-a-Chip system. This enhances safety and simplifies the procedure for rapid and accurate measurement of labile carbon in soil samples.

They developed and validated protocols for p-nitrophenyl-based soil enzyme analysis, observing significant variations in enzyme activities influenced by soil properties. The Lab-on-a-Chip device can now do efficient field analysis of enzymes.

The modified Berthelot reaction (salicylate method) was proven suitable for measuring urease activity and ammonium levels, crucial for understanding nitrogen availability and improving fertilisation strategies.

These achievements mark substantial progress in the project's goal of advancing soil health assessment technologies.

Concurrently, the project team is conducting commercialisation and market studies to inform the device's design and cost (project 2.2.007).

Next steps

- Having collected varied soil samples from 10 locations across western and mid-NSW, the project team will now test soil enzymes, labile carbon, nitrate and other characteristics using the Lab-on-a-Chip device and compare the results to conventional laboratory methods.
- The intention is to develop a smartphone app that can automatically recognise the Lab-on-a-Chip and collect colorimetric data, providing quantified results for the target characteristics.
- The team will conduct field validation of their nitrate test using 40 3D-printed Lab-on-a-Chip devices.
- They will develop the device using a mould injection method to facilitate larger-scale field testing.

Project 2.1.008

Measuring soil microbes

Project leader: Dr Michael Rose, NSW Department of Primary Industries and Regional Development

Duration: 2021–2024

Participating organisations:

- NSW Department of Primary Industries and Regional Development
- Wheatbelt NRM
- Birchip Cropping Group
- Central West Farming Systems
- Northern Grower Alliance
- Primary Industries and Regions South Australia
- Southern Cross University
- Griffith University

Summary

This project aims to increase our understanding of the soil microbial indicators that drive agronomic decision-making, to improve soil biological performance, ecosystem services and agricultural productivity.

The project is evaluating a broad suite of microbial indicators and assessing their relevance to agronomic or environmental outcomes, such as crop yield, soil structure and nutrient availability.

Samples are being taken across broad spatial and temporal scales to determine whether relationships between indicators and functions can be generalised, or whether they are site or seasonally specific.

Activities

- Over 400 soil samples have been collected. In-depth analysis of all data from the first growing season was completed and analysis of the samples from the second season commenced.
- Selected soil samples (i.e. microbial indicator measures) were sent for metagenomic sequencing to provide increased resolution of microbial dynamics. This will also be used to show farmers how to interpret this kind of analysis.
- The project team are planning extension activities, including written material (e.g. fact sheets) and presentations to grower groups and at field days.

Results and findings

- Data analysis of the first growing season has shown the value of nematodes as biological indicators – responding to management practices such as fungicide application and crop rotations and reflecting food web structure (e.g. fungal to bacterial ratios).

Next steps

Statistical analysis of the final data set will now be completed, and the results will be used to prepare a paper on the effects of plant diversity on microbial indicators. The analysis will also inform a second paper on soil amendments on calcareous soils.

Recommendations will be made on which microbial indicators should be included as routine monitoring tools for increased agricultural productivity and resilience to environmental stressors such as drought.

Improved soil data management

Project 2.2.005

Project leader: Dr Nathan Robinson, Federation University Australia

Duration: 2021–2023

Participating organisations:

- Federation University Australia
- Charles Sturt University
- Manaaki Whenua Landcare Research (New Zealand)
- NSW Department of Primary Industries and Regional Development
- University of Tasmania

Summary

The Soil CRC is producing a large amount of new data across its 4 research programs. This project aimed to ensure data generated by Soil CRC projects is easily findable and accessible as well as reliably stored, appropriately shared and attributed, analysed and visualised.

Through co-design and trial with Soil CRC projects, this project developed guidelines, processes and policies that support the discovery and re-use of research data. This will make it easier for researchers, farmer groups, growers and advisors to contribute soil data including sensor data streams into automated systems as well as promote FAIR data (findable, accessible, interoperable, reusable).

Soil data that is both spatially and temporally explicit will help researchers use the data for foresight and allow multiple outcomes from data. This is also important for farmers, as being able to use soil data for decision-making is critical for optimising their soil productivity.

Activities

- High value use cases linked to current and future Soil CRC project milestones were selected and supported in their data management activities.
- Recommendations for making soil data generated through the Soil CRC projects FAIR were developed, including licensing and identification of data storage solutions.
- A Soil CRC Data Management Plan (DMP), guidelines and template were developed and socialised for participants to use in their projects.
- The training resources on data management, including a glossary of terms, training videos and webinars, were made available to Soil CRC participants to guide those managing data in their projects.

Results and findings

- The research found that a collective Soil CRC understanding of data management is limited and data is not often easily findable or shared within proper process or policy guidance. Participants' data management practices and systems varied widely, and many were unfamiliar with research data management terminology or accepted good practice.
- Participants also reported finding it difficult to calculate the cost of good data management.
- Participants identified a need for further training and education in all aspects of research data management, but most noticeably in the areas of data privacy, security, storage, standards, documentation, licensing, sharing and retention.
- Establishing best practice in research data management and its related infrastructure and data carpentries requires a coordinated effort from researchers, institutions, funding agencies, program leads and policymakers.
- Continued dialogue, training programs, and sharing of best practices can contribute to overcoming challenges and exploring opportunities for progress, which will inevitably lead to improved data management practices in research projects for both those funded by the Soil CRC and beyond.
- Key professional roles supporting data management and enduring online resources were identified as options to secure the data generated through the Soil CRC and for future research purposes.

Next steps

The project identified resourcing solutions to derive enduring value from vast arrays of data collected through the Soil CRC. By being proactive and clearly defining the benefits of better data management, the Soil CRC has an opportunity to guide the next generation of researchers.

Project 2.2.006

Commercialising the BILBY® – a below ground wireless sensor node

Project leader: Dr Marcus Hardie, University of Tasmania

Duration: 2023–2025

Participating organisation:

- University of Tasmania

Summary

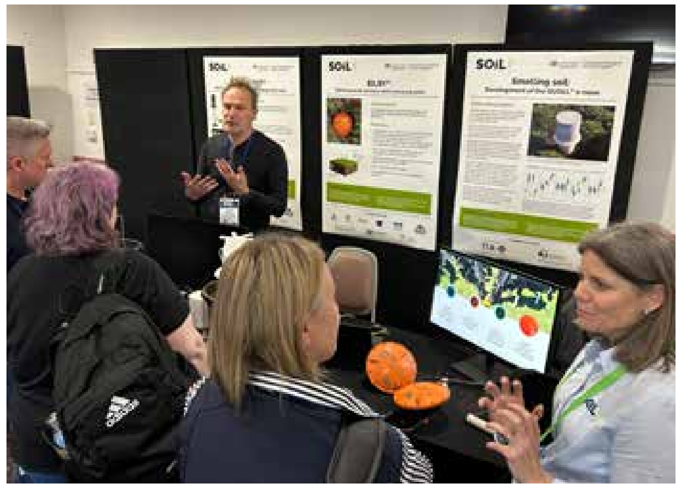
The BILBY® is a below-ground wireless communications node that sends data from soil moisture sensors to an above-ground receiver between 100 and 1,000 metres away, depending on installation depth, soil type and terrain.

The BILBY® allows farmers to install soil moisture probes complete with power supply and communications, completely underground, keeping it safe from damage by stock, machinery or pests.

This project will increase both the technical and commercial readiness of the BILBY® with the aim of delivering a field-tested, pre-commercialisation device that is ready for commercial investment, compliance testing, marketing, and manufacturing.

Activities and results

- Two field trials have been established with industry partners to co-develop and evaluate the BILBY® in real world scenarios.
- Trials include a range of gateways, soil moisture sensors, depths of burial, soil types and distances between BILBY® nodes and gateways.
- Data from field trial was successfully 'piped' to industry partners proving end-to-end connectivity and compatibility of the BILBY®.
- The BILBY® can send data from a depth of 30cm to a gateway located 150m away with a minimum of 95% successfully received packets.
- A method for improved installation was trialled and found to increase transmission by 5-10 decibel-milliwatts (dBm).
- Enclosures were re-engineered to be more waterproof and enable on-off switching without having to open the enclosure in the field.
- Industry feedback has led to design adjustments and improvements in the firmware.
- Negotiations with a potential commercial partner are progressing.
- A commercialisation partner has independently established a BILBY® trial to test the effect of crop biomass of transmission performance.



Next steps

- Review and refactor firmware and hardware to provide a commercially ready product for manufacture and distribution.
- Continue to monitor commercial trials.
- Negotiations with the potential commercial partner to licence the BILBY® for scalable adoption by Australian growers.

Project 2.2.008

Commercialising the smart penetrometer (BANDICOOT®)

Project leader: Dr Marcus Hardie, University of Tasmania

Duration: 2023–2025

Participating organisations:

- University of Tasmania
- Burdekin Productivity Services
- Birchip Cropping Group
- Riverine Plains Inc
- Southern Farming Systems

Summary

The Soil CRC's BANDICOOT® soil profiling tool simultaneously measures soil moisture, penetration resistance (compaction), salinity, and apparent conductivity.

This project seeks to continue the technical development of the BANDICOOT® and commence its commercial readiness. It will also undertake market analysis and gather grower feedback.

Commercialisation and manufacturing of the BANDICOOT® will give Australian growers' greater ability to measure and manage irrigation and soil moisture.

Activities and results

- A prototype BANDICOOT® was prepared for demonstration at the 2024 Soil CRC Participants Conference.
- Previous sensor tips were retested, and numerous tip designs evaluated to guide the next iteration of a 'manufacturer-able' sensor tip.
- Earlier sensor tip designs were found to cause resonance at 50 megahertz (MHz), the expected operating frequency for detecting soil moisture, leading to difficulty calibrating and unreliable estimation of soil moisture, and thus a need to explore new sensor tip designs and alternate operating frequencies.
- A range of alternate sensor tips have been designed and tested for their electromagnetic characteristics.
- The method for calibrating the sensor tip has been developed including the creation of scripts for automating evaluation of tip performance using a standard set of outputs.
- Operating at up to 100MHz was also explored, however this was found to result in phase change and was therefore unable to be calibrated.
- A new probe topology was identified which shows consistent performance across the 50-250MHz range.
- Significant refinements were made to the device's firmware.
- Initial concept design work for a bespoke electronics system commenced.
- The battery plug pack lock design was modified to enhance connection and use.

Next steps

Project team member Simon Edwards from the Tasmanian Institute of Agriculture has been selected to participate in the Beanstalk Drought Venture Studio, funded by the Australian Government's Future Drought Fund. This innovation program will help validate the commercial viability of the BANDICOOT® and develop a clear pathway to commercialisation.

A new project has commenced with Charles Sturt University to undertake market research on the BANDICOOT® with growers

Visualising Australasia's Soils: extending the soil data federation

Project leader: Associate Professor Peter Dahlhaus, Federation University Australia

Duration: 2021–2024

Participating organisations:

- Federation University Australia
- Manaaki Whenua Landcare Research (New Zealand)
- Southern Cross University
- University of Newcastle
- Agricultural Innovation and Research Eyre Peninsula
- Birchip Cropping Group
- Burdekin Productivity Services
- Central West Farming Systems
- Corrigin Farm Improvement
- Facey Group
- FarmLink Research
- The Gillamii Centre
- Hart Field Site Group
- Herbert Cane Productivity Services
- Holbrook Landcare Network
- Liebe Group
- MacKillop Farm Management Group
- Mallee Sustainable Farming
- North Central Catchment Management Authority
- Riverine Plains Inc
- Southern Farming Systems
- Western Australian No Tillage Farmers Association
- West Midlands Group
- Wheatbelt NRM
- Wimmera Catchment Management Authority

Summary

This project aims to provide Soil CRC researchers and the agriculture industry more broadly with access to data, information and knowledge on Australasian soils. The first phase of the project, completed in 2021, saw the launch of the Visualising Australasia's Soils (VAS) spatial data portal. The VAS portal provides an online place to discover and share soil information, activities and research from Australia and New Zealand.

This phase of the project is adding greater functionality to the VAS portal, including a self-serve data management system, improved filtering and reporting, seamless interoperability with the Australian National Soil Information System (ANSIS) and the inclusion of soil sensor data.

Key objectives are motivating soil data custodians to make their data 'Findable, Accessible, Interoperable and Reusable' (FAIR) and aligning with other initiatives to maximise discovery and reuse.

Activities

During 2023-24, the project team:

- Developed 4 use-cases (case studies) to help work through the barriers to data sharing.
- Revamped the VAS portal, adding a landing page that includes links to more information and resources such as user guides.
- Uploaded soil data from VAS participants, with a total of 16 contributors, 2,892 sites, 9,878 samples, and 201,967 observations, ranging from 1988 to 2024.
- Added over 600 million soil moisture and temperature probe observations from Southern Farming Systems.
- Added new functionality to the soil data reporting, specifically metadata reporting.

Results and findings

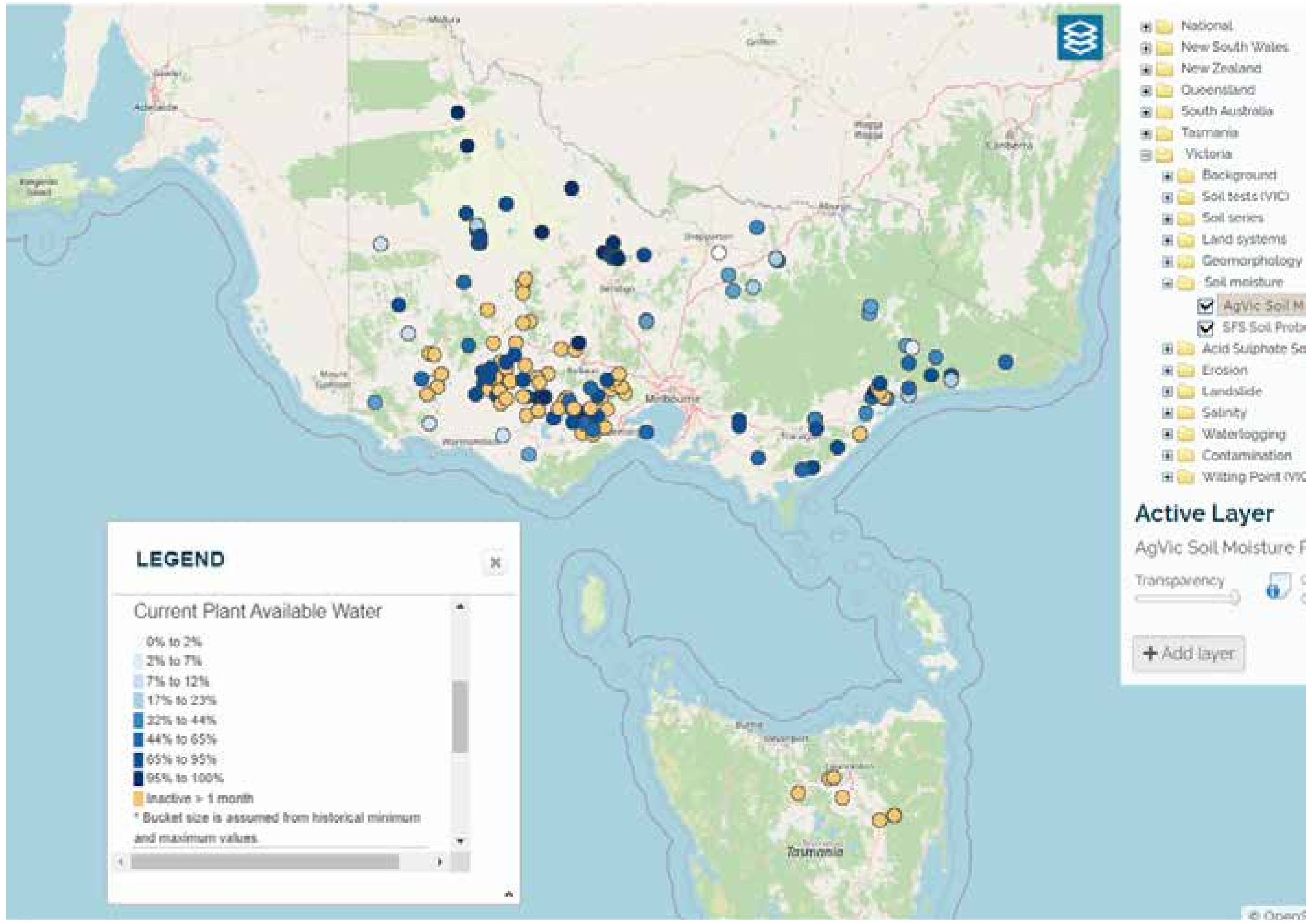
This research has shown that Australasian soils data, sourced from both the public and private sectors, can be made FAIR and shared, subject to the access rules set by the data custodians.

The research has developed and implemented a functional and useful soil data federation system, accessible via the soil data portal, co-developed with project participants to meet their needs and provide standardised data to researchers.

A clear value proposition for the farmer groups and catchment managers is access to a trusted, supported, web-based spatial soil data management system that suits their purposes and is relevant to their location.

Next steps

The final phase (Phase 3) of the project will establish a governance framework, business case and clear pragmatic value propositions for end users, to meet the goal of a creating self-sustaining and enduring Australasian soil data federation.



Increasing nutrient efficiency with new organic amendments

Project 3.1.005

Project leader: Professor Terry Rose, Southern Cross University

Duration: 2021–2025

Participating organisations:

- Southern Cross University
- NSW Department of Primary Industries and Regional Development
- FarmLink
- NSW Environment Protection Agency

Summary

Many farmers have access to manures or other organic amendments. But transport and spreading costs, along with uncertainty over crop responses and longer-term impacts on soils, limit their use.

The aim of this project is to develop recommendations for the use of animal manures and new organic amendment products, to give growers confidence to replace or partially replace mineral fertiliser inputs with organic amendment products.

The project is determining the fertiliser value of animal manures, including how new organic amendment products affect nutrient use efficiency in the field compared to traditional fertiliser inputs. It is resolving the mechanisms that drive nutrient use efficiency, using a combination of field and controlled-environment studies with locally available manure and treated (composted or thermally treated) manure sources.

Activities

- Harvest of the 2023 organic amendment trial and manure phosphorus trial were completed, and the data analysed.
- The final season of the manure versus synthetic phosphorus fertiliser trial commenced with a wheat crop sown at the FarmLink trial site in Tallimba, NSW.
- Pre-sowing soil samples and characterisation of the manure source were undertaken.
- Pot trial samples were analysed and data collated.
- Soil CRC PhD student Maryam Barati (Southern Cross University) completed her pot studies comparing cattle, pig and chicken manure as a phosphorus source to monoammonium phosphate.

Results and findings

- The 2023 data indicated no significant grain yield response to phosphorus fertiliser at the Tallimba site, due to high plot-to-plot variability. This was driven by the patchy emergence of the wheat crop in the dry start to the season, resulting in variable plant numbers in each plot.
- The 2024 trial at the same location looks promising, with even crop establishment, a healthy-looking crop at the tillering stage with high yield potential, and a visible response to phosphorus fertiliser.
- PhD student Maryam Barati's pot trials have indicated that a range of manures (chicken, pig and cattle) have similar agronomic phosphorus fertiliser efficiency to mineral P (MAP) across a range of soil types.

Next steps

- Maryam Barati is expected to submit her thesis in late 2024.
- The final field trial harvest at Tallimba will be done at the end of the 2024 season.
- Soil carbon results from NSW Department of Primary Industries and Regional Development pot trials will be analysed over the coming months.
- The project is on track to wrap up in 2025, when the full research findings will be shared.

New organic amendments for retaining soil moisture

Project 3.3.004

Project leader: Professor Chengrong Chen, Griffith University

Duration: 2021–2024

Participating organisations:

- Griffith University
- University of Newcastle
- Australian Organics Recycling Association
- Western Australian No-Tillage Farmers Association
- Herbert Cane Productivity Services
- Queensland Farmers Federation
- Mort & Co

Summary

Commercially available water retention materials include surfactants, which help to reduce soil water repellence and improve soil wetting processes. However, the effectiveness and environmental risk of some of these materials is unknown.

This project is aiming to develop cost effective, environmentally friendly moisture retention materials that will enable farmers to increase their soil's productivity and profitability.

The project team is developing a range of innovative products by evaluating, modifying and activating naturally occurring, locally available organic- and clay-based materials. These new products are expected to enhance soil moisture capture and retention, and improve seed germination, crop establishment and farming activity under dry conditions.

Activities

- Characterisation of newly synthesised organic- and clay-based materials from waste resources.
- Four novel moisture retention materials were synthesised and selected for testing – 2 organic-based and 2 clay-based. The materials will have their performance tested for improving seed germination and crop establishment in 2 different types of soils – a sandy soil in Western Australia and a clay soil in northern Queensland.

Results and findings

- Novel chemically modified organic- and clay-based materials had much higher water absorption capacity (>25 times) compared with materials before modification.
- Pot trials indicated that the novel materials that were developed can improve the water retention capacity of soils under drought conditions and have a significant positive effect on the germination and growth of wheat.
- Amendments of the four materials tested increased soil microbial activities, particularly for 2 organic-based high moisture retention materials.

Next steps

- Scale up production of high moisture retention materials for field trials prior to commercialisation of these novel materials.

Evaluation of innovative microbial carrier products

Project 3.4.002

Project leader: Professor Chengrong Chen, Griffith University

Duration: 2022–2026

Participating organisations:

- Griffith University
- University of Newcastle
- Hart Field Site Group
- Burdekin Productivity Services
- West Australian No-Tillage Farmers Association (WANTFA)
- Central West Farming Systems

Summary

This project builds on previous Soil CRC research (3.4.001) that assessed 100 potential organic rhizobial carriers and identified and developed the best 4 formulations – mill-mud based, biochar-based, diatomite-based and cow manure-based.

Under laboratory conditions, these formulations had higher rhizobial survival rates, nodulation and drought resistance than the commercially available peat inoculants.

The current research involves manufacturing of these novel formulations for seed coating and granular products. Large-scale glasshouse and field experiments are being used to evaluate their efficacy across different soil types, climatic zones and agricultural regions in Australia.

Activities

- Development of practical protocols for seed coating and granular inoculants.
- Quality control set up to test the nodulation efficacy of inoculants under controlled condition.
- A large-scale pot trial for legumes is underway, using soils from different regions and agro-ecological conditions across Australia.
- Field trials started at 3 different sites – a lentil crop trial with Hart Field Site Group in South Australia, a chickpea crop trial with Central West Farming Systems in New South Wales, and a field pea crop trial with WANTFA in Western Australia.

Results and findings

- All organic carriers are locally sourced, readily available and cost effective.
- Organic carriers are rich in nutrients and provide excellent habitat for rhizobia which can support rhizobial growth and survival in the soil.
- Preliminary results indicated good rhizobial shelf life and survival rates for all four carrier materials used. For example, biochar-based, mill-mud, cow manure based, and diatomite-based formulations showed more than 95% rhizobial survival rate.
- Large scale pot trial and field trials are underway, and data will be presented after harvest.

Next steps

- A soybean field trial will commence with Burdekin Productivity Services in Queensland in late 2024.
- Physicochemical analysis of soil and plants will be done after harvesting.
- Plant growth attributes, nodulation, nitrogenase activity ad physiological attributes will be determined and documented.

Project 4.1.005

Evaluating the role of ecosystem processes in enhancement of soil carbon and soil functional resilience

Project leader: Dr Mehran Rezaei Rashti, Griffith University

Duration: 2021–2024

Participating organisations:

- Griffith University
- NSW Department of Primary Industries and Regional Development
- Central West Farming Systems
- Herbert Cane Productivity Services
- Soils For Life
- Facey Group
- Primary Industries and Regions South Australia
- Australian Organics and Recycling Association

Summary

Many farmers are interested in using ecosystem-based management practices to enhance soil health and resilience. Ecosystem-based management can increase soil carbon storage, nutrient bioavailability and microbial biodiversity.

However, yield responses can depend on environmental factors and initial soil properties. Therefore, proper understanding of soil functional health and resilience is essential to the sustainability of the agricultural ecosystem.

This project assessed the role of ecosystem-based land managements (i.e. cover cropping, minimum tillage, conservation tillage, lime treatments, and deep ripping treatments) on soil health and resilience.

The project used the concept of soil resistance (ability of soil to maintain its functional stability after disturbance) and resilience (speed with which soil system can return to its pre-disturbance level) to assess the changes to soil health and resilience in long-term Soil CRC field sites.

The project investigated the impact of management practices on soil microbial and nutrient dynamics, focusing on microbial biomass, respiration, metabolic quotient, enzyme activities, nitrogen content and plant growth under different drought stress conditions.

Activities

- A literature review on the effects of drought stress on soil microbial functional resistance and resilience was conducted and the findings were published in a journal.
- Five incubation studies and 5 pot trials were conducted in collaboration with project partners and data analysis and interpretation was completed.
- A field trial is underway in collaboration with Griffith University and the NSW Department of Primary Industries and Regional Development.
- Meetings were held with project partners to interpret the research findings based on their individual needs and local issues.

Results and findings

Results indicated that ecosystem-based practices such as cover cropping and minimum tillage generally enhanced microbial resilience, improved nutrient availability, and supported better plant growth compared to conventional and excessively tilled soils.

Cover cropping increased microbial biomass and enzyme activity, particularly under moderate stress conditions, while minimum tillage improved nutrient retention. Shoot nitrogen content was consistently higher in cover cropping soils, while conventionally treated soils showed higher shoot carbon content under stress.

The ‘Bednar’ deep ripping method emerged as an effective strategy for mitigating the adverse effects of environmental stressors, maintaining stable microbial processes, and enhancing microbial biomass carbon and nitrogen concentrations, particularly under moderate drought stress.

Lime treatment showed significant potential in enhancing soil health and resilience to drought stress, offering insights into its capacity to mitigate nitrogen loss and facilitate nutrient cycling.

The collective findings from investigation into soil responses to stress conditions and diverse management practices underscored the pivotal role of strategic soil management in promoting resilience and nutrient dynamics within ecosystems.

Next steps

The project team will publish the findings of this research in a final report.

Further research is necessary to explain the underlying mechanisms governing soil resistance and resilience, thereby guiding the development of more robust and adaptive soil management practices in the face of changing environmental conditions.

Assessing soil water storage

Project 4.2.005

Project leader: Dr Alice Melland, University of Southern Queensland

Duration: 2022–2024

Participating organisations:

- University of Southern Queensland
- Federation University Australia
- NSW Department of Primary Industries and Regional Development
- Central West Farming Systems
- Riverine Plains Inc
- FarmLink

Summary

This project aims to quantify how the diagnosis and management of soil constraints changes soil water attributes such as infiltration, storage, drainage, and crop interaction.

Existing Soil CRC and Grains Research and Development Corporation field sites on commercial farms and a Central West Farming Systems research station field site is being used for continuous soil water monitoring. Soil water characteristic models will be developed for each site and treatment using a novel field-based method. The method makes use of paired soil water and soil matric potential sensors.

The sites were chosen to allow the study of medium to long term effects of treatments. At Burramine, Victoria, summer fallow cover crops were grown over three summers since 2019. At Armatree, NSW, lime/gypsum or elemental sulphur/organic matter blends were applied at depth in 2019. At Condobolin, NSW, surface gypsum and lime were applied 36 years ago.

The data will be used to develop knowledge that supports growers to predict the likely impact of changes in soil management on access to plant available soil water, both now and in the future.

Activities

- Field data collection is underway at 3 Soil CRC field sites, with contrasting soil types – Brown Sodosol at Burramine, Red Sodosol at Armatree and Grey Vertosol at Condobolin.
- Desktop modelling of plant available water capacity using digital soil map products was completed for Burramine and Armatree and will be extended to Condobolin.
- Surface soil sensors at Burramine and Armatree sites were removed prior to harvest in 2023 and replaced prior to sowing winter crops in 2024.
- Canopy temperature sensors were installed at Burramine and Condobolin in 2024 to identify crop and atmosphere limitations to soil water use.
- Water retention curve data were successfully processed from 198 sensors.
- Current field work is focused on soil moisture sensor calibration, and subsequent revision of soil water retention curves derived from the moisture-matric field sensor pairs, and early data collection from the observation study at Condobolin.

Above: Soil water content and matric potential sensor logger at Armatree, NSW. Photo credit: J. Eberhard, UniSQ

Top Right: Downhole permeameters measuring soil water infiltration at Burramine, Victoria. Photo credit: A. Melland, UniSQ

Bottom Right: Soil CRC Burramine site collaborators including the host farmer and researchers from UniSQ, SCU, NSW DPI&RD and Riverine Plains Inc. Photo credit: Riverine Plains Inc

Results and findings

- Cumulative impacts of summer fallow cover cropping on plant available water capacity might be measurable.
- Water retention curves were similar amongst field and lab methods tested for A horizon soil at Burramine.
- In-situ paired soil water and matric potential sensors can offer not only water use information but causation information to help quantify the potential value of treating soil constraints.

Next steps

The research will contribute to our understanding of the processes that influence soil, plant and atmosphere controls on plant available water. This knowledge will help quantify what, if any, soil amelioration is required to optimise crop productivity in a given evaporative environment (including in future climate scenarios). The novel field-based method to quantify the soil moisture characteristic curve warrants application in a wider range of soils and farming systems.

Diagnosis frameworks for multiple and complex soil constraints

Project 4.3.005

Project leader: Professor Keith Pembleton, University of Southern Queensland

Duration: 2021–2024

Participating organisations:

- University of Southern Queensland
- West Midlands Group
- Burdekin Productivity Services
- Birchip Cropping Group
- Riverine Plains Inc

Summary

This project aimed to diagnose and prioritise multiple and interacting soil constraints at the sub-field level using farmer generated and publicly available data. The project developed underpinning data-centric methods as a software code framework that decision support tools will use to diagnose soil constraints.

The goal of this research was to reduce the cost barrier (the need for detailed soil sampling at depth) for farmers diagnosing complex and multiple soil constraints in their fields. It achieved this by developing a hybrid modelling and diagnostic approach that brings together biophysical models, artificial intelligence (AI) and statistical approaches to analysing farmer and publicly available data to identify and diagnose soil constraints at a sub-field level.

Activities

This project applied a 2-stage approach to predict soil properties associated with soil constraints.

A reverse modelling framework using the Agricultural Production Systems sIMulator (APSIM), which is akin to running the APSIM model in reverse, was developed and applied to predict a soil plant available water holding capacity (PAWC). A decreased PAWC is related to physical constraints to root growth. This approach was tested against a national data set of soil properties and crop performance.

Machine learning models were developed for soil properties associated with soil constraints using national data sets of soil properties and other environmental and crop factors. The target soil constraints (and their associated properties) for the machine learning models were sodicity (exchangeable sodium percentage), salinity (electrical conductivity), acidity and alkalinity (pH), low nutrient holding capacity (cation exchange capacity), aluminium toxicity (exchangeable aluminium), and boron toxicity (exchangeable boron).

Results and findings

Using the reverse modelling framework, the project team were able to predict PAWC with a high degree of accuracy. Their approach worked across Australia and exceeded the accuracy of other methods, such as pedo-transfer functions or the current national soil grids.

They created a range of cubist-based machine learning models for the prediction of pH, chloride, electrical conductivity, effective cation exchange capacity and exchangeable sodium percentage (ESP) using simple soil test data as the inputs. The models worked well for all properties other than ESP and chloride. The ESP model development was limited by available data for these properties.

To address the shortcoming in modelling ESP and chloride and to develop models for aluminium and boron, the team then applied a range of different machine learning approaches to national datasets of soil properties. They found that random forest based models were the best approach for these properties.

Next steps

Other Soil CRC projects are developing tools that bring together the diagnosis approaches developed in this project with predictions of the soil and crop response to amelioration options within an economic analysis framework. These tools will help guide on-farm soil amelioration and re-engineering decisions.

Optimising soil constraint management through computer-based learning and modelling

Project 4.3.006

Project leader: Dr Chloe Lai, University of Southern Queensland

Duration: 2023–2025

Participating organisations:

- University of Southern Queensland
- Riverine Plains Inc
- Burdekin Productivity Services
- West Midlands Group
- Mallee Sustainable Farming

Summary

This project aims to find the best ways to manage multiple soil constraints, such as sodicity, acidity, and salinity, to help farmers make informed soil management decisions that maximise productivity and profitability.

There are different ways to manage constraints, but deciding which method to use and when can be challenging, especially when multiple constraints can occur at once. To tackle this, the project is using a computer-based approach to optimising soil constraint management.

Known as a knowledge-guided machine-learning modelling framework, it uses scientific understanding and learns from existing data to predict which combinations of soil management will work best for a particular soil affected by multiple constraints under specific conditions.

The project team is engaging growers in this research to cultivate early adopters and ensure that the eventual universal decision-support tool will be used by the industry.

Activities and findings

- Data collection from Soil CRC project participants is ongoing.
- Preliminary Agricultural Production Systems sIMulator (APSIM) modelling was performed on field trial data from existing Soil CRC projects. The modelling process is being tested and documented so that it can be easily applied to other sites in future.
- Three iterations of a literature search were performed for a meta-analysis. Screening resulted in 362 entries being included in the full text review.
- Types of soil constraints, their indicators and key soil functions related to the constraints and to agricultural systems were reviewed to determine the meta-data schema for data extraction from the full text review.

Next steps

- APSIM will be used to generate synthetic data for scenario modelling to assess crop performance and yield potential across different cropping regions.
- This data will be combined with spatially explicit soil information to develop machine learning algorithms to assess soil constraint management options.
- The algorithms will form a framework to evaluate soil productivity outcomes under different management strategies to facilitate decision support.

PhD student program

The Soil CRC's PhD student program underpins our 4 research programs to build capability in the future of Australia's soil research.

In 2023–24, we welcomed 6 new PhD students and saw 3 students complete their PhDs, bringing the total number of active students to 39 and the total number of completions to 7.

With 2 new PhD positions filled and one more open, the Soil CRC is well on the way to reaching its target of 40 PhD completions by the end of the CRC.

Our student cohort

Our PhD cohort brings together a huge wealth of knowledge, experiences, professional networks, and capabilities for our students to engage with and learn from.

Students are enrolled at 12 universities across Australia, are aged between 25 and 76 years, and reflect a wide range of disciplines and cultural backgrounds.

Highlights and achievements

- **Rahat Shabir** from Griffith University was conferred in August 2023.
- **Mathew Alexanderson** from Southern Cross University submitted his thesis in December 2023 and was conferred in April 2024.
- **Henry Luutu** from Southern Cross University submitted his thesis in December 2023 and was conferred in May 2024.
- **Seven students submitted their theses** – Linda Wirf (Charles Sturt University), James O'Connor (University of Western Australia), Melissa Wales (Charles Sturt University), Louise Hunt (Southern Cross University), Reuben Mah (University of Tasmania), Peter Weir (Federation University of Australia, and Win Win Pyone (Murdoch University).
- **Reuben Mah from the University of Tasmania was announced the winner of Cooperative Research Australia's 2024 Early Career Researcher Competition.** He competed against 4 other finalists who were selected from a pool of almost 70 entries.
- **30 current and completed students published their research,** authoring 46% of the Soil CRC's 111 publications in 2023-24.
- **28 students presented their research** at the 2023 Soil CRC Participants Conference in Launceston, Tasmania – 7 students delivered an oral presentation and 21 students prepared a poster for display.
- **A PhD Program Committee was established** to help guide the program – 7 students volunteered to sit on the committee and represent the PhD cohort.
- The annual **Soil CRC PhD Workshop Day** took place in conjunction with our 2023 Participants Conference – 27 students from 10 universities attended the workshop.
- We held **5 online PhD workshops** and **10 online 'Shut Up & Write' sessions** throughout the year.
- We continued to **profile students** and share their successes in our monthly newsletter, website and social media channels, highlighting how their research will benefit farmers.

In their words

"My PhD research has given me the opportunity to learn many new things, but the aspect I have enjoyed the most is meeting new people. Engaging with soil scientists, researchers, the Soil CRC PhD cohort, as well as farmers and advisors, has been incredibly enriching. Working with like-minded individuals who are passionate about agriculture and soil science has been inspiring. The collaborative environment and the support I have received throughout my studies have been invaluable, making my PhD journey both rewarding and enjoyable."

Suman Gajurel, University of Southern Queensland

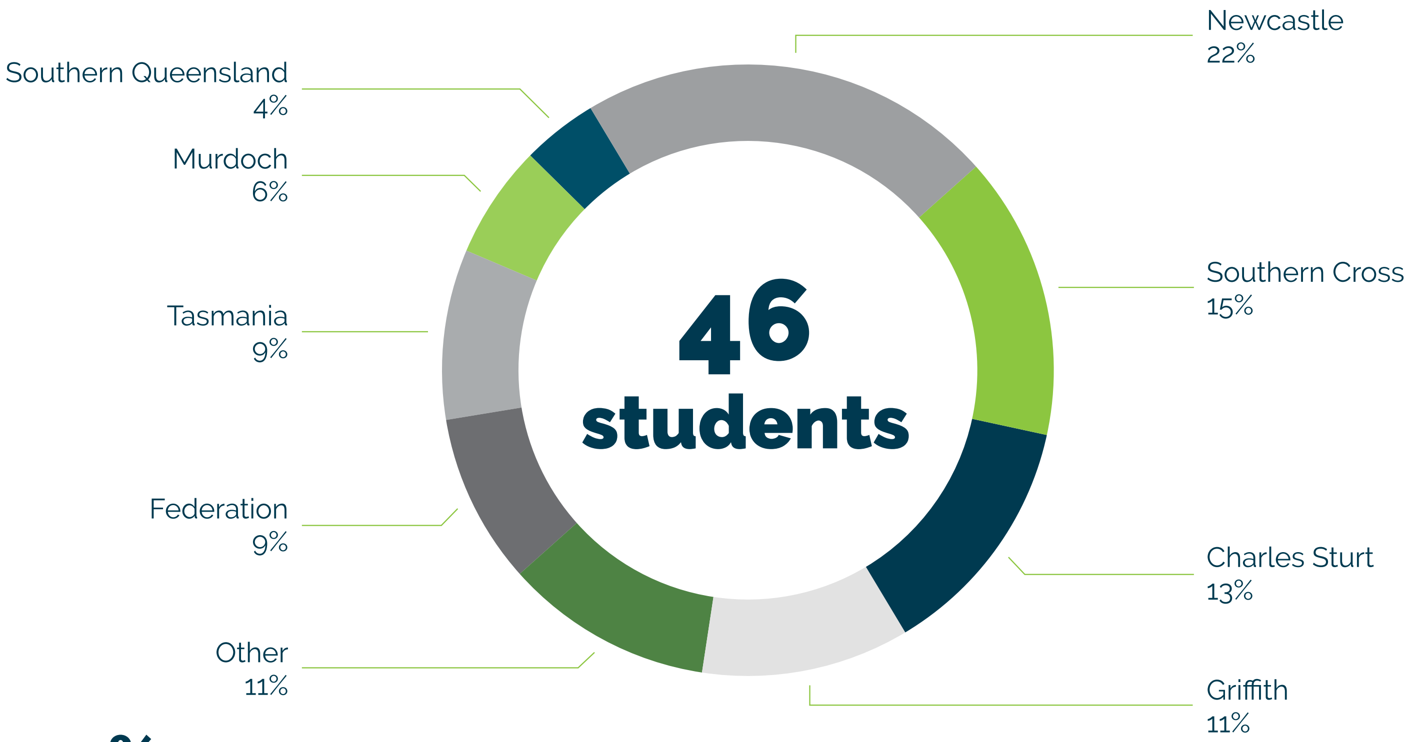
"I've really enjoyed working on a real-world challenge that has the potential to advance society and contribute to a sustainable future. I also love being part of the soil science community. I've truly appreciated the support of my supervisors, the Soil CRC and University of Western Australia staff and coworkers – they have been amazing."

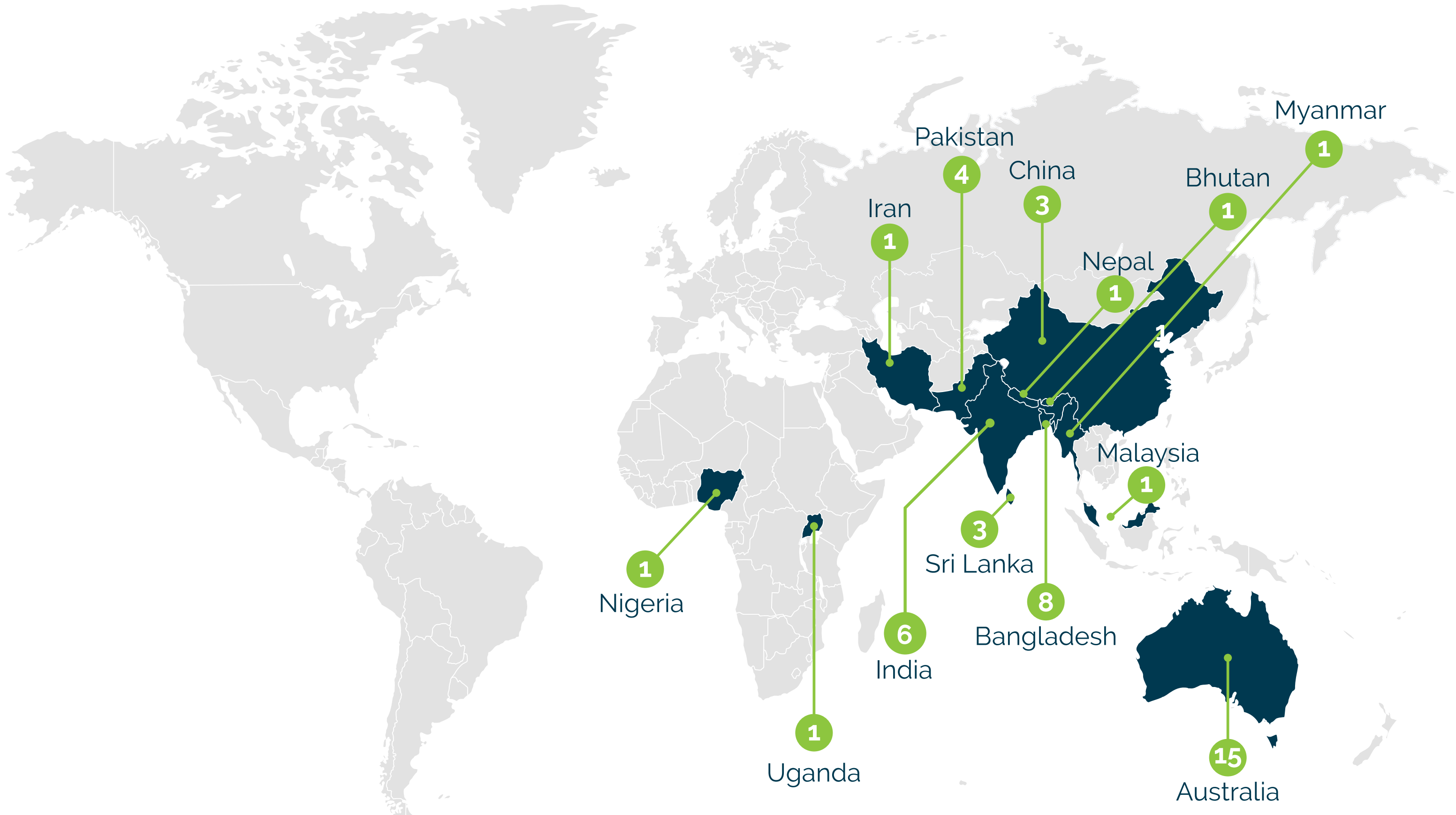
James O'Connor, University of Western Australia

"The Soil CRC Participants Conference 2023 was not only an academic endeavour but also a deep dive into real-world challenges. The PhD workshops were particularly enlightening, fostering both learning and a deeper understanding of critical subjects such as data management and intellectual property. Additionally, mingling with professionals from industry and non-academic backgrounds was invaluable."

Chenting Jiang, University of Tasmania

Students by university





Country of origin

Our PhD students

Student	University	PhD title	Program
Completed			
Mathew Alexanderson	Southern Cross University	The Trojan Horse is all Greek to Me! Exploring the social boundaries of Regenerative Agriculture	1
Sepide Abbasi	University of Newcastle	Phosphorus release and labile phosphorus from iron phosphate and biochar in rhizosphere induced by root exudates	3
Md. Zahangir Hossain	University of Newcastle	Biochar and nutrient interactions	3
Xiangyu Liu	Griffith University	Developing sensitive swoil health indicator of Australia agricultural land	4
Henry Luutu	Southern Cross University	Optimisation of hydrothermal carbonisation-treated wastes for use as novel soil amendments	3
Md. Aminur Rahman	University of Newcastle	Biochar modification for the generation of high quality phosphorus fertiliser products	3
Rahat Shabir	Griffith University	Developing effective biochar and biopolymer material as an alternative microbial carrier	3
Active 2023-24			
Adnan Al Moshi	Federation University Australia	Next generation below ground sensor communication using seismic waves for smart soil applications	2
Vijay Aralappanavar	University of South Australia	Diffusive Gradient in Thin-films methodology for assessing bioavailability of soil herbicide residues	4
Maryam Barati	Southern Cross University	Improving phosphorus acquisition in grain crops with organic amendments	3
Cameron Copeland	Southern Cross University	Understanding the mechanisms of soil microbial function and their role in cropping systems	4
Dristi Datta	Charles Sturt University	Developing a hyperspectral imagery-based decision support system for soil assessment using vegetation pattern	2
Suman Gajurel	University of Southern Queensland	Modelling and diagnosis of multiple soil constraints across Australian farming systems	4

Student	University	PhD title	Program
Louise Hunt	Southern Cross University	Negotiating the complexities of farming in the 21st century	1
Chenting Jiang	University of Tasmania	Machine learning the soil water function	2
Harleen Kaur	University of Newcastle	Biochar functionalisation to derive as P enriched fertilizer	3
Phillip Kay	University of Tasmania	Microbial changes associated with improved or reduced soil health	2
Muhammad Salik Ali Khan	University of Tasmania	Development and optimization of Soil Health Chip: An affordable device for rapid field-based assessment of soil fertility status	2
Salini Khuraijam	University of Newcastle	Exploring economic aspects of adopting soil amendments for ameliorating soil constraints in Australia	1
Stephen Lang	University of Adelaide	Impacts of soil modification on roots and the rhizosphere	4
Reuben Mah	University of Tasmania	3D printed devices for in-field soil measurements	2
Naveeda Majid	University of Newcastle	Non-wetting soils: the cause, mechanism of non-wetting and remediation	4
Evanna McGuinness	Southern Cross University	Soil organic carbon and nitrogen dynamics in topsoils and subsoils of grazing systems of the Northern Rivers region of NSW	2
Bhavya Mod	University of Newcastle	Carbon storage in soil using agro industry biowaste	3
Tania Monir	Murdoch University	Stability of soil carbon under different amendments in sandy soils	3
Kamrun Nahar	Griffith University	Enhancing soil resilience to alkaline sodicity and acidity constraints to improve soil productivity	4
Sadia Sabrin Nodi	Charles Sturt University	Development of a grower focused mobile app for estimating, analysing and recording soil properties	2
James O'Connor	University of Western Australia	Enhanced nutrient recovery from food waste anaerobic digestate	3

Student	University	PhD title	Program
Oluwadunsin Oyetunji	RMIT University	Value of compost-blended fertilizer products to boost nutrient-use efficiency and productivity in broadacre farming systems	3
Thilakshi Maheshika Paranavithana	Griffith University	Impacts of organic amendments on soil carbon sequestration: soil type, type of amendment & climatic condition	3
Kalani Randima Lakshani Pathira Arachchilage	University of Newcastle	Toward digital mapping of soil moisture	2
Vibin Perumalsamy	University of Newcastle	Reconciling carbon sequestration with fertiliser value of biowastes in farming systems through nanostabilisation of biowastes	3
Win Win Pyone	Murdoch University	Managing phytotoxicity of soil borne herbicide residues in grain cropping systems	4
Mohammad Arifur Rahman	Federation University Australia	A robust data-driven method to develop digital mapping of soil organic carbon	2
Pradeep Rai	Charles Sturt University	Economic, Social, and Environmental Contrasts of Regenerative Agriculture in Australian Farming Context	1
Sundus Saeed Qureshi	Griffith University	Developing novel cellulose-based moisture-retaining materials to mitigate drought in the soil system	3

Student	University	PhD title	Program
James Sargeant	Federation University Australia	An effective decision support system for soil health assessment and monitoring by integrating IoT technology and drone imaging	2
Prasanthi Sooriyakumar	University of Western Australia	Managing soil carbon to increase soil productivity	3
Maria Then	Murdoch University	Proximal sensing in soil water repellency management	2
Hayden Thompson	Southern Cross University	The impact of temporary legume intercropping on soil water balance and wheat yields	4
Mohd Arish Usman	University of Newcastle	Design and development of advanced biochar-clay composite	3
Melissa Wales	Charles Sturt University	Social norms of soil management	1
Peter Weir	Federation University Australia	In-paddock variability of plant available water	2
Christopher Wilmot	Charles Sturt University	Certifying soil stewardship management practices through the consumer market	1
Linda Wirf	Charles Sturt University	Beyond adoption: gendered knowledges in agricultural practice change in Australia	1
Hanlu Zhang	University of Southern Queensland	Soil-moisture profile dynamics affected by cover crop: Effect of changes in soil biology and structure	4

Our people

The Soil CRC is governed by a skills-based Board of Directors with an independent Chair, 4 independent members and 4 non-independent members. The Board provides oversight of the Soil CRC activities, performance and strategic direction.

The CEO reports to the Board on management of the Soil CRC. The CEO leads a team that operate the Soil CRC.

Soil CRC Board

- **Dr Paul Greenfield AO FTSE** – Chair
- **Professor Andrea Bishop** – Non-independent Director
- **Malcolm Buckby** – Non-independent Director (until 30 November 2023)
- **Dr Peter Carberry FAIAST FTSE FNAAS** – Independent Director (from 1 August 2024)
- **Dr Nathan Craig** – Non-independent Director (from 1 July 2024)
- **Professor Michael Friend** – Non-independent Director (from 1 December 2023)
- **Ralph Hardy** – Independent Director
- **Kate Lorimer-Ward** – Non-independent Director
- **Dr David Minkey** – Non-independent Director (until 1 May 2024)
- **Robbie Sefton AM** – Independent Director
- **Dr Simon Speirs** – Independent Director
- **Professor Roger Swift FTSE** – Independent Director (until 30 June 2024)

The Board has 5 committees that govern research, finance and risk, nominations, remuneration, and intellectual property and commercialisation.

L-R: Simon Speirs, Andrea Bishop, Ralph Hardy, Paul Greenfield, Peter Carberry, Robbie Sefton, Nathan Craig, Michael Friend. Absent: Kate Lorimer Ward.

Soil CRC Staff

- **Dr Michael Crawford**
  Chief Executive Officer
- **Heather Apps**
  Research Contracts Officer (until October 2023)
- **Mark Flick**
  Chief Financial Officer
- **Dr Rhona Hammond**
  Intellectual Property Officer
- **Felicity Harrop**
  Soil Knowledge Broker
- **Olivia Louis**
  Communications Manager
- **Jodi McLean**
  Chief Operating Officer
- **Sandy Slater**
  Finance Officer
- **Kathy Stokes**
  Executive Assistant to the CEO
- **Dr Cassandra Wardle**
  PhD Program Manager
- **Dr Lucy Weaver**
  Research Administration Officer

Soil CRC Patron

The Honourable Penelope Wensley AC is the Patron of the Soil CRC. She is also Patron of Soil Science Australia and works closely with both organisations to help promote Australia's strengths and capabilities in soil science and related disciplines, both nationally and internationally.

Program Leaders

Our 4 Program Leaders oversee and implement the research direction of the Soil CRC.

- **Professor Catherine Allan** – Program 1 Leader, Charles Sturt University
- **Associate Professor Richard Doyle** – Program 2 Leader, University of Tasmania
- **Professor Megharaj Mallavarapu** – Program 3 Leader, University of Newcastle
- **Dr Lukas Van Zwieten** – Program 4 Leader, NSW Department of Primary Industries and Regional Development

Financial summary

As extracted from the annual audited Financial Statements for the year ended 30 June 2024.

Profit or Loss

For the Year Ended 30 June 2024

	2024 $	2023 $
Revenue	26,667,313	22,938,739
Other income	525,690	349,654
Consultant fees	(77,765)	(82,063)
Employee benefits expense	(651,778)	(672,741)
Finance expenses	(587)	(763)
IT expenses	(57,481)	(98,991)
Legal expenses	(600)	(21,988)
Other expenses	(528,170)	(517,376)
Research expenditure - cash	(6,466,837)	(7,105,639)
Research expenditure - in kind	(19,348,784)	(14,728,241)
Travel expenses	(61,001)	(60,591)
Surplus before income tax	**-**	**-**
Income tax expense	-	-
Surplus for the year	**-**	**-**
Other comprehensive income for the year	-	-
Total comprehensive income for the year	**-**	**-**

Participants' Contributions (Cash basis ex GST)

For the Year Ended 30 June 2024

	2024 $	2023 $	Cumulative to 2022 $	Total $
Agricultural Innovation and Research - Eyre Peninsula				
Cash contributions	0	0	20,000	20,000
In-kind contributions				
- Staff	30,000	40,000	132,000	202,000
- Other	23,800	21,750	98,270	143,820
Total	**53,800**	**61,750**	**250,270**	**365,820**
Australian Organics Recycling Association Limited				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	32,500	45,000	136,250	213,750
- Other		0	2,000	2,000
Total	**32,500**	**45,000**	**138,250**	**215,750**
Birchip Cropping Group Inc				
Cash contributions	5,000	5,000	23,750	33,750
In-kind contributions				
- Staff	90,000	62,500	337,000	489,500
- Other	69,000	64,475	124,828	258,303
Total	**164,000**	**131,975**	**485,578**	**781,553**
Burdekin Productivity Services Limited				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	90,000	65,000	206,875	361,875
- Other	55,450	24,790	25,550	105,790
Total	**145,450**	**89,790**	**232,425**	**467,665**
Central West Farming Systems Inc				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	127,500	100,000	475,525	703,025
- Other	187,608	104,506	362,262	654,376
Total	**315,108**	**204,506**	**837,787**	**1,357,401**
Charles Sturt University				
Cash contributions	150,000	200,000	1,000,000	1,350,000
In-kind contributions				
- Staff	1,037,500	1,110,000	2,768,250	4,915,750
- Other	490,606	549,532	1,329,592	2,369,730
Total	**1,678,106**	**1,859,532**	**5,097,842**	**8,635,480**

	2024 $	2023 $	Cumulative to 2022 $	Total $
Corrigin Farm Improvement Group				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	70,000	42,500	30,000	142,500
- Other	157,360	56,900	1,398	215,658
Total	**227,360**	**99,400**	**31,398**	**358,158**
Department of Jobs, Precincts and Regions (VIC)				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	30,000	37,500	1,126,250	1,193,750
- Other	33,750	20,950	507,637	562,337
Total	**63,750**	**58,450**	**1,633,887**	**1,756,087**
Department of Regional NSW				
Cash contributions	0	0	525,000	525,000
In-kind contributions				
- Staff	467,500	992,500	3,628,000	5,088,000
- Other	436,636	469,250	2,036,958	2,942,844
Total	**904,136**	**1,461,750**	**6,189,958**	**8,555,844**
Department of Primary Industries and Regions (SA)				
Cash contributions	0	100,000	500,000	600,000
In-kind contributions				
- Staff	1,322,500	120,000	666,325	2,108,825
- Other	494,988	146,522	935,431	1,576,941
Total	**1,817,488**	**366,522**	**2,101,756**	**4,285,766**
Facey Group Inc				
Cash contributions	6,250	3,750	25,000	35,000
In-kind contributions				
- Staff	142,500	75,000	733,725	951,225
- Other	61,308	45,250	16,500	123,058
Total	**210,058**	**124,000**	**775,225**	**1,109,283**
Farmlink Research Limited				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	17,500	20,000	77,200	114,700
- Other	22,785	15,140	27,409	65,334
Total	**40,285**	**35,140**	**104,609**	**180,034**

Participants' Contributions (Cash basis ex GST) *cont.*

	2024 $	2023 $	Cumulative to 2022 $	Total $
Federation University Australia				
Cash contributions	100,000	100,000	500,000	700,000
In-kind contributions				
- Staff	1,097,500	855,000	2,212,800	4,165,300
- Other	623,200	471,271	1,053,611	2,148,082
Total	**1,820,700**	**1,426,271**	**3,766,411**	**7,013,382**
Griffith University				
Cash contributions	100,000	125,000	475,000	700,000
In-kind contributions				
- Staff	430,000	332,500	1,858,250	2,620,750
- OTher	636,752	535,388	1,151,895	2,324,035
Total	**1,166,752**	**992,888**	**3,485,145**	**5,644,785**
Hart Field Site Group Incorporated				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	35,000	20,000	101,450	156,450
- Other	15,000	25,500	160,342	200,842
Total	**50,000**	**45,500**	**261,792**	**357,292**
Herbert Cane Productivity Services Limited				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	290,000	102,500	297,000	689,500
- Other	64,420	27,840	155,523	247,783
Total	**354,420**	**130,340**	**452,523**	**937,283**
Holbrook Landcare Group				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	90,000	70,000	79,000	239,000
- Other	3,500	2,063	2,698	8,261
Total	**93,500**	**72,063**	**81,698**	**247,261**
Manaaki Whenua Landcare Research (New Zealand)				
Cash contributions	0	0	1,202,000	1,202,000
In-kind contributions				
- Staff	40,000	85,000	316,500	441,500
- Other	13,750	1,224	100,640	115,614
Total	**53,750**	**86,224**	**1,619,140**	**1,759,114**

	2024 $	2023 $	Cumulative to 2022 $	Total $
MacKillop Farm Management Group Inc				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	10,000	5,000	30,000	45,000
- Other		1,000	5,833	6,833
Total	**10,000**	**6,000**	**35,833**	**51,833**
Mallee Sustainable Farming Inc				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	25,000	22,500	35,000	82,500
- Other	8,680	0	250	8,930
Total	**33,680**	**22,500**	**35,250**	**91,430**
Murdoch University				
Cash contributions	150,000	187,500	713,000	1,050,500
In-kind contributions				
- Staff	570,000	457,500	1,249,500	2,277,000
- Other	447,450	323,383	921,186	1,692,019
Total	**1,167,450**	**968,383**	**2,883,686**	**5,019,519**
North Central Catchment Management Authority				
Cash contributions	0	0	15,000	15,000
In-kind contributions				
- Staff	15,000	0	232,500	247,500
- Other	0	27,400	18,500	45,900
Total	**15,000**	**27,400**	**266,000**	**308,400**
NSW Environment Protection Authority				
Cash contributions	0	30,000	100,000	130,000
In-kind contributions				
- Staff	0	2,500	11,250	13,750
- Other	7,500	0	0	7,500
Total	**7,500**	**32,500**	**111,250**	**151,250**
Nutrien Ag Solutions				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	35,000	210,000	741,500	986,500
- Other	800	0	84,050	84,850
Total	**35,800**	**210,000**	**825,550**	**1,071,350**

Participants' Contributions (Cash basis ex GST) *cont.*

	2024 $	2023 $	Cumulative to 2022 $	Total $
Riverine Plains Incorporated				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	45,000	42,500	105,450	192,950
- Other	72,814	27,051	97,458	197,323
Total	**117,814**	**69,551**	**202,908**	**390,273**
South Australian Grain Industry Trust Fund				
Cash contributions	150,000	150,000	750,000	1,050,000
In-kind contributions				
- Staff	5,000	22,500	94,800	122,300
- Other	20,000	35,000	7,500	62,500
Total	**175,000**	**207,500**	**852,300**	**1,234,800**
South East Water Corporation				
Cash contributions	30,000	30,000	150,000	210,000
In-kind contributions				
- Staff	0	25,000	411,625	436,625
- Other	0	1,000	163,625	164,625
Total	**30,000**	**56,000**	**725,250**	**811,250**
Southern Cross University				
Cash contributions	250,000	200,000	1,000,000	1,450,000
In-kind contributions				
- Staff	862,500	962,500	3,683,250	5,508,250
- Other	633,568	813,406	2,543,442	3,990,416
Total	**1,746,068**	**1,975,906**	**7,226,692**	**10,948,666**
Southern Farming Systems Limited				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	55,000	25,000	89,450	169,450
- Other	12,000	12,500	50,293	74,793
Total	**67,000**	**37,500**	**139,743**	**244,243**
Society of Precision Agriculture Australia (SPAA)				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	5,000	10,000	68,750	83,750
- Other	0	260	1,700	1,960
Total	**5,000**	**10,260**	**70,450**	**85,710**

	2024 $	2023 $	Cumulative to 2022 $	Total $
The Gillamii Centre				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	0	0	2,500	2,500
- Other	0	0	0	0
Total	**0**	**0**	**2,500**	**2,500**
The Liebe Group Inc				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	50,000	37,500	27,750	115,250
- Other	37,500	32,750	0	70,250
Total	**87,500**	**70,250**	**27,750**	**185,500**
The Trustee for Soils for Life Trust				
Cash contributions	20,000	20,000	100,000	140,000
In-kind contributions				
- Staff	605,000	220,000	492,775	1,317,775
- Other	45,230	44,793	80,140	170,163
Total	**670,230**	**284,793**	**672,915**	**1,627,938**
The University of Newcastle				
Cash contributions	300,000	300,000	1,500,000	2,100,000
In-kind contributions				
- Staff	1,447,500	867,500	3,971,718	6,286,718
- Other	1,090,067	754,613	3,132,358	4,977,038
Total	**2,837,567**	**1,922,113**	**8,604,076**	**13,363,756**
University of Southern Queensland				
Cash contributions	150,000	150,000	750,000	1,050,000
In-kind contributions				
- Staff	352,500	440,000	1,907,650	2,700,150
- Other	588,970	438,103	1,024,587	2,051,660
Total	**1,091,470**	**1,028,103**	**3,682,237**	**5,801,810**
University of Tasmania				
Cash contributions	150,000	150,000	713,000	1,013,000
In-kind contributions				
- Staff	667,500	495,000	3,405,000	4,567,500
- Other	1,343,277	743,611	2,461,827	4,548,715
Total	**2,160,777**	**1,388,611**	**6,579,827**	**10,129,215**

Participants' Contributions (Cash basis ex GST) *cont.*

	2024 $	2023 $	Cumulative to 2022 $	Total $
Western Australian No-Tillage Farmers Association				
Cash contributions	10,000	10,000	50,000	70,000
In-kind contributions				
- Staff	145,000	160,000	398,750	703,750
- Other	81,875	36,375	68,801	187,051
Total	**236,875**	**206,375**	**517,551**	**960,801**
West Midlands Group Incorporated				
Cash contributions	0	0	10,000	10,000
In-kind contributions				
- Staff	122,500	115,000	116,875	354,375
- Other	200,082	92,916	69,750	362,748
Total	**322,582**	**207,916**	**196,625**	**727,123**
Wheatbelt Natural Resource Management Incorporated				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	32,500	62,500	272,125	367,125
- Other	9,750	17,000	157,313	184,063
Total	**42,250**	**79,500**	**429,438**	**551,188**
Wimmera Catchment Authority				
Cash contributions	0	0	0	0
In-kind contributions				
- Staff	257,500	130,000	522,925	910,425
- Other	34,808	7,840	70,057	112,705
Total	**292,308**	**137,840**	**592,982**	**1,023,130**
Other Third Party				
Cash contributions	757,595	600,183	1,826,477	3,184,255
In-kind contributions				
- Staff	440,000	197,500	71,250	708,750
- Other	137,000	51,889	11,000	199,889
Total	**1,334,595**	**849,572**	**1,908,727**	**4,092,894**

	2024 $	2023 $	Cumulative to 2022 $	Total $
Total Participant Contribution				
Cash contributions	2,328,845	2,361,433	11,948,227	16,638,505
In-kind contributions				
- Staff	11,195,000	8,685,000	33,124,793	53,004,793
- Other	8,153,784	6,043,241	19,062,212	33,259,235
Total	**21,677,629**	**17,089,674**	**64,135,230**	**102,902,533**
Total Commonwealth Contribution				
Cash contributions	3,548,000	4,708,000	22,930,750	31,186,750
Total	**3,548,000**	**4,708,000**	**22,930,750**	**31,186,750**
Total Contributions				
Cash contributions	5,876,845	7,069,433	34,878,977	47,825,255
In-kind contributions				
- Staff	11,195,000	8,685,000	33,124,793	53,004,793
- Other	8,153,784	6,043,241	19,060,210	33,257,235
Total	**25,225,629**	**21,797,674**	**87,063,980**	**134,087,283**

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